Dominic Lammert

BRIDGING ACADEMIC SOFTWARE SUSTAINABILITY DESIGN WITH CORPORATE BUSINESS PLANNING

ACTA UNIVERSITATIS LAPPEENRANTAENSIS 1126

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Abstract

Dominic Lammert
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Software systems have become deeply intertwined with both our personal lives and our professional lives, blurring the demarcation between the colloquially referred 'real world' and 'digital world'. Consequently, software systems wield unintended influences on non-technical systems, encompassing the social, environmental, and economic dimensions. These three dimensions are commonly subsumed under the Triple Bottom Line (TBL), which serves as a conceptualisation of the term 'sustainability'. Sustainability is not a passing trend but an elementary requirement for today's and tomorrow's society that confronts software practitioners with a new spectrum of tasks and responsibilities.

This dissertation is aimed at bridging the gap between academia and industry within software sustainability design. A comparison of these two sides reveals different levels of awareness regarding the impacts of software products and services, as well as a different level of theoretical knowledge and practical approaches to set and achieve sustainability goals. To fill this gap, particular reference was made to the preliminary work of the signatories of the Karlskrona Manifesto for Sustainability Design, who developed the Sustainability Awareness Framework (SusAF). The SusAF is a tool that supports software practitioners in identifying the multi-dimensional impacts of software so that they can be considered requirements during the design phase. Employing the Design Science Research Methodology (DSRM), this dissertation extends the SusAF, tailoring it to the specific needs of software companies. Through a sequence of iterative case studies, an artefact named the Business-oriented Extension of the Sustainability Awareness Framework (BE-SusAF) has emerged.

The BE-SusAF contributes mainly through embedding four principles into industrial software design approaches, summarised as the four Is: 1) Interface positions for the orchestration of the artefact, 2) Integration of external stakeholders in the requirements elicitation process, 3) Implementation of the SusAF results within business design models, and 4) Incorporation of organisational conditions. While the artefact enables software companies to meet sustainability challenges, the research around it contributes in general to the transfer from academia to industry within software sustainability, a nexus that is gaining significance due to the progressing digital transformation.

Keywords: software sustainability, software sustainability design, software engineering, requirements engineering, software industry

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During the course of my doctoral journey, I had the honour to work with many inspiring personalities I thank all who have supported me in my work in various ways. Be it as an interesting conversation partner, presenter of an enlightening subject, altruistic counter-reader, or be it as a workshop participant, interview partner, survey respondent. A dissertation cannot develop solely through the work of one single person.

Dominic Lammert
January 2024
Freiburg, Germany

Contents

List of publications

The dissertation is based on the outcome of the following publications. In the doctoral thesis, these publications are referred to as *Publication I* to *Publication V*. The rights have been granted by publishers to include the articles in the dissertation.

I. Lammert, D., Betz, S., and Porras, J. (2022). Software Engineers in Transition: Self-Role Attribution and Awareness for Sustainability. *Proceedings of the 55th Hawaii International Conference on System Sciences (HICSS 2022)*, pp. 7794 - 7803, Handle: https://hdl.handle.net/10125/80279.

II. Lammert, D., Betz, S., Porras, J., and Oyedeji, S. (2024). Sustainability in the Software Industry: A Survey Study on the Assessment, Responsibility, and Motivation of Software Practitioners. *Special issue of the International Journal of Engineering Intelligent Systems (EIS),* Vol. 32(1), publication in process.

III. Lammert, D., Betz, S., and Porras, J. (2023). The Business-oriented Extension of the Sustainability Awareness Framework – a Design Science Study. *Lecture Notes in Networks and Systems, WorldS4 2023*, Berlin: Springer Nature, publication in process.

IV. Lammert, D., Abdullai, L.; Betz, S., and Porras, J. (2023). Sustainability for Artificial Intelligence Products and Services – Initial How-to for IT Practitioners. *Proceedings of the 56th Hawaii International Conference on System Sciences (HICSS 2023)*, pp. 6570-6579, Handle: https://hdl.handle.net/10125/103428.

V. Lammert, D., Betz, S., Wulf, N., and Porras, J. (2023). "Changing Death": Initial Insights for Software Practitioners in Thanatopractice. Karla, J. (ed.), Human Factors in Aging and Sepcial Needs. *14th International Conference on Applied Human Factors and Ergonomics (AHFE 2023)*, Vol. 88, pp. 113-123, doi: 10.54941/ahfe1003668.

Author's contribution

Dominic Lammert is the principal author and investigator in all five publications and led the writing. The supervisors guided him in the planning, data collection, and analysis, as well as validation of the results.

Related publications (not included in this thesis)

- Lammert, D. (2021). The Connection between the Sustainability Impacts of Software Products and the Role of Software Engineers. *Evaluation and Assessment in Software Engineering (ENASE)*, pp. 294-299, doi: 10.1145/3463274.3463346.
- Oyedeji, S., Shamshiri, H., Porras, J., and Lammert, D. (2021). Software Sustainability: Academic Understanding and Industry Perceptions. *Software Business: 12th International Conference, ICSOB 2021*, pp. 18-34, doi: 10.1007/978-3-030-91983-2_3.
- Seyff, N., Betz, S., Lammert, D., Porras, J., Duboc, L., Brooks, I., Chitchyan, R., Venters, C., and Penzenstadler, B. (2022). Transforming our World through Software: Mapping the Sustainability Awareness Framework to the UN Sustainable Development Goals. *Proceedings of the 17th International Conference on Evaluation of Novel Approaches to Software Engineering-ENASE*, pp. 417-425, doi: 10.5220/0011063200003176.
- Brooks, I., Seyff, N., Betz, S., Lammert, D., Porras, J., Duboc, L., Chitchyan, R., Venters, C. C., and Penzenstadler, B. (2023). Assessing Sustainability Impacts of Systems: SuSAF and the SDGs. *Evaluation of Novel Approaches to Software Engineering*, *Vol. 1829*, pp. 205-219, doi: 10.1007/978-3-031-36597-3_10.

Nomenclature

ADM	Automated Decision-Making
AI	Artificial Intelligence
BE-SusAF	Business-oriented Extension of the Sustainability Awareness Framework
BMC	Business Model Canvas
DSR	Design Science Research
DSRM	Design Science Research Methodology
EU	European Union
GDPR	General Data Protection Regulation
LCSA	Life Cycle Sustainability Assessment
MR	Management Role
RE	Requirements Engineer
S-BGQM	Sustainable Business Goal Question Metric
SDG	Sustainability Development Goal
SE	Software Engineer
SE4GD	Software Engineers for Green Deal, an Erasmus Master Programme
SLR	Systematic Literature Review
SROI	Social Return on Investment
SSD	Sustainable Software Development
SusAD	Sustainability Awareness Diagram
SusAF	Sustainability Awareness Framework
SUSO	Sustainable Software, a web platform that supports the software industry
SWEBOK	Software Engineering Body of Knowledge
TA	Technology Assessment
TBL	Triple Bottom Line
TL-BMC	‘Traffic Light’ Business Model Canvas
TR	Technical Role
VPC	Value Proposition Canvas

1 Introduction

In 2022, the British daily Morningstar summarised the view on sustainability of the chairman and Chief Executive Officer (CEO) of BlackRock with the following headline: 'Larry Fink: Sustainable Investing Is About Profits, Not Taking A Stand' (Norton, 2022). Regardless of a sustainability analysis of the world's largest investment company at this point, this headline can be interpreted as emblematic for the evolving significance that sustainability has gained in recent decades: Sustainability debates have already expanded societal and environmental considerations into the economic domain. Accordingly, the topic of sustainability has reached the scope of tasks and responsibilities of industrial stakeholders, such as software practitioners (Becker et al., 2014).

In science, the term sustainability is often proclaimed as 'the capacity to endure' (e.g. Becker et al., 2016; Penzenstadler, 2013). Scientists use this description in the industrial context to underline that it is worthwhile to consider sustainability in corporate strategy not only from a social and environmental perspective but also from an economic perspective. In other words, concurrently factoring the social, environmental, and economic dimensions, as summarised under the triple bottom line (TBL), contributes to the long-term existence and success of a company (Elkington, 1997). However, delving into sustainability also entails an additional workload that has associated costs. Practitioners in the software industry must remain cognisant of the notion that economic efficiency forms one of the basics for entrepreneurial existence. The integration of sustainability principles (Becker et al., 2014; Becker et al., 2015) must therefore harmonise with a business plan. For instance, depending on the software product or service, it could be argued that privacy suffers because of the display of personalised advertising. On the other hand, this solution enables a company to pursue a pricing policy that allows economically worse-off user groups to use the software. Without further analysing this scenario, this example underlines the complexity of designing and developing sustainable software products and services. Software companies face a dual task in joining the requirements of sustainability design and business plan design.

Consequently, this dissertation attempts to deliver answers to the following main research question (RQ): ***How can industrial software practitioners be enabled to effectively integrate sustainability design into their requirements engineering process?*** Addressing this question within the framework of the *Design Science Research Methodology (DSRM)* establishes not only a theoretically grounded and practically tested artefact, the *Business-oriented Extension of the Sustainability Awareness Framework (BE-SusAF)*, but also pathways for bridging the gap between academic theory and industrial practice.

The following introduction provides an overview of the background as well as the research scope and approach of this dissertation.

1.1 Background

The background section is divided into three parts. The first part explains why addressing sustainability challenges is a concern of today's industry. In the second part, the topic of sustainability in the industrial software engineering practice in particular is presented. The third part demonstrates the current main challenges of the software industry. This chapter thus forms the basic content knowledge of the dissertation.

1.1.1 Sustainability as a corporate issue

The concept of sustainability can be traced to 18th-century forestry, with its first recorded usage in the 1713 work *Sylvicultura Oeconomica* by the Saxon Hans Carl von Carlowitz (referred to as 'Nachhaltigkeit' in German). Carlowitz recognised the threat posed to forest ecosystems by the timber industry and advocated for a principle of 'never harvesting more than what the forest yields in new growth' (Wiersum, 1995). This principle marked an early understanding of sustainable resource management. Subsequently, the term sustainability expanded its scope and entered other domains, including agribusiness, as a means to describe the long-term use of natural resources.

In 1987, the *United Nations World Commission on Environment and Development* published the report 'Our Common Future', which is commonly known as the 'Brundtland Report' (Brundtland et al., 1987). This report is widely recognised as a pivotal milestone in the global sustainability discourse and continues to shape contemporary political decision-making in public debates. The report underscores the importance of all countries addressing interdependent social, environmental, and economic challenges to achieve sustainability. The authors assert that effectively promoting sustainability requires collaboration among governments, civil societies, and industries.

The next significant milestone for the concept of sustainability can be traced to the 1990s: John Elkington coined the TBL (1997), which has gained global recognition as a framework for defining sustainability. The foundations of this model originate in past works. For instance, Freer Spreckley's introduction of a list of social, environmental, and economic aspects within the framework of 'socially responsible enterprises' in 1981. His essay emphasised the importance of industrial companies considering sustainability aspects in their operations (Spreckley, 2021). The TBL, as illustrated in Figure 1, consists of three pillars commonly referred to as the 'three Ps':

- *People* represent a company's commitment to social responsibility towards its employees, customers, and the broader community.
- *Planet* pertains to the company's ecological impact on the environment, encompassing aspects such as energy efficiency, waste reduction, and the utilisation of renewable resources.
- *Profit* denotes the company's traditional financial performance and its ability to generate economic value.

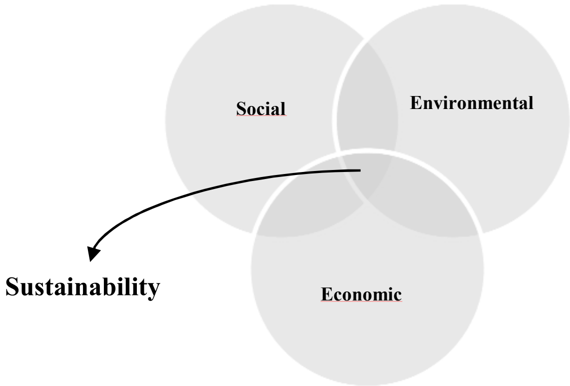

Figure 1: Sustainability according to the Triple Bottom Line (TBL).

These three pillars encompass the fundamental aspects that companies need to consider when evaluating and enhancing their sustainability practices.

In light of increasing concerns about environmental and societal challenges, the TPL assumes prominent importance from the perspective of many sustainability advocates as well as critics. The economist Kate Raworth describes the environment as a distinct system parameter in her concept of the ‘Doughnut Economy’ (2018). In this conceptual construct, Raworth underscores the inimitable nature of the earth as an irreplaceable boundary. Accordingly, the two other domains – society and economy – are subject to the dictates of these planetary boundaries. An example of such a systemic visualisation of sustainability is shown in Figure 2.

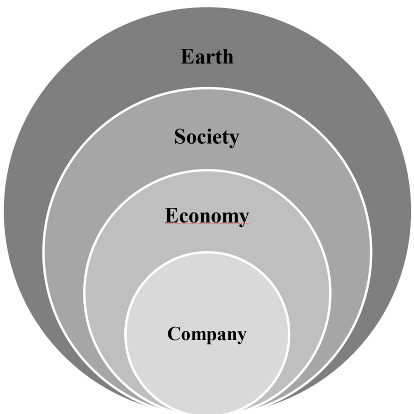

Figure 2: Sustainability from a systemic perspective.

Building upon the above-mentioned works, among others, the 17 *Sustainable Development Goals (SDGs)* were introduced in 2015 as part of the 2030 Agenda (United Nations), which are summarised in Figure 3. The SDGs are aimed at addressing global challenges such as poverty, climate change, inequality, and environmental degradation to create a sustainable future. The SDGs represent a substantial advancement in the pursuit of sustainable development by underscoring the importance of adopting a comprehensive approach that considers the interconnected social, environmental, and economic dimensions.

Figure 3: 17 SDGs of the United Nations General Assembly (United Nations, 2015).

Other developments in recent years, which cannot be detailed in this section due to space limitations, illustrate that the concept of sustainability is currently gaining in importance:

- *Corporate social responsibility (CSR)* summarises ethical corporate management from the 2000s. In 2010, the *International Organization for Standardization* (*ISO) Standard 26000* was created to follow this purpose.
- *Environment, social, and governance (ESG)* criteria originate from the financial sector. With the *Corporate Sustainability Reporting Directive (CSRD)*, the European Commission has for the first time established a uniform framework for the reporting of non-financial data and thus demands detailed information on sustainability strategies and indicators from companies.
- The *European Green Deal* pursues the goal of developing Europe into a climate-neutral and resource-conserving continent by 2050. Funding programs will be set up to, for example, transform companies' business models.

These selected examples, which are provided in various corporate guidebooks (e.g. Engelien et al., 2023), are intended to illustrate the impact of development towards sustainability, which is present in different facets within various corporate functions:

- The realm of *management* spearheads the formulation of a comprehensive sustainability strategy and orchestrates employee management.
- In the sphere of *finance* and *controlling*, an imperative role is vested in data management, entailing the collation and computation of sustainability metrics, coupled with meticulous documentation to ensure transparency and adherence to established standards.
- *Production* and *supply management* are entrusted with the responsibility of fostering energy efficiency and championing resource preservation, notably within the precincts of the circular economy paradigm.
- *Sales* shoulders the onus of aligning itself with the diverse demands of business-to-business (B2B) and business-to-consumer (B2C) clientele within the ambit of sustainability, thus necessitating harmonisation with these requisites.
- *Human resources (HR)* emerges as a custodian of fostering diversity, inclusivity, and equity.
- The roles of *software engineers (SEs)* and *requirements engineers (REs)* find themselves influenced by these dynamics, tasked with the synthesis of technical solutions that seamlessly incorporate sustainability principles.

It can thus be concluded that sustainability exerts indirect and direct influences on companies. This list shows that shared overall responsibility is needed. Management may choose to have a sustainability officer or even a sustainability team, but it is recommended that each professional role somehow contribute to fulfil the demanded requirements that the sustainability issue poses.

1.1.2 **Sustainability in the software engineering practice**

According to Duboc et al. (2019), software systems have permeated various aspects of our everyday life, encompassing domains such as commerce, communication, education, energy, entertainment, finance, governance, and defence. Consequently, Becker et al. (2016) argue that software products and services are interwoven with both socioeconomic systems and natural systems, although these interdependencies may not be immediately evident at first glance. Booch succinctly encapsulates this relationship by stating ‘Every line of code has a moral and ethical implication’ (2015). This phrase highlights the profound impact that software engineering can have. The researchers introduced this term, which they borrowed from finance, to highlight the sustainability issues within the software industry. Betz et al. also sums up the sustainability issue within software engineering by establishing the term ‘sustainability debt’ (2016). The researchers thus borrowed a term from the financial sector to highlight the responsibility of the software industry:

> *Sustainability matters for all software systems, even if the application domain of the system is not related to sustainability, because any new software creates dependencies and obligations as it becomes part of our technical infrastructure, and its ongoing use may entail new burdens on social and ecological systems. (Betz et al., 2016)*

Overall, scientists play an important role in the establishment, implementation, and achievement of sustainability in the software industry: By promoting awareness and understanding of sustainability, developing approaches and methods to support its achievement, and conducting practical studies within the industry to address sustainability challenges (Lammert et al., 2022).

Oyedeji et al. (2018 and 2021) delineate four distinct sustainability task areas within the domain of today's software engineering practice:

1. *Design (sustainability in software development)* refers to the approach of integrating sustainable practices and principles into the software design process. Sustainability in this context refers to the TBL-like efforts to develop socially responsible, environmentally friendly, and economically sustainable software solutions.
2. *Usage (software for sustainability)* refers to how software solutions can help achieve sustainability goals and positively impact society, the environment, and the economy.
3. *Focused impact (green software systems)* refers to the targeted impact or specific influence of green or environmentally friendly software solutions.
4. *Net effect (sustainability of software ecosystems)* refers to the overall impact or result in terms of sustainability of software ecosystems.

To achieve sustainability goals, Oyedeji et al. (2018) list seven approaches that have emerged within academia. Each of these approaches delivers a different perspective that allows SEs and REs to transfer aspects of sustainability into the software:

- *Sustainability Awareness Framework (SusAF):* This tool, which is one of the basic preliminary works of this dissertation, will be further detailed in section '2.3 Karlskrona Manifesto for Sustainability Design and the Sustainability Awareness Framework (SusAF)'. First, the impacts of a software system, which are divided into five dimensions (social, individual, environmental, economic, and technical) and three effect levels (immediate, enabling, and structural), are identified. Second, the results are transferred into a visualisation tool, the *Sustainability Awareness Diagram (SusAD)*. Last, the impacts are discussed and taken into account as requirements within the design phase.
- *Flourishing Business Canvas (or Sustainable Business Canvas):* This business model tool focuses on creating a sustainable and thriving business by considering the dimensions of business value, environmental impact, and social impact.

- *Sustainability Requirement Template:* This template helps define and capture sustainability requirements for software projects and supports the inclusion of environmentally and socially responsible aspects in the development process.
- *Goal Model:* This modelling tool establishes distinct and measurable goals for sustainable development. The tool enables the visualisation of goal hierarchies and relationships to support the alignment of activities and measures towards sustainability.
- *Life Cycle Sustainability Assessment (LCSA):* This method assesses the sustainability performance of products or systems over their entire life cycle. LCSA takes into account environmental impacts, social aspects, and economic considerations to provide a comprehensive assessment of sustainability.
- *Social Return on Investment (SROI):* A method for measuring and evaluating the social value added to the investment. SROI takes into account not only financial returns but also social and environmental impacts to provide a more comprehensive assessment of the benefits of an investment.
- *Biomimicry:* In this design method, solutions and innovations are derived from nature. By analysing natural systems and processes, sustainable solutions that are inspired by nature’s patterns and principles can be developed.

When academia raises questions about the perception and assessment of software practitioners regarding sustainability, interview studies, in particular, stand out. Giovannoni and Fabietti's observation in 2010 shows that the integration of sustainability aspects into the software engineering process has yet to be reflected in official standards and models. In their interview study, Chitchyan et al. (2016) discovered a lack of knowledge, experience, and methodological tools among REs (n=13) for addressing sustainability. The understanding of sustainability was limited to environmental issues, such as the availability of natural resources and waste reduction. Groher and Rainer (2017) reached a similar conclusion in their interview study conducted with software practitioners (n=10) on sustainability concerns in software development projects: ‘[Software] practitioners regard software sustainability as important but are technically minded concerning sustainability.’ Despite making the interconnectedness of software and sustainability visible, it becomes apparent that SEs and REs do not sufficiently fulfil to pay their sustainability debt.

In summary, the scientific community agrees that further efforts are needed within the software industry. There is no doubt that the three Ps (People, Planet, and Profit) also apply to the development of software products and services (Rondeau et al., 2015; Giovanni et al., 2013; Kuhlmann et al., 2010).

1.1.3 Challenges of the software industry

Over the past decade, several studies have been conducted on software sustainability in an industrial context. Several unanswered questions have been identified, of which three answers in particular will be presented in this sub-section. First, there is a lack of a fundamental understanding of software sustainability in theory and, second, a lack of software sustainability design approaches in practice. Third, in this context, the exchange between academia and industry proves to be expandable.

Understanding software sustainability: Studies indicate a lack of common understanding and consensus regarding the term *Sustainable Software Development (SSD)*, leading to a selective approach to the topic (Karita et al., 2022; Norman et al., 2022). Seyff et al. emphasise the necessity of addressing this issue, stating: "We can only achieve something if we clearly define what it is, for whom we are achieving it, for how long, and at what cost [...], and therefore we need a clear definition and template for scoping the impact of the system" (2021). The presence of a "lack of theoretical fundamentals" (Tejera-Hernández et al., 2018) within software engineering workplaces is evident.

Approaching software sustainability: The implementation of the (multi-dimensional) requirements that sustainability demands create organisational challenges related to the distribution of responsibilities and the formulation of a business strategy (Al-Sarayreh et al., 2021; Büdel et al., 2020). Thus, numerous interview studies explain that there is not only a lack of understanding but also a lack of methodological approaches to address sustainability practically (see section '1.1.2 Sustainability in Software Engineering practice').

Linking sustainability and business design: While economic interests can be listed among the motivating factors for software companies to address sustainability (Hsieh, 2015; Bomfim et al., 2014), the existing academic tools for sustainability design (Oyedeji et al., 2017) lack approaches that facilitate the translation of findings into a business plan. In the tools created so far, as enumerated by Oyedeji et al. (2018), sustainability and business are separately considered. An exception is the Flourishing Business Canvas (or Sustainable Business Canvas).

Overall, the current research shows a general need to establish a connection between academia and industry.

1.2 Research Scope and Approach

To build a bridge between academia and industry regarding software sustainability, qualitative and quantitative empirical methods were employed. The DSRM provided the methodological framework for the dissertation. The result is a theoretically grounded and practically tested artefact that can be implemented in the design phase within the industrial software engineering process: the *BE-SusAF*. Moreover, the dissertation delivers results that have the potential to influence further academic research in the field of software sustainability. The research process is divided into three phases, as shown in Figure 4.

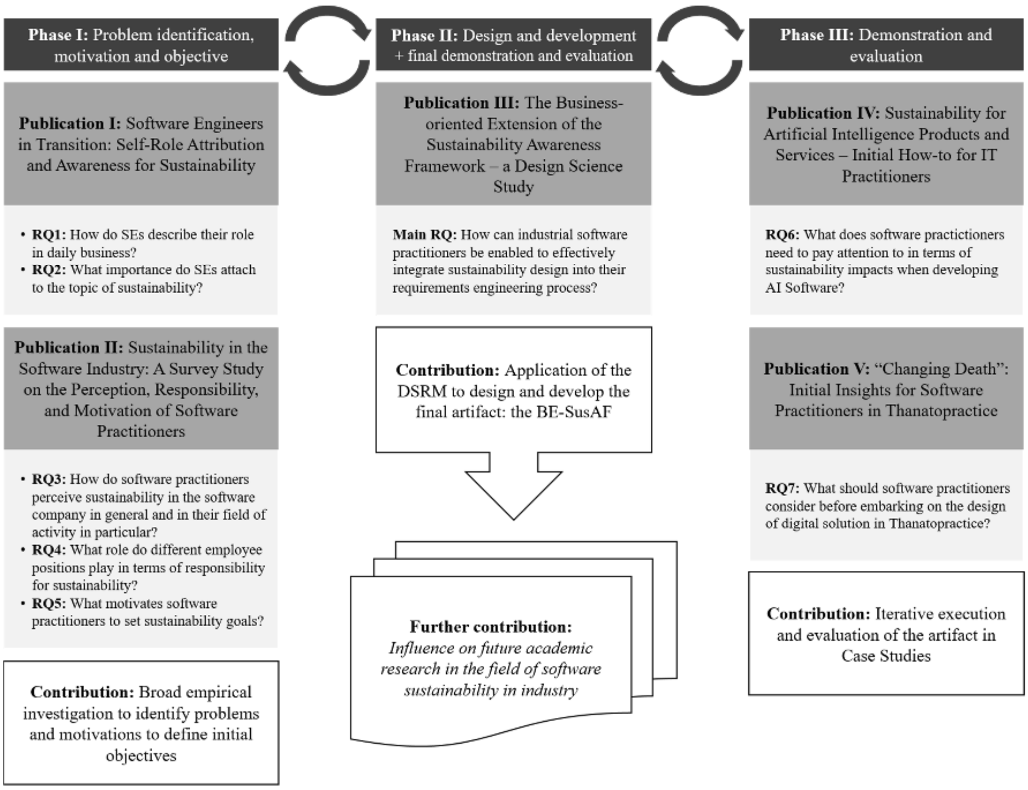

Figure 4: Research Approach Overview I

Phase I: Problem identification, motivation, and objective: The first phase focused on the role of SEs within the software industry. Through qualitative interviews, their self-role attribution and awareness of sustainability were analysed (Publication I). Additionally, this phase included a survey study that quantitatively supplemented the insights gained from the interviews on how software practitioners in general perceive and approach the topic of software sustainability (Publication II). These two studies acted as an initial basis for the identification of actual problems and motivations and in defining initial objectives to be utilised in the extension of the artefact.

Phase II: Design and development (plus final demonstration and evaluation): The results from the two studies in Phase I and the two studies in Phase III were iteratively referenced to obtain answers to the main RQ of this dissertation: *How can companies effectively integrate software sustainability design requirements into the business plan?* Throughout the dissertation, this phase was revisited until the established objectives were met, at which point the artefact could be demonstrated (Publication III). The result, the BE-SusAF, can be implemented within the software industry in terms of its content and structure, as well as its organisational components.

Phase III: Demonstration and evaluation: The artefact was iteratively executed, developed, and evaluated in case studies (Publication IV and Publication V). The case studies are based on workshops in which industrial software practitioners collaborate with other stakeholders within principles of the *Participatory Design*.

The primary objective of each exploratory study in this thesis was to address the RQ by developing an artefact.

1.2.1 Intended contributions

The contributions of the dissertation can be transferred to two sides: academia and industry.

First, this dissertation provides insights that contribute to the understanding of industrial realities on the part of academia. Therefore, the dissertation broadens the basis for synergies aimed at sustainability. Collaborations between science and industry play a crucial role in translating new knowledge and technologies into practical applications. If a scientist considers establishing theoretical models and practical tools for the industrial software engineering practice, the dissertation provides fundamental considerations that have the potential to serve as a support. Sustainability has been integrated into the curricula of bachelor's and master's degree programs of LUT University and Furtwangen University, and this work could contribute to the Erasmus master's program *Software Engineers for Green Deal (SE4GD)*[1] in summer semester 2023. This program is aimed at educating and training students with a mind-set focused on improving software solutions for sustainability. As part of our efforts, we will incorporate our artefact as a topic in selected lectures and seminars. Simultaneously, representatives from the software industry are invited to foster collaboration.

Second, the artefact equips the software industry with theoretical knowledge and practical approaches that originate in academia, focusing on gaps that are prevalent in software companies. The artefact serves software companies as a comprehensive guide for a sustainability strategy that is broken down step by step. This artefact starts in the planning phase, with evaluation of the sustainability requirements for software products and services. This does not exclude the business plan; instead, it forms an integral part of the artefact. To ensure wider dissemination of our artefact, we plan to use not only academic channels but also science communication channels that are specifically targeted at the software industry. Our platform *Sustainable Software (SUSO)*[2] provides knowledge, tools, and collaboration possibilities with research facilities. By making software sustainability formats accessible, we aim to stimulate and encourage software companies to incorporate sustainability goals and strategies into their businesses.

[1] https://se4gd.lutsoftware.com/

[2] https://www.suso.academy/en/

1.2.2 Thesis Outline

Chapter 2 provides an overview of related research within the addressed topics. Chapter 3 presents the research design and methods. In Chapter 4, the results of Publications I to V are summarised as an overview. Chapter 5 discusses and reflects on the content and procedure. In Chapter 6, a conclusion is drawn.

2 Related research

This chapter presents the research on which this dissertation is based and, in the process, reveals research gaps. In the first section, the current academic understanding of software sustainability within the academic discipline of software engineering is explained. In particular, it is characterised by the expansion from a selective technology-focused view to an interdisciplinary-oriented view. The second section addresses the actual role of the SE within the software industry, which combines the levels of awareness, knowledge, and approach regarding the development of sustainable products and services. Here, a comparison between the academic theories is performed (overlaps and contrasts). The third section addresses the *Karlskrona Manifesto for Sustainability Design* and its *associated SusAF*. The underlying sustainability design principles and approaches therein form the foundation of the artefact that can be described as an extension of this preliminary work.

2.1 From a technology-focused to an interdisciplinary-oriented understanding of sustainability

Some of the most utilised key works in the Software Engineering curriculum include ‘Software Engineering’ by Ian Sommerville (2015) and ‘Software Engineering Body of Knowledge (SWEBOK)’ by Pierre Bourque and Richard E. Fairley (2014). Sommerville defines software engineering as a discipline that encompasses ‘all aspects of software production from the early stages of system specification to maintaining the system after it has gone into use.’ His book’s chapter overview indicates that software engineering extends beyond technical concerns, explicitly addressing topics such as ‘project management’ and ‘finance’. Bourque and Fairley also advocate for an interdisciplinary perspective, emphasising that terms like ‘management’ and ‘economy’ are integral to the field of software engineering and should not be disregarded through a sole technology-oriented focus that cannot adequately represent the complexity of this discipline. With this interdisciplinary mind-set, at this point, a transition to the topic of software sustainability is suggested.

During a Systematic Literature Review (SLR) study published in 2012, Penzenstadler et al. highlighted the lack of academic research on software engineering compared to other fields with regard to the integration of sustainability topics. However, in a 2017 systematic mapping study, Wolfram et al. observed a ‘growing interest in the SE research community in the area of green and sustainable software’. Continuing this trend, Imran and Koster, in an SLR from 2022, identified the transition of sustainability issues as one of the major challenges within software engineering.

More than a decade ago, scientific publications predominantly exhibited a technology-focused understanding of sustainability. For instance, Koziolek (2011) defined software sustainability as a ‘long-living system that should last for more than 15 years and can be cost-efficiently maintained and evolved over its entire life cycle,’ which only addresses two areas of sustainability: technical and economic. Similarly, Seacord et al. (2003) described sustainability as the 'ability to modify a software system based on customer needs and to deploy these modifications,' encompassing two dimensions: technical and social. However, in recent research, in the last decade, a more interdisciplinary-oriented understanding of software engineering has been embraced (Penzenstadler et al. 2014). To summarise these understandings, Calero et al., (2013), presented two interpretations of the term sustainable software: 'the software code being sustainable, agnostic of purpose, or the software purpose being to support sustainable goals, i.e. improving sustainability of humankind on our planet)'. Becker et al. (2016) agree with this further development by declaring that it is necessary to 'think outside the box' within software and requirements engineering:

> *Focusing on sustainability design, software engineers must adopt a mind-set quite different from the puzzle-solving attitude often found in engineering and business. Now, the objective is to identify and understand 'wicked problems': problems that are deeply embedded in a complex system with no definitive formulation and no clear stopping rule. (Becker et al. 2016)*

In summary, academia adopts a more holistic understanding and adaptable approach to address sustainability challenges, which makes it necessary for SEs and REs to think and act beyond their specialised boundaries.

2.2 Sustainability as an area of responsibility for SEs and REs

In the early 21st century, a notable paradigm shift in process models within software companies emerged alongside the ongoing digital transformation. Before the millennium, the *Waterfall Model* stood as a prevalent approach. However, the *Manifesto for Agile Software Development*[3] in 2001 increasingly introduced *Agile Methods* as an alternative (Sohail et al., 2022; Bogdan-Alexandru et al., 2019; Meade et al., 2019). It is worth taking a closer look at this development, because it clarifies the changing role of SEs and REs.

Originating in the 1970s, the Waterfall Model derives its name from the sequential flow of project phases, resembling a cascading waterfall (Figure 5). Each phase is linearly executed, necessitating the completion of one phase before the subsequent phase can commence. The Waterfall Model operates on the premise that software requirements are fully defined and unambiguous from the project's outset, with minimal changes anticipated during its progression. Consequently, this model remains suitable for projects that are characterised by distinct and stable requirements, enabling effective planning. However, challenges arise when unexpected modifications occur, necessitating adaptations that the Waterfall Model is less equipped to handle (Casteren, 2017).

[3] https://agilemanifesto.org/

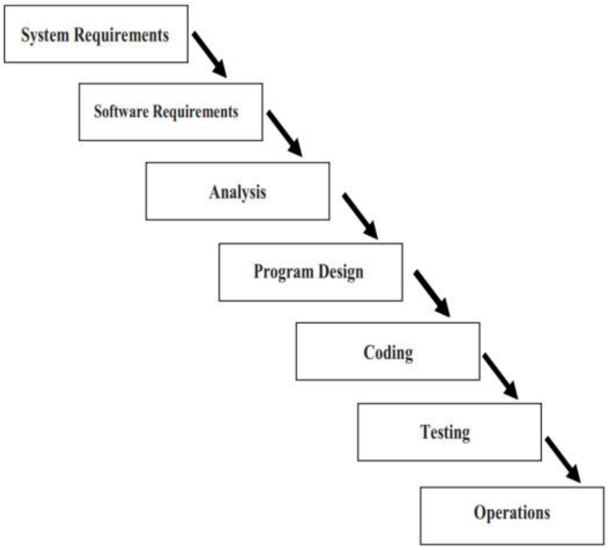

Figure 5: Waterfall Model (Casteren, 2017).

The delineation of tasks necessitates a corresponding division of roles within software engineering. The work is organised into specialised and delimited departments. Within this structure, SEs bear primary responsibility for the technical aspects, particularly in the construction of software systems. In support of this notion, Reece (1985) characterises SEs as ‘problem solvers’ and ‘practical people’ in her article ‘The Role of Software Engineer in the System Design Process’. Foster (2014), almost three decades later, still concurs with this perspective, noting that SEs have a relatively inconspicuous role in the overall software engineering process.

The turn of the millennium witnessed the emergence of Agile Methods, which encompass a collection of iterative approaches within the software engineering domain (Hamid et al., 2020; Sharma et al., 2012; Cohen and Costa, 2004). These methodologies prioritise flexible adaptation to changing requirements and foster close interdisciplinary collaboration. Software products or services are developed in short periods, which are referred to as ‘sprints’, with a focus on continuous testing and improvement. Notably, Scrum (Elahe and Hasan, 2014) stands out as the most prominent example of Agile Methods. This method is widely regarded as playing a ‘central role in the software industry’ (Hayat et al., 2019). Originating from rugby, the term ‘Scrum’ denotes a game action in which players bond, offering mutual support and deliberating on the next move. Figure 6 illustrates that the three roles in Scrum – Product Owner, Scrum Master, and Scrum Team (including SEs) –position themselves on an equal level, without a hierarchical distinction. Close team communication among all participants, as well as project transparency, constitutes a pivotal factor within this method.

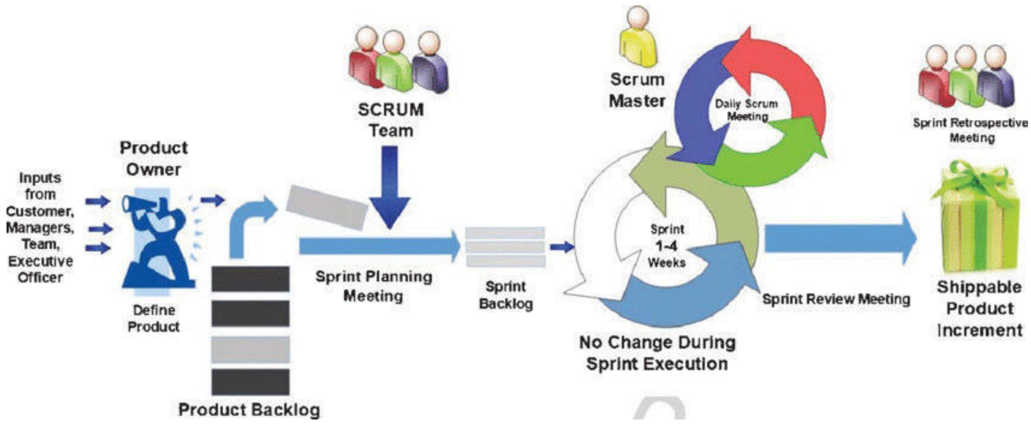

Figure 6: Scrum process as an example of Agile Methods (Hamid et al., 2020)

This dissertation is not aimed at delving into all the components depicted in the diagram presented here due to its limited scope. However, the role of SEs has expanded, becoming ‘broader and more heterogeneous’, as highlighted by Meade et al. (2019). This evolution has transformed the software engineering process into a ‘complex socio-technical activity’. Alexander and Robertsen provide evidence of this paradigm shift through the observation of job title changes and department renaming (2004). Foster (2014) further emphasises that SEs should be well informed about organisational planning changes, as their versatile knowledge can prove valuable at any stage of the software engineering process. In theory, he explains, SEs should be equipped to serve as key points of contact for the implementation of sustainability in industrial projects.

However, in their study on sustainable software development, Fontana et al. (2015) argue that ‘real decision-makers’, such as product designers and product managers, are those who should receive direct access to the body of sustainability knowledge. According to the authors, these employees are responsible for evaluating, comparing, and ranking alternative products, product elements, technologies, suppliers, energy sources, and transportation means. Therefore, it can be argued that interface professionals in the workspace, who oversee the selection, organisation, and management of sustainability approaches (as discussed in the previous section), should be considered the appropriate contact persons within the software company with regard to sustainability because they possess the necessary expertise to navigate the intricacies of decision-making processes.

In our related study (Oyedeji et al. 2021), we conducted workshops and an interview study with software practitioners (n=13) that confirmed the findings of the aforementioned evaluation (the interview studies presented in section ‘1.1.2 Sustainability in the Software Engineering practice’):

- None of the participants defined software sustainability that encompassed all three dimensions of the TBL. Social sustainability was entirely overlooked by all participants.
- Among junior-level software practitioners, 75 percent lacked any knowledge of sustainability, while the remaining 25 percent only had a partial understanding. In contrast, at the middle to senior level, 75 percent of participants demonstrated existing knowledge of software sustainability, while the remaining 25 percent struggled to incorporate any sustainability knowledge into their definition.
- A significant majority (95 percent) of participants regarded the economic dimension as a crucial factor in sustainability.

The findings highlight the need to align academic understanding with the current state of software sustainability in the software industry.

2.3 The Karlskrona Manifesto for Sustainability Design and the Sustainability Awareness Framework (SusAF)

One of the most important steps towards software sustainability dates to 2014. Here, a group of international scientists gathered to establish the Karlskrona Manifesto for Sustainability Design.[4] The signatories advocated for the integration of sustainability into the work of software practitioners (Becker et al., 2014; Becker et al., 2015). The principles of the Karlskrona Manifesto state that sustainability is systemic and that it cannot be treated in isolation from its environment. Software systems inevitably lead to multidimensional impacts that can be characterised as social, individual, environmental, economic, and technical. Thus, software practitioners must think and act in an interdisciplinary way, i.e. beyond their disciplinary boundaries. From these principles, the signatories developed the SusAF[5] to help software practitioners identify and discuss the impacts of software systems for consideration in the design phase.

The SusAF is a tool that facilitates the identification of five sustainability dimensions (Table 1) and three levels of impact (Table 2) within software systems. The SusAF employs a workshop-based process, consisting of a set of questions and a template, to visualise the impacts of a software system in a diagram (Figure 7), which aids participants in analysing and discussing these impacts. For a detailed description of the SusAF, a workbook is attached in the appendix of this dissertation.

[4] https://www.sustainabilitydesign.org/
[5] https://www.suso.academy/en/sustainability-awareness-framework-susaf/

Table 1. Five dimensions of sustainability are based on the SusAF (Penzenstadler et al., 2020).

Dimension	Description
Social	'covers the relationships between individuals and groups'
Individual	'covers the individual's ability to thrive, exercise their rights, and develop freely'
Environmental	'covers the individual's ability to thrive, exercise their rights, and develop freely'
Economic	'covers the financial aspects and business value'
Technical	'covers the technical system's ability to accommodate changes'

Table 2. Three types of effects are based on the SusAF (Penzenstadler et al., 2020).

Effect	Description
Immediate	'are direct effects of the production, operation, use, and disposal of socio-technical systems'
Enabling	'of operation and use of a system include any change enabled or induced by the system'
Structural	'represent structural changes caused by the ongoing operation and use of the socio-technical system'

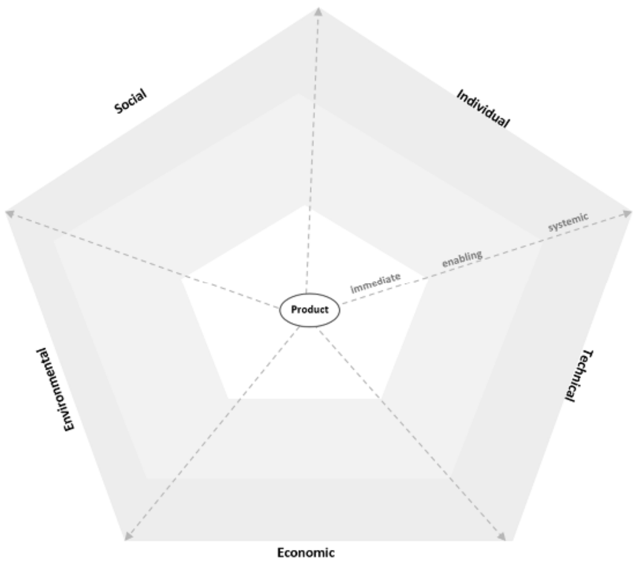

Figure 7: SusAD (Penzenstadler et al., 2020).

Given the intricate task of analysing the potential impacts of software systems on sustainability, a recent discussion paper by Seyff et al. (2022), which was complemented by Brooks et al. (2023), evaluate the extent to which the sub-items of the SDG align with the questions posed by the SusAF. Hence, the authors conducted an initial mapping exercise. This mapping was aimed at establishing connections based on shared or similar terminologies. The analysis of this mapping revealed a significant number of interconnections, as depicted in Figure 8.

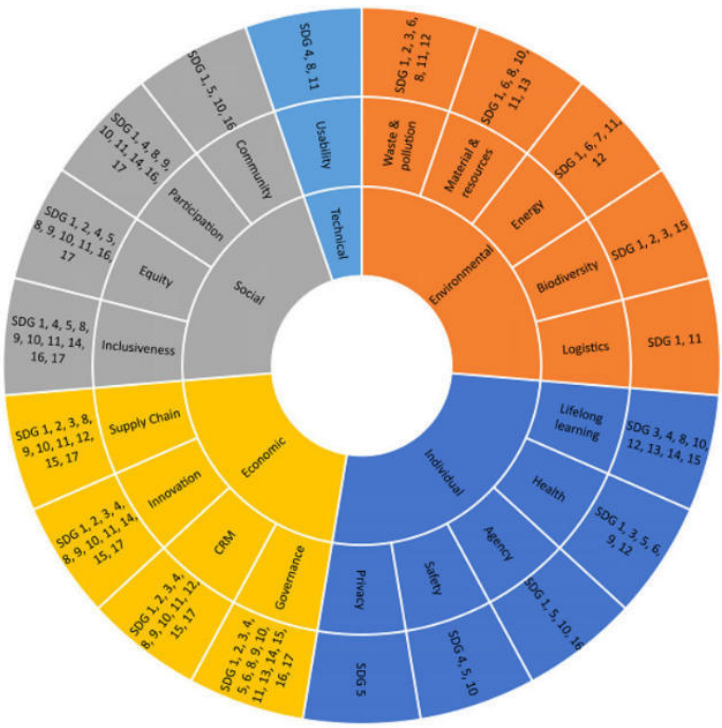

Figure 8: Mapping between SusAF and SDGs (Seyff et al., 2022).

The researchers demonstrate the existence of numerous intersections between the SusAF questions and the descriptions of the 17 SDGs. Accordingly, they emphasise the need to develop appropriate methods and tools to effectively address the challenges in software and requirements engineering.

3 Research Design and Methods

This chapter embodies the research approach employed in the dissertation. The first section presents the research gap and the rationale behind addressing it. The second section introduces the research philosophy underpinning this thesis. The third section delves into the research approaches associated with this study. The concluding section outlines the ethical principles governing the research.

To adequately capture the complexity of this chapter, Figure 9 will be referenced at the outset, summarising the research process in an illustrative manner. The arrows within the "stage" category depict the iterative nature inherent to the dissertation, firmly rooted in the DSRM.

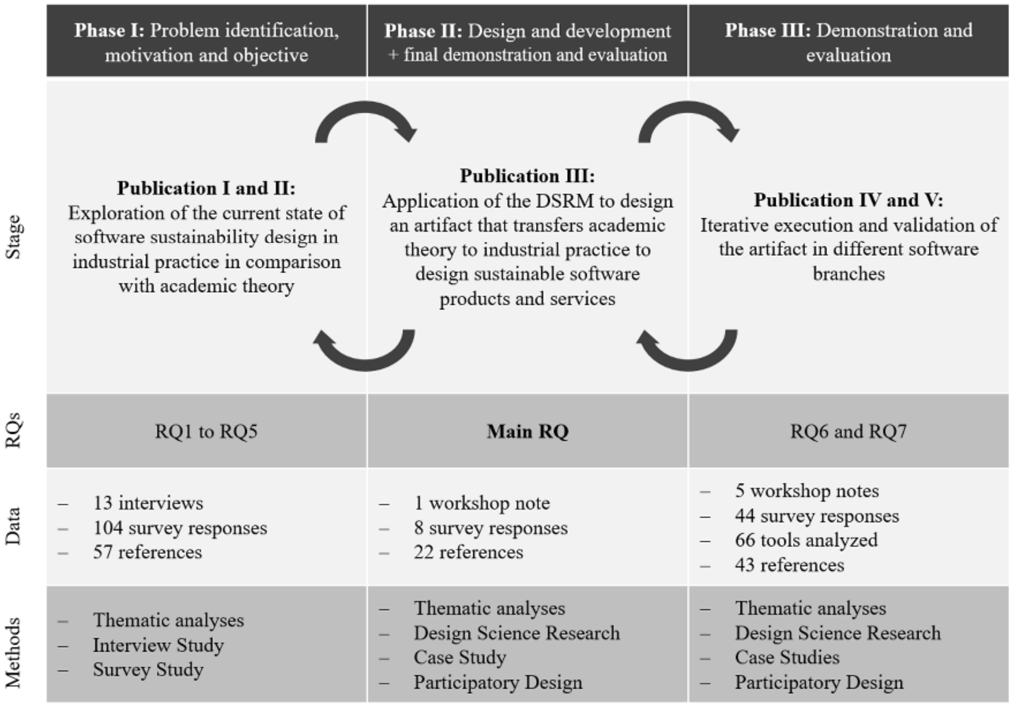

Figure 9: Research Approach Overview II

3.1 Research Gap

The preceding chapter has revealed that sustainability is a relatively nascent field within software engineering. Consequently, numerous unanswered research inquiries have emerged, particularly in the context of industrial practice. The overarching RQ is formulated as follows:

- *Main RQ:* How can industrial software practitioners be enabled to effectively integrate sustainability design into their requirements engineering process?

Despite advancements in scientific understanding, the extent to which software companies have genuinely transcended traditional role patterns and embraced a broader perspective beyond technological aspects remains unclear. Sociological literature suggests that roles tend to become entrenched over time, hindering change, even when desirable (Goffman, 1957). Consequently, the interview study (Publication I) conducted in Phase I addresses two subordinate RQs:

- *RQ1*: How do SEs describe their role in daily business?
- *RQ2:* What importance do SEs attach to the topic of sustainability?

While sustainability gains increasing attention within the scientific community, it is crucial to explore how this development is perceived and addressed within the software industry. The survey study (Publication II), which is also part of Phase I, is aimed at answering three questions to obtain a comprehensive understanding of sustainability in the software engineering process within industrial settings:

- *RQ3:* How do software practitioners assess sustainability in the software company in general and in their field of activity in particular?
- *RQ4:* What role do different employee positions play in terms of responsibility for sustainability?
- *RQ5:* What motivates software practitioners to set sustainability goals?

Phase II, employing the DSRM (Publication III), focuses on the *main RQ* derived from the previous findings. The objective is to develop an artefact that bridges the gap between theoretical knowledge from academia and practical application within the software industry.

In Phase III, which encompasses iterative artefact development, two RQs are addressed (Publications IV and V):

- *RQ6:* How should software practitioners focus their attention in terms of sustainability impacts when developing artificial intelligence (AI) software?
- *RQ7:* What should software practitioners consider before embarking on the design of digital solutions in thanatopractice?

The answers to these two RQs are specifically limited to the respective application areas and serve as preliminary insights, providing a foundation for future studies. However, the publications in Phase III are primarily aimed at further refining the artefact. The results obtained in Phase III are subordinate to the main RQ. Consequently, the substantive findings should be mentioned here only insofar as they contribute to conclusions about the artefact's development.

3.2 Research Philosophy

The dissertation follows an *explorative mixed-method approach*, which is aimed at acquiring novel insights within the research field and at examining existing phenomena from a new perspective. In this regard, the emphasis is on generating knowledge and fostering a deeper understanding of the research domain, rather than solely testing and validating hypotheses. It is worth addressing potential concerns regarding the generalisability of findings that may arise. However, it should be emphasised that the insights obtained serve as a valuable basis for subsequent quantitative studies. Additionally, the phenomenological approach employed in this study warrants attention as it captures the subjective experiences of participants, allowing for the inclusion of their perspectives. Nevertheless, it is important to acknowledge that the exploratory nature of this approach may render it susceptible to subjective interpretations and biases, potentially raising questions about the objectivity of the results. To mitigate these concerns, multiple researchers meticulously reviewed the interpretations across all studies. Furthermore, participant diversity was considered during the recruitment process, and stakeholders were actively engaged in the selection process to ensure comprehensive representation before the artefact was conducted.

The adoption of *Design Science Research (DSR)* proves highly suitable, given its objective of comprehending and improving design processes through iterative artefact development and critical evaluation. DSR is particularly valuable when addressing 'unsolved and important business problems' (Hevner et al., 2004). The DSRM, which relies on in-depth *Case Studies* involving organisations and groups, served as the foundation for this research. The publications encompassed six distinct case studies that examine software systems across various industries. These case studies enable in-depth and contextual analyses, providing qualitative and quantitative data to test and utilise the artefact. While case studies offer rich insights into individual cases, they do not provide comprehensive statistical generalisations (Sneed et al., 2020).

The case studies were applied on the basis of *Participatory Design*. The overarching goal of this approach is to give heterogeneous ensembles of stakeholders (directly and/or indirectly affected persons of the respective software product or service) the opportunity to actively participate in the design process. The resulting multidisciplinarity makes it possible to derive recommendations for actions. Participatory Design undergoes four phases: requirements analysis, analysis and design, implementation, and testing (Simonsen and Robertson, 2012). In our case studies, we focus only on the first phase (requirements analysis) as an initial step in the respective emerging research area within the design phase of software engineering.

3.3 Research Approach

The methods within the three phases are detailed below.

3.3.1 Phase I: Problem identification, motivation, and objective (Publications I and II)

The initial phase is based on qualitative and quantitative research approaches that are aimed at developing a comprehensive understanding of the current state of practice regarding theoretical knowledge, practical utilisation, and motivation of sustainability in application. To achieve this objective, two studies were conducted: First, qualitatively, an interview study involving 13 SEs from different software companies *(Publication I)*; second, quantitatively, a survey study with 104 survey responses from industrial software practitioners with 14 different job positions in total *(Publication II)*. These studies, in the context of the DSRM, contributed to the artefact through problem identification, motivation, and objective.

- *Methods:* The interview study is an explorative qualitative research approach following the guidelines of Elmer (2016). The interview guide has a semi-structured concept. This form of interview is time-consuming in its execution but is a suitable instrument for collecting extensive statements. The interview was divided into two parts. The first part pertained to the profession of SEs in general, i.e. the tasks and responsibilities as well as the self-role attribution associated with them. The second part pertained to the implications of the software products and services built by the company.
- *Participants:* Twelve of the interviewees work in Germany and one interviewee works France. All interviewees are employed in small and medium-sized enterprises in various sectors: finance (2), information technology (IT) Security (2), web and App development (2), big data, e-commerce, energy, environment, language learning, marketing, and social media. Their professional experience as SEs ranges from 2 to 22 years (7.7 years on average). All SEs were aged between 29 and 55 years and male.
- *Data analysis:* The interviews were recorded and transcribed. We chose an open coding strategy, in which two researchers coded the interviews through a deductive category application and peer-reviewed each other's work. A codebook was drafted, and a compromise was sought in the case of a disagreement.

The survey study was designed as follows:

- *Procedure and methods:* To supplement the previous interview study with a broader generalisability and statistical analyses by conducting a larger sample size (n), the design of the survey study is based on the process established by Pfleeger and Kitchenham (2001). Descriptive surveys are conducted with the intent to explore a particular population group – in this case, industrial software practitioners. The survey questionnaire covered perception, responsibility, and motivation in the area of sustainability within the respective company.

- *Data collection:* The participants of the survey study were assigned to 14 different job positions with varying numbers of years of work experience. A range of 13 corporate sectors is given, with employee numbers ranging from 10 to over 250. In the evaluation, attention was paid to the comparison among job roles in addition to the total: the 'technical role' (TR), which included software engineers, software developers, and software architects (n=54), and the 'management role' (MR), which consisted of project managers, product owners, and business development managers (n=21).
- *Data analysis:* Within the data analysis, we also followed Pfleeger and Kitchenham (2001), who refer to the trinity of data validation, partitioning, and data coding. Two types of closed-ended questions were used: binary questions (yes/no/not sure) and a five-point Likert scale. This approach allowed the calculation of averages and the normalisation of responses to standardised procedures, which helped access a quantitative analysis.

3.3.2 Phase II Design and development, plus final demonstration and evaluation (Publication III)

The first phase yielded significant findings, indicating that organisational and content-related requirements within companies are inadequately addressed by existing academic sustainability approaches. As a result, the second phase focused on applying the DSRM to facilitate the translation of these requirements into an artefact (Figure 10). This endeavour involved the implementation of participatory action research, which was carried out through a series of case studies.

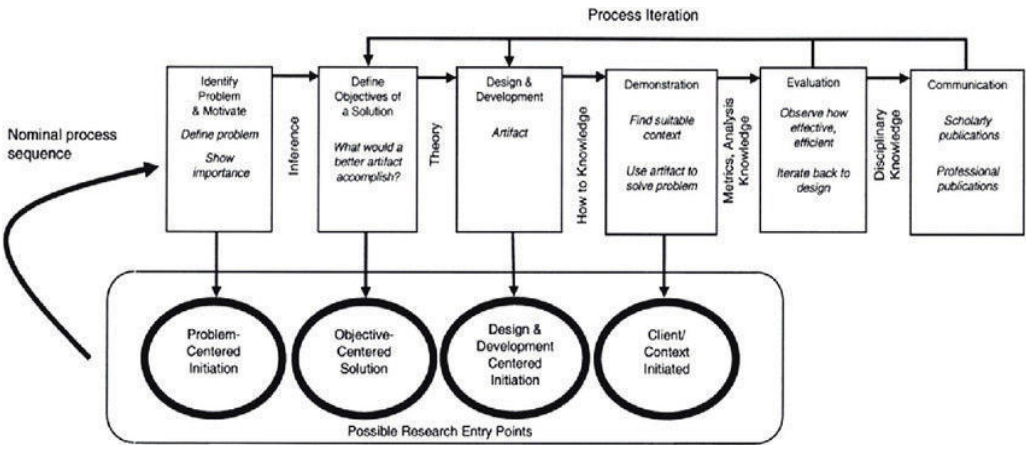

Figure 10: DSR process model by Peffers et al. (2008).

- *Procedure and methods:* In conducting DSR, we followed the model of Peffers et al. (2008), which, as noted by Brocke et al., is one of the most widely employed DSR models (Brocke et al., 2020). We strictly followed the given six steps in conducting the study: 1) problem identification and motivation; 2) definition of the objectives for a solution (conducted in Publications I and II); 3) design and development (conducted in this Publication); and 4) demonstration and 5) evaluation (conducted in Publications IV and V); and 6) communication. We conducted a total of six case studies, in which we expanded the artefact step by step, whereas the sixth case study was performed in this study.
- *Participants:* The final case study, in which the artefact is presented using the example of software for the automated analysis of manuscripts in the publishing industry, consists of eight participants following the participatory design approach. Four of the participants were employed by the company, and four participated as external stakeholders. A webmaster in the role of project manager guided the participants through the BE-SusAF. The participants were between 33 years old and 67 years old, of which three were female and five were male, and collectively had between 5 and 41 years of experience in their field of activity.
- *Data collection:* The results of the case studies were recorded. Additionally, we conducted a survey among the participants, focusing on the content, structure, and (possible) extensions.

3.3.3 **Phase III: Demonstration and evaluation (Publications IV and V)**

The subsequent two publications adopt a similar approach, primarily differing in their thematic focus. Publication IV explores three AI-based software systems, namely, autonomous driving, music composition, and memory avatars. On the other hand, Publication V centres around thanatopractical software systems, specifically, online pastoral care, virtual graveyards, and memory avatars.

- *Procedure and methods:* Both studies use the intermediate version of the artefact within the DSR. In both studies, in addition to the case studies, the participatory design approach should be mentioned.
- *Participants:* In the total case studies, there were 44 participants, including internal and external stakeholders (nine on average), as described in Phase II. The participants ranged in age from 18 to 69, with an average age of 30.2. There was an equal distribution of female and male participants. Their experience in the field under consideration ranged from less than one year to 38 years (average of 4.8 years).
- *Data collection:* The results of all five case studies were recorded. At the end of the workshop, we conducted a survey with questions about the participants, sustainability awareness, conduction and process of the workshop, comprehensibility, time factor, and improvisation. Two researchers independently analysed the data to compare the findings. A discussion about the contradictions followed, which lasted until both researchers could agree on the results. The data served as a basis for improving and expanding the next workshop.

3.4 Research Ethics

All five publications adhere to the ethical principles of research as outlined by TENK (Finish Advisory Board on Research Integrity, 2012). These principles provide comprehensive guidelines for the planning, execution, and dissemination of research. In accordance with these guidelines, the participants of the empirical studies were fully informed about the research purpose. They were provided a clear understanding of the methodological procedures employed and, upon request, granted access to the study results. Utmost confidentiality was maintained to ensure the protection of the collected data. These measures were implemented by the *European General Data Protection Regulation (GDPR)*, which was enacted on 25 May 2018, to enhance the safeguarding of personal data and strengthen individuals' rights to their own data (European Parliament, 2016).

4 Explorations

This chapter provides a comprehensive overview of the five publications included in the dissertation. Each publication is structured into three key sections: 1) background and objectives, 2) results and main contribution, and 3) relation to the overall thesis. However, these synopses only provide a condensed summary of the publications. For a more thorough insight, reference should be made to the complete and original versions, which are provided at the end of the dissertation. The second section of this chapter offers a summary of the design reflections. The aim of this section is to provide a concise overview of the design considerations and insights derived from the research process.

4.1 Overview of the Publications

4.1.1 Publication I: Software Engineers in Transition: Self-Role Attribution and Awareness for Sustainability

Background and objectives

Within an industrial context, software can be conceptualised as the outcome of a unique collaboration involving employees and other stakeholders (Meade et al., 2016), as depicted in Figure 11. A diverse ensemble of roles, including SEs, collectively contribute to the development of a software product or service. Consequently, these collaborative efforts have implications for sustainability outcomes.

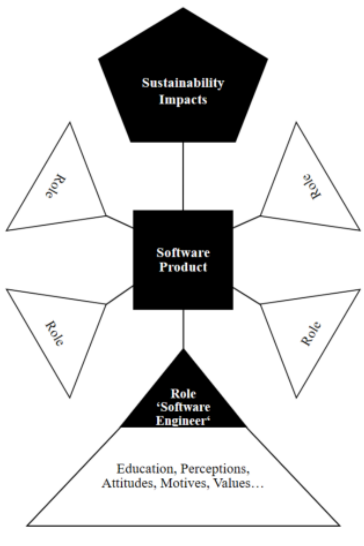

Figure 11: Software products as an outcome of the collaboration of roles and its sustainability impacts (Lammert, 2021).

The evolution from the Waterfall Model to Agile Methods, starting with the Manifesto for Agile Software Development signed in 2001 (Beck et al., 2001), prompted a far-reaching change in the profession of SE. This evolution is illustrated in Figure 12.

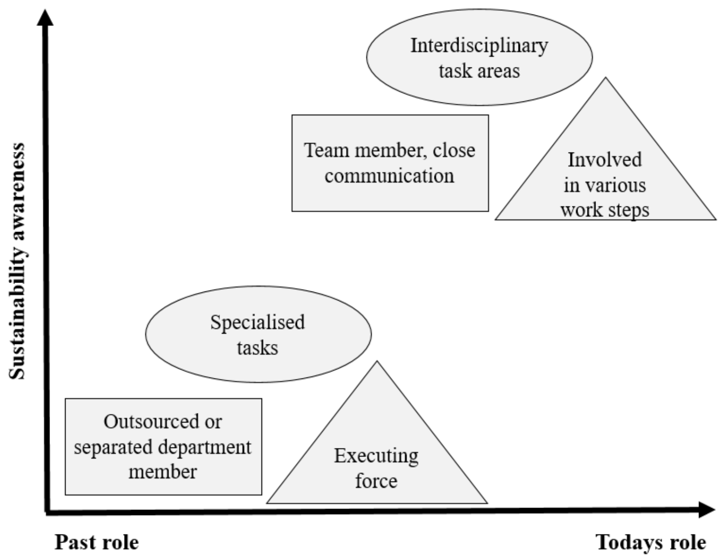

Figure 12: Self-role attribution and sustainability awareness of SEs in the past and today (Lammert et al., 2022).

Formerly, SEs held more executive positions. However, their role has evolved, and they now engage in various stages of the software engineering process. Consequently, their areas of responsibility have become interdisciplinary rather than confined to technology-specific domains. Throughout the software development lifecycle, from design to market launch, SEs actively contribute to planning and financial decisions and provide technical expertise (Sommerville, 2015; Bourque and Fairley, 2014). To facilitate collaboration, SEs are often organised in cross-disciplinary teams, emphasising close communication rather than being isolated in separate departments or relying solely on outsourced IT service providers (John et al., 2015; DeMarco and Lister, 2013; Wohlin et al., 2015).

Additionally, the Karlskrona Manifesto for Sustainability Design (Becker et al., 2014; Becker et al., 2015) highlights another aspect of SEs' responsibility: The consideration of the multidimensional impacts (social, individual, environmental, economic, and technical) and multi-layered impacts (immediate effects, enabling effects, and structural effects) associated with software systems. The SusAF, which is introduced in workshops, addresses these impacts.

Given these developments, it raises questions about the readiness of SEs in industry to meet the new requirements presented by academia. This study is aimed at examining the role of SEs, including their self-perception and awareness of sustainability. Through 13 interviews with SEs, we sought to understand their perception of their own role and the extent to which they integrate sustainability into their daily work.

Results and main contribution

The analysis of the interviews reveals discrepancies between academic theory and industrial practice, encompassing the role of SEs and their awareness of sustainability.

Tasks, skills, and competencies: The interviewees identify five areas of activity: technology, communication, project management, finance, and others (generating ideas, learning, presenting, holding workshops, or even campaigning and political work). This result confirms the interdisciplinary nature of their profession. However, they evaluate the success of their work based on their programming skills, emphasising the importance of ‘efficient code’, ‘good coding’, ‘satisfying outcome of code’, ‘clear code’, ‘clean code’, and ‘working code’. The technological component remains in central focus.

Relationship with other stakeholders: The significance of social skills is evident in statements describing interactions with other professionals, such as product owners, customers, designers, facilitators, marketers, project managers, and scientists. Nonetheless, SEs still perceive themselves primarily as the executing force, referring to themselves as ‘doers’, individuals who ‘get things done’, and those who ‘really focus on getting stuff done’. Consequently, they seek ‘clear tasks’ on which to concentrate.

Working environment: The interviews emphasise the distinction between SEs and other team members in terms of the working environment. SEs desire ‘undisturbed work’, ‘room for silence’, and ‘room for concentration’.” One interviewee even suggests the need for two separate rooms: one room for collaborative exchange and another room for focused execution.

Integration throughout the design process: SEs are primarily included in the design process to provide a technical perspective and identify compromises between ideal design and practical feasibility. SEs also play an indispensable role in addressing financial considerations, requiring a business-oriented mind-set. However, their technology-focused mind-set tends to slow processes, and a lack of communication skills is recognised. One interviewee specifically highlights the need for someone who can effectively communicate with SEs.

*Awareness for sustainability***:** Only two of the 13 SEs consider the importance of ethical issues in their activities. Regarding sustainability, eleven SEs mention data security as an important concern (individual dimension), while two SEs do not perceive themselves as directly confronted with sustainability issues in their work. Nevertheless, nine SEs acknowledge the significance of impacts that need to be considered in the software design process. Only three SEs reported receiving sustainability training during their education.

Relation to the whole

This study has provided valuable insights into the limited implementation of the academic understanding of SEs in industrial practice. The findings regarding self-role attribution and sustainability awareness among industrial SEs differ from the prevailing academic perspective within the field of software engineering. The results confirm the results of the interview studies mentioned in the background and related work chapters (see sections '1.1.2 Sustainability in the Software Engineering practice' and "2.2 Sustainability as an area of responsibility for SEs and REs").

In relation to the artefact, it became evident that SEs have limited suitability for the planning, organisation, and facilitation of workshops. This limitation stems from their technological focus and lack of consideration for organisational issues, despite the SusAF being rooted in the software engineering discipline. The interview results suggest that individuals in interface positions (e.g. IT product managers and product owners) are better suited for this role, as they bring an interdisciplinary perspective to the table, as stated by Fontana et al. (2015).

4.1.2 Publication II: Sustainability in the Software Industry: A Survey Study on the Perception, Responsibility, and Motivation of Software Practitioners

Background and objectives

Several SLRs during the last decade highlight the increasing importance of sustainability within software engineering (e.g. Imran and Koster, 2022; Gustavsson and Penzenstadler, 2020; Calero et al., 2013). This development also seems to have arrived in the software industry, as evidenced by empirical studies. Software companies understand sustainable software products and services as a strategic goal and a prominent challenge in improving a customer's quality of life (Kwak et al., 2019), as a competitive advantage with the potential for any type of business (Kasurinen et al., 2017), and as a reputational asset for acquiring customers and employees (Bomfim et al., 2014).

However, interview studies with software practitioners, particularly SEs and REs, suggest knowledge and methodology deficits as it pertains to the understanding and implementation of sustainability goals within a software company (Bambazek et al., 2022; Karita et al., 2022; Lammert et al., 2022; Oyedeji et al., 2021; Groher and Weinreich, 2017; Chitchyan et al., 2016). For example, an interview study by Oyedeji et al. indicates that of the 13 software practitioners interviewed, not one was able to provide a definition of sustainability that combined social, environmental, and economic dimensions (in the sense of the trinity of the TBL).

In this respect, Wolfram et al. (2017) argued in their Systematic Mapping Study for the use industrial software engineering practices to bridge this gap, which they observed in the dual role of software companies: It is necessary to meet the multidimensional complexity of sustainability while maintaining profitability and competitiveness. Because software sustainability is becoming increasingly important in academia, the need to improve the understanding and implementation of software sustainability in industrial practice is decidedly high. Therefore, in this publication, we investigate how software practitioners assess the topic of sustainability in their daily work. In this way, we aim to more closely analyse the realities and requirements of companies so that we can incorporate them into the artefact.

Results and main contribution

The study provides results in three areas: 1) perceptions of sustainability in general and in the software company in particular, 2) degree of responsibility with regard to software sustainability, and 3) motivation in setting and implementation of sustainability goals. Notably, a conspicuous distinction surfaces within the employee landscape, distinguishing between two roles:

- roles encompassing a pronounced technological focus (e.g. SEs), referred to as technology-oriented roles or technology roles (TRs) (n=54), and

– roles oriented towards management (such as project managers), termed management-oriented roles or MRs (n=21).

A breakdown of software practitioner respondents' job positions and their company's industry sectors are provided in Tables I and II within this publication.

Perception of software sustainability: In general, the participants evaluated their level of knowledge as modest, with an average score of 2.2 on a scale ranging from one (very low) to five (very high). Participants in TRs marked their understanding as lower at 1.9, while those in MRs rated their comprehension notably higher at 2.9, suggesting a moderate level of awareness. Regarding the significance of sustainability, the overall rating leaned towards modest, garnering a score of 2.8 out of 5 (where one indicates very low relevance and five signifies very high importance). Among the TRs, sustainability's relevance was rated slightly lower at 2.6, whereas the MR group assigned it a higher rating of 3.5, signifying a high relevance. This distinction is also mirrored in the responses concerning whether a greater workload pertaining to sustainability is desired within the company. Among all respondents, slightly more than half (51%) responded positively, while 28% expressed uncertainty and 21% replied negatively. Of the participants in TRs, 49% favoured a heightened workload in this regard, whereas 64% of the participants in MRs favoured a heightened workload.

Responsibility for software sustainability: Regarding their specific spheres of responsibility, the assessment of sustainability was marked with a middling rating of 2.5 on average (see Table 3). In the context of TRs, sustainability tended to receive a score of 2.4. Conversely, participants in MRs leaned towards categorising it as moderately significant, registering a value of 2.8. When scrutinising the prioritisation of individual sustainability aspects, disparities between the total respondents and those in TRs showed minimal variations, ranging from 0.2 to 0.4 on the downside. However, participants in MRs demonstrated elevated values across all dimensions, ranging from 0.1 to 0.8 on the upside.

Table 3. Importance of sustainability in general and in the dimensions of one's area of responsibility (n=104).

Role	***General***	***Soc.***	***Ind.***	***Env.***	***Eco.***	***Tec.***
MR (n=21)	2,8↑	3,0↑	3,0↑	3,6↑	3,9↑	3,4↑
Total (n=104)	2,5	2,4	2,3	3,0	3,1	3,3
TR (n=54)	2,4↓	2,2↓	2,1↓	2,7↓	2,7↓	3,1↓

The majority of respondents, 66%, reported the absence of a designated employee bearing primary responsibility for sustainability within their respective companies. In contrast, 28% of the respondents affirmed the presence of such a role, while 5% of the respondents expressed uncertainty about the matter. Among the 29 respondents who affirmed the existence of a sustainability-focused position, 41% identified the project manager as the individual responsible within the topic of sustainability. Other highlighted roles included business development manager, product owner, requirements engineer, and chief executive officer, each accounting for 10% of the responses. Notably, no specific position within the TR was explicitly cited in this context.

Motivation for software sustainability: The respondents were tasked with rating the significance of various domains contributing to the realisation of sustainability objectives within their respective companies. The evaluation encompassed nine distinct areas, as outlined in Table 4. The respondents were also provided the opportunity to expound on their motivations, thereby yielding deeper insights. The results underscore a nuanced differentiation: TR held a solitary motivational factor in higher regard than both MR and the overall respondent pool. This finding pertained to the significance of fostering a durable software system – a notion intrinsically linked to a software system's adaptability to change. In contrast, MR exhibited heightened motivation across seven domains, with a solitary instance deviating slightly below the overall average – pertaining to the acquisition of funding. Furthermore, participants furnished motivations that extended beyond the predefined list. These additional impetuses included personal incentives, fostering networked collaborations with partners, investing for the future, surpassing competitors, securing government project contracts, and complying with external mandates.

Table 4. Motivation for setting sustainability goals (n=104).

Motivation	*MR (n=21)*	*Total (n=104)*	*TR (n=54)*
Reduce neg. impacts	3,3↑	2,6	2,3↓
Long lasting software	3,3↓	3,5	3,6↑
Reduce risks	3,9↑	3,4	3,4→
Reduce costs	3,5↑	3,2	2,0↓
Profit	3,1↑	2,9	2,8↓
Image/reputation	3,7↑	3,1	2,9↓
Marketing	3,6↑	3,3	2,7↓
Acquire/bind employees	3,2↑	2,7	2↓
Receive fundings	2↓	2,1	2,1→

In terms of enthusiasm for engaging in a workshop centred around sustainable software design, the collective interest garnered a moderate rating of 3.4. Among the respondents, the majority (34%) signified a 'rather high' level of interest, whereas the minority (7%) indicated a 'very low' level of interest. Within the subset of TR, a relatively elevated interest level emerged, registering a rating of 3.5. Conversely, MR displayed a notably heightened interest level, attaining a value of 4.

Relation to the whole

In our survey study, we were able to demonstrate remarkable differences in perceptions, responsibilities, and motivations for sustainability between industrial software practitioners and current academic theory. Our quantitative results are consistent with previous qualitative interview studies, supporting them with further insights. The artefact benefits from numerous considerations.

Perception of software sustainability: The findings emerging from our study reflect a moderate valuation of sustainability among professionals in the industrial software domain. While a stepwise focus on specific dimensions (e.g. individual dimensions) or aspects (e.g. data protection) can be a logical progression, it entails the potential risk of disregarding other crucial dimensions. In an unfavourable scenario, a software product or service might be deemed sustainable through a selective lens, while a holistic perception of sustainability exposes numerous vulnerabilities. Acknowledging the existing knowledge gaps in the realm of sustainability, a pragmatic approach involves incorporating a heterogeneous ensemble of stakeholders in the requirements analysis through participatory design – a recommendation that is underscored by a variety of studies (Karita et al., 2022; Simonsen and Robertsen, 2012; Mussbacher and Nuttall, 2014; Fontana et al., 2015; Ferrari et al., 2022). This approach tactfully addresses the diverse knowledge levels of individual employees and fosters collaborative synergy.

Responsibility for software sustainability: In the strategic formulation and execution of sustainability initiatives, roles positioned at the interfaces of interdisciplinary expertise, such as project managers, emerge as adept candidates. Notably, among these positions, MRs are frequently singled out as pivotal with regard to sustainability topics. This recommendation is consistent with prior research insights (Duboc et al., 2019; Penzenstadler et al., 2018), and underscores the imperative of cultivating sustainability literacy within future software professionals.

Motivation for software sustainability: Establishing and attaining sustainability goals is accompanied by business imperatives, encompassing factors such as profitability, competitive edge, and risk mitigation. This prompts the inquiry into whether personal, intrinsic motivations alone hold sufficient sway within an industry or if extrinsic, profit-driven motives might wield a more potent influence over achieving sustainability targets. Financial aspects should not be disregarded. The insights gained from our study can potentially serve as a bridge, linking established sustainability design approaches with business design approaches that are focused on the overarching goal of expanding and improving existing artefacts.

All in all, this study forms the fundament for establishing the objectives for the artefact.

4.1.3 Publication III: The Business-oriented Extension of the Sustainability Awareness Framework – a Design Science Study

Background and objectives

Hevner et al. (2004) propose a three-fold division of problem identification and motivation, which forms the basis for defining solution objectives: people, organisational systems, and technical systems. The findings from Phase I served as the initial foundation for establishing the elementary objectives of the artefact. Subsequent observations in the case studies and follow-up surveys revealed additional problems and motivations, leading to an iterative expansion of the objective list.

People: It is questionable whether the orchestration of the workshop should be left to someone in a TR. Another issue is whether the employees within a software company are sufficiently trained in the area of sustainability so that the involvement of external stakeholders in the sense of participatory design becomes indispensable. The following objectives are established to obtain a solution:

- selection of a staff member in an interface role to plan, manage, and follow up on the artefact and
- application of a participatory approach involving a wide range of external stakeholders; the potential client/user occupies a special position within the stakeholder ensemble and should therefore be given special consideration.

Organisational systems: Here, the various structural conditions within a software company, which are the framework conditions for achieving the company's goals, are addressed. In particular, the SusAF lacks consideration of profitability. This business management principle stipulates that income that is at least equal in amount expenditures is generated. The following objectives to obtain a solution were established:

- inclusion of the field of business modelling,
- inclusion of public funding as a supporting instrument, and
- consideration of the time frame.

Technical systems: The artefact should also be independent of the sector. Accordingly, it should apply to a wide range of software systems and not be restricted to one single topic within the case studies.

Results and main contribution

Figure 13 provides a comprehensive overview of the final artefact. Notably, the artefact is organised into three distinct stages: preparation, workshop, and follow-up. The subsequent presentation of the artefact will follow this structure, guided by the objectives outlined in the preceding section.

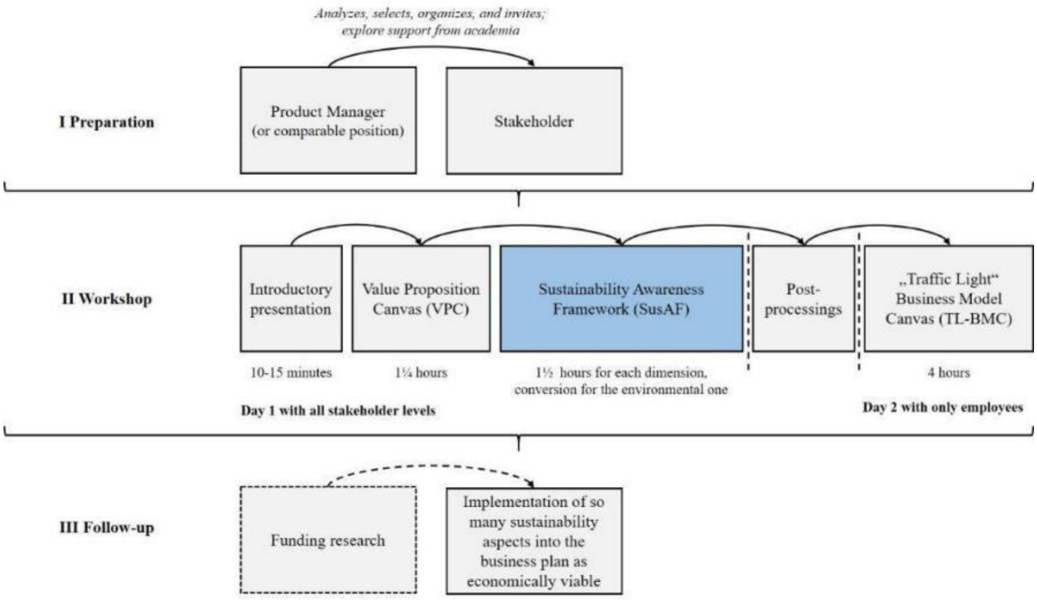

Figure 13: Final artefact: BE-SusAF (Lammert et al., 2023b).

I Preparation

1a) Selection of an employee in an interface function for planning, managing, and following up the artefact: This employee could be someone in an MR, for example, the IT product manager or product owner.

1b) Participatory approach involving a diverse range of external stakeholders: To achieve these objectives, a preliminary stakeholder analysis is necessary. During the workshop, it is crucial to ensure the inclusivity of stakeholders and address their diverse backgrounds and motivations. Figure 14 provides an overview of stakeholder structuring, offering valuable insights in this regard. Collaborating with research institutions is highly recommended, as they possess expertise in recruiting test participants and uphold objectivity in accordance with the principles of scientific rigour.

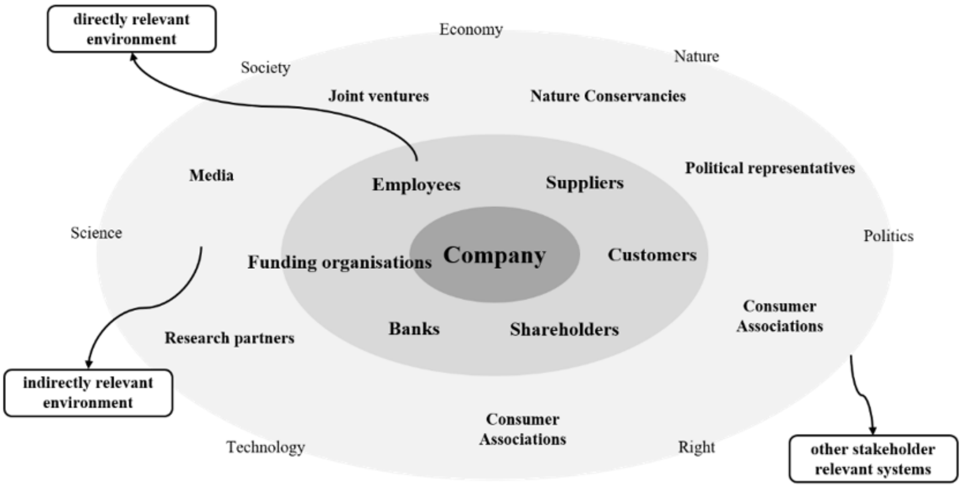

Figure 14: Stakeholder levels (Simonsen and Robertsen, 2012).

II Workshop

Time frame: Consideration of time frame is important, as revealed in our surveys. Ideally, two working days should be planned for the workshop part of the artefact (i.e. excluding preparation and follow-up): Eight hours designated for external stakeholders (presentation, VPC, SusAF, and another four hours designated for in-house stakeholders with the TL-BMC.

2a) Introductory presentation: An introductory presentation is recommended to expand the stakeholders' level of knowledge and thus eliminate fundamental knowledge gaps. In the preparatory phase, stakeholders can also be provided with introductory material to inform them in advance.

2b) Value Proposition Canvas (VPC): The potential customer or user occupies a special position within the stakeholder ensemble. The workshop should utilise the VPC (Osterwalder and Pigneur, 2010), as joins and visualises both the customer side (needs, tasks, challenges, wishes, etc.) and the product side (features, characteristics, functions, etc.), as shown in Figure 15.

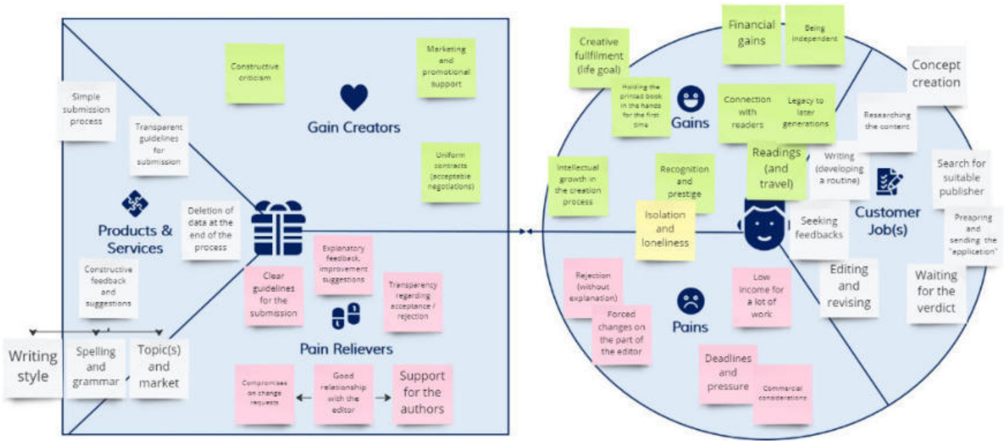

Figure 15: Artefact (BE-SusAF) (Lammert et al., 2023b).

2c) SusAF: The work on the SusAF is the core of the artefact (see Figure 16). A summary of this tool is provided in section '2.3 Karlskrona Manifesto for Sustainability Design and the Sustainability Awareness Framework (SusAF). For a detailed description of the SusAF, a workbook is attached in the appendix of this dissertation.

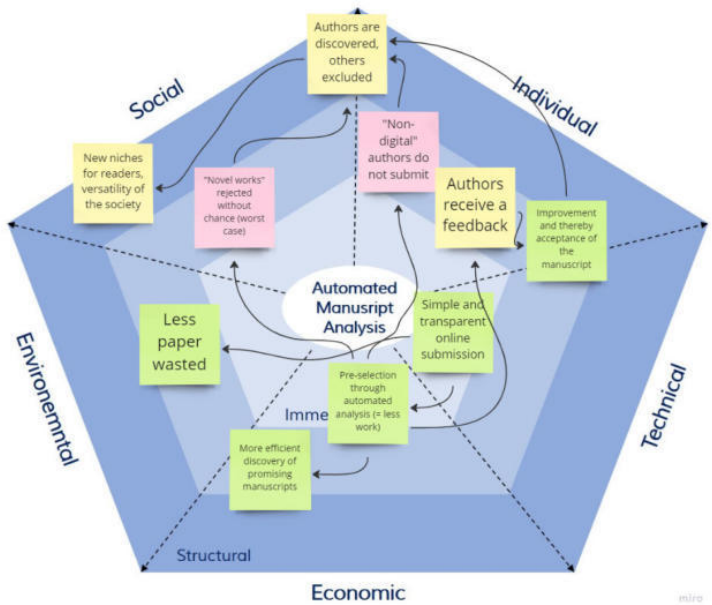

Figure 16: SusAD: automated manuscript analysis (Lammert et al., 2023b).

2d) Traffic Light Business Model Canvas (TL-BMC): After the functionality (within the VPC) and the requirements (within the SusAF) of the software have been gathered, aspects from business modelling should be utilised. Here, the *Business Model Canvas (BMC)*, which gathers the nine key factors of the BMC and relates them to each other, was a suitable approach (Osterwalder and Pigneur, 2010). The BMC has been modified so that stakeholders divide it into three levels: green – sustainable, yellow – appropriate, and red – unsustainable. At this point, the distribution to the sustainability levels is assigned by the stakeholders themselves during the discussion. The extended tool is reminiscent of traffic lights in road traffic, hence the name 'Traffic Light Business Model Canvas' (see Figure 17).

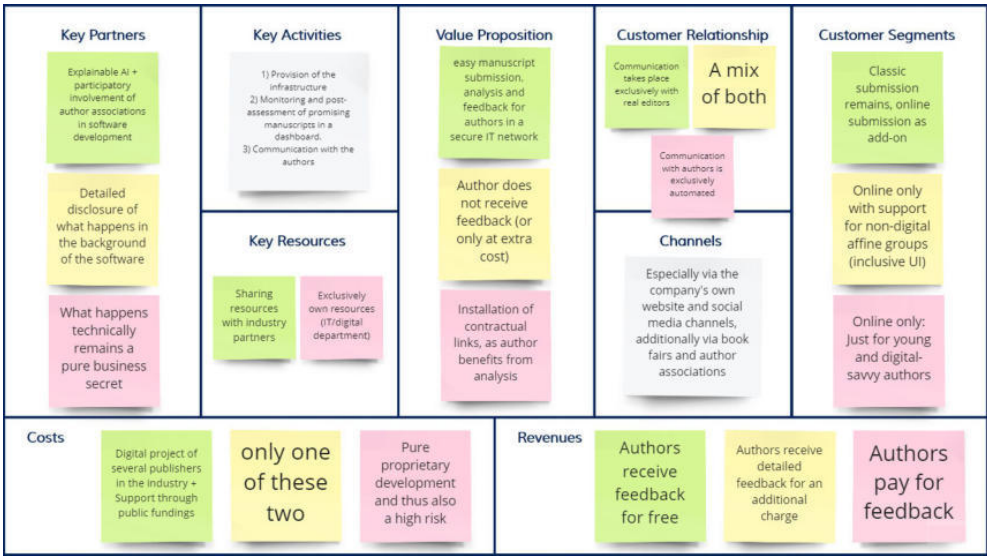

Figure 17: Completed TL-BMC of the workshop.

During the workshops, it became evident that the TL-BMC should be exclusively utilised for internal purposes, excluding external stakeholders. In cases where this protocol was not followed, it became apparent that discussing and deliberating the nine key factors within the BMC required explaining a 'corporate language', thus impeding the progress when external stakeholders had to gain a working knowledge of this language. Moreover, the involvement of external stakeholders proved to be more hesitant and reserved in comparison.

III Follow-up

Funding research: In the follow-up phase, the integration of public funding emerges as a valuable instrument for incorporating sustainability considerations. Public funding can contribute to enhancing the integration of sustainability aspects into the business plan through various means, such as financial support, staff training initiatives, and collaborations with research institutions. Notably, funding opportunities are accessible to small, medium-sized, and large software companies worldwide, spanning across countries on all continents, as documented by Lammert et al. (2022).

Transfer to the business and financial plan: The TL-BMC results provide guidance for incorporation into the final software business and financial plan. The consideration of economic efficiency shows that it should probably prove difficult or impossible to implement only the aspects at the green level. Rather, prioritisation should be based on stakeholders.

Relation to the whole

The artefact serves as a bridge between two distinct design areas: software sustainability design and business model design. By leveraging the DSRM to create an artefact that merges academic knowledge and methodologies pertaining to sustainability in software engineering with industrial practices concerning business planning and corresponding organisational needs. This research endeavour facilitates the establishment of a connection between the academic domain and the industrial domains, thereby making a valuable contribution to fostering collaboration and knowledge exchange between these two spheres.

4.1.4 Publication IV: Sustainability for Artificial Intelligence Products and Services – Initial How-to for IT Practitioners

Background and objectives

IAI is an emerging technology that is increasingly permeating various aspects of our society. While Rahwan et al. (2019) assert that AI will have both intended and unintended consequences in neutral language, Voneky (2020) posits the thesis that AI could potentially lead to the most catastrophic event in human history. Through AI, software companies are confronted with a multifaceted challenge that encompasses not only technical considerations but also ethical implications. This duality is particularly evident in AI systems, where software engineering entails grappling with both technological quandaries and ethical quandaries (Ahmad et al., 2021). Numerous studies have identified a lack of knowledge and methodologies among software practitioners to effectively address the impacts of AI in the requirements phase (Galaz et al., 2021; Khakurel et al.; 2018, Wynsberghe, 2021). According to Suárez and Varona's study, which surveyed 503 courses across 66 universities in 16 states, these essential aspects are inadequately covered in technical curricula (2021).

To aid in the analysis of *Automated Decision-Making (ADM)* and its dual nature, AlgorithmWatch[6], a non-profit research and advocacy organisation, has compiled a comprehensive list of 160 tools. We evaluated these tools for our project, which focuses on integrating sustainability aspects into software products and services. Of the 160 tools, 66 were deemed suitable and subjected to further analysis. These tools can be categorised into three distinct areas:

- Tools at the *first level* are dedicated to multiple and diverse areas; that is, they take a multidimensional view of the impacts that an AI system can have. These are aimed at software practitioners in general. Examples are SusAF and SustAIn.
- The *second level* addresses selected issues such as fairness (e.g. Fairness Aware Ranking) or bias (e.g. Imperial Machines Project). As a rule, these issues are addressed to software developers.
- The *third level* addresses the verification of algorithms, for example, the tools AI-Fariness360 or Fairlearn, which are aimed at data scientists.

At this juncture, it is important to emphasise that the aforementioned tools are not mutually exclusive but rather complementary in nature.

Results and main contribution

Following the principles of the DSRM, a series of case studies was conducted as part of this study, with the overarching objective of designing, developing, demonstrating, and evaluating the artefact. These workshops encompassed three distinct domains: autonomous driving, music composition, and memory avatars. The outcomes of these

[6] https://algorithmwatch.org/en/

workshops, as depicted in Figures 17, 18, and 19, are presented in the form of the SusAD. Note that the results from the VPC and TL-BMC during these three case studies were only presented in Publication III to avoid overloading the content of this study.

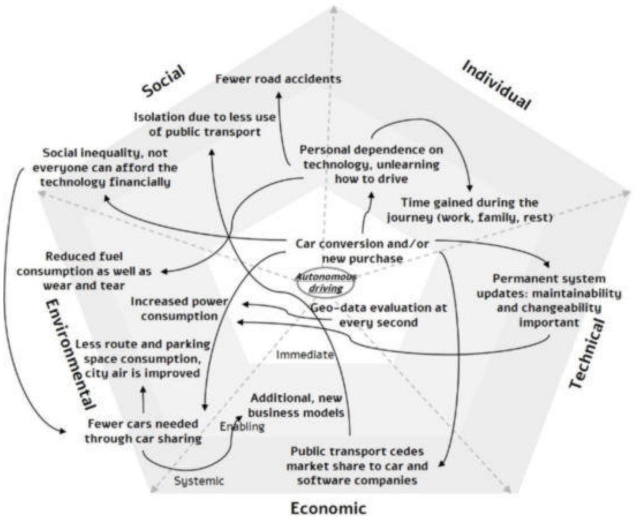

Figure 18: SusAD: autonomous driving (Lammert et al., 2023c).

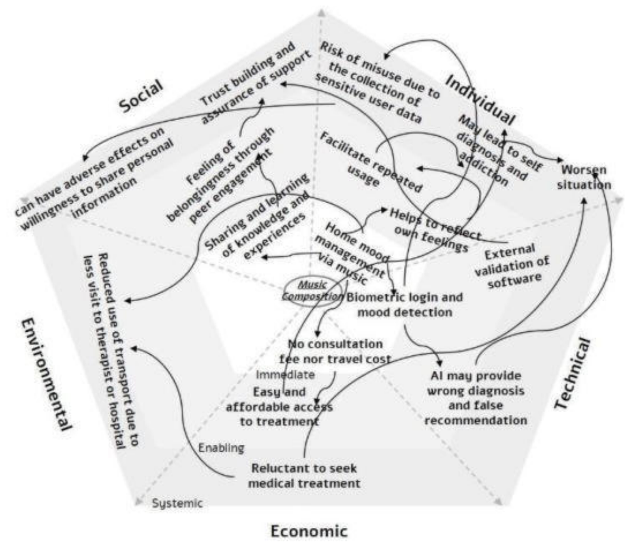

Figure 19: SusAD: music composition (Lammert et al., 2023c).

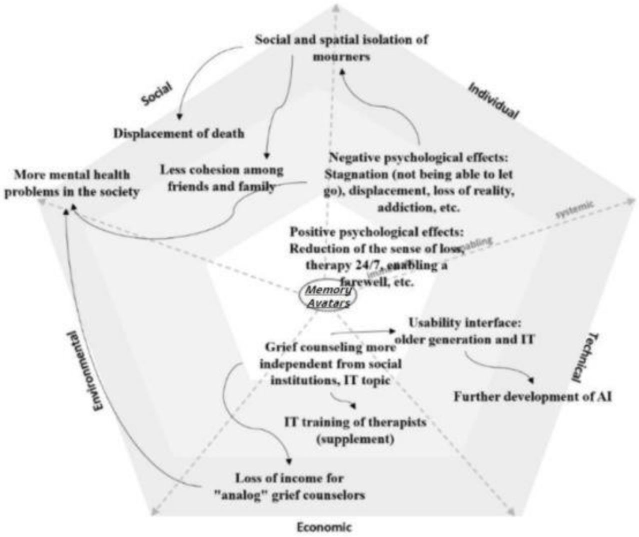

Figure 20: SusAD: memory avatars (Lammert et al., 2023c).

It is beyond the scope of this doctoral thesis to delve into the content of the three topics mentioned above. However, it is crucial to highlight the aspects within the case studies that contribute to the further advancement of the artefact.

It is important to discuss the feedback received through the surveys. Participants from all three workshops unanimously reported a shift in their perceptions and attitudes towards the subject matter. Furthermore, approximately nine out of ten participants acknowledged gaining new insights that they had not previously possessed. Overall, the workshops were deemed comprehensible to highly comprehensible, with participants recognising their potential for promoting holistic sustainability considerations in software products and services. Additionally, nine out of ten participants expressed a desire for training opportunities, such as staff training, and emphasised the importance of continued collaboration and knowledge exchange between academia and industry. Moreover, four out of ten participants highlighted the significance of funding opportunities as enabling mechanisms for realising sustainable AI initiatives.

From the case studies, three key lessons were derived:

Align the knowledge: Especially in complex topics such as AI, basic knowledge on the part of all stakeholders is indispensable to appropriately participating in the workshop. Preliminary information in the invitation, the possibility of preparatory training, and an introductory presentation that covers the technical aspects, in particular, are suitable for this purpose.

A multidimensional tool first, a focusing tool(s) second: Some participants have already delved more or less into selected aspects within the sustainability dimensions. It is important to acknowledge and incorporate these insights into the discussion without delving into excessive detail at this stage (as it pertains to the creation of requirements for software design). Focal points can be established, but they should not overshadow the holistic understanding of sustainability.

Create incentives for sustainable enterprises: This point is directed at stakeholders outside the industrial sector who can assist software companies in implementing sustainability strategies. Two groups are addressed in terms of their needs: Universities could consider providing training, preparing teaching materials for enterprises, and making them publicly available. Policy-makers, on the other hand, could establish support programs that offer financial relief for software companies that take their responsibility seriously.

Relation to the whole

The case studies played a crucial role in the iterative improvement of both the content and organisational development of the artefact, culminating in the final version of the BE-SusAF.

The selection of tools was facilitated by the overview provided by AlgorithmWatch. The SusAF adopts a holistic approach, allowing it to be categorised as a first-level framework. It encompasses multiple and diverse areas, as well as their short-, medium-, and long-term consequences at different levels of impact. This approach facilitates interaction, discussion, and the visualisation of results in a comprehensible manner through the SusAD, benefiting various internal and external stakeholders. Moreover, the practical nature of the SusAF, designed as a workshop, simplifies its application.

Simultaneously, this study has revealed the importance of considering the second and third levels. However, addressing these levels will be a subsequent step based on the findings of the SusAF. Initiating the process at the second or third level, focusing solely on more specific topics, such as privacy and the underlying algorithms, poses the risk of adopting a narrowed perspective that overlooks the ‘big picture’ and therefore relevant aspects within the design phase.

4.1.5 Publication V: ”Changing Death” – Initial Insights for Software Practitioners in Thanatopractice

Background and objectives

The thematic section of this publication showcases case studies that highlight the entering of digital transformation into sensitive areas such as end-of-life care, sepulchral culture, and grief management through online pastoral care, virtual graveyards, and memory avatars. Thieme (2018) acknowledges the increasing individualisation of thanatopractice in recent years, with software products and services facilitating this individualisation. While the subject of death and dying may not always be at the forefront of our everyday lives, it impacts each of us in various stages of life.

In a previous study (Wulf et al., 2022), we categorised the digitisation of Thanatopractice into five themes: 1) *end-of-life care*, 2) *sepulchral culture*, 3) *coping with grief*, 4) *estate administration*, and 5) *transhumanism/posthumanism*. For the purpose of this case study, we excluded the last two themes from the list. Many studies have explored (digital) estate management (e.g. Silva and Medeiros, 2021; Dissanayake and Cook, 2019; Cook et al., 2019), while the other areas continue to raise numerous questions. The subject of transhumanism/posthumanism, although garnering increasing media attention, may not be relevant to all individuals.

- Meier et al. (2016) demonstrate that end-of-life care is a multifaceted issue, encompassing ten needs, such as emotional well-being, family reconciliation, and quality of life. The following question arises: How can software systems assist in meeting these needs, such as by connecting loved ones through voice over internet protocol (VoIP) platforms?
- Sepulchral culture encompasses the rituals associated with funerals and mourning, including eulogies, graveside care, and the management of mementos. Software systems face emotional challenges in this realm as well, such as when creating online memorial sites, which are sometimes included in the service offerings of funeral homes (Bundesverband Bestattungsbedarf, 2016) or when constructing virtual graveyards that can be visited using Virtual Reality (VR) glasses (Häkkilä et al., 2019; Ryan, 2013).
- Coping with grief, as described by Küchenhoff (2011), necessitates conditions that facilitate coming to terms with loss and enabling the bereaved to move forward. However, the introduction of memory avatars that recreate the deceased individual may impede the progression through the stages of grief, as they continue to ‘exist’ in digital form.

Through our case study in this research field, we aim to contribute to critical discussions and advance the application and evaluation of the artefact. This subject that affects everyone and therefore only seems invisible.

Results and main contribution

The finalised SusADs resulting from the workshops are presented in this section (see Figures 20 and 21). However, the data from the third workshop on memory avatars was also utilised in the previous publication. Therefore, it is already reflected in the previous publication (Lammert et al. 2023c) and should not be reiterated. The outcomes of the VPC and TL-BMC were again exclusively retrieved in Publication III.

Figure 21: SusAD of online pastoral care (Lammert et al., 2023d).

Figure 22: SusAD on virtual graveyards (Lammert et al., 2023d).

Similar to the exploration of Publication IV, delving into the detailed content of the examined topics would exceed the scope of this dissertation. Instead, the focus will be highlighting the aspects that contribute an understanding and further development of the artefact.

The survey results indicate that the artefact (or its intermediate version) caused a shift in perception and handling of the discussed software services. This shift was observed in approximately three out of four participants. Nearly nine out of ten participants expressed gaining new insights. All participants believed that the SusAF would impact the services. Participants expressed a desire for ongoing education through staff training, as well as increased collaboration between academia and industry (approximately eight out of ten). Additionally, there was a request for more material related to the BE-SusAF (approximately six out of ten participants). The topic of funding programs was also mentioned by nearly half of the participants.

The case studies yielded further lessons learned, which proved beneficial to the artefact. The most significant lessons are highlighted below:

Engaging external stakeholders as partners: It is crucial to acknowledge the concerns shared by all participants regarding the digitisation of thanatopractice, considering its sensitive nature. The case study participants agreed that digital tools can be valuable as supplementary elements but should not entirely replace analogue forms. As long as this understanding is respected by society and healthcare systems, collaborative ventures can be established between software companies and other institutions. For instance, online networking platforms could facilitate connections among terminally ill individuals, enhancing pastoral care through group conversations. Psychotherapists could integrate AI memory avatars into their therapy sessions to support patients who struggle with unresolved farewells. Software companies could seek partnerships with professional groups initially, such as counsellors and psychotherapists, who are involved in requirements and potential customers. However, marketing strategies that target vulnerable groups, such as the dying and grieving, were met with defensiveness.

Establishing transparent regulatory measures: Representatives from software companies expressed concerns and uncertainty about initiating projects related to thanatopractice. They emphasised the importance of clear regulations to ensure sustainable project implementation. Starting a project that might face cancellation due to regulatory reasons would not be feasible. Engaging stakeholders and establishing transparent regulatory measures can help foster acceptance and confidence.

Taking into account different group needs in the implementation: The workshops conducted during the Coronavirus Disease 2019 (COVID-19) pandemic were held online or in hybrid formats, which posed challenges in participation, especially for older individuals who were less familiar with digital tools. Moreover, it became evident that the needs of participants varied across generations and cultures. Not all groups assessed the digitisation of thanatopractice in the same manner, highlighting the importance of considering diverse perspectives and tailoring implementations accordingly.

Relation to the whole

The case studies served as a means to develop the artefact, leading to the findings that are documented in the BE-SusAF. The most significant findings are presented in a consolidated manner in section ‘4.2 Summary of Design Reflections’.

4.2 Summary of Design Reflections

Publications I to V employ a mixed-method strategy, which collectively aids in identifying approaches to address the requirements of software companies by extending the SusAF through content, structural, and organisational components. Furthermore, a set of design reflections was developed that may provide valuable insights for similar studies in this domain. These reflections can be categorised into five areas, which will be summarised in the following sections.

Recruitment

The recruitment process in Participatory Design research should not be underestimated in its complexity. Researchers should ensure that stakeholders are involved and engaged in the early stages of the study, preceded by a thorough stakeholder analysis. It is important to recruit a diverse ensemble of stakeholders that reflects the complexity of the research field being addressed. Stakeholders encompass individuals, groups, or institutions that are directly or indirectly affected by the activities of a company or those with a vested interest in these activities. By including a range of perspectives and opinions, representativeness can be achieved, thereby mitigating external doubts regarding the study's quality. According to Grunwald (2018), two criteria should be considered: completeness and transparency in stakeholder representation.

During the selection process, it is crucial to acknowledge that stakeholders have different motivations and skill sets based on their roles (e.g. professions). It is also important to recognise that personal backgrounds, including generational differences, cultural influences, and individual values, can influence research outcomes.

To counteract bias, the recruitment process should not be solely entrusted to one person or a specific group of individuals. Here, software companies could partner with research institutions or other appropriate public organisations.

Incentives

At the outset, it is essential to conduct an analysis of potential incentives that can impact the recruitment of participants and motivate engagement within the field. In the case studies of the dissertation, the incentives primarily revolved around the opportunity to contribute to improvements through constructive exchange in relevant social, environmental, and economic discourses. Even if one holds a critical view of the subject area (as evidenced in publication V), it is argued that this critical perspective should be heard and actively participate through feedback within the dialogue.

This premise is significant because participants can expand the knowledge base and value system through their involvement. Contemporary projects are characterised by the collaboration of diverse individuals and groups. It is crucial to foster social interaction among the different participants (Blake et al., 2011).

Trust

Research projects involving collaborations among diverse stakeholders require a high degree of openness and transparency. Therefore, the project's motives should be explained in a manner appropriate to the target audience to generate understanding.

Anticipating objections can help minimise communication risks. It is normal to have limited knowledge in interdisciplinary projects, so researchers or research teams should seek advice from external experts. Organisers must recognise the need to allocate sufficient time in the pre-and post-project phases for engaging in conversations with stakeholders, demonstrating empathy in their approach.

The climate of trust should not be evaluated solely in times of conflict. If necessary, measures to strengthen trust should be implemented.

Feedback

In research, it is crucial not only to allow criticism and suggestions but also to actively encourage them, for example, through explicit inquiries. Regular evaluation of feedback is an integral part of DSR, through both oral feedback during action research and surveys. The participants need to see that their feedback has been incorporated into the work, such as in the discussion section of a scientific publication.

Data Literacy

As discussed in section '3.4 Research Ethics', data literacy is of utmost importance. It should be emphasised that information derived from the data should always be interpreted by at least two researchers. In a subsequent step, these interpretations should be compared and discussed until a consensus that is understandable and comprehensible to all parties involved is reached.

Furthermore, the research findings should be integrated into the academic infrastructure, within science communication prepared in terms of content, and into other sectors such as industry. Through collaboration with software companies and other organisations, it became evident that making the results publicly available in the form of processed information can be beneficial. Science communication contributes to raising public awareness, fostering critical thinking, and promoting new approaches to solutions, which can ultimately benefit society as a whole.

5 Discussion

This chapter is structured into three sections. The first section is aimed at elucidating the research contributions in addressing the main RQ and sub RQs 1-7. The second section focuses on the evaluation of the research, discussing potential threats to validity and acknowledging limitations encountered during the study. The third section presents suggestions for future research endeavours.

5.1 Revisiting the Research Question and Contributions

To be able to answer the main RQ, five publications were executed. In this section, answers to the main RQ followed by answers to sub RQs 1-7 are provided.

Main RQ: How can companies effectively integrate software sustainability design requirements into the business plan?

The artefact is summarised in Figure 13 in the section '4.2.3 Publication III: The Business-oriented Extension of the Sustainability Awareness Framework - a Design Science Study' and explained under the heading 'Results and main contribution'. For a more detailed description of the artefact, it is recommended to read chapter 4 of the original article, which is provided in the appendix of this dissertation. While the artefact focuses on the approaches and their structure, its core principles are elaborated here. These principles allow for transferability to other academic sustainability tools (approaches, models, methods, etc.) that are being developed for industrial software engineering practice. To make these core principles more memorable, they are referred to as the "Four Is".

1. *Interface positions for the orchestration of the artefact:* Due to the interdisciplinary complexity inherent in software sustainability design, the planning, organisation, and facilitation of the artefact are best suited for employees in interface positions, such as IT product managers or product owners. These employees possess a broader knowledge base than SEs and can effectively consider the various aspects of the software development process. Although SEs play an essential role as team members in agile projects, their training and focus on technical aspects may hinder their ability to lead the workshops. Responses to RQs 1, 2, 3, and 4 lead to this conclusion.
2. *Integration of external stakeholders in the requirements elicitation process:* Sustainability encompasses a wide range of complex issues, making a participatory approach essential for involving external stakeholders and gaining a broader perspective. The priorities of these stakeholders must be reflected in the requirements of the software products and services being developed. Conclusions can be drawn from the responses to RQs 3, 4, 6, and 7.
3. *Implementation of the SusAF results within business design models:* Combining sustainability requirements into the business plan is crucial. It is important to

recognise that sustainability cannot be achieved at any cost, as complete sustainability is an ideal rather than a practical reality. Consequently, trade-offs may be necessary. Decision-making should involve coordination with external stakeholders to ensure appropriate outcomes and garner acceptance. Software companies should also explore funding programs that can serve as financial instruments to support their sustainability efforts. The need for this connection arises from the responses to RQ5, 6, and 7.

4. *Incorporation of organisational conditions within software companies:* The time frame for executing the approach should be carefully considered. While allocating more time may yield more results, it can pose scheduling challenges for both internal stakeholders and external stakeholders. Additional organisational aspects (e.g. exploring funding programs) will be described in the presentation of the artefact. These results were evident in the case studies that led to responses to RQs 6 and 7.

Answering the main RQ thus provides insight into the following seven RQs, which are addressed below.

RQ1: How do software engineers describe their role in daily business?

The transition from the Waterfall Model to agile methods in the 21st century has caused a shift in the traditional roles within the software industry, including the role of the SEs. Software engineering has evolved from a predominantly technical–executive department to a workforce functioning within interdisciplinary teams, where responsibilities and tasks are carried out throughout all project phases, starting from the design stage. However, it is not accurate to claim that SEs have fully embraced this approach. The interview findings revealed that SEs primarily gauge the success of their work based on code-related metrics. Consequently, SEs often tend to distance themselves from non-technical aspects and prioritise implementation to ‘get things done’. The heavy emphasis on technology makes team communication challenging.

RQ2: What importance do software engineers attach to the topic of sustainability?

The findings from the response to RQ1 indicate that SEs are expanding their activities to include technical aspects, causing non-technical requirements to take a backseat. This observation aligns with other studies examining the sustainability awareness of SEs. The holistic understanding of sustainability and the adoption of sustainability methods are not integrated into their toolkit. Only certain facets of sustainability, such as ‘data security’ (placed in the individual dimension of the SusAF), ‘business mind-set’ (economic dimension), and ‘code efficiency’ (technical dimension), receive attention. Meeting sustainability obligations necessitates additional training, standards, and an expanded scope of activities. This knowledge gap affects not only SEs but also the software industry as a whole.

RQ3: How do software practitioners perceive sustainability in the software company in general and in their field of activity in particular?

Overall, software practitioners rate their knowledge about sustainability as low, whereas the topic is assigned a medium weight. Software practitioners should not be generalised here, because there is a significant difference between technology-oriented roles (e.g. SEs) and management-oriented roles (e.g. project manager). The latter attributes a higher level of knowledge, awareness, and responsibility within the field of software sustainability to the latter role.

Furthermore, it is noticeable that the five dimensions of sustainability are weighted differently, which can lead to a selective perception instead of a holistic perception of sustainability. Based on the analysis of 66 different tools, it was concluded that in the initial project phase, when gathering requirements, a multidimensional tool should be utilised, taking a holistic perspective on sustainability (Level 1). Subsequently, tools that focus on specific areas of individual sustainability dimensions (Level 2) and that address algorithms (Level 3) should be applied.

Moreover, it is indispensable for the artefact not only to fall back on the human resources of the respective software company but to expand this by consulting other stakeholders in the sense of participatory design.

RQ4: What role do different employee positions play in terms of responsibility for sustainability?

In answering this question, it is relevant not to examine the 'software practitioner per se' but to make a division into roles. Here, the distinction between the technology-oriented role (which includes, for example, the SE) and the management-oriented role (which includes, for example, the project manager) is essentially striking. This distinction clearly shows that the management-oriented role is better suited as an interface position with regard to setting up and implementing sustainability goals, as they have more interdisciplinary knowledge and a greater sense of responsibility for sustainability issues. Therefore, for appointing a contact person for sustainability issues, the management-oriented role is chosen. This role proved equally interested in participating in a sustainability workshop (such as the artefact). In contrast, a technology-oriented role was not named as a contact person for sustainability issues, and their interest in a sustainability workshop was low. All in all, sustainability competencies should be more developed in both roles and among software practitioners as a whole.

RQ5: What motivates software practitioners to set sustainability goals?

Within the survey study in Publication II as well as the case studies in Publications III–V, a variety of motivations for setting sustainability goals could be gathered. Within the software industry, it is evident that the development of sustainable software products and services complements business needs, including profitability, competitive advantage, and risk mitigation. This finding shows that finance should not be opposed to sustainability, but must go hand in hand, which can be achieved by combining sustainability design approaches with business design approaches. This connection forms an important requirement for the artefact.

RQ6 and RQ7: How should software practitioners focus their attention in terms of sustainability impacts when developing AI software and what should software practitioners consider before embarking on the design of digital solution in thanatopractice?

The responses to the RQs can be synthesised as they address different aspects but follow a similar structure. During the iteration stages of the DSR, it became evident that aligning stakeholders' knowledge at the outset of the workshop (and potentially even before the workshop, depending on the complexity of the topic) is crucial. Early collaboration with external stakeholders during the design phase proved beneficial for software companies, as it allowed them to involve these stakeholders as partners in a joint venture that mutually benefits both parties.

In addition, requirements were placed on stakeholders outside the industry sector:

- Representatives of *science* were asked to integrate interdisciplinary content on the topic of sustainability into software engineering education and to develop teaching materials that can be used by software companies.
- With regard to *politics*, the desire was expressed for the development of funding programs to support software companies on their path to sustainability.
- Both studies also highlighted the need for transparent regulatory measures that could be facilitated through collaboration with external stakeholders in the form of an acceptance campaign. This point was directed at representatives of *society* who can provide input in further formats, such as the artefact, on the basis of Participatory Design.

5.2 Assessment of the Research

The research conducted in this study can be characterised as exploratory mixed-methods empirical research with a primary focus on qualitative aspects. Several factors could potentially compromise the validity of the results. These concerns were methodically examined, and four types of threats to validity were addressed: Construct validity, internal validity, external validity, and reliability. Note that the objective of this study was not to achieve generalisability but rather to generate insights and answers to the RQs. The findings from this research can serve as a valuable contribution to future studies, particularly those that are aimed at quantitatively verifying the findings. By combining qualitative and quantitative approaches, future research can build upon the insights gained in this study and provide a more comprehensive understanding of the topic at hand.

Construct validity

Construct validity refers to the degree to which the measures employed in a study accurately capture the concepts that they are intended to represent. In this research, the interview study (Publication I), survey study (Publication II), and case studies (Publications III, IV, and V) carried a risk of potential misunderstanding of the questions, leading to incorrect evaluations by the researchers. To mitigate this risk, all studies underwent a pilot phase carried out with colleagues or students at universities. Feedback was collected to enhance the questions by refining the wording. Additionally, the workshops conducted within the case studies were based on established and empirically evaluated approaches (VPC, SusAF, and BMC).

To address any potential lack of understanding regarding the topics or tasks, participants were given the opportunity to ask clarifying questions at any time. Written instructions were provided alongside verbal instructions in remote workshops to ensure clarity. For participants with limited IT knowledge, an introductory lecture was given. Technical terms that arose during the workshops were explained by the workshop leader or other participants.

The presence of researchers in the interviews or workshops may lead to a reactive bias, where participants alter their responses due to this circumstance. To address this issue, measures were taken to ensure anonymity within the collected data. In online or hybrid interviews/workshops, participants had the option to use pseudonyms as names and to turn off their cameras. Surveys were completed after the workshops, allowing participants to provide anonymous assessments, impressions, and opinions. However, within group settings, a certain level of social desirability bias may still exist.

Internal validity

In the selection of the interview partners and survey respondents, as well as the participants in the workshops, the possible biased selection of participants should be acknowledged. Efforts were made to achieve diversity in recruitment, considering factors such as age, gender, academic, and professional backgrounds. However, all 13 interviewees were male, reflecting the male-dominated nature of the software engineering domain. Additionally, the predominantly European origin of the participants and the empirical research conducted in Europe should be taken into account. To minimise the selection bias within the survey study, various common platforms for survey distribution were employed. The application of the artefact in other regions may yield different findings. Participatory Design principles were employed in the workshop participant selection, involving stakeholders in the composition process and ensuring representative group formation before scheduling the workshops.

It is essential to emphasise that the goal of these studies is not to generalise the results. Rather, the aim is to demonstrate the feasibility of the artefact in an industrial context and to contribute to the advancement of sustainable software products and services.

External validity

The case studies are not aimed at statistical representativeness, as mentioned in the introduction of this section, because the focus is a qualitative approach. Diverse data sets were obtained by drawing on different subject areas. In the interview study and survey study, care was taken to include SEs from various industry sectors and company sizes. However, there might be industry-specific differences regarding the approach to the topic of sustainability.

Reliability

In all five studies, data were evaluated through pairwise comparison. Disagreements were discussed until a consensus was reached, ensuring that the final assessments were understandable and comprehensible to all researchers involved.

5.3 Future Research

The development of the artefact and the associated studies open up pathways for further research. Here, a special system connection comes to light: The survey results of the case studies highlighted areas of tasks and responsibilities that concern industry as well as science, politics, and society (see the last paragraph in section '5.1 Revisiting the Research Question and Contributions'). In this respect, research on sustainable software engineering should include representatives of these systems or stakeholders.

Conduct quantitative evaluations of the BE-SusAF: To enhance the artefact's effectiveness, a comprehensive quantitative evaluation should be conducted to identify areas that may require supplements and optimisation. This evaluation would contribute to the verifiability of the artefact's applicability across a wide range of industries. The workshop components within the artefact, such as VPC, SusAF, and TL-BMC, are designed to be open in terms of content or topic, making them potentially suitable for any industrial context. To test this hypothesis, a survey could be conducted, querying the industry sector as an indicator. The survey results may indicate the need for modifications to the artefact based on the specific industry. Other variables, such as the geographic and cultural context of the software company, might also necessitate adjustments. Additionally, a long-term study could examine the impact of implementing the BE-SusAF on the analysed software products, services, and the software companies themselves.

Create comprehensive reporting strategies: The environmental dimension allows quantifiable parameters such as energy consumption, CO2 emissions, and resource consumption through standardised metrics and technological solutions such as virtualisation, cloud computing, and energy efficiency measures. In contrast, measuring the social and economic dimensions is more challenging due to the given rather qualitative complexities. Indicators such as accessibility, transparency, and data protection can be quantified to some extent with appropriate measures, but the interaction among stakeholders with different views, values, and cultural characteristics makes it difficult to distinguish between sustainable practices and non-sustainable practices here. Initial solutions such as the Sustainable Business Goal Question Metric (S-BGQM)

(Oyedeji et al., 2017) exist, but this is still a relatively new research area that would need further exploration. Especially due to the emerging CSRD in the European Union (EU) (see section '1.1.1 Sustainability as a corporate issue'), it will be essential for companies to implement comprehensible reporting guidelines that feature sustainability metrics and indicators.

Implementation of the topic of sustainability in the curriculum of SEs: Studies on the education of SEs, including 'The Ethical Skills We Are Not Teaching' (Suarez and Varona, 2021) and 'Educating Software and AI Stakeholders about Algorithmic Fairness, Accountability, Transparency and Ethics' (Bogina et al., 2021), highlight the disregard for interdisciplinary topics in university computer science education. An interdisciplinary approach is crucial for the success of software products and services, particularly in agile teams, and forms the foundation for implementing sustainability dimensions. SEs should embrace this responsibility. The Erasmus program SE4GD serves as an example of a curriculum that addresses these aspects (see section '1.2.1 Intended contributions'). SE4GD equips future SEs at LUT University, the University of L'Aquila, and the Vrije Universiteit Amsterdam with theoretical knowledge and practical approaches to address sustainability challenges.

Preparation of research results for industrial software sustainability in the context of science communication: Society benefits from collaboration between academia and industry, as scientific findings can drive technological innovations that address social, environmental, and economic challenges. Research projects that address technological advancements create a fertile ground for marketable software products and services that benefit society. An example is the SUSO web platform, developed through discussions with industrial representatives during this dissertation (see section '1.2.1 Intended contributions'). In addition to providing accessible knowledge about sustainability in software engineering, the platform offers tools to support software companies in their sustainability implementation efforts. AlgorithmWatch, a non-profit research and advocacy organisation featured in Publication IV, exemplifies the contribution of science communication insights to the sustainability of software systems. Research projects within science communication can also involve users or customers of software products and services, fostering awareness of sustainable practices through education.

6 Conclusion

In recent years, there has been a notable increase in research on the intersection between software engineering and requirements engineering with sustainability. A comprehensive understanding of sustainability, encompassing social, environmental, and economic dimensions, necessitates an interdisciplinary approach, prompting researchers to collaborate across their disciplinary boundaries. Within the field of software sustainability design, numerous research gaps have surfaced, one of which pertains to the impact of this development on the software industry. This research field is characterised by a lack of transfer between software sustainability design and business plan design. This dissertation endeavours to contribute to filling this research gap by addressing the following overarching RQ: ***How can industrial software practitioners be enabled to effectively integrate sustainability design into their requirements engineering process?***

To answer this RQ, an exploratory mixed-methods approach is employed, encompassing an initial assessment of current industrial software engineering practices, followed by the development and evaluation of theoretically grounded and practically tested solutions. At the core of this approach lies the DSRM, which is aimed at comprehending, developing, assessing, and enhancing design processes through an iterative framework. The RQ is addressed through iteratively repeated case studies, ultimately resulting in the creation of a theoretically rigorous and empirically validated artefact: BE-SusAF.

In the initial phase, qualitative interviews were conducted to analyse the role of industrial SEs and their level of awareness regarding sustainability (Publication I). Then, a quantitatively supplementing survey was conducted, which highlighted the perception, responsibility, and motivation of industrial software practitioners with regard to software sustainability (Publication II). These studies revealed a significant gap between academic theory and industrial practice. On the one hand, the findings indicated a lack of emphasis on software sustainability design in the industrial software engineering practice. On the other hand, the scientific community showed a limited understanding of the software industry's needs in terms of addressing the multi-dimensional nature of sustainability that needs to be integrated into the business plans of software products and services.

The subsequent phase focused on the conceptualisation of the development of the artefact, with a primary focus on extending the existing SusAF (Publication III). The SusAF, which was initially created by an international group of scientists, serves as a workshop tool that supports users in gathering, visualising, and discussing the various impacts of software systems within a multidimensional and multilevel perspective, allowing for a consideration of requirements in the early stages of the software design phase. The objective of the extension was to meet the specific needs of software companies.

In the third phase, the SusAF was further developed through a series of case studies conducted in different industries (Publication III, IV, and V). The BE-SusAF encompasses four key extensions that render it suitable for industrial application. To encapsulate these fundamental principles, they were named the "four Is":

1. *Interface position for the orchestration of the artefact* (e.g. IT product managers) are suitable for the preparation, implementation, and follow-up of the SusAF as they (in contrast to the more technology-focused SEs) apply interdisciplinary knowhow in their function
2. *Integration of external stakeholders in the requirements elicitation process* in the workshop sessions through participatory design, enabling the consideration of sustainability-related content requirements and the identification of priorities.
3. *Implementation of the SusAF results within business design models*, facilitating the implementation of sustainability requirements within the business and financial plans of software companies.
4. *Incorporation of organisational conditions within software companies*, such as assigning an interface role, such as the IT product manager, to orchestrate the artefact, acknowledging time constraints as a limiting factor in each step of the artefact, and integrating funding opportunities.

Overall, this dissertation supports the achievement of sustainability goals in two ways. The artefact facilitates the software industry by introducing sustainable software products and services to the market and combining software sustainability design and business plan design in a theoretically grounded and practically tested way. The research around the artefact empowers academia in including the realities within the corporate landscape in the development of further approaches to sustainability design. In this regard, this work is also to be understood as an invitation to both industry and academia, to participate in building bridges by entering collaborations. The further the digital transformation progresses, the more significant the topic of software sustainability will be. In response to emerging challenges, a collective effort forms the basis for solutions.

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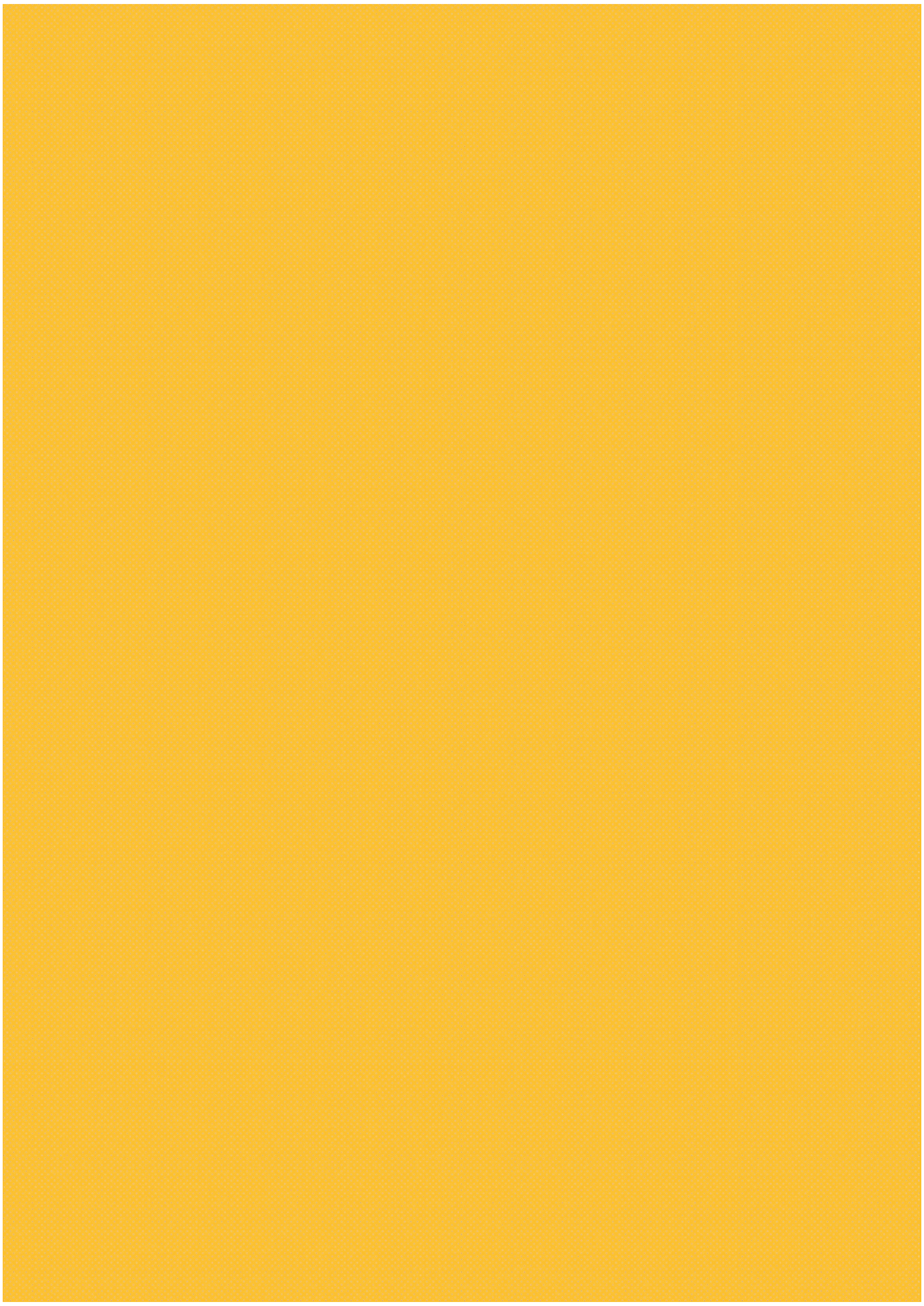
Appendix A: Sustainability Awareness Framework (SusAF)

SusAF

The Sustainability Awareness Framework

Workbook



SusAF

–

The Sustainability Awareness Framework

The SusAF is a tool for sustainability design.
The SusAF workbook enables a guided elicitation and analysis of the potential sustainability effects of IT products and services.

Workbook

Overview: The SusAF

The process

Warm-Up	Introduction of the participants, the SusAF, and the IT product under analysis	20 Min
Capture	Collect and categorise potential effects of the IT products regarding sustainability	60 Min
Analysis	Build chains of effects in order to discover causal relationships	20 Min
Synthesis	Discuss opportunities and risks, and develop corresponding actions	20 Min

The dimensions

There are five dimensions of sustainability:

Social

Individual

Environmental

Economic

Technical

The templates

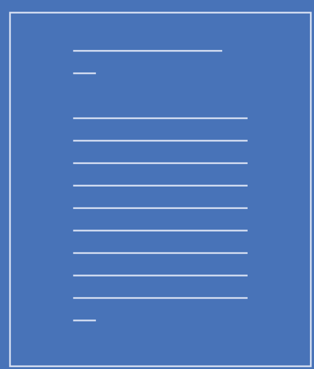
The templates provide examples, and instruction as well as fillable worksheets.

The diagram

The diagram supports the visualisation of the analysed chains of effects.

The report

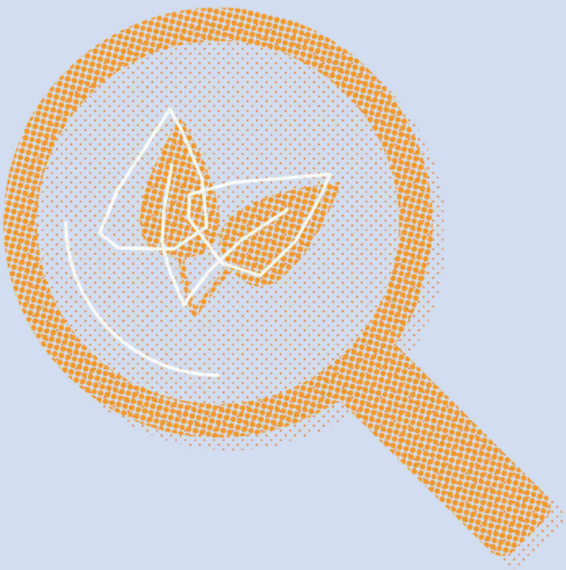
The report summarizes the most important results and measures.



Warm-Up

–

Introduce participants,
the SusAF,
and the IT product



Description of the IT **Product or Service:**

10 Min

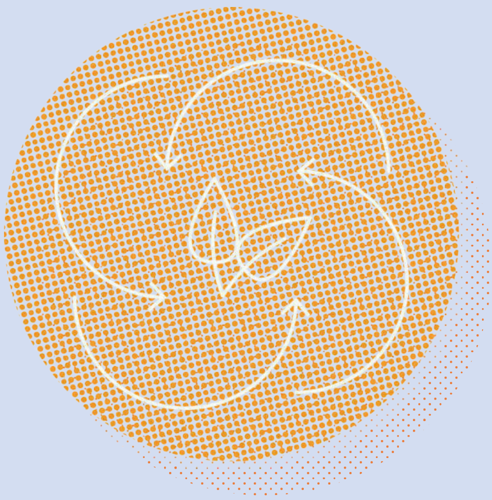
List the **known sustainability effects** (SDG? CSR?):

10 Min

Capture

—

Collect and
Categorise Effects



Brainstorm

Instructions

2-5 Min brainstorm for every single question

1 Read the questions (starting page 11)

2 Write down the first effects that come to mind in your notes sheets (1 minute)
- **a.** Consider effects of the product/service, working process and business model.
- **b.** Positive effects on blue cards and negative effects on orange cards, (with 'rationale', if it was mentioned)
- **c.** Remember, quantity over quality

3 Present all the ideas within the team (5 minutes max.)
- **a.** Do not judge
- **b.** Do not worry if you are not able to comment on all ideas
- **c.** If applicable, cluster ideas

(Rationale: Rent rooms in private homes)

Effect: close contact with another culture

(Rationale: the product is community based)

Effect: develop a strong sense of community among equals
⟶ less tolerance

(Rationale: a lot of legacy code)

Effect: the software developer feels frustrated
⟶ less job satisfaction
⟶ less loyalty to the project

(Rationale: The customer allowscritical discussions)

Effects: The group is able to question possible effects and requirements

Discuss & Select

Instructions

⏱ 7 Min discuss & select for every single question

Discuss all the ideas within the team
- **a.** Decide which effects are worth capturing
- **a.** Paste in likelihood & impact matrix

more contact to the landloard
⟶ *closer contact to other cultures*
⟶ *change of worldview*

additional income
⟶ *incentive for short-term renting*

develop a strong sense of community among like mindet people
⟶ *enhance personal believs*
⟶ *increasing intolerance*

Prioritize: Classify the effects using their likelihood and their level of impact

Dimensions: Social

Sense of community means the feeling of belonging to an organization, to an area or to a group of like-minded people.

- How can the product or service affect a person's sense of belonging to these groups?

Trust means having a firm belief in the reliability, truth, or ability of someone or something.

- How can the product or service change the trust between the users and the business that owns the system?

Inclusiveness and diversity refers to the inclusion of people who might otherwise be excluded or marginalized.

- How can the product or service impact on how people perceive others? What effects can it have on users with different backgrounds, age groups, education levels, or other differences?

Equity means the quality of being fair and impartial.

- How can the system make people to be treated differently from each other? (think data analytics or decision support)

Participation and communication refers to imparting or interchanging thoughts, opinions or information by speech, writing, or signs.

- How can the product or service change the way people:
  › create networks?
  › participate in group work?
  › support, criticize or argue with others?

Dimensions: Individual

Health means the state of a person‘s mental or physical condition.

- How can the product or service improve or worsen a person’s physical, mental, and/or emotional health?
- (For example, can it make a person feel anything good or bad - e.g. (under)valued, (dis) respected, (in)dependent, or coerced?)

Lifelong learning means the use of learning opportunities throughout people‘s lives for continuous development.

- How can the product or service affect people’s competencies?

Privacy means being free from intrusion or disturbance in one‘s private life.

- How can the product or service expose (or help to hide) a person’s identity, whereabouts or relations?

Safety means being protected from danger, risk, or injury.

- How can the product or service expose (or protect) a person from physical harm? How can it make a person feel more (or less) exposed to harm?
- What if used in an unintended way?

Self-awareness and Free will means the capacity of an individual to act or make decisions on their own.

- How can the product or service empower (or prevent) a person from taking an action / decision when necessary?
- Can those affected by the product or service understand its implications, express concerns or be represented by someone?

Dimensions: Environmental

Material and resources includes everything that is needed to produce, deploy, operate, and cease a product or service.

- How are materials consumed to produce the product or service?
- What about to operate the product or service? E.g., requires hardware.
- How can it change the way people consume material? E.g., encourage to buy more?

Waste & pollution means effects the product or service might have on soil, atmospheric, and water pollution.

- How can producing parts or supplies generate waste or emissions?
- How can the use itself produce waste or emissions?
- How can it influence how much waste or emissions are generated?
- How can it promote (or impair) recycling?

Biodiversity includes the effects of a product or service on biodiversity in its operational environment and other affected land.

- How can it impact the plants or animals around it? Or elsewhere?
- How can it change composition of the soil around it? E.g., occupying / cropland? What about elsewhere?

Energy means all energy use that results from producing and using a product or service.

- How can the product of service affect the need for production of energy?
- What about the use of energy? E.g. encourages less energy.
- Does the hardware run on renewable energy? Is there a way to incentivise that?

Logistics means the effects of the product or service on moving people and/or goods.

- How can it affect the need (and distance) for moving people or goods?
- How can it affect the means by which people or goods move?

Dimensions: Economic

Value means the worth, or usefulness of something, principles or standards; judgement of what is important in life.

- How can the product or service create or destroy monetary value? For whom?
- Are there any other related types of business value? For whom?

Customer Relationship Management steers a company's interaction with current and potential customers to improve business relationships (e.g. retention, growth).

- How can the product or service affect the relationship between the business and its customers?
- How can it enable co-creation or co-destruction of value?
- How can it impact the financial situation of their customers & others?

Supply Chain means a system of organizations, people, activities, information, and resources involved in moving a product or service from supplier to customer.

- How can the product or service affect the supply chain of the business who owns it?
- How can these changes in supply chain impact the financial situation?
- How can it impact the financial situation of their customers & others?

Governance means the processes of interaction and decision-making among the actors involved in a system through the laws, norms, power or language of an organized society.

- How can the product or service affect how and by whom such decisions are made?
- How can the product or service affect the communication channels by which the relationships takes place?
- How can these changes impact the financial situation of the business and partners?

Innovation refers to something new or to a change made to an existing product, idea, or field.

- Do (parts of) the product or service affect the investment on research & development?
- How can changes in innovation and R&D impact the financial situation?
- Can it also impact the financial situation of their customers & others?

Dimensions: Technical

Maintainability means the degree to which an application is understood, repaired, or enhanced.

- How are the operating system and runtime environment expected to change what does that required from maintainers of this system?
- How can the correctness of the system be affected by other systems or affect the correctness of others?

Usability means the ability of users to productively use the system for the intended purpose.

- What kind of knowledge or physical properties are required to use the system and how can this affect different types of users? For example, is good eyesight and small, sensitive hands required to operate a system on a small handheld device?

Adaptability means the ability of a system to adapt itself to fit its behaviour according to changes in its environment or in parts of the system itself.

How could someone want to use the system in another context?
What can make that easier/more difficult?
- What can make that easier/more difficult for the system to adapt itself to fit new usage scenarios?

Security means freedom from, or resilience against, potential harm (or other unwanted coercive change) caused by external or internal attacks.

- Which assets controlled by this system would be desirable to an attacker? E.g. financial information, people's whereabouts or preferences, etc. What are the risks associated with these assets?
- What are other likely vulnerabilities of the system?

Scalability means the systems ability to handle growing amounts of work in a graceful manner or to be enlarged horizontally or vertically and will continue to function with comparable response times.

How can the system support changes in workload?
- What can make that easier/more difficult?

Break

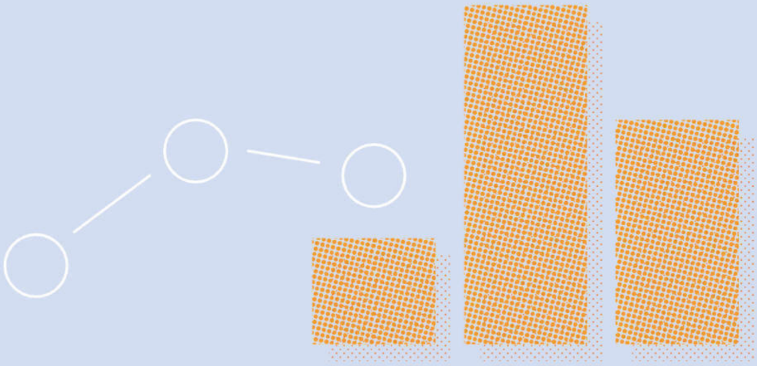
—

10 minutes

Analysis

—

Build chains
of effects in order
to discover
causal relationships

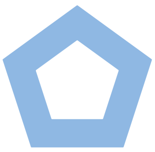


Orders of Effects

Orders of effects relate the short and long-term effects of the respective dimensions to each other. This way, chains of effects can be discovered.

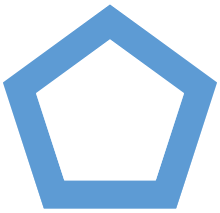
1. Immediate (First-Order)

Immediate are direct effects of the production, operation, use and disposal of socio-technical systems. This includes the properties and the full lifecycle impacts, such as in the Life-Cycle Assessment (LCA) approach.



2. Enabling (Second-Order)

Enabling of operation and use of a system include any change enabled or induced by the system. Specifically, effects that occur during usage and changed behaviour. For example, the shared use of resources like cars and tools.



3. Structural (Third-Order)

Structural represent structural changes caused by the ongoing operation and use of the socio-technical system. They originate in the continuous accumulated usage of software systems with many users. The effects manifest for example in politics, social norms and legislation.

Sustainability Awareness Diagram

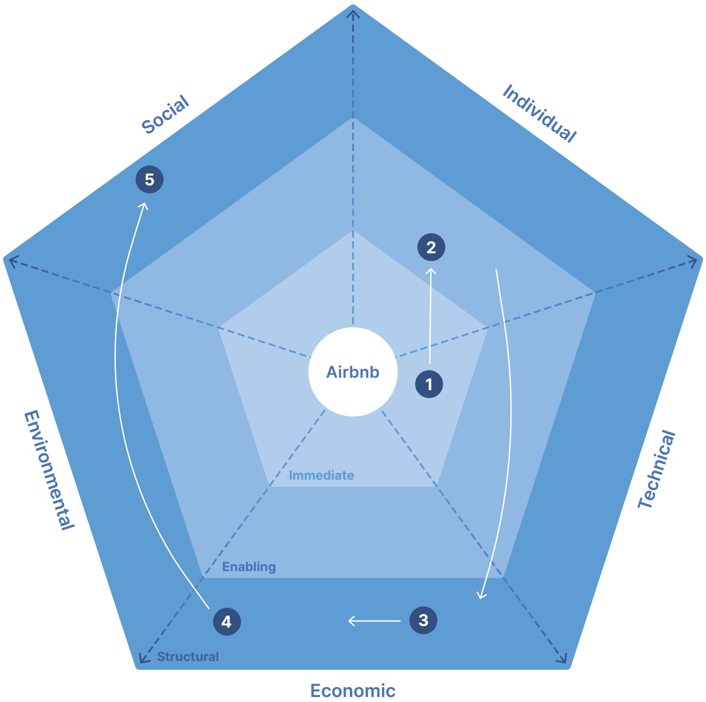
Is based on a radar chart

It is about cause and effects

› How do we get to a specific effect?

› What does this effect lead to?

Effects are placed in the dimensions and order of effects. They are connected with arrows (Cause and Effect); see Airbnb example.



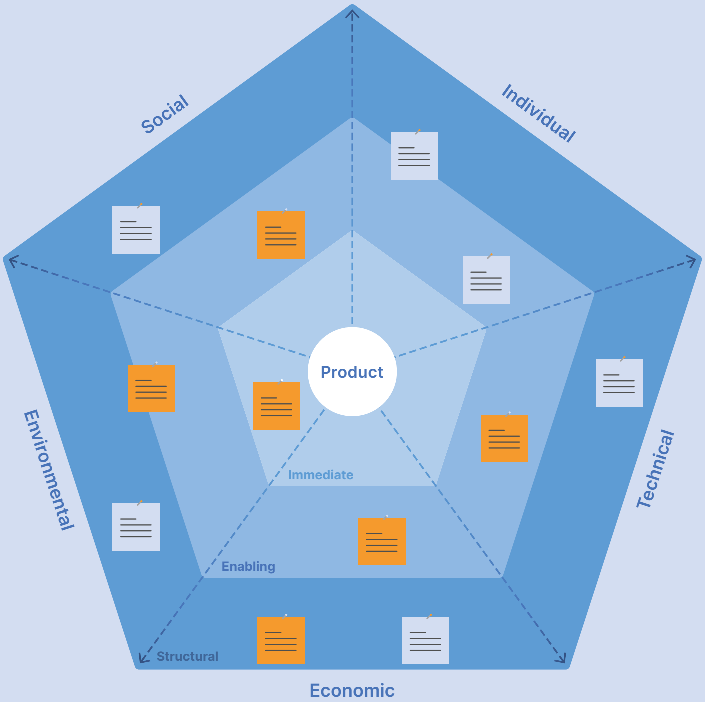
Filling the SusAD

15 Min

1. Paste the effects from the high impact and likelihood corner of the matrix onto the SusAD according to dimension and order of effect.

2. Look at the remaining, less likely or less impactful, ones and choose which ones to still add to the SusAD (so it does not get too crowded).

3. Imagine your IT product or service is being used by many people over an extended period of time. What consequences may this have? And how do they relate?



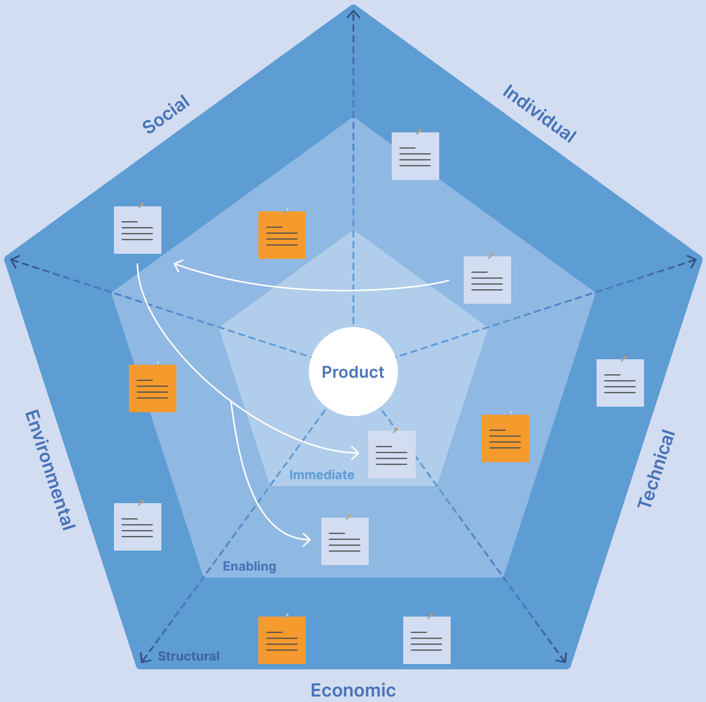
Chains of e ects

Identify chains of effect:

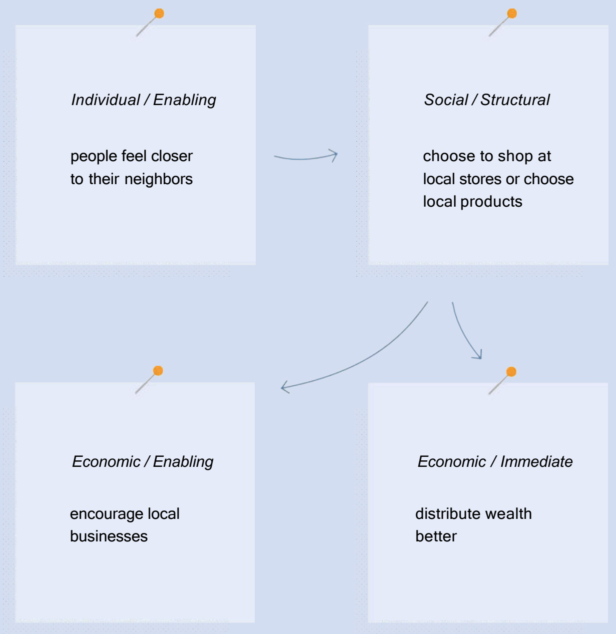
15 Min

Draw relations between the effects that may happen when many people use this product or service for several years:

1. Think about which second order effects stem from which first order effects, and
2. Which third order effects can be a consequence of some second order effects
3. Effects can also have a related effect of the same order, and/or of a different dimension



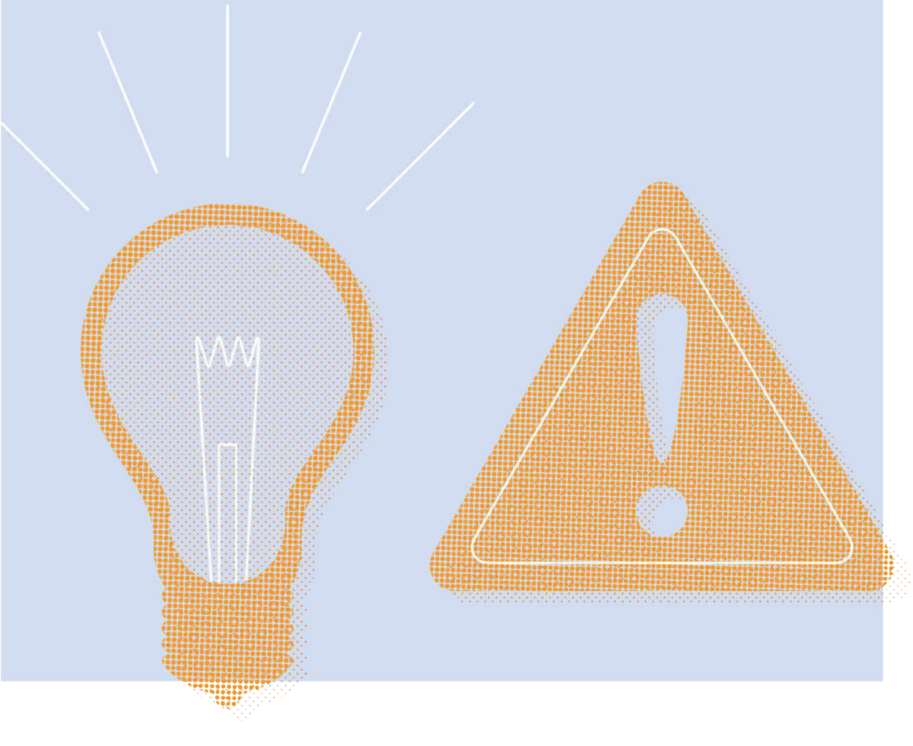
Example: If people feel closer to their neighbors, they can choose to shop at local stores or choose local products, which can encourage local businesses and ultimately distribute wealth better



Synthesis

—

Translate effects into opportunities and threats



Synthesis: Threats, opportunities, actions

Identification of the biggest threats and opportunities as well as the developmen of adequate measures

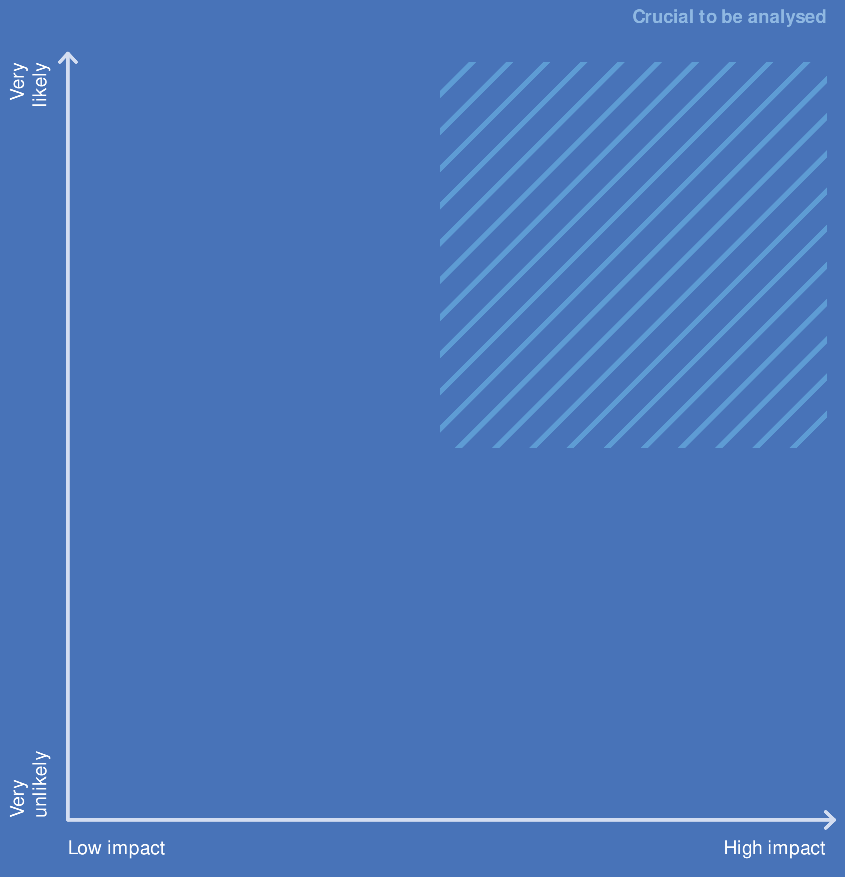
15 Min

Opportunities → Actions

Threats → Actions

Template 1

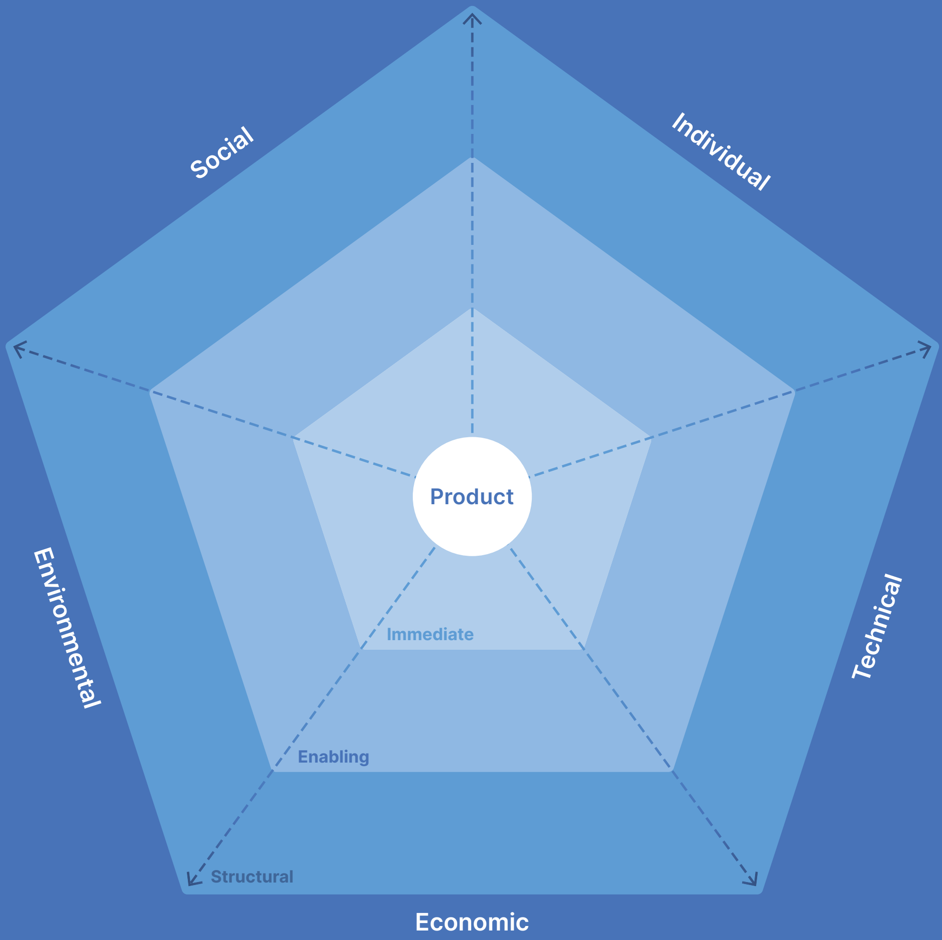
Classification of likelihood and impact



Template 2

—

The SusAD



Continued collaboration

approx. 90 min.

Interviews on the state of practice as a team of IT practitioners → you receive the results of your analysed interviews.

approx. 4 hours

A detailed workshop → you receive a detailed analysis regarding the sustainability of your IT product and services and the resulting opportunities and risks for your company.

Questionnaire

Was this useful to you?
Let us know in the survey! →

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Software Engineers in Transition: Self-Role Attribution and Awareness for Sustainability

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Software Engineers in Transition: Self-Role Attribution and Awareness for Sustainability

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Abstract

The Software Engineering process can be seen as a socio-technical activity that involves fulfilling one's role as part of a team. Accordingly, software products and services are the result of a specific collaboration between employees (and other stakeholders). In recent years, sustainability, which Requirements Engineers often paraphrase as the ability of a system to endure, is becoming part of the process and thus the responsibility of Software Engineers (SE) as well.

This study shines the spotlight on the role of the SE: their self-attribution and their awareness for sustainability. We interviewed 13 SEs to figure out how they perceive their own role and to which extent they implement the topic of sustainability in their daily work. By visualizing these two sides, it is possible to debate changes and their possible paths to benefit the Software Engineering process including sustainability design.

A discrepancy between the current role and the ideal role of SEs becomes visible. It is characterized in particular by dwelling on their "classic" or time-honored tasks as an executive force, such as coding. At the same time, they point out the still missing necessity of an interdisciplinary, from communication coined working method. According to our interviewees SEs are inefficiently involved in the design process. They do not sufficiently assume their responsibility for the software and its sustainability impacts.

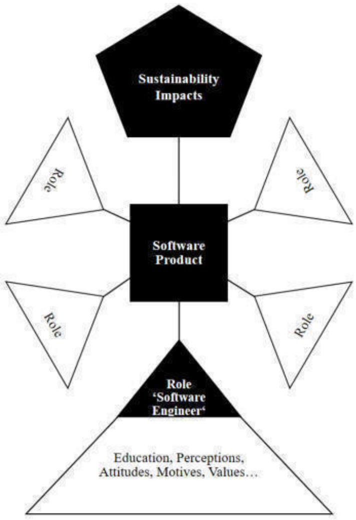

Figure 1. The software product as an outcome of the collaboration of roles and its sustainability impacts [2]

1. Introduction

Meade et al. perceive the transition to agile methods at the beginning of the 21st century as one of the main reasons why the "traditional role" of the Software Engineer is dissolving. They describe the software creation process as a "complex socio-technical activity", which is no longer just about coding, but about fulfilling one's role as part of the agile group [1].

Sociology seeks to uncover how individuals behave in groups and how those groups shape their behavior. This interaction includes the formation of groups and their dynamics, as well as their maintenance and transformation [3]. If the social structures of a company change, such as the role distribution, this can have an impact on its products and services. In the last decades, an obvious paradigm shift has taken place, especially with regard to the role of the SEs. With the digital transformation, society as a whole is affected by a far-reaching change characterized by an easing of everyday and professional tasks, but also an increase in complexity due to the constant further development of existing adding new features and the ongoing emergence of new technologies, platforms and channels.

Today's SEs are no longer just an executive. SEs fulfill tasks that make them necessary in all phases of the product creation process: from design to completion [4, 5]. With the increasing involvement of SEs

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in the product development process, the question of taking responsibility with regard to sustainability is also becoming louder. Software products and services can have an impact that affects social, individual, environmental, economic and technical issues. Figure 1 summarizes the process. An ensemble of roles, including that of the SE, designs and builds the software. This software in turn brings sustainability impacts .

However, it remains open at this point whether the new role definitions have sufficiently arrived in the daily work of SEs. Studies and observations show a lack of knowledge, experience and methodological support for entering the paradigm shift, especially when it comes to integrating sustainability [6]. The question arises as to whether and to what extent SEs have actually shed their traditional self-perception in order to meet the responsibilities imposed on them today. This leads to the following two research questions: How do SEs describe their role in daily business? (RQ1) and What importance do SEs attach to the topic of Sustainability? (RQ2) To lay the foundations to answer the RQs we present the background regarding roles and sustainability in the following section.

2. Background and related work

In this chapter, we lay a basic understanding of the set of topics that align the three disciplines of Sociology, Software Engineering and Sustainability. Thus, we use of a threefold structure: The concept of roles from a sociological perspective, the changing role of SE and Sustainability Design as a component in Software Engineering.

2.1. The concept of roles from a sociological perspective

At the beginning, it should be said that sociology does not offer a uniform "understanding of roles", but rather a colorful bouquet of theories. In this paper, we have chosen to rely on the most cited basic sociological works taught at universities today [3, 7, 8]. The way our social system is constructed affects each one of us in many ways. Sociological studies range from the analysis of social processes, structures, and systems to practical applications in social policy [3]. One sociological theory is that of the division of individuals into so-called "roles". The Encyclopedia Britannica describes roles as follows: "Role, in sociology, the behaviour expected of an individual who occupies a given social position or status. A role is a comprehensive pattern of behaviour that is socially recognized, providing a means of identifying and placing an individual in a society. It also serves as a strategy for coping with recurrent situations and dealing with the roles of others (e.g., parent-child roles)." [9]

When building a theoretical understanding of roles, the sociologist Erving Goffman needs to be mentioned. In his publication "The Representation of the Self in Everyday Life" [10], Goffman describes how society creates a whole range of roles and makes them available to its members. Behavior, word choice, and even clothing are symbols that are important to this role creation. They are meant to help us make the social system functional. The individual members of society classify these roles classified as "normal". Here, Goffman prefers the term "virtual identity". This is contrasted with the self-identity we have in private, where we are not under social control. Goffman calls it the "actual identity". When there is a discrepancy between our virtual identity and our self-identity, there is a risk of negative labeling that, if repeated, degenerates into stigma. Under certain conditions, roles can thus also paralyze a social system.

In contrast, we would like to add a fundamentally different sociological perspective – that of the sociologist Pierre Bourdieu. In his most widely read work "Distinction: A Social Critique of the Judgement of Taste" [11] Bourdieu recognized that people who belong to a certain class, class fraction or subclass are connected by a common taste: They prefer the same things and they reject the same things. These tastes turn out to be indicators of whether or not they "fit" into their class. Socially internalized dispositions that influence a person's perceptions, feelings, and actions are subsumed under the term "habitus". Habitus is the result of an interplay between the individual self, group culture, and social institutions. Acting out these dispositions strengthens the habitus of the individual and the group. Deviation, on the other hand, consequently causes exclusion.

The Goffman and Bourdieu approaches differ in that one suggests "people act this way" (Goffman) and the other asserts "people are this way" (Bourdieu). What both approaches have in common is that roles become socially entrenched over a period of time and, accordingly, involve a difficulty of change – whether or not a change in role is desirable. For this reason, it may be worthwhile to become aware of SE's understanding of roles. On this basis, strategies could be developed that entail an improving adjustment for collaboration in the corporate environment. In research on role understandings, the respective individual context must always be taken into account. Instead of committing ourselves to a specific role theory and applying it to SEs (inductive approach), we address the field in order to derive theories (deductive approach).

2.2. The changing role of Software Engineers

Coinciding with the changing role of SE in the 21st century, one can observe an increase in research on the connection of social sciences within the discipline of Software Engineering in numerous studies. By combining the keywords "Software Engineering" with "roles" and feed them into "Web of Science" (the world's largest publisher-neutral citation index and research intelligence platform) the increasing number of papers on this topic becomes apparent (see figure 2).

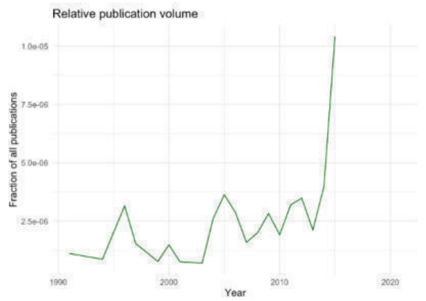

Figure 2. Output of the relative publication volume to the connection of "Software Engineering" with "roles" using "Web of Science"

It is therefore not surprising that a whole range of topics are touched upon. Michael John et al. assert that human and social factors have a significant impact on the success of software development efforts and the resulting system [12]. Tom De Marco and Tim Lister claim, "software development is highly dependent on people"[13]. Wohlin et al. explain that software development is about "balancing human, social, and organizational capital" [14]. In the following, a time-based structuring of the understanding of the role of SEs is applied, as this clarifies the paradigm shift.

Until the early 2000s: The Waterfall Model Era

The oldest publication we found which directly addresses the present topic with the title "The Role of the Software Engineer in the System Design Process" was written by Reece in 1985 in the "IEEE Military Communication Conference" [15]. The author criticizes that in design issues are decided without software expertise and that SEs should instead be involved from the beginning. The reason she gives for this is that it can reduce software implementation problems. She describes engineers as "problem solvers" and "practical people", but she also attributes management tasks to them. Three characteristics distinguish a capable SE in her opinion: technical talent, the ability to understand management concepts, and the ability to communicate. During this time, work structures were already necessary to cope with the complexity and scope of engineering tasks, such as the waterfall model. The waterfall model consists of a sequential process in which entry into each new phase requires that the previous phase has been completed. Meade et al. state that before the introduction of today's known methodologies, projects often suffered from a lack of communication between the SEs and the users [1]. Foster recognizes another difficulty. Back then, systems were managed by the system and process analysts. As a rule, the SEs were assigned to the finance department. Most systems were correspondingly accounting-oriented, which resulted in an imbalance, which consisted in the fact that the SEs were more inconspicuous in the overall process. Their role was largely limited to execution. The work of the systems and procedures analyst on the other hand was complex, also by the fact that they had to collect the information from different departments [16]. Communication with other departments was thus less common for SEs.What also characterizes the Waterfall Model Era is that the tasks of SEs held a much narrower spectrum. They were not responsible for testing, for example, but had their own software testers. One can deduct from this that taking responsibility for their own code only became important in later years: "Software Engineers today have become more adaptable and have more responsibilities in the context of the broader project [1]."

2001 to 2011: The Agile Methods Era

The paradigm shift was apparently initiated in the year 2001, when SEs published the "Manifesto for Agile Software Development" [17]. It stands for a profound review and reorientation of the practice of Software Engineering. Meade et al. cite that as software development has evolved, the role of a SE has become "broader and more heterogeneous." Technological advancements had resulted in a change in the role of SEs and changed the needs of companies. This development is not standing still, as new technologies – the authors cite artificial intelligence and machine learning as examples – are constantly being added [1]. Open source software likewise contributed to the paradigm shift by creating the path to communities of collaborators and contributors on a variety of projects [1]. Today's employees can no longer limit themselves to their so-called department and what they were "classically" trained to do. The change in job titles, the renaming of departments and the repartitioning of

organizations attest to this shift [18]. Foster attributes to today's SEs that they serve in an advisory capacity to the entire organization, and they are a change agent who advocates (and implements) system improvements from a wide variety of viewpoints. In doing so, they must be aware of all planned organizational changes that relate to the software system they develop [16].
At this point, it can be observed that the role of SEs is becoming more versatile. New areas of responsibility, in which they have to familiarize themselves depending on the project, are added. (Interdisciplinary) communication is gaining in importance. A SE has a say in the design of the software.

Since 2011: The Start up Era (or Agile Methods 2.0)

Based on that, the start-up scene and its mentality brought an additional level of agility to the stage. The next level agile methods are characterized by iterations, as can be seen for example in the "Lean Startup Circle" by Eric Ries. It is about constantly building, measuring and learning where Business Economists, Marketers, SEs and other stakeholders need to put their heads together strategically as team members to move the company forward [19]. In addition, a differentiation of a psychological component regarding SE can be seen in current publications. The number of types of SEs is immeasurable. Feldt et al. detect correlations between SE personality views and attitudes [20]. Soomro et al. find an influence of SEs' personality traits on team climate and performance [21]. Karimi et al. seek to understand the influence of a bundle of personality factors on programming styles and performance [22].
Capretz and Ahmed offer a mapping of soft skills and psychological traits to the main phases of the software lifecycle to reflect the complexity and importance of the topic. For this mapping, the researchers used the Myers-Briggs Type Indicator (MBTI), a well-known instrument for measuring and understanding individual personality types. They conclude that software developers are "introverted (I), feeling (S), thinking (T) types." [23] Gorla and Lam explain that the variation of personalities in a project can have a balancing effect in the workplace [24].
SEs today contribute to a large extent to the design of the software, which was not a matter of course in the past. Depending on how much importance is attached to the topic of sustainability, software has different positive and negative impacts for which SEs share responsibility.

2.3. 2014 until our-days: The Software Sustainability Era

We would like to start this section with a famous quote from Grady Booch: "every line of code has a moral and ethical implication." [25] This statement requires an explanation.
According to a study of Wolfram et al., the increasing concern with climate change as well as a growing awareness of social inequality have led to the topic of sustainability being accorded increasing importance overall, from which Software Engineering is not unaffected. In 2017, the researchers set up a systematic mapping study with the aim of identifying where and how the issue of sustainability is being addressed in Software Engineering. To this end, they evaluated 1035 studies on the topic of sustainability and green IT [26].
In 2014, Becker et al. established the "Sustainability Principles for Software Engineering" in the so-called "Karlskrona Manifesto for Sustainability Design" [27], which can be considered the starting point for the current era. As can be seen from the website www.sustainabilitydesign.org, the authors and signatories of the manifesto (software practitioners and researchers) write that their intention is to align concern for the planet and society with Software Engineering. According to them, the narrative about sustainability and the role it plays in the profession of SEs, among others, needs a redefinition. The work of SEs is accompanied by a responsibility regarding sustainability impacts of the software systems they design that they have to face. The signatories establish a broad understanding of the term "sustainability" by pointing out its five correlated dimensions:

- Social: includes relationships between individuals and groups.
- Individual: includes the ability of individuals to flourish, exercise their rights, and develop freely.
- Environment: includes the use and management of natural resources.
- Economic: includes the financial aspects and business value.
- Technical: includes the ability of the technical system to adapt to change.

Furthermore, a distinction is made between three different effects: immediate effects (start with the production, use, and disposal), enabling effects (arise over time), and structural effects (changes on the macro level that alter our society). This is also the definition of sustainability as it applies to software for

purposes of this research.
In the same year, Betz et al. introduced the concept of "sustainability debt". This metaphor, borrowed from economics, is intended to help discover, document, and communicate sustainability issues in Requirements Engineering: "Sustainability matters for all software systems, even if the application domain of the system is not related to sustainability, because any new software creates dependencies and obligations as it becomes part of our technical infrastructure, and its on-going use may entail new burdens on social and ecological systems." [28] SEs usually focus on technical issues. However, software systems also affect non-technical systems. Only at a second glance we perceive their societal, environmental, and economic interactions. SEs should not abdicate this responsibility [27].
In 2016, Becker et al. agreed to this circumstance by claiming that the social role of software, which is often considered critical, necessitates a paradigm shift in the mindset of SEs. The authors explain that designing for sustainability poses a major challenge. Complex software-intensive systems influence sustainability in the five correlated dimensions. In terms of sustainability, SEs would have to adopt a mindset different from that of the puzzle solver. Rather, they now face "wicked problems", or problems that are entrenched in a complex system. Responsibility can only be sufficiently taken into account if there is an awareness of sustainability [27].
Oyedeji et al. present concepts that can be used to evaluate green and sustainable software systems. This includes measurement of the five software sustainability dimensions [29]. On the other hand, in 2016, Chitchyan et al. addressed the relevance of sustainability in Software Engineering discipline while emphasizing that there is little knowledge about how it is perceived by SEs and, as a result, how sustainability design can become part of the design process. The 13 respondents in this study only associated sustainability with the availability of natural resources and the reduction of waste, only with the environmental dimension. There is a lack of knowledge and therefore awareness of the other four dimensions [30]. The measurement methods thus still need to be further developed and established.
2019, Duboc et al. stated that software occupies every component of social life (from commerce, communication, education, to energy, entertainment, finance, governance, and defense, etc.), making socio-technical systems a key factor in sustainability [31]. As recently as 2020, however, Duboc et al. emphasized that Requirements Engineers lacked the knowledge, experience, and methodological support for this task. For several years, various tools have been developed to help Requirements and SEs consider sustainability in the software development process [6].
In summary, the number of publications in this thematic field is likewise growing. We can divide these as follows. First, scientists publish the basics in sustainable Software Engineering and call for awareness and responsibility. Second, they teach methods that help to take account of the "sustainability debt". Thirdly, they carry out studies that examine software companies according to their approach to the issue of sustainability. The topic of sustainability is still quite new in Software Engineering, so that a formalization of sustainability as part of the Software Engineering "have yet to make their way into official standards and models" [26]. Going back to Fig. 1, the software is the result of collaboration between different roles. The software in turn leads to sustainability impacts. Scientists worldwide agree that SEs must take their responsibility into account more strongly than has been the case to date. We concur with the scientific findings cited in this section and proclaim that SEs integrate the five dimensions of sustainability as well as its three effect levels into their work.

3. Research gaps

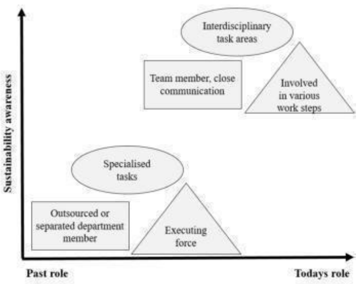

Figure 3. Self-role attribution and sustainability awareness of SEs in the past and today

Putting the last chapter together, we can say that over the past decades, the role of SEs has been subject to numerous upheavals. Until the transition from the "Waterfall Era" to the "Agile Methods Era", they move closer and closer to colleagues from other areas with whom they formed teams. Specific tasks that made them the executive force of companies became interdisciplinary task areas that integrated them in different work steps. This inevitably increased the responsibility for the product. SE can no longer be measured only by the quality of their code; they also bears responsibility for the design of the overall project. This also applies to the responsibility for

sustainable Software Engineering. Figure 3 summarises this development.
One of the questions that has not yet been adequately answered is how the transition actually looks like in practical implementation. It is about the given circumstances in companies towards the combination of the self-role attribution of SEs on the one hand and on the other hand their awareness for sustainability. The purpose of this explorative study is to get a closer look at the actual state of software companies in order to check to what extent the current status corresponds to this transition. This study serves to provide initial answers to this research gap in order to build a bridge for the development of follow-up studies.

4. Interview study design

This study is part of a broader investigation on the connection between Software Engineering and sustainability design. Here, we conducted an exploratory qualitative research by conducting 13 interviews with SEs. Within the qualitative research guidelines, we followed scientific rules in the field of interviews summarized by Elmer [32]. We did not ask the SEs directly for a description of their self-role attribution, nor did we ask them directly for a definition of sustainability. If we had asked for these two, there would be a risk that the answers would correspond to social desirability. The first part of the interview was about the SEs' profession in general and their role in the company. Here it was interesting to see if the interviewees bring in the term sustainability themselves and if any of the described activities can be related to sustainability. The second part of the interview was about the impact of software. Here, too, the interviewees were to be as free as possible in describing their view of things, the "status quo", when it comes to impacts. We have chosen a semi-structured form in order to achieve a flexible survey, although it can be time-consuming to conduct and evaluate and it also means that the number of respondents is rather small. On the other hand, it is a recommendable form of research to ensure understanding and to obtain extensive statements.
In the planning phase, we opted for a deductive sample, since there is of course already knowledge about the people who can provide information about the question. The respondents should be employees whose job title falls under the term "Software Engineers". To remain constant, we left it at this company size (including those who consider themselves as startups) for all interviews. We do not intend to aim for representativeness for the "typical" SE.
We conducted half of the data collection through face-to-face interviews and the other half through voice over IP platforms. Twelve software practitioners worked in Germany and one in France. All interviewees have been working in their professional field for more than one year: between 2 and 22 years. The average was 7.7 years. We made sure to cover different industries to create versatility. The 13 interviewees belong to the following industries: Finance (2x), IT Security (2x), Web and App Development (2x), Big Data, eCommerce, Energy, Environment, Language Learning, Marketing, and Social Media. Five of them had a close connection with universities in their daily work. Four of the SEs received a one-year scientific start-up grant, which provides guidance from a university professor as well as the relevant university start-up office. Two startups are based on a business concept developed during proseminars at the university. Here, there are contacts to the former lecturers of these seminars as well as to student founder initiatives, which support the respective startup with know-how and networking. One of the startups was a university project in which several universities are involved in the founding. The respondents were all male and their age ranged from 29 to 55 years. They all had a diploma, master's or bachelor's degree. All interviews we carried out in English. They were recorded and transcribed (anonymised). The implementation took place in the months of May to September 2020. The interviews took about an hour each.
In the data analysis, to structure the responses, we developed an open coding strategy. Two researchers read through each of the interviews, coded them, and additionally peer-reviewed each other's work to establish a codebook on which all agree. For qualitative content analysis, we selected the approach of a deductive category application. We used text analysis software as a tool here. The results of this interview study fall into two categories: self-role attribution and sustainability awareness.

5. Study findings

In this chapter, we present our most important results and findings. We divide the study findings in two parts: Self-role attribution and Awareness for Sustainability.

5.1. Self-role attribution

With the first part, we want to get an insight into how SEs would describe their role within the company itself. We asked this question directly: "How would you describe your role as a software developer within your company to others?" Next, we asked them to describe a regular working day and what they thought would make an ideal working day. Explicitly, we asked about the skills and competences a SE needs. Finally, we asked about the advantages and disadvantages of integrating the SE into the overall product development process. The answers to these questions should contribute to the overall picture of the role. We started coding job description, which led us to a bundle of tasks mixed up with required skills and competencies. This includes a list of codes, which constitute a regular and an ideal working day in the eyes of the SEs. Here, the relationship and a distinction from other stakeholders became clear. The interviewees also answered by letting us know about framework conditions or the working environment. Finally, we created two code lists that we divided into the opportunities and the risks that lie in the integration of the SEs into the entire product creation process: from generating an idea until the market entry.

Tasks, skills and competencies. The SEs describe their areas of responsibility as diverse. We divided the tasks, and thus the required skills and competencies, into five areas based on the respondents' answers: Technology, Communication, Project Management, Finance and Others.

The focus is clearly on the first area and its complexity: Technology. In total, the interviewees count on 25 different technical tasks when it comes to their regular work. It turned out that it is not enough to go into everything in an interview lasting around an hour. One interviewee stated: "So my role in my company is to develop projects and software from A to Z." An idealization of programming skills is particularly evident. Terms such as "efficient code", "good coding", "satisfying outcome of code", "clear code", "clean code" and "working code" are used. The respondents describe a comprehensive knowledge and understanding of programming languages, software architecture and the system as equally important.

The communication area appears second most frequently. They address it in both the current and the ideal role conception. Discussions, mutual understanding and efficient communication with meetings and digital communication (chats and e-mails) are clearly considered relevant.

Project management tasks are in third place. Activities such as organising, planning and coordinating tasks are standard in this profession. This aspect also applies to some SEs in the fourth area: Finance. One interviewee speaks of the relevance of a "business-oriented mind", which SEs should ideally have. Other tasks, skills and competencies differ from company to company. It can be about generating ideas, learning, presenting, holding workshops or even campaigning and political work.

Relationship with other stakeholders. One of the most obvious things in the entire evaluation is that SEs distinguish themselves from their other colleagues by identifying themselves as the "doers", as those who "get things done": "In my experience, the developer is at least the one who is doing the things, who has to get the things done. And many times he has a lot of people around him who are talking, and planning, and organizing money and other political things. But finally the core product is my daily work, is my job. And yeah, so I have to be the one who gets things done."

This narrative is often encountered, also concerning the ideal SE: "[...] someone who is really focusing on getting stuff done." Accordingly, clear tasks are ideally expected: "I think really important is to have a clear task that we can focus on." This circumstance does not coincide with the responsibility that SEs have to participate in the product design and thus also in the accompanying task orientation. Some of them prefer to be given tasks that they then only have to carry out rather than participating in defining them.

In contrast, the interviewees often mentioned the term "teamwork" as well as their relationship to other "professional groups": product / project owner, customer, designer, facilitator, marketer, project manager and scientist. SEs have to sit at the table here because (unlike the other groups of colleagues) they knows what is feasible and what is not. Here is one example about the connection between the designer and the SE: "[. . .] the designer knows what the best practices are for example, or best workflows with some interfaces, but the programmer knows what is doable and what is, according to that time and that amount of money, this project tests, what is doable." Therefore, they also mentioned social skills. One interviewee emphasizes that the software is the result of teamwork. "And then also there's this cliché of software developers of being the weird nerds down in the basement, and that is totally wrong. It does have that part as well, but it's not like this is 90 percent. [...] It's always teamwork. And so, the team aspect and the social aspect is very important for communicating problems and getting things done well."

Working environment. The interviewees did not mention much about the general situation of the working environment. Some said that they do not have a regular working day and the term "home office" came up, which can be attributed to the consequences of the regulations due to the current Corona situation.

More interesting was what they made known about their ideal ideas of a work environment. They made statements that can be put under the heading of "undisturbed work". One interviewee explained: "Not to be disturbed by other colleagues or customers, who can work normally, straight way." Another one found similar words: "Room for silence" and "room for concentration" are necessary to "dive in and be un-disturbed and work for like three hours on some development topic." The need for privacy can be transferred to programming, because only in this activity is the presence of other colleagues not needed. Seen in this light, the question arises as to whether SEs do not need two rooms: a common one for exchange and a sole one for execution.

Integration throughout the design process. The advantages of involving SEs in the entire product development process clearly outweighed the disadvantages. They were primarily recorded in bringing in a technical perspective, to "find the compromise between this perfect design and what's really doable." Additionally, answering financial questions also played a role here: "So, I think software developers generally should have an entrepreneurial mind and understand what is the value of that what they are building?" A third reason lies in the enrichment through a different way of thinking and working: "I think the developer should be part of the whole process because they bring in another point of view, a technical point of view." The disadvantages referred to the fact that the greatest strength, the technical focus, can degenerate. SEs tend to slow down processes because they become rigid on technical aspects: "I would say the biggest threat for a self-motivated developer is working too long on unnecessary things. A classical problem would be early optimization or working on features that nobody requests. That is, I think the biggest problem."
Another threat is that they are not involving themselves into the discussion: "And software development is sitting on the site is listening, is not saying something." One respondent mentioned the lack of communication skills by stating that someone is necessary "who can speak as well the language of developers".

5.2. Awareness for sustainability

The second part of the questions we started by asking about the use of tools and frameworks. Our intention was to check whether the topic of sustainability is addressed here on its own. We then asked if they also use tools or frameworks that address questions about ethics, consequences or sustainability. Afterwards, we addressed questions about the importance of such issues within the company. Finally, the questions focused on the integration of these issues into the training of SEs.
Not a single SE interviewed uses ethical frameworks or tools as a guidance. Twelve of them have never heard of the ACM Code of Ethics and Professional Conduct, only one of them knew the term.
When it comes to moral issues within their work, eleven of them raise the issue of data security. The other dimensions of sustainability and their effect levels (see section 2.3) do not come up. Two SEs claim not to encounter any moral issues. From this, a truncated understanding of sustainability could be derived. Four SEs attach importance to ethics in their work, compared to nine who do not share this view. In the case of the importance of impacts, nine attribute an importance to the topic. Two see an importance here, but classify it as rather low. Two others do not assign any importance to impacts.
Accordingly, with nine, the majority of SEs thinks about impacts when creating a product or service. In contrast, four interviewees answered this question in the negative. Nine of the interviewees are also of the opinion that the topics dealt with here should be integrated more strongly into Software Engineering.
The question of whether SEs should be trained differently in the future was mostly not addressed in terms of ethical questions or questions about impacts and sustainability. Six of the interviewees answered this question in the negative. Of these, four claim that it is more about personal issues. Another interviewee claimed that SEs need to acquire knowledge on these topics themselves. In addition, one stated that SEs do not need to be strong in every area. Three interviewees stated that they had absolved a training in these topics during their training. In contrast, there were ten for whom this was not the case. Only one of the SEs needs help in dealing with these issues. Five of them showed openness or interest. Seven answered in the negative.

6. Discussion

RQ1: We can conclude that the SE has evolved into a team member who communicates closely with other team members, who covers interdisciplinary task areas and who is involved in various work steps. However, we cannot say that the SE does yet seem to have fully arrived in this new role. The focus lies on technology and seems to be so strong and the interdisciplinary way of working so low that non-technical tasks in communication become more difficult and even being perceived as disturbing. SEs have not yet completely dissolved their role as a purely executive force. They continue to see themselves in the role of doers who need clear tasks.
RQ2: At the same time, SEs shy away from their responsibilities, which can be seen in particular in the sustainability consequences. The application of methods regarding sustainability is not part of their toolbox; the consequences are mainly seen in data

security. However, this does not mean that they are not aware of sustainability issues. With nine interviewees, the majority stated that these topics should be integrated more strongly into the Software Engineering process than before. They were not usually trained in this topic, but half of them brings up a motivation to catch up (six out of thirteen). This can be seen as motivation to tackle the issue.Standards are required as well as an expansion of the scope of activities in order to meet the sustainability debt.

Overall, there are still uncertainties in the "right" way to deal with this issue. We know from sociology that roles solidify over time and that it is not possible to dissolve and transform them overnight. As far as sustainability design as a component in Software Engineering is concerned, we are also dealing with a relatively new research topic. Developments with regard to both research questions can certainly be identified, but the desired theory and the real practice still diverge significantly.

7. Limitations

We have conducted a qualitative study thus there are a number of aspects threating the validity of our findings. We have considered these systematically, discussing the four threats to validity: construct validity, internal validity, external validity, and reliability.

Construct validity: A threat to construct validity may be that interviewees may not understand the questions, and the interviewer may misinterpret data. To minimize this threat, we ensured that the interviewees had sufficient experience in Software Engineering; further on, to provide a context for some of the questions, we asked the interviewees to read a small part of the ACM Code of ethics before the second stage of the interview started. Furthermore, we piloted the interview to make sure that the questions were clearly stated and answerable. Moreover, the interviews were taped allowing the researchers to listen to the interviews again to limit misinterpretation. Lastly, coding was then conducted pairwise. Another threat to construct validity is reactive bias to the presence of a researcher. To reduce that threat, interviewees have been assured their anonymity and we use open questions in the interviews as a way to reduce interviewer bias. Also, an interview guideline had been agreed upon the three authors and followed after the first pilot interview.

Internal validity: To minimize the impact of confounding factors influencing the analysis we applied qualitative analysis techniques. Additionally, we do not claim that we collected any other data but that for practitioners perceptions and attitudes related to their work practices and to sustainability, and how these may shift when an ideal working situation is considered. However, threat of confounding factors cannot be ruled out completely.

External validity: The cases presented here are not statistically representative and are not intended to as this is a qualitative study, and statistical generalization is not our goal. Our explorative, qualitative study was designed to help us identify the perceptions of the interviewees with regard to their roles, their responsibilities and possible to enable sustainability design. By selecting practitioners from different application domains, and company sizes, we focused on the collection of a rich set of data.

Reliability: To minimize threats to reliability, coding was done pairwise. Any mapping disagreements were discussed until consensus was reached.

8. Conclusion and future work

If we look at software companies through a sociological lens, we see that every employee has a role to play in order for the software to be completed. The role of SEs has changed since the early 2000s with the rise of Agile Methods. Ideally, SEs no longer limit themselves to specialized tasks, but to interdisciplinary task areas. Today, they can no longer be described as an executive force alone, as they are and must be involved in numerous work steps. They work less in outsourced or separated departments and more in close teams with a high degree of communication. For some years now, we have been able to observe that the topic of sustainability is becoming a component that can only be implemented with the help of SEs. For this development to gain momentum, it is essential that SEs receive a sense of responsibility for the fact that their work has an impact on five dimensions: social, individual, environmental, economic and technical. In addition to publications on Sustainability Design to raise awareness, researchers are publishing methods to help meet the sustainability debt. With both topics, self-role attribution and awareness of sustainability, it is evident due to some discrepancies that the path from former to today's desired structures has not been completed. SEs are insufficiently involved in the design process because their focus on technical issues is so strong that there are communication difficulties with team colleagues from other areas. Their sense of responsibility is thus also on the technical side, such as whether the code works adequately. Sustainability concepts intended for the software design process do not adequately take into account the fact that SEs lack sustainability awareness and a general sense of responsibility for their Software.

This is limited to the issue of data security.

For future studies, we consider two areas to be relevant. First, we plan to complement our qualitative approach quantitatively to ensure that our findings reveal a broader problem rather than an isolated one. A qualitative study such as this entails aspects that threaten the validity of the results. Second, the existing sustainability design methods that are already in use in the Software Engineering process should be reviewed. In this way, the feedback from the participants can be analyzed so that readjustments can be made. These adjustments should take into account the SEs self-role attribution as well as their sustainability awareness.

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Publication II

Lammert, D., Betz, S., Porras, J., and Oyedeji, S.
Sustainability in the Software Industry: A Survey Study on the Assessment, Responsibility, and Motivation of Software Practitioners

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Sustainability in the Software Industry: A Survey Study on the Perception, Responsibility, and Motivation of Software Practitioners

Abstract—While the topic of software sustainability is gaining increasing significance in academia, there is a need to explore its implementation in industrial practice. In this paper, we investigate how software practitioners assess sustainability as a topic within their profession. We conducted a survey study with 104 software practitioners, and the data provides evidence that companies assign moderate importance to sustainability. Different occupational roles indicate varying perceptions and levels of responsibility regarding the development of sustainable software products and services. Notably, technology-oriented roles (e.g., Software Engineers) exhibit lower valuation and responsibility of sustainability aspects compared to management-oriented roles (e.g., Project Managers). The motivation to engage with sustainability shows a connection to business factors such as profitability, competitive opportunities, and risk mitigation. Consequently, researchers should give greater consideration to the circumstances and requirements of businesses, incorporating them into practical approaches to contribute to sustainability.

Index Terms—software sustainability, sustainability design, software engineering, software industry

I. Introduction

In the last decade, there has been a growing interest in the field of Information and Communication Technology (ICT) towards sustainability, particularly within the domains of Software Engineering (SE) and Requirements Engineering (RE). Several Systematic Literature Reviews have identified the significance of sustainability: Calero et al. [1] highlight sustainability as a key factor in SE, Gustavsson and Penzenstadler [2] advocate for a more interdisciplinary understanding of SE that goes beyond a narrow focus on technology, and Imran and Koster [3] acknowledge sustainability as one of the major challenges faced by the SE discipline.

While academia generates novel ideas, concepts, and technologies, industry possesses the expertise and resources required to transform these innovations into profitable products and services. Thus, fostering collaboration between academia and industry is crucial for translating new knowledge into practical applications that generate value for society, the environment, and the economy. Recognizing the importance of bridging this gap, Wolfram et al. [4], in their Systematic Mapping Study on industrial SE practices, advocate for enhanced understanding and collaboration between research institutions and industrial companies. The industry is faced with the dual challenge of grappling with the complexity associated with the multidimensional nature of sustainability, while also ensuring profitability and competitiveness in its implementation.

To address these issues, we conducted a survey involving a total of 104 software practitioners from various industries in the field of software. The objective of this study is to examine the implementation of sustainability within the software industry, with a focus on answering three research questions:

- RQ1: How do software practitioners assess sustainability in the software company in general and in their field of activity in particular?
- RQ2: What role do different employee positions play in terms of responsibility for sustainability?
- RQ3: What motivates software practitioners to set sustainability goals?

Our findings indicate that the topic of sustainability is generally given a mediocre valuation within industry. However, it is crucial to distinguish between two employee roles: those with a more technology-oriented role, such as software engineers, and those with a more management-oriented role, such as project managers. Comparatively, the former role demonstrates a below-average level of engagement and responsibility with sustainability, whereas the latter role excels in terms of their overall commitment. Additionally, our study reveals variations in the prioritization of sustainability dimensions: The technical, environmental, and economic dimensions are considered more significant than the social and individual dimensions. Consequently, there appears to be less motivation to address negative social, ecological, and economic aspects within the context of the Triple Bottom Line (TBL) [5]. The motivation is also driven by market-related benefits, such as gaining a competitive advantage in marketing, reducing costs and risks, and attracting and retaining employees. Our study lays the foundation for future research endeavors aimed at bridging the gap between academia and industry.

In the chapter *Background and related work*, we first review relevant studies that bring together sustainability and software in an industrial context and then present related interview studies that provide first qualitative insights on how the paradigm shift is perceived by software practitioners. In the next chapter, we present our *Research design*. Our survey *Results* are presented in the fourth chapter along the three RQs. The fourth chapter, *Discussion*, is composed of an interpretation of our findings as well as the limitations (threats to validity) of our survey study. Finally, we summarize our results in a *Conclusion*.

II. Background and Related Work

The Karlskrona Manifesto for Sustainability Design, endorsed in 2014 by an array of international scientists, brought significant attention to the imperative of encompassing the social, individual, environmental, economic, and technical impacts of software systems [6]. As part of their efforts, they introduced the Sustainability Awareness Framework (SusAF), a workshop tool designed to aid users in identifying the multifaceted impacts of software systems through guiding questions, a visual representation in a diagram, and ensuing discussions [7]. Seyff et al. [8] established connections between the SusAF questions and the descriptions of the United Nations' 17 Sustainable Development Goals (SDGs). Here, it becomes clear that software companies also share responsibility when it comes to achieving sustainability, as illustrated by Becker et al. [9]. The authors of this article describe the software engineering practice as a process for addressing "wicked problems" with which they express that technical and non-technical systems are intertwined. They emphasized that sustainable requirement engineering necessitates a mindset shift away from a "puzzle-solving attitude" focused on technical and economic issues towards a comprehensive consideration of impacts that require an interdisciplinary understanding of software systems.

In the software industry, the sustainability-related perspective on software has also arrived. Turning attention to empirical studies about the interplay of sustainability and the software industry, Bomfim et al. [10] observed that software companies have started recognizing the significance of cultivating a public image as a "sustainable organization," given the increasing consumer preference for sustainable products and services. Kwak et al. [11] corroborated this finding, stating that global companies have progressively embraced sustainability, with sustainable development being a subject of discussion in politics, business, and society as a long-term strategic goal and a prominent challenge for enhancing the quality of life. Kasurinen et al. [12] concluded that sustainability has become a prevalent trend across various industries, no longer regarded as an "extra feature" but rather as a "competitive advantage in the marketplace" and a critical consideration in the realm of global competition. It has the potential to generate revenue "for any type of organization."

Nonetheless, Karita et al. [13] underscored the lack of knowledge, particularly among software engineers, in their understanding of Sustainable Software Development (SSD). A thematically related survey study was conducted by Bambazek et al. [14]. The software practitioners surveyed (n=47) rated the overall potential for addressing the sustainability impacts of software systems through the Agile method Scrum as high. This study is intended to serve as a basis for adding sustainability elements to Scrum. In total, our research led us predominantly to qualitative studies that address this issue. In the course of this, we would like to point to some interview studies. Chitchyan et al. [15] found in their interviews with requirement practitioners in software companies (n=13) that this role lacks knowledge, experience, and methodological tools for dealing with sustainability. This is also in line with Groher and Rainer [16] who came to a similar conclusion in their interview study (n=10) on sustainability aspects in software development projects: "[Software] practitioners regard software sustainability as important but are technically minded with respect to sustainability." Oyedeji et al. [17] interview study with software practitioners (n=16) showed that this role cannot deliver a definition of sustainability that combines social, environmental, and economic aspects in terms of the trinity of TBL.

Lammert et al. [18] show in interviews with Software Engineers within industry (n=13) that this group, especially due to the transition from the Waterfall Model to Agile Methods at the beginning of the 21st century, has evolved as a team member towards different work steps and thus an interdisciplinary scope of tasks, but has not yet arrived in the role. SEs tend to take on the role of the "executive force" with specialized tasks (mainly coding) withdrawing from team communication in the design process and slowing it down through a technical focus. They recognize the relevance of sustainability in software design but have insufficient knowledge and methods to meet the requirements. All in all, Figure 1 thus corresponds more to the academic understanding than to the industrial understanding of the self-role description and sustainability awareness of SEs.

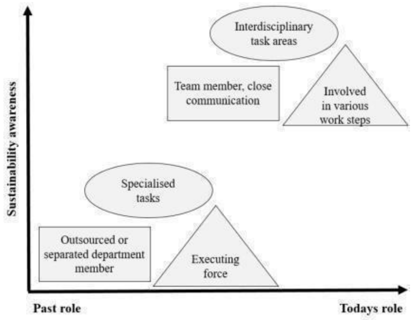

Fig. 1. Role-attribution and sustainability awareness of SEs [17]

Taking this study landscape into account, it becomes evident that the topic of sustainability has permeated both academia and industry. However, qualitative interviews with industrial software practitioners, particularly those of SEs an REs, reveal deficiencies in dealing with the topic of sustainability.

III. Research Design

The data for this study is derived from a survey conducted among software practitioners in industry, with a total sample size of 104 participants. Our design is based on the process established by Pfleeger and Kitchenham [19]. Subsequently, we provide a detailed description of our research design.

A. Objectives and content of the survey

The goal of our survey is derived from the empirical knowledge gaps that were made abundantly clear in the interview studies (see Chapter 2). These were made abundantly clear in the interview studies. Qualitative studies provide valuable, in-depth insights into certain phenomena, but they often lack the ability to generalize the results to a larger population. By conducting a survey study with a larger sample size (n), we can collect quantitative data that allow for broader generalizations and statistical analyses. This quantitative approach complements existing qualitative research by providing a more comprehensive understanding of the topic under study.

The survey questionnaire covered three main areas based on the three RQs: First, participants were asked to rate the overall importance of sustainability in their company in general as well as their knowledge level. They were also asked to rate sustainability in relation to their task area and more specifically in relation to the five dimensions. The survey also asked whether, and if so, which tools are used to implement sustainability. Second, participants were asked if there is a responsible employee for sustainability in their company, and if yes, what that employee's role is. Thirdly, the survey aimed to identify the motivations behind setting sustainability goals within their companies.

B. Data collection

As Pfleeger and Kitchenham describe, descriptive surveys are conducted with the intent, to explain characteristics of a particular population. This is made up of industrial software practitioners. All surveys were administered using Google Forms as the data collection tool. To reach a diverse range of software practitioners, the survey links were primarily shared through various channels such as social networks (e.g., LinkedIn) and online forums for software practitioners (e.g., Stack Overflow).

The participants in the survey can be categorized into 14 job areas, with an average work experience ranging from 5 to 10 years (30%) and over 10 years (33%) (see Table 1). Software Engineers account for 36% of the respondents, followed by Software Developers at 13%. Together, these two groups represent nearly half of the total participants. The surveyed companies span 13 different industry sectors (see Table 2). Approximately one-fourth of the companies (27%) belong to the Information and Communication Technologies sector. Regarding company size distribution, large companies with more than 250 employees constitute 35% of the sample, while medium-sized companies with 50 to 250 employees account for 27%. These two categories combined form the majority of the surveyed companies.

In addition to the overall analysis, we conducted a comparative examination of two specific roles:

- the Technical Role (TR), which included Software Engineers, Software Developers, and Software Architects (n=54) and
- the Management Role (MR), comprising Project Managers, Product Owners, and Business Development Managers (n=21).

This subgroup analysis allows for a more detailed understanding of the perspectives and differences between these two distinct roles within the surveyed software practitioners.

TABLE I
OVERVIEW OF RESPONDENTS' JOB POSITIONS (N=104)

Job Position	*n*	*Years of exp.*	*n*
Software Engineer (*TR*)	37	> 10	34
Software Developer (*TR*)	14	5-10	31
Project Manager (*MR*)	14	3-5	24
IT Manager	9	0-3	15
CEO	5		
Product Owner (*MR*)	5		
UI/UX Designer	5		
CTO	4		
Requirements Engineer	3		
Software Architect (*TR*)	3		
Business Dev. Manager (*MR*)	2		
Data analyst	1		
Tech. Mananager Digital	1		
Webmaster/Content Manager	1		

TABLE II
OVERVIEW OF RESPONDENTS' INDUSTRY SECTORS (N=104)

Industry sector	*n*	*Staff count*	*n*
Information and Communication Tech.	28	Large > 250	36
Media and Entertainment	13	Medium < 250	28
Finance and Insurance	10	Small < 50	24
Community, Social, Personal Activities	7	Micro < 10	16
Health and Social Work	7		
Manufacturing	7		
Transportation and Storage	7		
Electricity, Gas, and Water Supply	6		
Construction	3		
Agriculture, Forestry, and Fishing	2		
Public Administration	2		
Real Estate	1		
Other	2		

C. Data analysis

In terms of the analysis process, we follow Pfleeger's and Kitchenham's tripartite division [19] into data *data validation* (checking consistency and completeness and identifying and processing responses to ambiguous questions), *partitioning of responses* (additional division of the total of responses: TR and MR), and *data coding*. Regarding this point, two types of closed-ended questions were utilized in the surveys: binary (yes/no/not sure) and a 5-point Likert scale. To analyze and evaluate the responses in relation to the research questions, the binary responses were mapped to numerical values (e.g., yes=1, no=0), while the Likert scale responses were assigned numerical values ranging from 1 to 5. This allowed for the calculation of average scores and the normalization of responses on standardized scales, facilitating the quantitative analysis of the data.

IV. Results

The structure of this chapter follows the three RQs.

A. Perception of software sustainability (RQ1)

Overall, the topic of sustainability received a medium-high rating of 2.8 on a scale from 1 to 5, with 1 representing very low importance and 5 representing very high importance. There was a noticeable difference in the ratings between the total respondents, the TR and the MR. The TR rated sustainability somewhat lower with a score of 2.6, while the MR rated it higher at 3.5, indicating a moderate to high level of importance. This difference is also reflected in the question of whether a higher workload related to sustainability was desired in the company. Among the total respondents, just over half (51%) answered in the affirmative, while 28% were unsure, and 21% answered negatively. In the TR, 49% favored a higher workload, while among the MR, the figure was 64%.

Regarding their own areas of responsibility, sustainability was given a medium weighting of 2.5 overall. The TR tended to view sustainability as "rather unimportant" with a score of 2.4. In contrast, the MR showed a stronger inclination towards moderate importance, with a score of 2.8. The weighting of individual sustainability dimensions did not differ significantly between the total respondents and the TR, with differences ranging from 0.2 to 0.4. However, the MR had higher scores across the dimensions, ranging from 0.1 to 0.8.

TABLE III
Importance of sustainability in general and in the dimensions of one's own area of responsibility (n=104)

Role	*General*	*Soc.*	*Ind.*	*Env.*	*Eco.*	*Tec.*
MR (n=21)	2,8↑	3,0↑	3,0↑	3,6↑	3,9↑	3,4↑
Total (n=104)	2,5	2,4	2,3	3,0	3,1	3,3
TR (n=54)	2,4↓	2,2↓	2,1↓	2,7↓	2,7↓	3,1↓

In terms of tools addressing sustainability, 28 different tools were mentioned, with the majority (11) being related to green server hosting (such as renewable energy usage, energy consumption reduction, and CO2 offsetting through climate projects). Two tools focused on reducing e-waste by utilizing used equipment. Additionally, usability/UX tools (4) and IT security or data privacy tools (3) were mentioned as addressing the social and individual dimensions of sustainability. Three tools explicitly addressed the multidimensional nature of sustainability, including the Sustainability Awareness Framework (SusAF) and the Flourishing Business Model Canvas. Some respondents indicated a high number of tools without providing specific details, while others mentioned that the choice of tools depended on the project. The remaining answers were too imprecise to be categorized.

B. Responsibility for software sustainability (RQ2)

According to the survey, 66% of respondents stated that there is no employee with primary responsibility for sustainability in their company. 28% answered affirmatively, while 5% were unsure. Among the 29 respondents who indicated a responsible employee, 41% mentioned the project manager as the role with sustainability responsibility. Other job roles mentioned as responsible included Business Development Manager, Product Owner, Requirements Engineer, and Chief Executive Officer, each accounting for 10% of the responses. Three respondents mentioned "Other" and emphasized that responsibility for sustainability lies with everyone in the company. No specific role within the Technical Role (TR) (Software Engineer, Software Developer, and Software Architect) was explicitly named.

This information corresponds to the estimation of knowledge levels regarding sustainability. Overall, respondents rated their knowledge as low with a score of 2.2 on a scale of 1 (very low) to 5 (very high). The TR scored slightly lower with 1.9, while the MR rated their knowledge significantly higher at 2.9, indicating a moderate level of knowledge.

Only one-third (33%) of the total respondents reported implementing sustainability tools, while the majority (60%) answered negatively, and a smaller proportion (7%) were unsure. Among the TR, 30% reported implementing tools, slightly below the overall group, while among the MR, the average was higher at 41

C. Motivation for software sustainability (RQ3)

In the survey, respondents were asked to rate the importance of various areas for achieving sustainability goals within their company. Nine specific areas were provided for evaluation (refer to Table 4). Additionally, respondents had the option to provide additional reasons for motivation.

TABLE IV
Motivation for setting sustainability goals (n=104)

Motivation	*MR (n=21)*	*Total (n=104)*	*TR (n=54)*
Reduce neg. impacts	3,3↑	2,6	2,3↓
Long lasting software	3,3↓	3,5	3,6↑
Reduce risks	3,9↑	3,4	3,4→
Reduce costs	3,5↑	3,2	2,0↓
Profit	3,1↑	2,9	2,8↓
Image/reputation	3,7↑	3,1	2,9↓
Marketing	3,6↑	3,3	2,7↓
Acquire/bind employees	3,2↑	2,7	2↓
Receive fundings	2↓	2,1	2,1→

The results indicate that the TR rates only one motivation reason higher than the MR and the overall respondents: the importance of a long-lasting software system, referring to how well a piece of software system/service can adapt to changes. The MR shows a higher motivation for sustainability goals in seven areas, with only a slight deviation below the average in one area: receiving fundings.

Additionally, respondents provided motivations that were not included in the predefined list. These motivations include personal reasons, network cooperation with partners, investing in the future, surpassing the competition, receiving government project orders, and external demands.

Regarding interest in participating in a workshop on sustainable software design, the overall interest was rated as moderate with a value of 3.4. The majority (34%) rated their interest as "rather high," while the minority (7%) rated it as "very low." The TR showed slightly higher interest with a rating of 3.5, while the MR exhibited a higher interest with a rating of 4, indicating a "high" level of interest.

V. Discussion

The findings are now discussed, providing insights and interpretations. In the final section, the limitations of the study design are addressed, acknowledging the constraints and potential factors that may have influenced the results.

A. Perception of software sustainability (RQ1)

Our findings align with the related interview studies mentioned in Chapter 2 [15]–[18] indicating a divergence in the understanding and valuation of sustainability between academia and industry. Sustainability appears to be moderately prioritized in the software industry. Besides this, we can observe a connection with business aspects such as profitability, competitive opportunities, and risk mitigation.

Although it makes sense in a second step to focus on individual areas (e.g., individual dimension) or aspects (e.g., privacy) depending on the software system, there is a risk that other dimensions will be overlooked. In the worst case, a software product or service can be classified as sustainable on the basis of a selective view, even though a comprehensive perspective reveals numerous weak points. In this sense, a holistic view of the topic of sustainability should first be taken, which gives importance to all dimensions.

Since there are deficits in the knowledge surrounding the topic of sustainability, it offers it is recommended to involve external stakeholders in requirements analysis through participatory design, as suggested by various studies (e.g., [13], [22], [23], [24], and [25]. This approach acknowledges the diverse levels of knowledge among individual employees and promotes collaboration.

B. Responsibility for software sustainability (RQ2)

In the planning and implementation of sustainability approaches, interdisciplinary professional roles in interface positions, such as project managers, are well-suited for the task. The MR is also most likely to be mentioned when identifying a person responsible for sustainability. The MR not only rates sustainability's relevance higher but also possesses a higher level of knowledge in this area.

Considering the importance of sustainability in planning and implementation across all fields of activity, it is recommended to enhance the inclusion of sustainability knowledge in the curriculum of software practitioner education, as already suggested in previous studies (e.g., [20] and [21]).

C. Motivation for software sustainability (RQ3)

The question is whether personal, intrinsic motivational factors alone are sufficient in an industrial context or whether extrinsic, commercially motivated motivational factors could exert a stronger force in achieving sustainability goals. When establishing sustainability goals based on models such as the TBL or the SDGs, it is important to consider the requirements of a profit-focused operation and its organizational structure, emphasizing the need for a balanced approach that incorporates both sustainability and financial considerations.

Like the Scrum-related study by Bambazek et al. [?], the results of our study could be used to link existing approaches in the field of sustainability design with business designs that target the outcome of extending existing artifacts.

D. Limitations

Construct validity: There is a potential threat to validity regarding the extent to which our survey questions fully capture the complexity of the subject matter, and it is possible that individual survey items, such as the scales used, may have limited it. Moreover, there is a risk that some participants may not have fully understood the questions, leading to potential misinterpretations during the follow-up step. To mitigate these concerns, we conducted multiple iterations of the survey, incorporating feedback to enhance the consideration of the topic and refine the wording of the questions.

Internal validity: It is important to acknowledge that there might be additional variables influencing the relationship between the independent and dependent variables in our survey. Factors such as personal circumstances (e.g., prior experience or cultural background) could lead to variations. Additionally, although we employed various common platforms for survey distribution to minimize selection bias, it is possible that software practitioners with a pre-existing interest in the topic were more inclined to participate. To address this, we employed a random sampling technique to provide an equal opportunity for software practitioners to be represented in the study.

External validity: While we made efforts to gather a large and diverse dataset during the recruitment process, certain characteristics of our sample may limit the generalizability of the results to the broader software industry. Although our study encompassed a wide range of occupational roles and business sectors, there may be industry-specific differences in the way sustainability is approached that were not fully captured in this study. Future research should consider these nuances to enhance the generalizability of findings.

Reliability: The evaluation process involved all researchers, ensuring that any discrepancies in classification were discussed and resolved through consensus. To mitigate potential reactive bias, where participants may provide responses influenced by social desirability, the surveys were conducted anonymously.

VI. Conclusion

In our survey study, we have demonstrated notable disparities in the perception, responsibility, and motivation for sustainability between industrial software practitioners and the current academic theory. Our quantitative findings align with and substantiate previous qualitative interview studies, providing further validation to the existing body of knowledge.

The results of our study demonstrated that the subject of sustainability is accorded a moderate valuation by industrial software practitioners. Our analysis has revealed a discernible distinction between the professions that lean towards technical orientations (namely Software Engineer, Software Developer, and Software Architect) and those that adopt a more interdisciplinary approach in management (such as Project Manager, Product Owner, and Business Development Manager). The latter role places greater emphasis on sustainability, possesses more understanding of the topic, and assumes a higher level of responsibility when it comes to implementing sustainability into software products and services. The impetus to establish and attain sustainability objectives is intricately linked to business interests, including factors such as profitability, competitive advantages, and risk mitigation.

Our study highlights the significance of bridging the gap between academia and industry, enabling the translation of sustainability principles into tangible software products and services. It is through this synergy that we can collectively strive toward a more sustainable future for software systems.

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Publication III

Lammert, D., Betz, S., and Porras, J.
The Business-oriented Extension of the Sustainability Awareness Framework – a Design Science Study

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The Business-oriented Extension of the Sustainability Awareness Framework – a Design Science Study

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Abstract. This Design Science Research outlines a systematic extension of the Sustainability Awareness Framework (SusAF) that was created by scientists worldwide to identify and consider potential sustainability impacts of their software systems during the design phase. The artifact, the Business-oriented Extension of the SusAF, includes the industrial needs, such as corporate structure and commercial criteria, for designing sustainable software products and services. Using Design Science Research, our artifact provides a guideline that shows that profitability and sustainability are not only not mutually exclusive but can go hand in hand. While the current SusAF is often addressed directly to software and requirements engineers, we recommend someone with an interface position, such as the product manager, to organize and conduct the workshop. In order to do justice to the complexity of sustainability, we advocate the involvement of external stakeholders in a participatory approach. Business-related points, such as a time frame, cost-effectiveness, and transfer to the financial plan, should also be taken into account. Industrial aspects have not yet been sufficiently explored in the scientific literature. Our work contributes to bridging the gap between academic theory and industrial practice.

Keywords: Software Sustainability, Software Engineering, Requirements Engineering, Sustainability Awareness Framework, Software Industry, Design Science.

1 Introduction

Given the indispensable role of software systems in our everyday and professional lives, it is unsurprising that they exert a significant influence on the "3Ps" - namely, people, planet, and profit – as presented by John Elkington in the Triple Bottom Line Model [1]. However, Becker et al. [2] declare that software engineers tend to adopt a one-dimensional technological approach to software systems by overlooking the complex interplay between software and its impacts. This underscores the urgent need to develop sustainable software solutions, which represents a significant challenge that is transforming the field of software engineering in profound ways.

In light of the pressing need to incorporate sustainability into software, a team of global scientists developed the Sustainability Awareness Framework (SusAF). It offers software and requirements engineers a comprehensive workshop to visualize and evaluate the potential impacts of software across five sustainability dimensions – social, individual, environmental, economic, and technical [3]. The objective of the SusAF is to facilitate the integration of sustainability considerations into the design phase of the software development process. Indeed, the SusAF has emerged as one of many widely utilized tools worldwide for sustainable software development [4].

According to Chitchyan et al.'s empirical study "Sustainability design in requirements engineering: State of practice" [5], which involved interviews with 13 software engineers, sustainability is now a major societal concern. The study, among others, underlines that the SusAF offers only limited guidance for implementing sustainability in software companies, lacking answers that address the issues faced by the industry.

In the context of sustainable software development in industry, we are devoted to a methodical and structured approach to addressing a research problem, specifically the creation of an artifact through Design Science Research (DSR). As described by Brocke et al. [6], DSR is a problem-solving paradigm that aims to enhance human knowledge by creating innovative artifacts. The goal of DSR is to understand and improve design processes by creating an artifact to solve a problem, with an underlying analysis of its performance [7]. Hevner adds that the artifact must relate to a "heretofore unsolved and important business problem". This process is also referred to as "learning by building" [8]. Our artifact is the "Business-oriented extension of the SusAF".

Peffers et al. [9] collated seven distinct methodologies for DSR that had arisen from the field of Information Science (IS) and other related disciplines. The present authors have undertaken a study to distill the core elements of these methodologies into a diagram, as depicted in Figure 1. Our approach is founded upon the DSR Methodology of Peffers et al. [9], which has emerged as the most frequently cited model, as noted by Brocke et al. [6]. This methodology involves six steps: 1) problem identification and motivation, 2) definition of the objectives for a solution, 3) design and development, 4) demonstration, 5) evaluation, and 6) communication.

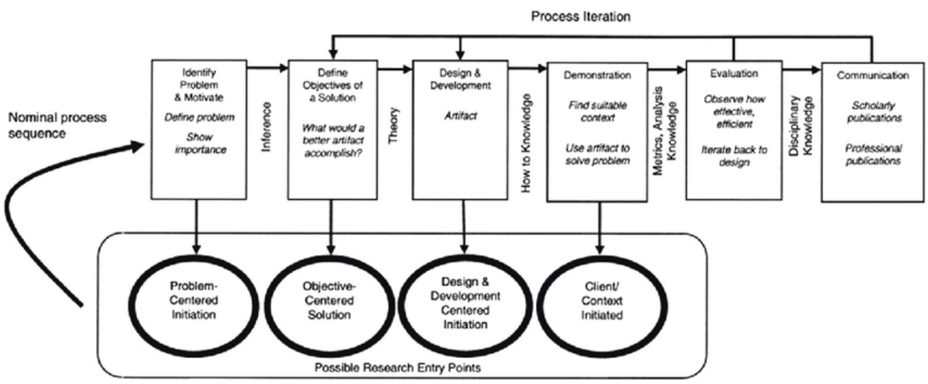

Fig. 1. Design science research process model by Peffers et al. (2008).

Although the linear chapter structure of this study is based on the six steps, the iterative process of creating the artifact should be emphasized at this point. The chapters were by no means dealt with and checked off step by step; instead, we returned to the previous steps several times. In the chapter *Problem identification, motivation, and objective*, we address the research gap and provide justification for the need of a solution. Here, we identified problem areas and opportunities. Our findings enabled us to define the application context, determine the requirements for the artifact, and establish success criteria. In the second chapter, *Design and development*, we utilized the creation of our knowledge base to develop a preliminary extension of the SusAF, which was then tested and evaluated in the field. In *Demonstration and evaluation*, we present the artifact that resulted from the research iterations through a conducted workshop. Chapter five, *Communication*, addresses the release of the artifact for industrial practice. In the next chapter, *Limitations*, we discuss the threats to validity that should be considered for our result. Finally, we outline our results in the last chapter, *Conclusion*.

2 Problem identification, motivation, and objective

In the first section of this chapter, we provide an introduction to designing sustainable software. Here, we also demonstrate the process of the SusAF as a tool to address this topic. Secondly, we define the objectives for our artifact.

2.1 The integration of sustainability into software design

In 1987, the United Nations World Commission on Environment and Development published the report "Our Common Future" [10] that is widely regarded as a crucial milestone in the global discourse on sustainability and remains influential in shaping contemporary political and economic decisions. The authors stress the importance of countries accounting for the interrelated environmental, social, and economic factors in achieving sustainability. The authors assert that to effective promotion of sustainability requires a collaborative effort involving industry, governments, and civil society.

2000, the UN declared the eight Millenium Development Goals (MDGs) as well as the 17 Sustainable Development Goals (SDGs) as part of the 2030 Agenda in the year 2015 [11]. Those goals seek to tackle global issues such as poverty, climate change, inequality, and environmental degradation. They represent a significant advancement in the pursuit of sustainable development and underscore the criticality of a comprehensive approach that considers the interrelated dimensions of sustainability.

Although SDGs represent a high-level perception of sustainable development, the visibility of the needs has affected many scientific disciplines. A group of international computer scientists published the "Karlskrona Manifesto for Sustainability Design" [12]. The signatories contend that software practitioners carry a special responsibility. They assert that sustainability is a multi-dimensional and multi-layered notion that must be factored in during the design phase of software systems.

The SusAF was devised to aid software practitioners in examining the five dimensions (Table 1) and three levels of effect (Table 2). It is conceived as a tool that aims to identify, comprehend, analyse, and subsequently discuss the potential impacts that software systems may have. The SusAF workbook provides a guide to the application process, example questions for each dimension, templates to fill out, and a visualization tool known as the Sustainability Awareness Diagram (SusAD) – presented in Figure 2.

Table 1. The five dimensions of sustainability based on the SusAF [13].

Dimension	Description
Social	"covers the relationships between individuals and groups."
Individual	"covers the individual's ability to thrive, exercise their rights, and develop freely."
Environmental	"covers the use and stewardship of natural resources."
Economic	"covers the financial aspects and business value."
Technical	"covers the technical system's ability to accommodate changes."

Table 2. The three types of effects based on the SusAF [13].

Dimension	Description
Immediate	"are direct effects of the production, operation, use and disposal of socio-technical systems."
Enabling	"of operation and use of a system include any change enabled or induced by the system."
Structural	"represent structural changes caused by the ongoing operation and use of the socio-technical system."

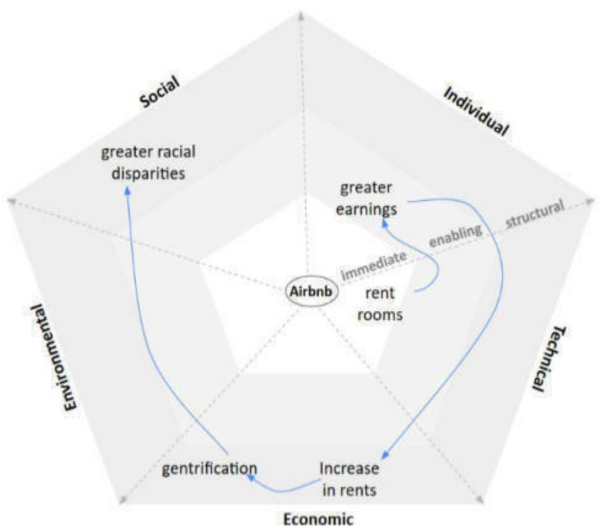

Fig. 2. Example of SusAD for one chain-of-effects in Airbnb [13].

Given the complexity of analysing the potential impact of software systems on sustainability, our group of nine researchers argued in a recent discussion paper [14] that the development of appropriate methods and tools is crucial to address the challenge in requirements engineering. To assess the degree to which the sub-items of the 17 SDGs can be linked to the questions raised by the SusAF in requirements engineering, the authors conducted an initial mapping that establishes connections based on shared or similar terminologies. The analysis revealed a significant number of interconnections.

In an interview study, "Sustainability Design in Requirements Engineering: State of Practice", a number of the signatories of the Karlskrona Manifesto and thus the creators of the SusAF take up criticism of the implementation of the SusAF [5]. The 13 interviews with software engineering practitioners showed that they have difficulties in adequately addressing the complexity of the topic of sustainability. Gaps were found in the areas of knowledge and experience as well as in methodology and tool support, among others. As a mitigation strategy, among other things, more education and training are recommended, as well as a new tool and methodology development.

Furthermore, numerous scientists speak out for the inclusion of the sustainability idea in the business plan. For instance, Kasurinen et al. [15] argue that sustainability should not be considered an "extra feature," but rather a "competitive advantage in the market." Similarly, Bomfim et al. [16] suggest that consumers increasingly prefer products and services with a sustainable character. Nevertheless, sustainability can also incur costs that software companies must consider from an economic standpoint.

2.2 The current SusAF process and the objectives for a solution

The process that software companies go through with the SusAF is summarized in Figure 3. First, the software or requirements engineer uses the workbook to gain familiarity with the topic of sustainability. Then, they conduct a workshop with representatives from the company or in the form of a project with partners from the university. The result of the workshop, usually in the form of a report consisting of various impacts and their visualizations as SusADs, is then passed on to the responsible stakeholders in the company, such as the management. The results are then analyzed and subjected to corporate scrutiny. Finally, the topic of sustainability is to be integrated into the respective software product or service and considered in the business plan

Hevner [7] recommends that the problems and opportunities be grouped under the headings of People, Organizational Systems, and Technical Systems.

People: Our preliminary work enumerates reasons to question whether the organization and execution of the workshop should fall to the software or requirements engineer. The most important ones are the one-sided technical focus, low communication, and lack of interdisciplinarity. In addition, the question arises as to whether the representatives of the company itself can adequately consider the topic of sustainability or whether the involvement of other stakeholders is necessary. Identifying and selecting the key personnel responsible for organizing and implementing SusAF workshops is crucial. Additionally, a participatory approach that involves stakeholders is crucial to comprehensively addressing the multi-dimensional topic of sustainability.

Organizational Systems: The company organization refers to the holistic approach to how the various structural components of a company operate, as well as the coordination and alignment of these components with the overarching corporate goals. Business administration literature provides an extensive list of organizational forms, including hierarchical, functional, horizontal, interdepartmental, team-based, and network-based structures, among others. The SusAF targets small, medium, and large software companies. Unlike the original SusAF, our extension does not rely on external organizations such as civil law foundations, registered associations, or cooperatives. Our focus is on creating a sustainable software, following the principle of profitability, which entails generating income equal to or greater than expenses.

Technical Systems: Our artifact is designed to facilitate a topic and industry-agnostic use for preliminary insights. As with the original SusAF, the artifact is intended to be applicable to a wide range of software products and services, rather than being restricted to a single topic or industry. Due to its ability to establish individual focal points, the SusAF, including its extension, retains its flexible applicability.

By adopting a participatory approach and a business perspective, software companies should be able to balance their corporate goals with sustainability.

3 Design and development: The interim version of the artifact

In this chapter, the information from the previous cycles is used to develop, test, and evaluate the second development stage of the SusAF. Then, we summarize the "intermediate artifact stage" that has been applied in five workshops regarding the topics Autonomous Driving, AI in Music Composition, AI Memory Avatars Online Pastoral Care, and Virtual Graveyards. Our more detailed findings were published in two peer-reviewed articles [17] and [18]. A total of 38 participants attended the workshops, resulting in an average of 8 participants. The average age of the participants was 30.2 years (19 to 69). An equal distribution of female and male participants was observed. On average, they had 4.8 years of professional experience (less than a year to 38 years).

3.1 Select the right employee for the organization and implementation

In the current version of SusAF, the focus was on software and requirements engineers but also product owners and sustainability managers. We conducted workshops to identify suitable candidates for 1) preparing the workshops, 2) leading them, and 3) initiating follow-up actions. We recommend that an employee with an interface function be selected for these roles. This means that the selected employee should be involved in multiple work steps, including design, development, market entry, and market monitoring. Typically, these employees belong to interdisciplinary professions, such as product managers and product owners.

3.2 Participatory approach through stakeholder involvement

Our approach to involving stakeholders is based on common stakeholder analysis models [19]. Stakeholders are broadly defined as individuals, groups, or institutions that are directly or indirectly impacted by a company's activities or have a vested interest in them, and thus seek to influence project activities based on their interests. Stakeholders are of paramount importance to a company, and management must always remain cognizant of the identity, interests, expectations, and demands of these individuals and institutions, as well as their impact on the company's success. Software companies are provided with four questions that enable a heterogeneous stakeholder breakdown: 1) Who are the stakeholders? 2) What is the importance of each stakeholder and how close are they to your IT product or service? 3) What impact does the software have on the stakeholders, and what requirements do they have for the software? 4) How does the product manager respond to this challenge?

During the workshop, it is crucial to consider the diverse backgrounds of the stakeholders. To address this, an introductory presentation regarding the software concept should be prepared, which also explains the technical interrelationships in a comprehensible manner. The presentation is followed by a question-and-answer session.

Furthermore, it is essential to clarify the benefits of the software for the users. To achieve this, we recommend initiating the extended workshop with the Value Proposition Canvas (VPC). The VPC is a worldwide used tool that aids in developing and visualizing the value proposition of a product or service [20]. The VPC comprises two sides: The customer side of the VPC pertains to the customers' needs, tasks, challenges, and desires. It involves creating customer profiles and analyzing their behavioral patterns to gain a better understanding of their challenges, as well as their needs. On the other hand, the product side of the VPC encompasses the features, characteristics, and functions of the product. This includes analyzing the problems that the product aims to solve and the benefits it provides to customers.

3.3 Embed the business orientation

The Business Model Canvas (BMC) is a method that enables companies to examine nine key factors of their business model, e.g. revenue streams, key activities, and key resources. It supports the development and revision of innovative and complex business models. We have chosen to incorporate a modified version of the classic Business Model Canvas (BMC) in our workshop, which includes a unique feature. We ask the participants to classify each of the nine key factors into three distinct "sustainability levels" for the user, with level 1 representing the lowest sustainability and level 3 the highest. It is important to note that these sustainability levels are determined by the stakeholders themselves during the discussion.

Here is an example of how this classification would work for the "revenue sources" key factor. **Level 3:** The customer can cancel their software product and associated payment at any time for at least at the end of the month. Economically disadvantaged customer groups, such as students, receive a permanent discount. **Level 2:** The software product is valid for one year, irrespective of whether the customer uses it or not. After the year, the customer must actively request an extension. Economically disadvantaged customer groups are granted a discount that expires after a specified period (e.g., three months). **Level 1:** The software product is automatically renewed after one year without the customer's explicit agreement, as the customer has already agreed to the extension by checking a box during the buying process. All customer groups pay the same price, with discounts available only in isolated marketing campaigns to acquire customers.

The "Traffic Light"-Business Model Canvas (TL-BMC) provides a basis for examining, evaluating, and selecting key aspects of the business and financial plan for the software company. It is important to note that under economic conditions, it is not sufficient to only integrate aspects that belong to the first sustainability level. Rather, it is necessary to set priorities and align them with the stakeholders' priorities and the financing options of the company.

3.4 The intermediate stage of the artifact and further requirements

The workshop is embedded in a preparation phase that focuses on organizing a heterogeneous stakeholder ensemble and a follow-up phase for the implementation of (selected) sustainability aspects into the business plan. The workshop consists of four stages: An introductory presentation, the VPC, the SusAF, and the TL-BMC. The feedback on the interim version highlighted five areas for improvement.

TL-BMC for internal stakeholders only: During the workshops, it became evident that the software companies are utilizing the TL-BMC tool for internal purposes only. This is because the content of the tool, which includes nine key factors in business models, uses a language that requires explanation and relates to internal structures. Additionally, due to the protection of business secrets, it can be hypothesized that the software companies are working on the TL-BMC in terms of desirability. Consequently, the workshop for extern stakeholders should conclude once the SusAF is completed.

Consideration of funding programs: In the intermediate stage of our artifact, it was suggested that "selected" aspects of sustainability should be taken into account in the business plan that are important for the stakeholders. To achieve greater consideration of sustainability aspects in the business plan, companies can apply for appropriate funding programs. Public funding is available in various parts of the world for companies that prioritize sustainability, including in the software sector.

Adjustment of the time frame: Based on the results of our survey, it is recommended to schedule the workshop for a maximum of 8 to 12 hours. To ensure optimal participation from external stakeholders, it is advisable to limit their involvement to one day. Considering the TL-BMC is now conducted only within the internal company round, the workshop should be split into two daysOn the second day, only internal stakeholders would participate on the TL-BMC (up to 4 hours).

4 Demonstration and evaluation: The final artifact

Figure 3 summarizes the outcome of the final artifact based on the information in the previous section.

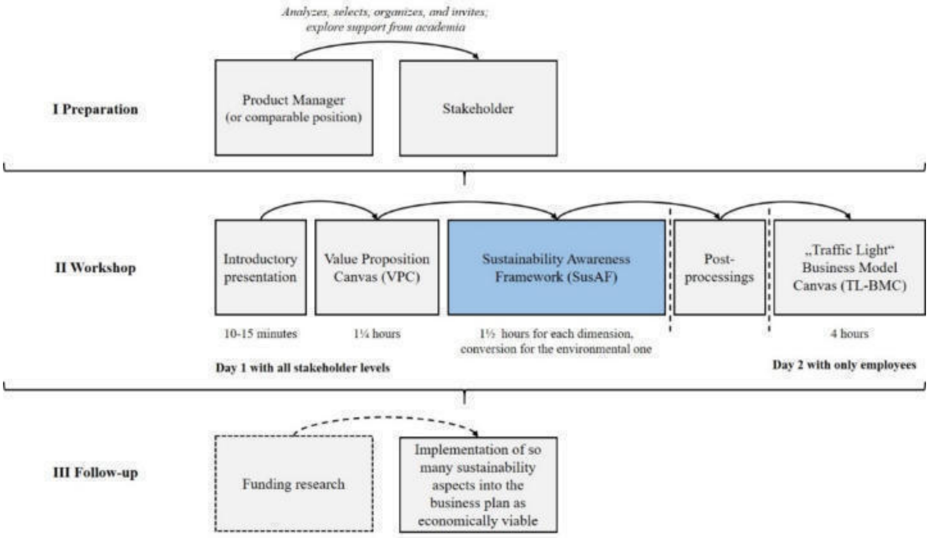

Fig. 3. The artifact (Business-oriented Extension of the SusAF)

In this chapter, we will demonstrate and evaluate the artifact in s step-by-step procedure.

4.1 Demonstration

We established communication with the IT/digital department of a German publishing house. It had a project, tentatively named "Automatic Manuscript Analysis," which involved the use of AI technology to evaluate unsolicited manuscripts. To submit a manuscript, authors would visit the publisher's website and click on an automated submission button. Once submitted, the AI system would evaluate the manuscript and provide a score between one and ten, which indicates the likelihood of success. These are the four main variables according to which the AI evaluates the manuscripts: 1) Author's network, 2) proofreading effort, 3) writing style, and 4) target audience analysis based on the subject matter. If a manuscript achieves a high overall ranking (e.g., seven to ten) in the evaluation, it will be examined by the editorial office.

4.2.1 Preparation

The management appointed the webmaster as the project manager for the "Automated Manuscript Analysis" project. In today's industry, webmasters play a crucial role in the planning, development, maintenance, and administration of websites and web applications. They are typically the primary point of contact for technical issues, queries, and suggestions concerning a website.

To follow our recommended guidelines, the webmaster assembled a group of eight stakeholders, which are presented in Table 3. This group comprises individuals with relevant expertise and responsibilities in the project.

Table 3. Composition of participants.

Dataset	Description
Age	Between 33 and 67
Gender	Female: 3 participants, male: 5 participants
Profession	- Webmaster and Project Manager - Software Developer with expertise in Big Data and AI - Editor - Content Marketer - 2 Authors (of the publishing house) - Municipal event manager (also for literature readings) - Bookseller
Experience	Between 5 and 41 years

4.2.2 Workshop

The project plan was presented by the webmaster and the software developer, which included a ten-minute explanation of the core functions. This was followed by a five-minute introduction to AI by the software developer alone. After that, there was time for stakeholders to ask questions.

The **VPC** was then performed. The group identified the author as the most affected by the software.

Gains, pains and customer jobs: The line of work enjoys creativity “like hardly any other”. Additional benefits are financial gains and the independence that the job brings, as well as the opportunity to grow intellectually through researching and writing. Above all, debut authors and unknown authors are said to suffer from the rejection of their manuscript, especially if this is unfounded. There is the compulsion to make changes to the manuscript that are desired by the editor. Authors are said to suffer from deadlines, as this causes pressure as well as commercial decisions (such as a small selection to “test” the book first). Authors must create a concept, do research, develop a writing routine, get feedback, and improve the text. Once the manuscript is ready (or not yet) they have to search a suitable publisher, prepare the manuscript and wait for the verdict. In many cases, the two authors said (and the editor agreed) that no response comes, so the manuscript can be considered rejected after a few months.

Gain creators, pain relievers and requirements for the software: Authors should benefit from receiving an answer with constructive criticism as well as information that supports them in marketing and promotion. There should be transparency in the contract. Authors would benefit from clear guidelines for submission as well as transparency for the decision in case of rejection. Reasoned feedback with suggestions for improvement should be considered in the software. The submission process should be easy to understand even for non-digital-savvy authors. Transparent guidelines for submission are equally important. The software must provide the author with constructive feedback with suggestions for improvement. Finally, it is important that the author, as the owner of his or her work, can delete it from the system at any time.

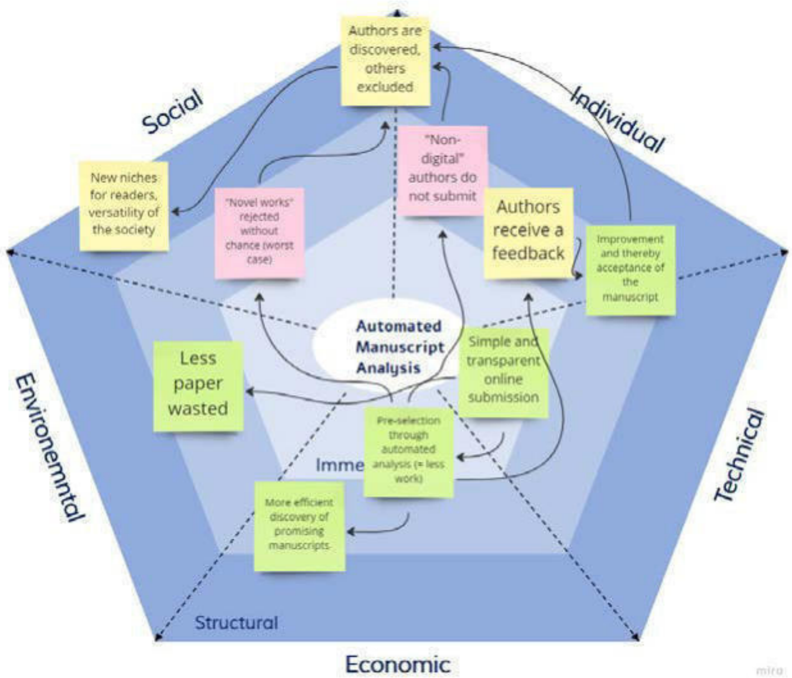

Fig. 4. The completed SusAD of the workshop.

In addition to the set of questions from the SusAF, workshop participants were guided by the results of the VPC to complete the SusAD (see Figure 4). The group started on the immediate level of the **technical dimension** with the point "Simple and transparent online submission", which is made possible by the software. On the **economic dimension**, this leads to less work for the publisher, as he can save money through pre-selection. Over time, i.e. in the enabling stage, this leads to a more efficient search for promising manuscripts. On the **environmental dimension**, less paper consumption can be expected in the enabling stage, as manuscripts are submitted digitally. Several issues arise from the pre-selection of manuscripts. First, the feedback is shared by the system with the authors on the **individual dimension**, which some participants did not want to be evaluated as either positive (green) or negative (red), as it was an AI that was too questioning to make this evaluation. Nevertheless, they could use the information for improvement, which in turn would lead to a subsequent acceptance of the manuscript. On the negative side, non-digital-savvy authors completely refrain from submitting their manuscripts. In the **social dimension**, this leads to the discovery of new authors who were previously lost in the mass of unsolicited manuscripts (positive), but other authors stay away from the publisher (negative). If other publishers use the same system, which can be assumed if it proves successful, social or structural changes could be expected. The negative character of this circumstance is reinforced by the danger that the AI will assign a poor ranking to the novel, i.e., non-established or experimental, text forms from the outset. At the same time, and this was also placed on the structural level, new niches can be opened up or destroyed.

In summary, the workshop unveiled potential sustainability benefits as well as risks that the publishing house must consider when deciding to use the automated manuscript analysis software. This was the conclusion drawn at the end of the first day of the workshop. It became evident that the current in-house solutions would not be adequate to address all the challenges, and the publishing house would require additional training and personnel to undertake the project. The workshop highlighted the importance of considering topics such as Explainable AI, Green AI, and Green Cloud Computing. To address these concerns, the software developer was assigned the task of conducting further research on these topics and their implications on the project workload.

The group continued with the **TL-BMC** the following week. Here, only the four internal stakeholders, the employees of the publishing house, were present. The completed TL-BMC is shown in Figure 5.

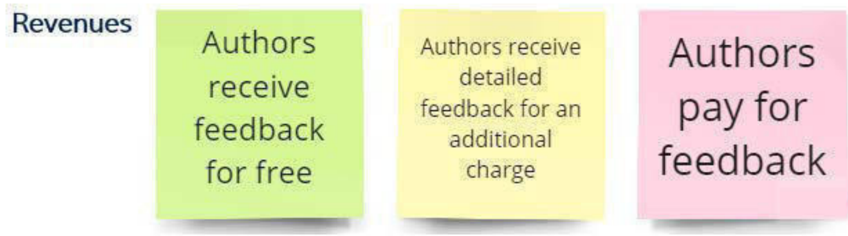

Fig. 5. Example result of the factor “Revenues” of the TL-BMC.

To avoid getting lost in the detailed content of the demonstration, we will focus on three key factors of the TL-BMC model that we believe is exemplary.

Revenues: The publishing house needs to consider the revenue streams associated with user-centered design, specifically whether authors should receive feedback on their manuscripts free of charge (green) or with an additional fee (yellow or red). However, the cost of the project needs to be considered as well. It remains to be seen if the author can cover the costs associated with publishing alone.

Key Resources: The Automated Manuscript Analysis only appears economically sustainable if it can be shared with industry partners (green). These partners could share the system for their purposes and save on development and maintenance costs.

Key Partners: It would be desirable for the AI algorithms to be transparent, sometimes even running open source, in order, for example, to win over authors’ associations as partners and involve them in the software design in a participatory manner (green). Alternatively, to protect trade secrets, a detailed description could be made available on the website of what happens in the background of the software without it being possible for competitors to copy it (yellow). It would not be user-friendly if everything that happens in the background remained a pure corporate secret (red).

All in all, these points make it clear that a sustainable software solution can be associated with corporate risks that relate to revenue opportunities, cost recovery, and competition. Failing to adequately consider sustainability aspects in the project could prove fatal, as key partners may be unwilling to support the project if sustainability concerns are not addressed.

4.2.3 Follow-up

After analyzing the results of the workshop, it became evident that certain conditions needed to be met for the development of the software to be feasible, and to minimize the risk associated with it. Firstly, it required the participation of industry partners, and secondly, a successful application for an appropriate funding program.

As part of one of the author's dissertations in this study, a platform was created [21] to support software companies in implementing sustainability. The platform includes a map- and table-based collection of public funding opportunities towards sustainability, which could be applicable to software companies. In Germany alone, the platform has identified 65 grant opportunities, with 20 aimed at established companies and 45 at start-ups. Collaboration with a start-up in the publishing house is also a possibility.

The feasibility of the project, as well as its level of consideration of sustainability aspects in the business plan, primarily depends on the outcome of these points.

4.2 Evaluation

All eight participants answered the question in the affirmative as to whether their perception of sustainability had changed as a result of the workshop. The reason given twice was the multidimensionality, which the participants were not aware of. One participant stated that he had "expanded his overall understanding," another participant spoke of the "complexity," and one participant even said that it was a whole new topic." Furthermore, the participatory approach was cited as successful. Accordingly, all participants said they had gained insights they had not had before. Furthermore, all participants would recommend the workshop to others, and seven out of eight are interested in holding a similar workshop again in the future. Most of the participants (seven out of eight) found the workshop profitable or very profitable.

Most of the participants considered the workshop as rather easy to understand or easy to understand. One participant clicked on "nor difficult / nor easy"). Nobody clicked on "rather difficult" or "difficult".

We asked for an individual evaluation of the four workshop steps, which followed the following scale: "1 = not valuable" to "5 = valuable". It should be noted here that the fourth workshop was attended by only four participants, the internal stakeholders. Each step can be rated as positive to very positive with an average of more than 4.

The delegation of tasks to individuals, which encompasses three key aspects (organization of leadership and diverse composition of stakeholders), was positively evaluated by the participants and was predominantly rated as "useful" by five participants, "rather useful" by two and in between by one.

As far as the time aspect was concerned, the majority of participants (five out of eight) were in favor of eight to twelve hours. No one positioned in favor of a shorter time frame, three persons voted for more time. It should be noted that the first date had to be postponed twice because not all participants were available. At the first workshop, one participant had to leave an hour earlier due to scheduling reasons. The scheduling of appointments with all stakeholders is a weak point of the artifact, but one that can hardly be avoided. After all, all eight participants answered in the affirmative to the question of whether the value of the results justifies the time spent.

Three participants made suggestions for improvements. Two participants (both employees) spoke in favor of an additional workshop on funding and another (also an employee) in favor of an introductory presentation of training opportunities.

5 Communication

It is important to address the potential issue of “greenwashing” by software companies. There is a risk that companies may use the developed artifact to implement sustainability only minimally or superficially and use it for marketing purposes. To address this concern, we propose two approaches. Firstly, external stakeholders play a crucial role in setting the priorities of the requirements. Proper application of the artifact requires incorporating these priorities into the business model. Failure to do so could result in reputational damage for the company if stakeholders perceive the software requirements as insufficiently met. Secondly, it is difficult to achieve “full” sustainability while also ensuring economic viability and competitiveness. Therefore, any steps towards sustainability should be welcomed. Although, software companies should not be expected to face this challenge alone. Sustainability is a goal that is also influenced by society and politics. Our artifact is one element that can contribute to this goal. We will incorporate it into academic teaching, for example within the subject of socioinformatics.

6 Limitations

The results of our study are based on exploratory mixed-methods empirical research that focuses on mainly qualitative aspects. As such, several factors may compromise the validity of the results. The aim was not to achieve generalizability but to generate answers to the RQ. Our study demonstrates that using the demonstrated artifact is effective in implementing sustainability into software products and services.

The biased selection of participants for the workshops should be mentioned as a threat to internal validity. To minimize this, we selected participants based on diverse backgrounds and Participatory Design principles. To ensure a comprehensive dataset, we selected participants with diverse gender, age, and academic and professional backgrounds. However, the participants are biased as they were not selected randomly based on the population. We do not aim to generalize our results or compare outcomes, but rather to demonstrate the feasibility of our artifact and provide initial steps. All participants had European backgrounds and academic qualifications. Conducting the workshops in other regions could accordingly lead to different results.

The construct validity may be compromised by a range of factors, especially, the participant’s lack of understanding of the tasks and questions as well as a reactive bias caused by the researcher’s presence. To mitigate those two threats, several measures were implemented. Firstly, participants received verbal and written instructions in the workshops. They were allowed to ask questions at any time before and during each task. It should also be mentioned that we made use of already empirically evaluated approaches. Confounding factors may also be present. One such factor is differences in knowledge regarding IT topics in general, which could affect the workshop results. To minimize this, we delivered introductory sessions and instructions to the workshop participants. To minimize the threat of reactive bias, the risk that workshop participants may perform their tasks in a socially desirable manner, particularly in response to the presence of researchers and other participants, the participants were guaranteed anonymity. Furthermore, they were free to use any names and camera settings.

To enhance the reliability of the study, coding was conducted in pairs. In the event of any discrepancies between the coders, discussions were held until a consensus was reached to ensure consistency and reliability of the coding process.

7 Conclusion

The topic of sustainability in industrial software engineering practice has received insufficient attention in the scientific literature. With our study, we intend to contribute to bridging the gap between the theoretical academic and the practical industrial side. We developed an artifact that extends the existing SusAF to a business-oriented tool that combines sustainability with industrial needs. Our artifact caters more to the needs of software companies that need to integrate sustainability into their business plans. Through numerous workshops and empirical studies, we have identified five crucial extensions and adaptations of SusAF that are necessary for its practical use in a business context, particularly in the development of software products and services.

8 Acknowledgements

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Publication IV

Lammert, D., Abdullai, L., Betz, S., and Porras, J.

Sustainability for Artificial Intelligence Products and Services – Initial How-to for IT Practitioners

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Sustainability for Artificial Intelligence Products and Services – Initial How-to for IT Practitioners

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Abstract

Year after year, software engineers celebrate new achievements in the field of AI. At the same time, the question about the impacts of AI on society remains insufficiently answered in terms of a comprehensive technology assessment. This article aims to provide software practitioners with a theoretically grounded and practically tested approach that enables an initial understanding of the potential multidimensional impacts. Subsequently, the results form the basis for discussions on AI software requirements. The approach is based on the Sustainability Awareness Framework (SusAF) and Participatory Design. We conducted three workshops on different AI topics: 1. Autonomous Driving, 2. Music Composition, and 3. Memory Avatars. Based on the results of the workshops we conclude that a two-level approach should be adopted: First, a broad one that includes a diverse selection of stakeholders and overall impact analysis. Then, in a second step, specific approaches narrowing down the stakeholders and focusing on one or few impact areas.

Keywords: Sustainable Artificial Intelligence, Software Sustainability, Requirements Engineering, Software Engineering, Software Development

1. Introduction

AI is expected to have an immense impact on our lives through possibilities such as autonomous driving, better healthcare services, big data analytics, and even employment opportunities. On the other hand, it could also, become the worst event in the history of humanity (Vöneky, 2020). In any case, it is hard to deny that AI is changing and will continue to change our lives in intended and unintended ways (Rahwan et al., 2019). Therefore, the positive changes brought by AI should be contrasted with the adverse effects of this technology.

Van Wynsberghe proposes the following definition of sustainable AI: "Sustainable AI is a movement to promote change throughout the lifecycle of AI products (i.e. idea generation, training, tuning, implementation, governance) towards greater environmental integrity and social justice. Sustainable AI thus focuses not only on AI applications but on the entire AI socio-technical system." Furthermore, the researcher suggests that in order to be sustainable, AI places sustainable development at the core of its development "with the three associated tensions between AI innovation and equitable resource distribution, inter-and intra-generational equity, and between the environment, society and the economy." (Wynsberghe, 2021). The development of AI software is thus a dual-task. It has to be approached from both technical and social justice points of view. Technical considerations refer to the performance of the AI system. They can be described as functional properties that can be examined using metrics from the field of machine learning, such as accuracy or precision. On the contrary, the social justice considerations are undoubtedly no less complex. These include ensuring principles such as transparency, interpretability, and fairness. We are confronted with non-functional properties that prove to be much more complex because we cannot rely on standardized metrics and procedures from the field of machine learning.

Therefore, inter- and transdisciplinary research is needed to develop and implement suitable testing strategies. The diversity of possible use cases for AI is too great for a single universal solution to suffice. In addition, complex systems are usually not static but are subject to constant change. Hence, it must be continuously iterative, improved and optimized.

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Numerous studies and frameworks focus on a single selected impact within an impact dimension of AI software. For example, one of the best known and among the most studied challenges in the social dimension is fairness (Agarwal et al., 2022; Angell et al., 2018; Brun & Meliou, 2018; Chouldechova & Roth, 2020; Sharma et al., 2019). Scientists repeatedly point out in their conclusions that further research on these areas are relevant. There is yet or will never be a one-size-fits-all solution. In this article, we would like to take a bird's eye view of the impacts of AI software, not focusing our attention on a single selected impact, but looking at the "big picture". Vöneky explains that AI is a complex subject to understand completely (Vöneky, 2020). Similar argument applies to the multidimensional and multilayered impacts of AI.

Nonetheless, despite having a plethora of academic discourse and guidelines concerning, for instance, AI ethics (Berendt, 2019), yet, research conducted by the Pew Research Center revealed that experts doubt that ethical AI or for that matter sustainability issues will be at the center of AI design in the next decade (Rainie et al., 2021). In the report, the researchers posit that developers and designers of AI are primarily focused on profit and social control at the expense of the possible consequences. In other words, for many AI designers and developers, there is an attitude of being the first to innovate and rectify the damages late. The problem with such an attitude is that some of the consequences may not be reparable after the damage has been done. According to Berendt, there are four characteristics of AI practices that may account for reasons why the notion of "common good" or reflecting on the potential adverse effects of AI are not considered during the design face: the problem-solving and approach of the AI engineer or developer, the inclusion of diverse stakeholders, the role of knowledge, and the awareness of side effects and dynamics (Berendt, 2019).

Software practitioners, in particular, lack the knowledge and methods to consider AI software impacts on software requirements (Galaz et al., 2021; Khakurel et al., 2018; Wynsberghe, 2021). Perhaps, having a simple but encompassing framework which engages both AI engineers, developers, researchers, policymakers, users and other stakeholders on the sustainability issues that could potentially be affected as a result of a technology, product or service could be the starting point for AI engineers to consider sustainability as a requirement during AI design face. Thus, we pose the following research question: What does software practitioners need to pay attention to in terms of sustainability impacts when developing AI software?

To answer our research question, we conducted three workshops using the *Sustainability Awareness Framework (SusAF)* according to the principle of *Participatory Design*. The SusAF is a tool developed by an international group of researchers that aims to raise awareness of the relationship between software and social, individual, environmental, economic, and technical sustainability, as well as their potential immediate, enabling, and structural impacts.We brought together different stakeholders to discuss AI software, identified potential impacts, and thus provide guidance on how such systems should and should not be designed. We conducted the workshops on three completely different topics: Autonomous Driving, Music Composition and Memory Avatars.

In all three workshops, several implications emerged that had not been considered beforehand. As a result, it is essential to take a two-level approach when designing AI. At first, a broad one that includes a diverse selection of stakeholders and a multidimensional impact analysis at first. Then, in a second step, specific approaches should be used, narrowing down the stakeholders and focusing on one or a few selected impacts.

2. Background

Khakurel et al. recognize that AI companies are showing an increased interest in joining the AI trend. However, it is unclear what social, environmental, and economic impacts this will have (Khakurel et al., 2018). Meantime, we are confronted with the fact that trust in AI is rather low among the general population. The study "Trust in Artificial Intelligence - A five country study" (Gillespie et al., 2021), based on surveys in the USA, Canada, Germany, Great Britain, and Australia indicates that "most citizens being unwilling or ambivalent about trusting AI in healthcare (63 percent) and HR (77 percent)." Therefore, we must enhance trust in AI products and services. Since the foundation of a system are its requirements, we suggest starting with the assessment of the possible impacts during the requirements engineering phase.

2.1. Requirements Engineering for AI

What makes AI Products and Services so unique in their effects that they must be examined separately from other technologies? The answer to this can be found in its socio-technical impacts.

Technical side: In an article on the interplay of requirements, technology, and AI, Kostova et al. conclude that their analysis raises more questions than answers (Kostova et al., 2020). Ahmad et al. answer this question in their SLR study, "What is up with Requirements Engineering for Artificial Intelligence

Systems" by stating that the development process of AI systems differ from traditional approaches (Ahmad et al., 2021; Sculley et al., 2015). The authors of the SLR study recommends that requirements engineers bridge with data scientists and machine learning specialists. They refer to Amershi et al. (Amershi et al., 2019), who again point out that "both data scientists and software engineers should improve their knowledge and understanding of the issues that arise from incorporating AI into most software projects and learn to work together."

Social justice side: Software engineers focus too one-sidedly on technology - "artificial systems with clear boundaries and identifiable parts and connections, modules and dependencies (Becker et al., 2016)" - while other systems, such as social, environmental, and economic consequences are not sufficiently considered. At this point, a second SLR study by Ahmad should be mentioned, which allows for a "human-centric" approach due to the considerable new challenges in Requirements Engineering (Ahmad et al., 2021). Ahmad explains: "Human-centric approaches involve providing systems that are interpretable, explainable, transparent, secure and fair". Here the author refers to Fagbola and Thakur, who want the aspect of multidimensional impacts to be understood as an open problem (Fagbola & Thakur, 2019). In Ahmad's opinion, there is little research on Requirements Engineering techniques for building AI systems.

When requirements engineers plan the use of AI software, they must not neglect the unintended and unforeseen impacts of AI systems. Add to this the fact that these impacts may not be foreseeable. The system will probably need to be iteratively readjusted even after market entry. At this point, reference should be made to the report "The Ethical Skills We Are Not Teaching" (Suárez & Varona, 2021) of Suárez and Varona. The authors conducted a textual analysis of 503 courses on non-functional issues of AI at 66 universities in 16 states and conclude that instructors are not training their students in ethical skills. Bogina et al. come to a similar conclusion and recommend that the need for such education must be met to meet the challenges of AI impacts (Bogina et al., 2021).

2.2. Sustainability Frameworks in AI

Establishing social justice development of software has become increasingly important in recent years. One of the organizations that comprehensively addresses the software practitioner's endeavor to integrate social, environmental, and economic issues in terms of ethics, morality, and sustainability is AlgorithmWatch: "AlgorithmWatch is a non-profit research and advocacy organization that is committed to watching, unpacking and analyzing automated decision-making (ADM) systems and their impact on society."[1] Today, the organization lists over 160 tools, which we looked at in preparation for this article. 66 tools are directly or indirectly focused on our endeavour, and we subjected them to closer analysis.

The frameworks can be roughly categorized: First, is generally focused on multiple and diverse areas. They take a bird's eye view of the possible impacts of the software systems and are thus suitable for identifying and discussing them. The *(SustAIn)* and the *(SusAF)* should be mentioned here. In addition, it is noticeable that these frameworks are aimed at software practitioners. Second, it addresses specific, selected issues, for example, bias *(The Imperial Machines Project)*, fairness *(Fairness Aware Ranking)* and privacy *(VBRE)*. In most cases, they are aimed at software developers. The third is the development of technical tools for checking algorithms. Most of these tools, including *AI-Fairness360* and *Fairlearn*, for example, focus on analyzing biases in data sets. In most cases, they are aimed at data scientists.

There are a variety of arguments that led us to apply the SusAF in our workshops. It helps software practitioners engage in conversation with different stakeholders. Thus it is a participatory approach. Participants look together for interactions between software and five dimensions: social, individual, environmental, economic, and technical. Additionally, SuSAF enables participants to identify impacts over time, different dimensions and time layers can be analyzed. In addition, the SusAF has a straightforward procedure designed as a workshop; thus, it is easy to apply.

3. Empirical study

The study utilized data from three different workshops to gain insight into the possible sustainability impacts of AI-based software. To achieve this, we used Participatory Design and the SusAF to identify the effects of AI. The subsequent section discusses the processes and methods adopted to carry out our explorative mixed-method study.

3.1. Methodological background

3.1.1. Participatory Design (PD)

The overarching aim of PD is to enable diverse stakeholders to interact

[1] https://inventory.algorithmwatch.org/

and actively participate in contributing different layers of tacit knowledge and expertise for value co-creation and co-design. In the context of our study, this means the engagement of project managers, developers, potential customers, researchers, and other stakeholders to examine various aspects of sustainability issues in the design and development of AI. This methodology enabled us to make recommendations for policies, actions, industry, and society (Grunwald, 2020). According to Simonsen and Robertsen (Simonsen & Robertson, 2012), there are four stages in PD, namely Requirement Analysis, Analysis and Design, Implementation, and Test. Nonetheless, this paper only focuses on the Requirement Analysis as the first step into this new research phenomenon. Furthermore, the focus of PD lies on three types of sources (i.e., stakeholders, documents, and systems) to ensure user-centered design.

3.1.2. Sustainability Awareness Framework (SusAF) The SusAF is a sustainability impact awareness tool that provides a set of questions, a visualization tool, guidelines, and templates that help software practitioners to identify and discuss potential sustainability impacts of their AI on people, society, and IT systems. Becker et al. have shown that SusAF helps to identify potential effects and chains of effects of a sociotechnical system and start a conversation about its impacts (Becker et al., 2016). Companies often are aware of the direct impact of their IT products and services but SusAF challenges designers and businesses to reflect beyond and be aware of the systemic chain of effects of their IT systems. Hence, participants are supported by scenarios to consider not only the immediate characteristics and impacts of their product or service but also their medium-to-long-term interconnected chain of effects (see tables 1 and 2). Using the Sustainability Awareness Diagram (SusAD), a radar chart, we can to map out the positive and negative chains of effects (Duboc et al., 2019), that AI software could potentially have based on the five sustainability dimensions (see figures 1, 2 and 3). Finally, as mentioned earlier, the SusAF process is straightforward and already designed as a workshop.

3.2. Workshop design

3.2.1. Planning phase The study is empirically supported by three workshops, with each addressing different topics: AI for Autonomous Driving, AI for Music Composition, and AI for Memory Avatars. Following (Simonsen & Robertson, 2012), we gathered three types of sources: Stakeholders, Documents, and Systems in operation for our PD. *Stakeholders* as a source means the recognition of the process requires a heterogeneous composition of participants. The participants must feel represented in a balanced way. The appointment of mediators could promote a balanced agreement and fair compliance with the rules of procedure. We included the various stakeholders in the participant composition. *Documents* contain information from which requirements can be derived. These can be experience reports, legal texts, standards, ethical value discussions, error reports on suitable alternative systems, etc. *System in operation* by testing and analyzing predecessor and/or competitor systems may result in new or modified requirements. Below, we describe how each of the three sources was used in our study. The first step was a schematic stakeholder identification. In particular, we discussed these questions: Who is considered to be affected by the project, and what exact processes are affected by the proposed project? Initially, we came up with a list of stakeholders, which we had to evaluate, prioritize and map (see section 4. Results).

This study is supported empirically by both primary (workshop) and secondary data (literature). We first reviewed and analyzed scientific and grey documents to understand the state-of-the-art of the phenomenon, its challenges, and future promise. Armed with this background, we were able to explore and select areas to carry out our sustainability awareness workshops and identified some possible sustainability impacts of AI systems.

The schedule of workshops was as follows:

1. Warm-up: One of the authors (i.e., facilitator) presents the SusAF and the purpose of the workshop. Another short presentation followed this by the project manager about their AI product or service and their initial perception about the sustainability impact of their AI product or service which participants were allowed to contribute.

2. SusAF: Next was to use PD to engage, challenge, and provoke participants' thoughts about the sustainability impacts of the topic under discussion with the sets of questions from SusAF as a guide.

3. Discussion: Finally, participants together with one of the authors discussed the answers and summarized the elements of the SusAF that were most important to them and clarified any ambiguities. Together, the three parts of each workshop lasted about three hours.

Table 1. The three types of effects based on the SusAF (Penzenstadler et al., 2020)

Effect	Description
Immediate	"are direct effects of the production, operation, use and disposal of socio-technical systems."
Enabling	"of operation and use of a system include any change enabled or induced by the system."
Structural	"represent structural changes caused by the ongoing operation and use of the socio-technical system."

Table 2. The five dimensions of sustainability based on the SusAF (Penzenstadler et al., 2020)

Dimension	Description
Social	"covers the relationships between individuals and groups."
Individual	"covers the ability of individuals to flourish, exercise their rights, and develop freely."
Environmental	"covers the use and stewardship of natural resources."
Economic	"covers the financial aspects and business value."
Technical	"cover the technical system's ability to accommodate changes."

4. Survey: At the end, each participant received a survey questionnaire regarding the content and the structure of the workshop.

3.2.2. Data collection The participatory workshops were divided into three main sessions. In the first session, we provided an introduction to the SusAF workbook and explained the online whiteboard workstation to the participants. The participants were sent links to the whiteboard a day before the workshop to familiarise themselves with the tools for a smooth workshop. All technical issues regarding the use of the whiteboard were cleared in this session. The second session was the engagement part where participants were actively engaged in the brainstorming of the perceived sustainability impact of the topic under discussion. The participants wrote their responses on the Miro board from which the SusAD was developed. The final session was the feedback part, where participants gave verbal comments about the workshop and completed a survey. The survey included personal questions about the characteristics of the participants, such as gender, industry and position, age, and years of work experience, to a broader perspective about sustainability awareness, the importance of the workshop, and the engagement method (see section 4.4).

3.2.3. Data analysis After the workshop, the authors individually collected and summarized the data from the Miro board into SusAD. We then compared our findings and where there were discrepancies, we revisited the original data on the Miro board to reconcile any differences. Finally, after resolving all ambiguities, we had three different SusADs showing the potential sustainability impacts and chain-of-effects for each of the topics discussed in the workshop.

4. Results

We made sure to involve suitable stakeholders in each workshop:

- Autonomous Driving: *Age:* between 22-41 (Ø 29); *Gender:* 2 female and 7 male; *professions:* mechanical engineer, urban planner, UX Designer, 6 IT students; *Working experience:* 2 to 14 years (Ø 5 years)
- Music Composition: *Age:* 25-38 (Ø 34); *Gender:* female: 1, male: 4; *professions:* 4 Researchers (Music Science and Software Engineering) and IT student; *Working experience:* 1 to 2 years (Ø 1.4 years)
- Memory Avatars: *Age:* 18-69 (Ø 30); *Gender:* female: 20, male: 10; *professions:* University: 10 Social Sciences, 8 Computer Science, 3 Theology, 2 Educational Science, Environmental Science, Media Science, Industry and church: Account Manager, Grief counselor and content manager, Licensing manager, Pastor, Theologian (also a supervisor and personal coach); *Working experience:* 0 to 38 years (Ø 5.4 years)

Each participant was offered a one-on-one or group session in advance that included an introduction to the technical basics of AI. This allowed us to ensure that even those participants who were not previously familiar with AI had a basic understanding of the subject matter and were familiar with the common technical vocabulary.

At the outset, we must point out that the findings in Sections 4.1 through 4.3 are primarily intended to understand the potential contribution of this research. Nevertheless, some arguments need to be verified and supported by studies. Thus, the three diagrams are by no means intended to represent the state of the science.

4.1. Autonomous Driving

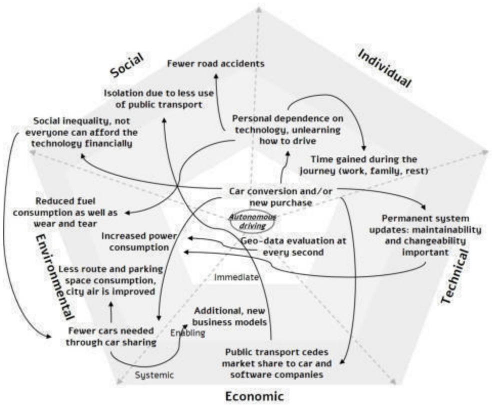

Figure 1. SusAD: Autonomous Driving

At the beginning of the first analysis, it should be noted that in comparison to the other two analyses, fundamental contradictions arose between the stakeholders in the case of Autonomous Driving. One of the first impacts that arose was the fact that drivers would have to retrofit their car or buy a new one (immediate effect in the individual dimension). This impact is linked to a positive and a negative impact chain. On the one hand, the stakeholders expect savings because fewer cars are needed through car-sharing (systemic effect in the environmental dimension). A circumstance that should lead to further business models (enabling effect in the economic dimension). Another positive impact that appears in this chain of effects is the reduced consumption of space on the streets and car parks, which in turn benefits the city air (systemic effect in the environmental dimension). However, the retrofitting and purchase of new cars would also result in public transport losing market share to car and software companies (systemic effect in the economic dimension). This in turn would lead to social isolation within society, which would be the result of less use of public transport (systemic effect in the social dimension).

Another positive impact is expected on the individual dimension. Although the enabling effects show that the ability to drive a car is lost over time, in return one gains time that can be used more sensibly for family, work and rest.

In the environmental dimension, there is disagreement about whether CO2 consumption will rise or fall as a result of Autonomous Driving. Permanent system updates and geo-data evaluation (technical dimension) lead to an increase in energy consumption. On the other hand, the previously mentioned decrease in the number of cars on the road and lower fuel consumption. In addition, the wear and tear on the car should also decrease.

4.2. Music Composition

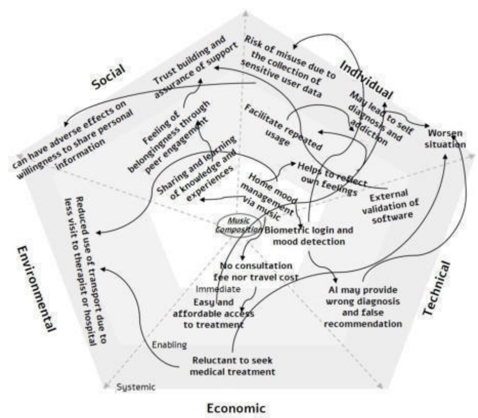

Figure 2. SusAD: Music Composition

The chain of effects (as shown in figure 2) makes AI-based music selection interesting. While the service results in many direct impacts, it also has enabling and unintended systemic consequences. For instance, participants mentioned that the primary stakeholder, thus the individual user can directly and positively manage his/her mood at home without visiting the hospital nor the psychologist. However, this positive impact creates self-awareness of an individual's immediate environment and therefore enables repeated listening to the recommended music. Overtime, this may negatively lead to self-diagnosis and addiction and also, worsen the mental health situation of the user.

From the economic perspective, mood management in the comfort of an individual's home through music recommended by AI positively eliminates medical consultation fees and travel costs as a direct impact. As a result, it means easy and affordable access to treatment. However, this may cause users to feel reluctant to seek medical treatment in the long-run. Although this has enabling effect on the environment by less usage of transport, the systemic effect is that it gradually deteriorates the health condition of the individual user. Furthermore, to access the app, one of the technical requirements is personal login and mood recognition.

Although, participants feared that AI might process this information wrongly and consequently provide inaccurate recommendations. Eventually, the reliance of users on the false decisions provided by the AI may result in worsening the situation of the user.

4.3. Memory Avatars

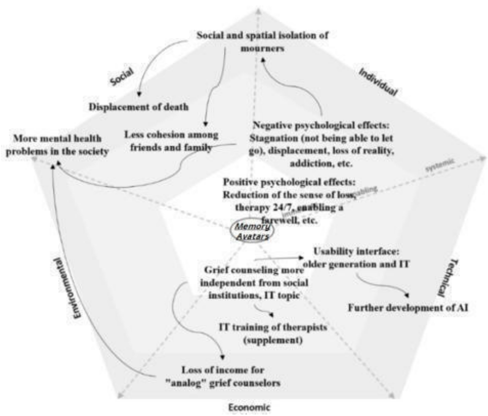

Figure 3. SusAD: Memory Avatars

The results from the workshop on Memory Avatars revealed worrying concern about the use of these technologies. For instance, although participants mentioned that the bereaved individuals might achieve temporal psychological satisfaction, such as minimizing the pain associated with losing a loved one through the use of memory avatars is without a series of negative effects. Thus, the impact of minimizing the pain in the death of a loved one leads to series of negative consequences. For example, this could lead to a person living in the past and not coming to terms with reality. As a result, individuals become dependant on technology as a coping mechanism which leads to severe problems such as mental health problems, addiction and abuse of technology.

As social animals, people gather to share happiness for a positive milestone in one's life or empathize when there is a tragedy. However, using Memory Avatars will decrease social affection, and people will stop caring about each other. Soon, death becomes an unspoken word the social fabric that holds families and friends together begins to fall apart. As such, this might even lead to worse social vices like kidnapping, unjustified killing without prosecution, and failure to demand justice when someone commits murder.

Economically, participants mentioned the loss of income as a negative impact. In other words, participants feared that AI Memory Avatars might replace therapists whose work is to ensure that people professionally deal with grief and sorrow. This follows a general skepticism that some people think in the future, AI will displace humans and render a lot of people unemployed. Even if health professionals proving therapy for the bereaved person decides to use memory avatars as a complement to their work, it will create economic inequality as not every person can afford to buy memory avatars.

From the technical perspective, although people of all ages can die at any time, death is witnessed often among older adults. Hence, the participants envisaged that IT companies would have to place their best bet on the elderly to establish a working system.It was also mentioned that this type of technology requires heavy investment in AI to facilitate the enhancement of Memory Avatars. Nonetheless, a technical problem or fault in the functioning of a Memory Avatar could lead to a far-reaching negative consequences like heart failure when the technology malfunctions and suddenly a person has to deal with the bitter reality.

4.4. Survey

Overall, 38 participants completed the survey questionnaire in all three workshops: Nine in Autonomous Driving, 5 in Music Composition and 24 in Memory Avatars. For ease of understanding, we classified the results into a ratio of one to ten.

Change of attitude towards the subject: Seven to eight out of ten participants stated that their perception of sustainability impacts had changed as a result of the workshop. This was evident as participants became aware of for example: "Wide range of possible impacts", "Sustainability is multidimensional (my focus was on ecology)" and "different dimensions in the framework used". In particular, participants became aware of the social and technical dimensions, which they had neglected before. Approximately nine out of ten participants gained insights they had not had before.

Comprehension and benefit from the SusAF: For about nine out of ten participants, the workshop was somewhat understandable and comprehensible or very understandable and comprehensible. All participants agree that the workshop should be repeated over time. The question of whether the value of the results is commensurate with the time spent was answered in the affirmative by eight out of ten of the participants. Seven to eight out of ten participants felt that their AI would benefit from sustainability integration, and nearly all participants would recommend the workshop to others. All participants answered the question, "Do you think that the use of the Extended SusAF will have an impact on products and services in terms of sustainability in your company or in other companies?" with a yes. Eight out of ten participants indicated that they would be interested in performing a similar analysis for future AI software.

Future studies: For further work on AI software, nine out of ten participants would like to see offers for education and training for employees in the area of sustainable AI as well as communication between science and industry. Eight out of ten participants would like to see (interactive) material on SusAF and other sustainability tools. Four out of ten of the participants would like to see public funding programs for companies tackling sustainable AI.

5. Discussion

We first answer our RQ with three lessons learned. Then, we explain the threats for validity of our study.

5.1. Lessons learned

Lesson 1 - Align the knowledge: In addition to an introductory presentation on the respective market environment of AI, all stakeholders must have a basic understanding of what AI is. Additional explanation time should be allowed for those participants who have not or hardly dealt with AI so far but still want to contribute to the discourse. A general understandable explanation should be built into the introductory presentation accordingly. In each workshop, in order to include different perceptions and to bring new views, the participants dealt with the impacts of AI on the field under investigation. A sufficient number of stakeholders from different areas is elementary to collect valuable results.

Lesson 2 - A multidimensional tool first, focusing tool(s) second: In each workshop, some participants had already dealt with a greater or lesser extent with individual impacts of AI on the field under investigation. The survey shows that a multidimensional sustainability analysis broadens the view of the impacts and thus expands them. Dimensions were taken into account that they had not been considered before. As an example, Autonomous Driving has an impact on social interaction (fewer encounters due to the elimination of public transport). When the impacts of Autonomous Driving are discussed, the focus is almost exclusively on the economic and ecological dimensions (also in scientific studies). As soon as the overview has been expanded with the help of tools such as the SusAF, it is possible in a second step to select tools that sharpen the view, e.g., about fairness. If the analysis were to focus on one dimension or selected aspects within a dimension right in the beginning, this would lead to disregard or, in other words, too much would fall by the wayside. Additional issues will need to be explored in the future, such as privacy concerns and third-party impacts, especially for Autonomous Driving.

Lesson 3 - Create incentives for sustainable enterprises: This lesson is addressed to policymakers in the AI sector but can probably be applied to almost all industries. Incentives should be created so that companies strive for sustainability in their products and services. Science should not ignore the fact that the industry must think and act economically to be able to exist. The questionnaire picks up on this fact and makes it clear that there is interest on the part of the industry in support, e.g., in the form of further training for employees, provision of prepared materials, the establishment of funding programs, and other financial reliefs.

5.2. Threats to validity

The conducted study is an explorative mixed-method empirical research. However, the focus is on the explorative and qualitative parts. Therefore, we do not intend to achieve generalisability but to generate answers to our RQ. Our findings are the first step and should be useful for follow-up studies that contribute to verification and deepening. Nevertheless, we have focused on collecting a comprehensive data set by selecting participants of different gender, age, and academic and professional backgrounds. Regarding the risk of reliability, the authors analyzed the workshop results separately. When discrepancies arose, we discussed them until we reached a consensus.

A risk to construct validity is that the workshop participants did not understand their tasks properly. Therefore, we used written and verbal instructions. Additionally, we allowed workshop participants to ask questions at any time. Moreover, we used an already empirically evaluated tool (SusAF).

The threat that the workshop participants perform their tasks is socially desirable, especially as a reactive bias to the presence of the researcher and the other participants cannot be argued. To reduce this threat, we assured the participants of their anonymity when dealing with the data. Participants were also free to use their cameras and any names they chose during the workshops. Nonetheless, this is a threat challenging to avoid when working with groups of participants.

Confounding factors cannot be ruled out. One factor affecting the results of the workshops is the differences in knowledge regarding AI. Although, we aim to ensure a similar perspective on AI and knowledge of sustainability and the SusAF method by delivering introductory sessions and instructions to the workshop participants and by selecting participants with at least a basic knowledge regarding AI.

During these Covid-driven times, we cannot exclude the risk of confounding factors caused by the workshops that took place online. If the workshops are to be repeated, we recommend that a comparison will be made where all participants are physically present. A major confounding factor and threat to validity are the participants themselves. A different set of workshop participants might lead to different outcomes. To minimalize this threat, we selected a diverse set of participants in age, experience, and basic knowledge regarding AI, and we included experts (e.g., musicians and researchers). All participants are European and have an academic background.

Similarly, a threat to internal validity is the biased selection of the participants for the workshops. As we selected people with diverse backgrounds and based on PD principles, we tried to minimize this threat. However, the participants are biased as we did not select them randomly based on the population. Regarding the participants themselves, we want to clarify again that we do not want to generalize our results, and we do not compare the outcome. Instead, we want to show the feasibility of our approach and provide initial steps toward sustainable AI.

Our study made it clear that using the SusAF in the participatory workshops was effective in creating sustainability awareness in the AI-related topics. Future studies could extend the use of this framework in other AI related activities.

6. Summary

Software companies should be aware that they create powerful tools that have a profound and multidimensional impacts. For this reason, they should be self-critical of their decisions and aware of their responsibility to minimize the risk of unintended negative impacts. Our three workshops have shown partly unexpected positive and negative short and long-term impacts in the different dimensions that companies need to address. Key areas of focus to guide the initial movement toward sustainable AI products and services are, for example, that Autonomous Driving which could lead to more social isolation as public transportation loses market share. AI in Music Composition could affect a user's mental health status. Finally, that Memory Avatars could extend the grieving process. The SusAF is thus particularly suitable as an instrument for assessing the possible impacts of a product, service or system. Subsequently, tools that deepen individual aspects can be selected and applied. Software companies are likely to show more interest in sustainability issues in future as many stakeholders become more aware about sustainability. It is essential to emphasize a heterogeneous and diverse composition of stakeholders based on PD to be able to cover all dimensions adequately. Just as non-technical stakeholders are expected to acquire a basic understanding of AI to participate in the discourse, requirements and software engineers must open up to new fields. On this basis, a profitable exchange can take place.

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Publication V

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"Changing Death": Initial Insights for Software Practitioners in Thanatopractice

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"Changing Death": Initial Insights for Software Practitioners in Thanatopractice

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ABSTRACT

Digital transformation is now reaching into topics like End-of-life Care, Funeral Culture, and Coping with Grief. Those developments are inevitably accompanied by the growing challenge to design IT systems that are appropriate and helpful for the stakeholders involved. Our aim in this paper is to further introduce the rather new combined research field of Socioinformatics and Thanatology (the scientific study of death and dying) and to present it with the first results on which requirements to consider for the design of digital tools within 'Thanatopractice'. By using Participatory Design and the Sustainability Awareness Framework (SusAF) in the context of three workshops on socio-technical systems (Online Pastoral Care, Virtual Graveyards, and AI Memory Avatars), we want to sensitize software practitioners to the multidimensional impacts of their products and services in a field, which the participants in the workshops often described as "highly sensitive".

Keywords: Software development, Software engineering, Requirements engineering, Software sustainability, Socioinformatics, Thanatology, End-of-life care, Funeral culture, Coping with grief

INTRODUCTION

Whereas at the beginning of the 20th century, the majority of people from the western world died within their own four walls, today this is not even the case for a quarter of people. Today, we die in hospitals, retirement homes, or hospices (Dasch et al., 2015). Death seems to be less and less an experience in togetherness. At the same time, Thieme observes an individualization of the Thanatopractice (Thieme, 2018). Digitization enables such individualization but also contains the potential for the opposite. Accordingly, we pose the following research question: What should software practitioners consider before embarking on the design of digital solutions in Thanatopractice? Addressees of our results are software practitioners who plan and implement such tools as well as professionals involved who are practicing or considering the use of such or comparable IT systems.

For our purpose, we made use of the principle of Participatory Design and the Sustainability Awareness Framework (SusAF) in the context of three workshops on socio-technical systems. The workshops served to bring together relevant stakeholders to discuss the Digitization of Thanatopractice, identify potential negative impacts, and thus provide guidance on how such systems should or should not be designed. The participatory approach provides for the active involvement of various stakeholders in the design process, thus minimizing the risk of overlooking relevant needs.

The workshop groups agreed that the Digitization of Thanatopractice can be useful as an accompanying tool, thus complementing analog forms. However, it can by no means replace them, they concluded. In addition, the participants recommended a critical examination of the industry's IT products and services for Thanatopractice. More scientific studies in this highly sensitive field are needed so that it is not left to industry alone.

BACKGROUND AND RESEARCH GAP

In our previous work (Wulf et al., 2022), we divided Thanatopractice into five different areas/phases: End-of-life Care, Sepulchral culture, Coping with Grief, Estate Administration, and Transhumanism/Posthumanism. Here, we leave out the last two areas in this article. Moreover, digital Estate Management has been the most widely published area of research in recent years (e.g., Silva and Medeiros, 2021; Dissanayake and Cook, 2019; Cook et al., 2019). As for Transhumanism/Posthumanism, it is relevant at all stages but not for everyone.

A basis on which characteristics to pay special attention to when dealing with digital End-of-life Care is provided by Emily A. Meier et al. It identifies ten characteristics to which dying people attach a high degree of importance in their final phase of life (Meier et al., 2016) (e.g., Emotional well-being, Being at peace with family, and Quality of life. To satisfy the initial objective of designing IT systems in the field of Thanatopractice in such a way that they meet the needs of the dying and their relatives, they should be aligned with these ten aspects (Wulf et al., 2022). Accordingly, for example, traditional pastoral care could be supplemented with video telephony software, with so-called voice-over-IP platforms (e.g. Skype, Zoom, Microsoft Teams). These could also be used to communicate with relatives who are unable to arrange a visit.

Sepulchral culture comprises the totality of all rituals in the field of funeral and mourning culture (for example, the funeral oration, the burial, and a subsequent communal meal) (Thieme, 2018). Due to the complexity, emotional weight, and concomitant need for a high level of empathy, it is evident that software practitioners face arguably difficult challenges in this field. In the field of sepulchral culture, there are currently two growing digital tools available: Online Memorial Sites and Virtual Graveyards (Wulf et al., 2022). Online Memorial Sites can be created by the bereaved using simple Content Management Systems (CMS), which are offered for a fee or free of charge, depending on the provider. After designing them with texts, images, videos, and music, bereaved persons can light digital candles here, write in a book of condolence or invite people to a funeral service (Meier et al. 2016). They are also part of the product and service portfolio of numerous funeral homes (Bundesverband Bestattungsbedarf, 2016). Virtual Graveyards go one step further by acting as a supplement or even replacement for real cemeteries.

The range of functions varies depending on the provider. A Virtual Graveyard can be a website similar to the Online Memorial Site, but also a 360-degree world reminiscent of video games that we can enter with VR glasses (Häkkilä et al., 2019 and Huberman, 2013).

Coping with Grief is to be understood as a process until one reaches a step where one has managed to cope with grief (Thieme, 2018). A much-cited approach to understanding grief is that of Küchenoff, who states that mourners can successfully go through this process if they fulfill three conditions: a) being able to engage in a mourning process at all, b) being able to bear it emotionally, and c) being able to end it or bring it to a conclusion (Küchenhoff, 2011). Point c is where AI Memory Avatars become significant, as they could be viewed as one of the most extensive interventions in the mourning process in terms of digitization because they are designed to give users the feeling that the deceased person is still or once again among the living. While users may benefit from a feeling of comfort, it is questionable whether this mourning does not (re)start when the memory avatar is switched off and the use only postpones, even prolongs it. The avatars are usually implemented as Deep Learning-based representations that users can converse with on a screen, mimicking the appearance, voice, and word choice of the deceased person or avatar. In addition, software companies are working on AI Memory Avatars that support the use of VR glasses with haptic hardware, so that, for example, a simulation of hugs becomes possible (Huberman, 2020).

EMPIRICAL STUDY

The goal of Participatory Design is to allow stakeholders to actively take part in the software design process. We envision the involvement of stakeholders or experts who conduct research and/or practical work in this context. One of the main tasks that Participatory Design places on its users is the generation of knowledge and opinions based on a heterogeneous stakeholder ensemble (multidisciplinarity). As a result, we can draw up recommendations for action for politics, industry, and society (Grunwald, 2010). Participatory Design goes through four stages: Requirement analysis, Analysis and Design, Implementation, and Test (Simonsen and Robertson, 2012). In this paper, we only focus on the first phase (Requirement Analysis) as a first step into the new research area.

The Sustainability Awareness Framework (SusAF), a question-based tool, addresses multidimensionality directly. Thus, it is a tool that is ideally suited to our endeavour, as it enables stakeholders with different viewpoints to start a discussion about the potential impact of a socio-technical system on sustainability based on a vivid visualization. The SusAF aims to raise awareness of the connection between software and a multi-dimensional and multi-layered understanding of sustainability (Duboc et al., 2020). The SusAF consists of a set of questions for different sustainability dimensions and topics (see Table 1), guidelines, a visualization tool (Sustainability Awareness Diagram, SusAD), and examples that help software practitioners identify and discuss the potential sustainability impacts of their software. Participants are

Table 1. Five dimensions of sustainability based on the SusAF (Penzenstadler et al., 2020).

Dimension	Description
Social	"(1) Sense of Community; (2) Trust; (3) Inclusiveness and Diversity; (4) Equality; (5) Participation and Communication;"
Individual	"(1) Health; (2) Lifelong learning; (3) Privacy; (4) Safety; (5) Agency;"
Environmental	"(1) Material and Resources; (2) Soil, Atmospheric and Water Pollution; (3) Energy; (4) Biodiversity and Land Use; (5) Logistics and Transportation;"
Economic	"(1) Value; (2) Customer Relationship Management (CRM); (3) Supply chain; (4) Governance and Processes; (5) Innovation, R and D;"
Technical	"(1) Maintainability; (2) Usability; (3) Extensibility and Adaptability; (4) Security; (5) Scalability;"

Table 2. The three types of effects based on the SusAF (Penzenstadler et al., 2020).

Effect	Description
Immediate	"are direct effects of the production, operation, use and disposal of socio-technical systems."
Enabling	"of operation and use of a system include any change enabled or induced by the system."
Structural	"represent structural changes caused by the ongoing operation and use of the socio-technical system."

Table 3. Composition of participants.

Dataset	Description
Age	between 18 and 69 years (average: 30 years)
Gender	female: 20 participants, male: 10 participants
Education	10 cultural, social and human sciences, 9 Computer Sciences (e.g., IT Product Management), 7 Theology, 2 Educational Sciences, 1 Environmental Sciences, 1 Media Studies
Professional exp.	from 0 to 38 years of experience (average: 5.4 years)

supported by scenarios to consider not only the immediate characteristics and impacts of software but also their longer-term aggregate and cumulative impacts (see Table 2). Following, these affects and chains of effects are visualized by using SusAD (Duboc et al., 2019).

In the planning phase, we gathered three types of sources that Participatory Design presupposes based on Simonsen and Robertson (Simonsen and Robertsen, 2012): Stakeholders, Documents, and Systems in operation:

- Stakeholders: The first step was a schematic stakeholder identification. In particular, we discussed these questions: Who is considered to be affected by the project, and what exact processes are affected by the proposed project? Initially, we came up with a list of stakeholders, which we had to evaluate, prioritize and map. The workshops were held only when the composition was signed off on both sides, the socio-informaticians, and the thanatologists. The final composition of the participants can be seen in Table 3.

- Documents: Both in preparation for the topic Digitization in Thanatopractice in general and the individual three areas of each workshop, we collected, analysed, and evaluated scientific texts, experience reports, and ethical values discussion (from documentaries and newspapers), etc.
- Systems in operation: Within the workshops, we have dealt with the use of IT systems mainly theoretically, since at this stage we are not yet talking to potential users (the dying and bereaved), but to selected professionals who know and work with them.

In terms of data collection, we made a transcript of the workshops, the SusADs developed in the workshop, and oral feedback. Thus, we ended up with three SusADs summarizing the potential impacts and their chains-of effects identified by the participants. We first performed this task (the summarizing) independently of each other to compare our results. We checked each other's results and discussed discrepancies as a group until we reached a collective view that everyone could agree on. Finally, we analysed the data of the survey (questions about the persons, sustainability awareness, conduction and process of the workshop, comprehensibility, time factor, and improvement).

ANALYSIS

In the following, we first present the main findings regarding each workshop. We want to point out that we do intend to establish a list of obligatory specifications with the presented SusADs. The figures show results that can be attained by the use of the framework. The SusAF allows stakeholders to discuss the potential impacts of the IT product or service to be designed. In doing this, we can develop guidelines that act as a basis for software design.

Online Pastoral Care (see Fig. 1) would result in relief for social institutions, as it would bring a quick personal contact possibility for acute cases. Accordingly, we listed this point as an immediate effect in the social dimension. From this point, an arrow in enabling effects on the individual dimension goes to "Outpatient care". Outpatient care is simplified or enabled. It also makes more individual care options accessible. This is only possible if the software developers design an interface adapted to the older generation, which would primarily use such a platform. In the technical dimension, a difficulty arises here.

On the other hand, the participants listed negative aspects on the social level that would go hand in hand with this digital transformation: a greater physical and spatial distance from dying persons.

On the economic level, the customizability of the support options would lead to a completely new branch of the economy unfolding, as the creative industry would turn to the topic. However, in the eyes of the workshop participants, this point entails a disadvantage on the structural level: There is a danger that digital care for the dying will turn out to be more cost-efficient, which means that analog care will be seen as expensive or too expensive. A further divide between social classes could be the result.

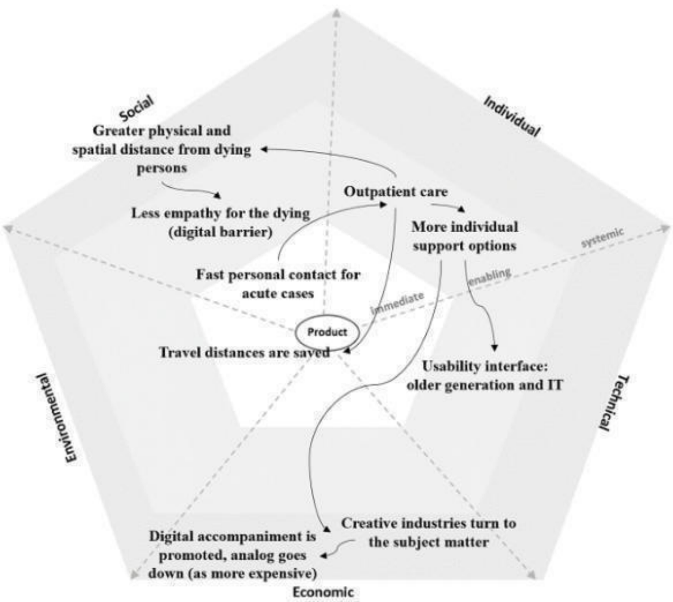

Figure 1: The completed SusAD for online pastoral care.

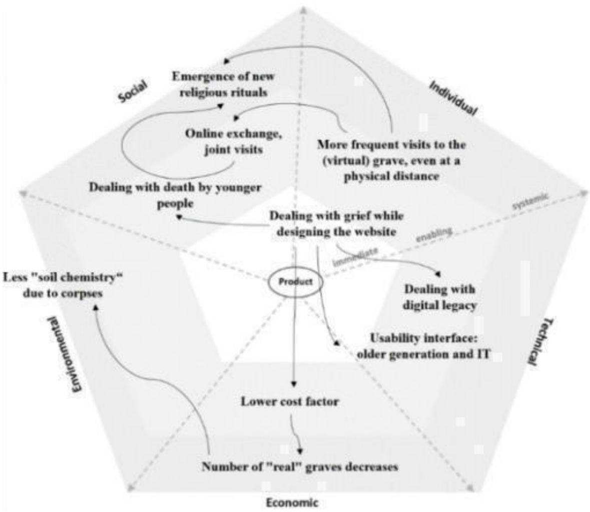

Figure 2: The completed SusAD for virtual graveyards.

Concerning the environmental dimension, the participants mentioned only one point: Travel costs (e.g. by car) can be reduced, which benefits CO_2 savings.

First, the creation of Virtual Graveyards (see Fig. 2) in the individual dimension has a direct impact on those who design the online page: They are encouraged to come to terms with the death of a person and thus with their grief. The entry into the process of Coping with Grief benefits from "digital proximity," since a more frequent visit to the (virtual) grave becomes possible even at a spatial distance, which the participants classified as an activating effect in the individual dimension.

This leads to (online) exchange in the social dimension, as joint "visits" e.g. in form of text messages become possible. On the structural level, the increased use of virtual cemeteries could lead to the emergence of new rituals. In the social dimension, the engagement with death by younger people can also be seen as an activating effect, since it can be assumed that more digitally inclined people will take over the creation of the virtual grave because they are already more likely to have experience with the handling of a CMS.

The designers of Virtual Graveyards need to put themselves in the position of the older generation to adapt the usability accordingly and deal with the issue of "digital legacy." Both impacts are placed in the technical dimension.

Within the economic dimension, virtual graves mean a lower cost factor, which on the structural level can lead to a decrease in the number of real graves because this could result in an argument for cremation and against burial. Conventional cemeteries, places with cultural significance, could get into economic difficulties.

In the environmental dimension, this would result in less soil chemistry from cemeteries, although one of the participants, a pastor, added that the number of cremations is increasing every year, so this factor is no longer seen as particularly problematic anyway.

The last workshop was about AI Memory Avatars (see Fig. 3). On the one hand, the participants listed short-term positive psychological effects in the individual dimension: The minimization of the feeling of loss, therapy can be carried out around the clock and the farewell can be made up for

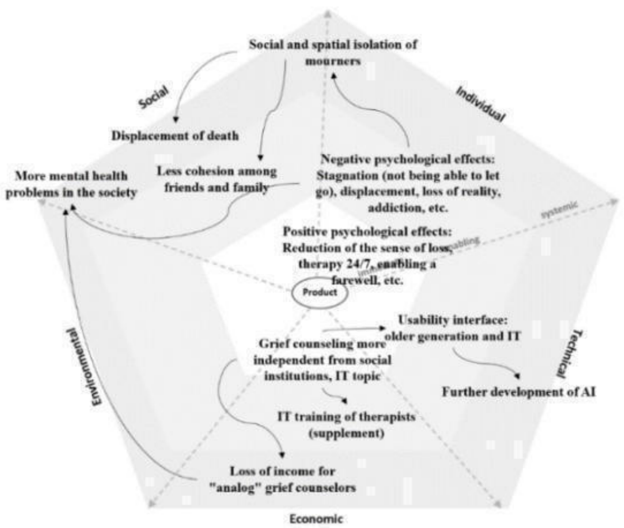

Figure 3: The completed SusAD for AI memory avatars (Lammert et al., 2022).

afterward. However, in the level above, in the enabling effects, the medium- and long-term negative psychological consequences that could be caused by AI Memory Avatars were dominant: Stagnation in the process of Coping with Grief ("not being able to let go"), suppression, loss of reality, addiction and others.

In the social dimension, AI Memory Avatars would bring about the overall and structural effect of social and spatial isolation of mourners. In addition, the workshop participants fear that this will increase the number of mental health problems in society. Furthermore, AI Memory Avatars could lead us to make the topic of death even more taboo than it is today. Social and spatial isolation would also lead to less support within networks such as friends and family.

In the economic dimension, participants concluded that establishing AI Memory Avatars would make grieving an "IT topic," which would alienate it from social institutions. As an enabling effect, they listed that therapists in particular would need to engage with IT topics in a complementary way, including establishing them as a supplement to their traditional way of working. In general, the participants feared that therapists working in the field of Coping with Grief would suffer a loss of income as a result, which would lead to a decline in supply and further increase the previously mentioned rise in mental illness in society.

In the technical dimension, as with the Virtual Graveyards, the participants stated that IT companies would have to turn to the target group of the older generation to be able to establish such a system. They also pointed out that this would require the further development of AI technologies and that this further development could be appropriately promoted by the topic of Memory Avatars.

Our survey showed the following. 75 percent of respondents indicated that their perception of sustainability impacts had changed because of the workshop. Explanations for this include "higher awareness of product design", "new food for thought" and a "differentiated perception". 88 percent of respondents said that they gained insights from the workshops that they did not have before. 75 percent would be willing to perform an analysis similar to the SusAF. 96 percent would recommend the SusAF to others. All respondents believe that the use of the SusAF will have an impact on the design of the IT products and services studied. Criticism emerged about the length of the workshop: 25 percent described the time as too short to do the complexity of the topic justice. Nonetheless, beneficial insights could also be obtained in a short period, as all respondents affirmed that the value of the results was commensurate with the time spent. The largest percentage of respondents (39 percent) indicated that software companies should realistically budget one to one and a half working days for the SusAF. The analysis of the results provides helpful insights into the design phase of IT systems in Thanatopractice, which, however, would need to be more in-depth. For example, different viewpoints between generations, cultures, and religious followers came up. There is also a need for additional tools to support software companies in implementing sustainability: Further education and training for employees in the area of sustainability (83 percent), communication between science and business (83 percent), interactive material for SusAF and other sustainability tools for support (58 percent) and funding programs (46 percent).

DISCUSSION

The Digitization of Thanatopractice must be classified as at least questionable. All workshop groups agreed that the investigated tools should at most be used to supplement analogue forms but could and should in no way replace them because it could take away from the fundamental human experience of death and grief.

The participants also addressed the complementary aspect of the target group of users. Particularly in the case of End-of-life Care and Coping with Grief, a majority of the participants rejected leaving the dying or mourning person alone. It should be made use of a pastoral or therapeutic companion. For example, a counsellor could connect the dying person with other dying people and thus initiate an online group through a voice-over-IP platform or an online forum. The mourner could receive the opportunity to make up for a failed goodbye by using an AI memory avatar while a therapist accompanies the process. Thus, the use of IT systems would need an accompanying capacity.

Digital Thanatopractice provided and executed by the industry was also considered critical by the participants and, accordingly, acceptable only when regulated. For example, software companies should not make any promises of salvation. In their marketing communication strategy, they should address professional groups or voluntary institutions directly.

An obstacle to constructing validity could be that the workshop participants at first did not understand the task description correctly. In this respect, we allowed workshop participants to ask questions at any time. We tested the workshops a few times to ensure that the tasks were understandable.

We cannot exclude the risk of confounding factors because the workshops took place online with the help of digital tools, which caused problems, especially for older participants. These may have had a negative impact on the internal validity. Nevertheless, we do not compare the results rather we want to show the feasibility of our approach and the importance of the new research area. It should be noted that digitization is not consistent in the international and cultural context.

Regarding external validity, it must be noted that the cases presented here are not intended to be statistically representative as this is a qualitative study. Finally, we do not attempt to generalize the findings from these three workshops; we only demonstrate the feasibility of applying SusAF and participatory design to identify the potential impacts of digital Thanatopractice. However, a broad-based quantitative study could prove to be a useful addition at a later stage. To minimize risks to reliability, two researchers conducted an analysis of the results and mixed qualitative and quantitative methods have been applied. When discrepancies in attribution arose, we discussed them until we reached a consensus. Two external researchers reviewed our results.

CONCLUSION

With this contribution, we hope to have contributed to a critical discussion on this topic and to have provided initial guidelines for software practitioners. In addition, we hope that other researchers will join our efforts and address the opportunities, risks, and limitations of digitizing Thanatopractice. We consider further participatory studies within the Digitization of Thanatopractice to be necessary, which examine and discuss the requirements of these and other IT systems in particular also in a more detailed way. In this context, generational and cultural differences must be taken into account.

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