Sustainability design in industry and academia

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***Abstract*—Sustainability design involves the design of sustainable software systems. There is a growing need to integrate sustainability issues into software development; therefore, many approaches have been developed in recent years. A widely used approach for sustainability design, the Sustainability Analysis Framework (SusAF), is applied in three cases, two industrial and one in academia. Following an exploratory, multiple case study research with workshops, interviews, and participant observations, this study discusses the experiences of applying SusAF. The results reveal that SusAF provides a space to conceptualise definitions and a vocabulary for sustainability. It also allows for negotiations on sustainability issues, bringing a multidisciplinary perspective and facilitating tool-based communication. Future work aims to compare SusAF with other sustainability design approaches.**

***Index Terms*—sustainability design, Sustainability Awareness Framework, industry, academia**

I. Introduction

The concept of sustainability has become increasingly important in the field of software engineering, prompting an assessment of current practices, methodologies, and tools to ensure long-term viability, efficiency, and minimal environmental impact, among other issues. The development of sustainable software requires a process that continuously assesses both positive and negative effects on sustainability. Therefore, the selection of best practices, methodologies, and tools is a key to ensure efficient sustainability design. The emergence of tool-supported sustainability design marks a growing need to integrate such issues into software development. A popular example is the Karlskrona Manifesto that provided a call to action and an inspiration to develop such approaches, since it treats sustainability as a systemic concept, describing a conceptual framework to apply sustainability [1], [2]. With a significant contribution to the field of software engineering, the Karlskrona Manifesto successfully established a common understanding and became a reference point for the global community of researchers and practitioners in the field.

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Recent literature reviews identified a wide variety of existing approaches for researchers and practitioners for sustainable design (e.g. [3], [4]). These approaches demonstrate a diversity of characteristics, such as the addressed requirements engineering activities, sustainability dimensions, and orders of effects. For example, many approaches incorporate the idea of direct, indirect and systemic impacts in sustainability design (e.g. [5], [6]), while a considerable number of approaches apply sustainability as a multidimensional concept, having five dimensions (e.g., [7], [8]). Furthermore, most studies support the elicitation and analysis of requirements engineering activities [3], [4].

In addition, there are considerable challenges when applying sustainability approaches. Examples of such challenges include the lack of common understanding of sustainability in software engineering, decision-making challenges on sustainability assessments, and challenges in tool support in sustainability approaches, related to documentation and visualisation of sustainability effects [3], [9], [10]. One of the key challenges concerns the modification of these approaches to a level, so that practitioners can apply them in industrial settings [3]. A popular sustainability approach has been evaluated in industrial cases in single or in two case studies (e.g., [11], [12]), although the majority of research is focused on the development of new sustainability approaches. However, it is necessary to apply existing approaches in extended practical evaluation [3]. Thus, it remains one of the key challenges in applying existing approaches is to reach a maturity level, so that practitioners can adapt and apply them in diverse cases [3].

To fill this gap, this exploratory research examines the application of a sustainability design approach (SusAF) and specifically asks ”how SusAF supports requirements elicitation in cross-disciplinary research for sustainability design?” This question will help identify tool’s features and process details that assist software development in cross-disciplinary research. Different cases are examined, two from industry and one from academia. The contribution of this paper lies in the qualitative

evaluation of SusAF in multiple cases and in the identification of tools' strengths and weaknesses.

The remainder of this paper introduces related work on empirical studies and approaches within sustainability design (Section II). Three case studies are introduced in Section IV, along with their project descriptions, technological solutions, and data collection details. The methodology is described in Section III, while Section V presents the results, organised into main discussion topics. Finally, advantages and challenges are presented in Section VI, followed by conclusions and future work in Section VIII.

II. Background

A. Approaches in sustainability design

There are many different possibilities for researchers to use existing approaches in sustainability design. A review identified 29 approaches to sustainability design that have been published in software engineering publication venues since 2000 [3]. Focussing on social sustainability, another review extracts a list of recommended tools and practices for software development [4]. By incorporating these approaches into software development, the software can be ensured to be both technically sustainable and socially responsible from a human perspective.

Several approaches are gaining attention, such as SusAF, AMDiRE, and INSURE/ENSURE. The approach most discussed in publications is the Sustainability Awareness Framework (SusAF) which will be further analysed in this paper [13], [14]. Artifact Model for Domain-independent RE (AMDiRE) [15] is a reference artifact model for domain-independent requirements engineering, where the artefact model consists of two basic submodels (the content model and the structure model), showing applicability in many industrial cases. Another framework, the INSURE/ENSURE (INcorporate SUstainability design in softwaRe Engineering life cycle) [16], is a meta-model for current and future sustainability requirements, captured in the viewpoints and business goals of stakeholders. The above approaches allow software engineers to embed sustainability requirements when developing a software system. However, it is common practice for researchers to evaluate their own developed sustainability approaches, which provides a likely biased perspective [3].

B. Sustainability Awareness Framework (SusAF)

The most discussed and applied approach in the requirements engineering field, according to [3], is SusAF. SusAF was developed based on design science and has made significant contributions in the realm of software engineering, particularly in requirements engineering, by enabling a comprehensive understanding of sustainability impacts in software systems [13], [14]. The main goal of the framework is to raise awareness, among all stakeholders involved in system design, of the sustainability effects that a software system could have in its intended context.

Based on SusAF, the sustainability of software systems encompasses five dimensions, namely social, individual, technical, environmental, and economic sustainability. Consisted of a set of instructions, forms and questions that can be used to guide discussions with the stakeholders, SuSAF can be applied either in the context of semi-structured interviews or workshops. The target group is requirements engineers who could translate discussions on sustainability to software requirements. SusAF supports stakeholders in addressing long-term sustainability aspects of software systems, facilitating a shift toward more sustainable development practices.

The framework is supported by the Sustainability Awareness Diagram (SusAD), which serves as a visualisation tool to facilitate discussions with stakeholders about sustainability. SusAD is divided into five equal parts, one for each dimension, and three concentric pentagons that represent the order of effects [13], [14]. It is used to highlight the chains of effects, which means the immediate, enabling and structural effects [17]. SusAF could be adopted to facilitate discussion with stakeholders during a workshop, or it can be used by system designers to extract requirements from other data sources. During the process, participants go through the set of SusAF questions to capture possible sustainability effects. Asking stakeholders to reflect on how one effect may lead to another over time and across dimensions is likely to lead to the identification of more potential effects.

III. Methodology

This paper reports on a multiple case study design [18]. It is exploratory research, which applies an existing requirements engineering framework, namely SusAF, in three cases in the context of sustainability design. All cases were conducted during 2023 and applied SusAF within industry (two cases) and academia (one case). The ultimate goal was to improve the sustainability of their technology. A printed version of the Sustainability Awareness Diagram (SusAD) [13] was used during the workshops that were organised as part of the corresponding project. The workshop process was similar across the cases and the participants had to complete three tasks (Table I). First, participants worked on a mapping exercise with SusAF and discussed the project's sustainability issues in five dimensions. Second, participants worked on classification of issues into levels of effects. Third, relations (chain of effects) within and

TABLE I
SusAF workshops' design

Workshop Design	**Case studies**		
	Case 1: Gaia	***Case 2: AudioNear***	***Case 3: Library***
Introduction	Yes	Yes/brief	Yes
Task 1: Mapping exercise	Yes	Yes	Yes
Task 2: Levels of effects	Yes	Yes	Yes
Task 3: Chain of effects	Brief	Yes	Yes
Sum-up	Yes	Yes	Yes
Identified issues	25	20	22
Roles	5 roles	5 roles	5 roles

across dimensions were drawn. Participants were delegated to five sustainability dimensions to work during the workshop, based on their background, but were not limited in discussions to this dimension exclusively. Workshop participants were selected based on their direct participation in the projects. In addition, participants with diverse educational background and project responsibilities that could correspond to the five sustainability dimensions were chosen.

To efficiently manage both the process and the discussions, driving questions were used. The questions supported the flow of the discussions and were adapted for the particular project. Hereafter, driving questions (e.g., in the Gaia project) were asked after a long pause, to provide focus on an issue or to explain further an issue:

- How can the technology change the trust between users and museum? (trust - social sustainability)
- How can the user interface be made more accessible? Does technology promote social inclusion? Is it adaptable to changing user needs? (universal design - individual sustainability)
- How can the technology affect the need for production of energy? What about the use of energy? (energy - environmental sustainability)
- How can technology affect the relationship between the museum and its visitors? (customer relationship management - economic sustainability)
- Which assets controlled by this technology would be desirable to an attacker? What are the risks associated with these assets? What are other likely vulnerabilities of the system? (security - technical sustainability)

In total, the workshops lasted approximately three hours, followed by additional discussions and clarifications on unclear issues.

A. Interviews

After the workshops, individual interviews were conducted to allow researchers to learn more on participants' experiences and views on sustainability, in relation with the identified issues, the technology and the project, as well as experiences with SusAF. We conducted semi-structured interviews using an interview guide with mainly open-ended questions (Appendix). The interviews were recorded and lasted around 30-40 minutes each. Verbatim transcripts of individual interviews were used as the basis for the coding and analysis of data. In data analysis, we used thematic analysis and open coding methods. This process helped identify and understand the central themes that emerged from the interviews. The primary topics of discussion encompassed participants' impressions of the workshop, their experiences with SusAF, and various elements of the process and tool, such as the dimensions and levels of effects, as well as chain of effects.

B. Participant observations

Two authors participated in the workshops. One of the two authors documented the interactions between the participants.

TABLE II
STUDY DESIGN

Methods Design	**Case studies**		
	Case 1: Gaia	***Case 2: AudioNear***	***Case 3: Library***
Workshop	Nov'23	May'23	Nov'23
Participants	5 developers	3 developers, 2 designers	4 librarians
Interviews	5	-	4
Participant Observations	Yes	Yes	Yes

Observations focused on communication styles and collaborative efforts to understand sustainability culture [19], [20], use of the tool, discussion topics, and challenges. This was treated as a secondary dataset that complemented interviews and workshop data. Observations enabled researchers to scrutinize the specific language used regarding sustainability in each context. It also facilitated the identification of emerging patterns in discussions, the prioritisation and negotiation of issues in accordance with the process, the dynamics of interaction and idea development among participants. In addition, the author actively participated in discussions, both to steer the conversation and to provide or seek clarifications on any points raised. Researcher's involvement was instrumental in ensuring the smooth progression of the workshop and in addressing any ambiguities that arose.

IV. SUSTAINABILITY DESIGN IN THREE CASE STUDIES

In this section, three case studies in sustainability design are presented, with corresponding description of data collection. The results of these cases are discussed together in Section V. Table II shows the study designs for each case study.

A. The Gaia Vesterålen project

1) Project description: Gaia Vesterålen is an environmental and history project for the Vesterålen area in Sortland (Norway) [21], [22]. The project aims to contribute to the sustainable development of the local area through innovation, research and technological development. Projection mapping technology is used in museum settings (Sortland Museum) to visualize a 3D model of the Vesterålen district, informing visitors about the history of the area and to demonstrate how the environment has changed over the years and how it may change in the future. Gaia Vesterålen targets residents, tourists, and stakeholders of the Vesterålen district, aiming to contribute to the sustainable development of the local community by raising environmental awareness and supporting decision-making processes that preserve cultural heritage and prevent environmental deterioration. Central to the project is the concept of sustainability across project objectives while an "environmental contract", i.e., an action plan with clearly defined environmental goals and actions at individual, corporate, and organisational levels, will be co-produced with actors in the local community.

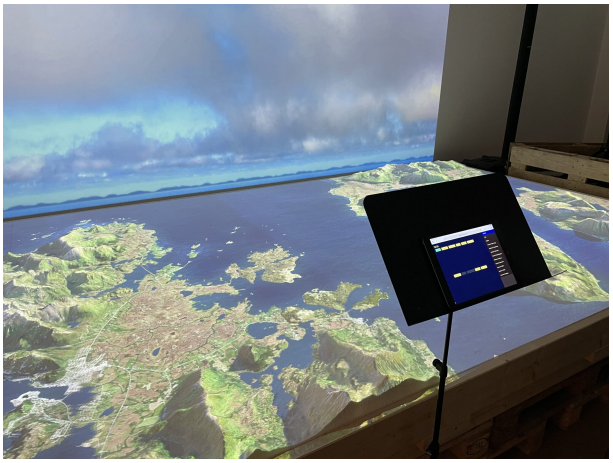

Fig. 1. The projection mapping system of the Gaia Vesterålen project.

2) Projection mapping system in museum: The goal of the projection mapping system is to seamlessly merge physical and virtual worlds by superimposing computer-generated graphics onto real surfaces, such as large buildings, cars, shoes, and furniture. Projection mapping has also been used for cultural applications in museum settings, usually displaying the history of a place or tradition. These projections can be displayed on walls, actual exhibits, and physical-scale models of a site of interest. These physical scale models are usually installed on tabletop surfaces, with the projector(s) being placed on the ceiling, hence the term "tabletop projection mapping" [21], [22] (Fig. 1).

Tabletop projection mapping is implemented in the Gaia Vesterålen project to visualise a digital twin of Vesterålen and display layers of information from the project's geographic knowledge base. A data pipeline architecture and a content delivery application facilitate the output to the projection mapping model, as shown in Fig. 2.

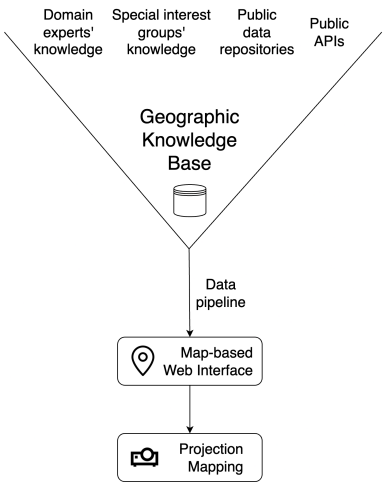

Fig. 2. A high-level description of the projection mapping architecture of the Gaia Vesterålen project.

3) Data collection: The need to examine sustainability issues in Gaia Vesterålen was driven by the complexity of the projection mapping system and its interaction with many different aspects of the project. To discuss sustainability issues and envision the development of a sustainable technology/project, a workshop and interviews with developers were arranged in November 2023. The workshop's objective was to delineate sustainability issues in relation with the technological system (projection mapping) as well as to envision the development of a sustainable project. Five developers, having expertise in software engineering, user experience, virtual and augmented reality, and programming, participated in the workshop. In addition, participant observations complemented the workshop data. More information on methods is discussed in Section IV on Methodology. Table II and I summarize the methodological and workshop details in case studies.

B. The AudioNear project

1) Project description: The project aims to redesign AudioNear, a mobile augmented reality (MAR) application, applying sustainability design [23]. More specifically, AudioNear as a tour guide application incorporates an audio MAR experience for the city of Oslo and provides real-time, speech-based auditory information about places of interest in the user's vicinity [24], [25].

The second version of AudioNear was developed conceptually in 2023 with a focus on sustainability aspects of the application. Following a four-step process, twenty sustainability issues were identified in MAR applications, and then eight were selected for further development. Examples of the identified sustainability issues in MAR applications, in relation with five dimensions of sustainability, were the following:

- responsible tourism, cultural preservation (social dimension)
- personalized travel experiences, usability and universal design (individual dimension)
- minimized carbon footprint, sustainable resource management (environmental dimension)
- sustainable business model, cost efficiency for travelers (economic dimension)
- technical safety, security and privacy, connectivity and accessibility (technical dimension)

A small group of the most vital issues was then selected for further development. Sustainability issues with immediate effects were developed further into design suggestions and mock-ups. Eight selected issues referred to responsible tourism, personalised travel experience, user safety & privacy, usability & universal design, environmental awareness, cost efficiency for travellers, technical safety, security & privacy, connectivity & accessibility. Based on selected issues, AudioNear design suggestions were formulated to reflect interrelations between overlapping sustainability issues. Examples of design suggestions are mentioned above [23]:

- The MAR travel guide application should provide information and recommendations on responsible tourism practices (DS2.1)

- The MAR travel guide application should offer a personalized travel experience (DS2.2)
- The MAR travel guide application should provide and prioritize information related to user safety and privacy on travel (DS2.3)

2) MAR technology in tourism: The first version of AudioNear was developed in 2018, as a web-based mobile application utilizing a 4G broadband connection. In a use scenario, users wear headphones and launch the audio tour guide app on their personal mobile devices. Based on their GPS-location, when users entered a designated radius around a specific location, an audio track provided detailed information about that place. The system uses the device's GPS coordinates to get the basic AR content about the AudioNear POIs and external links to content (e.g., audio tracks, images/icons).

In the first place, the main menu of the application offered functionality such as use instructions, a test audio track, a map, and the option to start using the main exploration functionality. The application was designed for Oslo and featured 16 sights as places of interest and corresponding audio tracks in English with information about history, architecture, and visiting hours. Based on previous work and existing literature in the field, the previous version of AudioNear v1.0 was designed following four design suggestions that addressed the topics of user interaction, interface design, and content delivery [25].

3) Data collection: The motivation for the redesign of AudioNear v1.0 was poor technical sustainability, such as the third party service (i.e. Layar), while sustainability design was chosen as a holistic approach to consider both front- and back-end characteristics. For this purpose, a workshop with developers and participant observations were arranged in May 2023 (Fig. 3). The objective of the workshop was to discuss the sustainability issues of the app and to envision the development of the app. To redesign the AudioNear app, an adapted version of a SusAF workshop [26] was done, following a top-down approach to sustainability design. Five developers who were previously involved in the development and research activities of AudioNear v1.0 participated in the workshop. The developers had previous experience in mobile system development, software engineering, and programming.

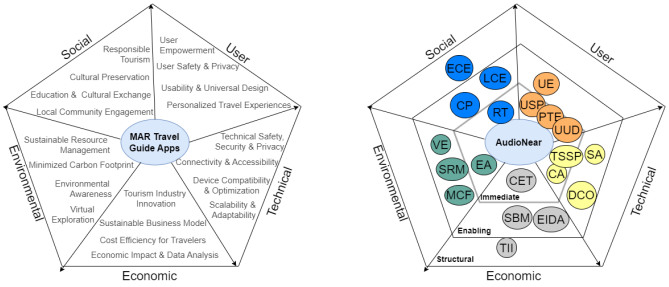

Fig. 3. Workshop results from AudioNear project were transferred in a digital format. Left: SusAD with identified sustainability issues for MAR travel guide apps. Right: classified issues into three levels of effects for the AudioNear app. Adapted from [23]

Based on workshop discussions and participant observations, design suggestions were visualised into high fidelity mock-ups of AudioNear v2.0.

C. The Library project

1) Project description: The University of Oslo Library is Norway's oldest library and supports approximately 27000 students and 7000 staff. In 2023, after OpenAI launched ChatGPT, the library had a growing demand for support regarding the use of Artificial Intelligence (AI) and AI-based tools in research. Usually, the process of choosing tools is often focused on the security and quality of the output. The University of Oslo, when choosing tools that support research, has strict security rules. Those rules include among others, GPDR for personal data, as well a complex chain of control steps which are followed to highlight possible aspects of tool's use in academic context [27]. Therefore, this study examines how data is used and stored, but also the sustainability issues of these tools. It is worth mentioning the existing tension between university's strict rules and the necessity for tools' testing which support research. The library started to approach AI already in 2017 [28] and tested a few AI-based tools. Therefore, using a sustainability framework to look into how sustainability is addressed when choosing AI-based tools was seen as unique.

2) AI tools in university: First, the aforementioned project looked at two AI-based tools, namely Iris [1] and Keenious [2]. They are made by Norwegian-based companies. which give possibilities for cooperation in the development of tools. Later, an open-source tool called ASReview [3] developed by Utrecht University was chosen to support systematic reviews. Finally, after the launch of ChatGPT in the fall of 2022, a locally supported instance of OpenAI software was launched at the University of Oslo.

3) Data collection: Examining AI tools' use in higher education context is an important and timely topic, relevant both for librarians who evaluate such tools and students who benefit from their use. A workshop with librarians was arranged in November 2023 (Fig. 4). The workshop's objective was to examine sustainability issues in relation with AI tools in the university and to envision a sustainable model of use. Four librarians participated in the workshop, two subject librarians and two librarian experts in systematic reviews. In addition, participant observations complemented the workshop data.

V. Results and Discussion

The three cases provided valuable insights into the multi-faceted nature of sustainability in cross-disciplinary research and the use of SusAF. The participants said that the workshop with SusAF was an enlightening experience, especially in understanding various dimensions of sustainability and in providing an overview of the project's overall sustainability aspects. The interconnectedness of these dimensions and the

[1]https://iris.ai/
[2]https://keenious.com/
[3]https://asreview.nl/

Fig. 4. Workshop at University of Oslo Library. Participants used post-it notes on SusAD and drew lines to visualize chain of effects.

importance of considering them holistically in project planning and execution was one of the key qualities of SusAF. The workshop and the tool served also as an educational platform, enhancing the understanding of sustainability by participants beyond mere environmental concerns, to encompass a broader societal and technological context. This broadened perspective is crucial to ensure that sustainability goals are addressed in a comprehensive way in both industry and academia. In addition, the qualitative analysis identified several strong recurrent themes. For the purposes of this paper, the authors focus on the themes that are directly related to the use and impact of SusAF, while discussing secondary topics alongside them.

Overall, results reveal a lack of common understanding of what sustainability means in each case and what makes a software system sustainable. Three themes were identified as relevant to discuss for the utilization of SusAF:

- Definitions and vocabulary: how the tool supported the creation of definitions and a vocabulary for sustainability
- Multidisciplinary view: how different roles supported the workshop to progress
- Tool-based communication: how the tool was experienced as a boundary object

Workshops, interviews and observations provided a rich understanding of how the tool supports conceptualization and operationalization of sustainability in the context of specific projects. The results are clustered according to identified themes and are presented in the following.

A. Defining sustainability: building a vocabulary

When participants started to work on SusAF, a reflection cycle was initiated on what sustainability means for the particular technology, project, department, and organisation. The structure of the workshop, based on tasks and roles, assisted individual and group reflections and negotiations on sustainability definitions. The participants had first some time alone to conceptualise at the beginning of each task and then more time to collaborate in problem solving with the group.

The results revealed that SusAF supported participants in building a specific vocabulary on sustainability to better understand what the concept means in relation to their project work. Especially in the first task of mapping sustainability issues, participants began to question the meaning of the concept by bringing keywords from their knowledge, scientific field, and project work into discussion.

For example, sustainability in the context of the Gaia project was seen to be necessary to ensure the inclusiveness of the project, to cater to diverse users and museum visitors, including those with disabilities, and to minimise negative environmental impacts. The emphasis was on creating a lasting and positive impact both for the environment and society, aligned with the United Nations' Sustainable Development Goals (SDGs) [29]. Furthermore, in the same project, sustainability was conceptualised as multidimensional, having as core dimensions the environment, society, and economy. SusAF was supportive of the conceptualisation and identification of the main elements that could make projection mapping technology and the project, in general, sustainable. Key terms like "carbon footprint", "visitor accessibility", and "project longevity" were frequently mentioned during the workshop and interviews. For instance, "carbon footprint" was associated with highly-demanding projectors in terms of energy consumption, where sustainability could start with green coding and other relevant practices. As the workshops progressed, key terms were circulated in the discussions indicating a process of building a vocabulary for sustainability. From the social sustainability point of view, participants defined it as the capability of the project to endure and benefit all users (e.g. museum visitors, technical staff, project members) without causing harm to various aspects such as the environment, society, and economy.

Furthermore, SusAF was applied to integrate sustainability into the design and development of the AudioNear app, focusing on two main dimensions, namely the user/individual and technology. The distinctive characteristic of this case was that SusAF's outcome was utilised for design suggestions for sustainable MAR app development. Therefore, sustainability in AudioNear was defined in terms of "safety and security in tourist navigation", "accessibility in tourist attractions", and "always connected to the Internet". The emphasis was on creating a sustainable and user-centred experience for tourists. Workshop participants defined sustainability in MAR applications placing "user safety and security" at the top of the design requirements' list. SusAF supported the identification and prioritisation of the main issues that could be further developed into design suggestions and later into mock-up designs. The dimensions of sustainability, the diverse roles and the printed format of SusAD established a common understanding of the definitions and key terms.

Additionally, in the Library project, the use of AI tools in

the university is a multifaceted topic, encompassing various issues such as educational aspects, ethical considerations, environmental sustainability issues, and future implications. The workshop participants defined sustainability according to environmental and economic issues. Economic sustainability was discussed in terms of developing financially viable and beneficial AI tools for long-term use. This included considerations of value creation, customer relationship management, and the overall economic impact of AI tools. In addition, the participants defined environmental sustainability in terms of reducing the energy consumption of AI systems, reflects a growing awareness of the need for environmentally sustainable practices in both the development and use of AI tools. Key terms such as "energy consumption" and "financial viability" were frequently mentioned. For instance, discussions about "energy consumption" of AI tools reflected concerns about the ecological footprint of AI technologies and their impact on natural resources. In addition, "water consumption" was associated with the cooling of hardware to train and use AI models, emphasising the need to consider the broader environmental impact of these technologies.

B. Multidisciplinary view: thinking differently on sustainability

The perception of sustainability as a multidimensional concept is crucial and was first mentioned more than three decades ago [30]. Many tools and approaches to sustainability design have already incorporated the idea of sustainability as a multidimensional concept [3]. SusAF workshops involved multidisciplinary teams, consisting of developers, designers, and managers, who approached sustainability issues in various ways, bringing to the discussions different views. In case studies, the following observations were made:

- Cross-disciplinary collaboration: Since there is a lot of individual work in projects and a lot of information to be managed, SusAF provided a unique space to gather and organise the information around dimensions. Therefore, such workshops can lead to a more comprehensive understanding of sustainability issues from multiple perspectives. Participants in Gaia, where the level of information, complexity and interaction is high, found SusAF an "information space" to delineate the project's complexity and a "negotiation space" to raise debates from disciplines, such as environmental science, sociology, and business science.
- User-Centered design: The focus on user needs and behaviours is not a new lens to design, but is neglected in some cases. SusAF brings the individual dimension to a visible position when sustainability issues are discussed. In AudioNear, during the first task of SusAF, developers considered primarily a system view of user interaction with the application and how these interactions can be made more sustainable. However, this involves understanding the social context in which the system will be used and the design context with long-term engagement and behaviour change. In later tasks, developers aligned their perspective with designers to understand the traveller's needs when navigate in unknown places.
- Ethical Considerations in multiple contexts: System developers were mindful of the ethical implications of their work, ensuring that the system does not raise social inequalities or negatively impact vulnerable communities. Similarly, ethical considerations were negotiated in the Library project. First from the technical sustainability point of view, the discussion on user data protection raised several connections with ethical considerations. Another perspective on this topic was raised from the social sustainability point of view, when the avoidance of biases and stereotypes in AI algorithms were considered as ethical issues for AI tools. During the second task in workshop, group reflections were focused on ethical and responsible use of AI tools in general for an educational setting like universities.
- Life-cycle Analysis: Software developers should consider the entire life-cycle of the system, from the development and deployment phase up to disposal. This includes assessing the environmental and social impact of the materials and processes used in development, as well as the system's efficiency and longevity. An example is with the AudioNear project. During the mapping exercise, designers insisted on including sustainable resource management (linked to the environmental dimension) that refers to "information on sustainable resource management practices, such as waste reduction, water conservation and energy-saving initiatives" [23]. Developers neglected the issue up to that point and juxtaposed their technical-orientated view on life-cycle management. Negotiations on the issue evolved around the app design, and participants finally reached an agreement. They decided to embed the issue with an enabling effect and design the feature in later versions of the app.
- Sustainability Metrics: Although there is a fundamental lack of metrics to estimate sustainability issues, e.g., in software architecture, particular development models include a list of metrics to measure specific dimensions of sustainability of each software engineering phase [31]. In case studies, few sustainability metrics and indicators were identified during SusAF workshops to guide the development process. Project collaborators could use these indicators to make informed decisions that align with sustainability goals. Sustainability metrics in the Gaia project involve energy efficiency, resource utilisation, carbon footprint, and social impact measures. An example concerns energy efficiency metrics. A design perspective on the projected 3D layers brought up the discussion on sustainability metrics. For projection mapping technology, sustainability metrics were largely dependent on energy efficiency of projection systems and the overall carbon footprint associated with 3D modelling and projection mapping display operation. Similarly, for AI tools, sustainability metrics could refer to the computational efficiency and energy use of AI systems, fairness and eth-

ical considerations in AI decision-making processes, and the long-term sustainability of AI technologies in terms of maintenance. However, at that stage of the project development sustainability metrics were not considered yet.

C. Communicating through a "boundary object"

The results of the cases indicate that SusAD was perceived as a boundary object [32]. In this context of workshops, the term "boundary object" refers to a "conceptual or physical entity used as a focal point to facilitate communication and understanding among participants from different backgrounds or with varying levels of expertise" [33]. Within groups, boundary objects could support the construction of meanings while translating, coordinating and aligning the perspectives of the different parties [34].

SusAD as a boundary object played a crucial role in the following activities:

- Facilitating Communication: As a shared reference point, SusAF helped bridge communication gaps among participants. This is important in a diverse group, where individuals may have different areas of expertise, perspectives, or professional backgrounds. An example from the AudioNear project reveals how SusAF bridged a communication gap. Two participants negotiated the chain of effects of responsible tourism, a sustainability issue for MAR in social dimension. One had a vague understanding of how issues are connected, and the other participant pointed to the SusAF's written notes to connect issues in chain of effects. The participant explained how responsible tourism could impact: a. environmental awareness, on the immediate effects, b. user empowerment, on the enabling effects, and c. tourism industry innovation, on the structural effects. This was made possible by the structure of SusAF and its material.
- Enhancing Understanding: A boundary object can aid in the conceptualisation of ideas and theories by providing a concrete ground for abstract discussions, making them more accessible and relatable to all participants. By centering discussions around a common object or concept, it allows for a more cohesive understanding of complex topics. This is particularly effective when dealing with abstract concepts like sustainability, for example in a complex technological system with projection mapping technology. SusAF provides a tangible focus for discussions, where participants note down or place post-its on top. In addition, boundary objects can serve as tools for collaboration, fostering a sense of shared purpose and focus among participants. They can help in aligning individual contributions towards a common goal, enhancing the collaborative effort [33].
- Enabling Inclusivity: By providing a common ground, a boundary object can make discussions more inclusive, allowing individuals with different levels of knowledge and backgrounds to contribute effectively to the conversation. Based on observations, SusAF enabled the removal of power imbalance in relation to the potential for co-creation of knowledge with other participants. Participants were encouraged to actively articulate themselves during the group discussions. Using SusAF to facilitate "storytelling", descriptions and discussions resulted in rich data collection also from quiet participants that might have been suppressed by dominant participants. This was achieved by assigning roles to all participants.

This approach becomes popular in fields such as education, business, and government, where physical objects serve as a means to organise, maintain, and document events that involve collaboration [3] . The role of SusAF in workshops, similar to other boundary objects, is to facilitate communication, improve understanding, encourage collaboration, assist in conceptualisation, and ensure inclusivity.

VI. Advantages and challenges with SusAF

First, it was a common finding in all cases that SusAF was perceived as a holistic approach to work in sustainability. SusAF likely provides a comprehensive and, in some cases, a common view of sustainability, considering five dimensions. This helps to ensure that all relevant sustainability issues are examined, despite the varied level of abstraction in each dimension. Second, SusAF is considered a guided approach in the decision-making process. By integrating the process of sustainability into design, SusAF can assist designers, developers, and other disciplines in making more informed decisions that align with sustainability goals. Third, the framework raises awareness among designers and stakeholders about the importance of sustainability, potentially leading to a shift in project and/or organisational culture toward more sustainable practices. Fourth, the targeted services or products designed with the help of SusAF are likely to be more sustainable, which can reduce negative environmental impacts and enhance social responsibility.

In contrast, a common challenge identified in all cases was the complexity of using the framework. Implementing a framework like SusAF can be complex and requires significant time and resources, particularly in organisations not accustomed to such practices. A second challenge concerns the preparation of the workshop. Usually, it takes time to gather related data to discuss sustainability issues, while developing driving questions can be complex and time-consuming. Third, during the workshop, there might be resistance within organizations/ projects, especially if sustainability practices conflict with established processes or short-term profit goals. Finally, implementing sustainable practices often involves higher upfront costs. Companies and organisations might not be ready to invest in sustainable practices, while it depends on the timing and how much time is left for a project. Sustainability is a rapidly evolving field. Keeping the framework up-to-date with the latest standards and practices could be challenging.

VII. Threats to Validity

This study is subject to threats to validity, including internal, external, construct, and conclusion validity. We are aware of

these threats and we tried to minimise them by employing different mitigation actions.

A. Internal validity

This relates to the selection of participants and researchers. First, selected participants joined the study through a convenience sampling method. They may not be representative, compared to the general population who works in these cases and projects. To mitigate this, participants were selected from different job positions. Another internal threat is reactive bias, as participants might have felt pressed to answer in a way that conformed to the expectations of the study, both in workshops and interviews. This bias was mitigated by reassuring them that every response is acceptable, that there is no right or wrong response, and that all responses would be equally valid. In addition, regarding researchers' bias, the quality of the data analysis is influenced by the knowledge, experience, and understanding of the first author. To mitigate this, the first author was guided by at least one of the other authors in each case, during the interpretation and data analysis, to ensure quality in the evaluation process. Finally, the moderators who led the workshops were two of the authors, different in each case. Except for one who is an experienced facilitator in SusAF, the rest were inexperienced in leading a workshop with SusAF. Therefore, they did not possess enough experience to efficiently conduct open discussions. This inexperience may have dampened the results of the workshop.

B. External validity

This relates to the generalisability of our findings, which means the assurance that this study provides that the challenges faced with SusAF are likely to occur when applying it to other cases. To mitigate this threat, we compared and referred to other studies in the literature with similar challenges and checked their approaches. The application of SusAF in three cases may not be sufficient and could always be increased to achieve a greater generalisation potential.

C. Construct validity

Construct validity refers to the question of whether constructs are measured and interpreted correctly. SusAF consists of many artifacts and it is difficult to control how and which ones work. To limit this threat, we sent participants information about SusAF before the workshops and had a detailed introduction to SusAF during the workshops. However, it is difficult to determine whether participants were affected by their unfamiliarity with the topic or the artifacts themselves. A learning curve is usually expected, as well as participants' understanding on sustainability dimensions in a particular context. Therefore, we cannot exclude novelty effects. All participants had a basic knowledge of sustainability in their project and had some experience in participating in workshops and applying design approaches.

D. Conclusion validity

This refers to the question of whether the study is reproducible by other researchers. To mitigate the challenges with the unreliability of treatment implementation, we followed the same process and facilitation during all workshops, with small contextual adaptations to the specific case.

VIII. Conclusions

This exploratory study investigates the application of SusAF in three cases, two in industry, and one in academia. This study answers the question of how the tool supports requirements elicitation in cross-disciplinary research for sustainability design. The contributions of this paper are three-fold. First, it presents three different cases with SusAF, providing rich methodological details and example topics from interviews. Second, it discusses cross-case discussion topics and approaches that were adopted in sustainability design with SusAF, providing qualitative evaluation of the approach. Third, it discusses a number of advantages and challenges that are likely to be encountered when using SusAF.

The results support the view that sustainability should be incorporated in all requirement engineering activities, while the software engineering community should be open to sharing experiences and lessons learnt on how such tools can be applied in industry and academia [3], [35]. Starting from the requirement elicitation phase, a critical phase in the software engineering process, stakeholders try to define what a software system should do, how it should perform, and the requirements of sustainability issues. By adopting a sustainability design in the initial phases of software development, it helps to ensure that the final product meets the expectations and requirements of its users and stakeholder. In general, the results reveal a lack of common understanding of sustainability within project groups and what makes a software system sustainable. SusAF supports this direction, providing a space to conceptualise definitions and a vocabulary for sustainability, to negotiate issues with a multidisciplinary view, and to facilitate tool-based communication. The structure and process of SusAF with five dimensions, tasks, roles, and a tangible format facilitate participants' participation in discussions about sustainability. SusAF has particular qualities that make it well known among sustainability approaches. This study also discusses advantages and challenges that can be used further to improve the SusAF process. Future work aims at carrying out additional case studies to evaluate SusAF with different methods, e.g. questionnaire, and to follow up previous cases for sustainability assessment. Comparison of SusAF with other sustainability approaches is also part of future research.

Acknowledgment

We would like to thank all study participants who supported this research. This research was funded by the Norwegian University of Science and Technology (NTNU) under the Center for Sustainable ICT (CESICT, no. 2575079) for D. Chasanidou and J. Krogstie, and by the Research Council of

Norway under the Gaia Vesterålen project (no. 321550) for C. Boletsis.

APPENDIX

Example topics in interviews:

- Overall experience with the workshop
- Structure of SusAF
- Process of SusAF
- Artifacts of SusAF
- Challenges with SusAF
- Suggestions for improving SusAF
- Definition of sustainability (context-specific)
- Sustainability dimensions (prioritisation, overlaps across dimensions)
- Identified sustainability issues (overlaps across dimensions, chain of effects)

REFERENCES

[1] C. Becker, R. Chitchyan, L. Duboc, S. Easterbrook, B. Penzenstadler, N. Seyff, and C. C. Venters, "Sustainability design and software: The karlskrona manifesto," in *2015 IEEE/ACM 37th IEEE International Conference on Software Engineering*, vol. 2, pp. 467–476, IEEE, 2015.

[2] B. Penzenstadler, "Sustainability and requirements: A manifesto," *IEEE Software*, vol. 32, no. 5, pp. 90–92, 2015.

[3] P. Bambazek, I. Groher, and N. Seyff, "Requirements engineering for sustainable software systems: a systematic mapping study," *Requirements Engineering*, pp. 1–25, 2023.

[4] A. C. Moises de Souza, D. Soares Cruzes, L. Jaccheri, and J. Krogstie, "Social sustainability approaches for software development: A systematic literature review," in *International Conference on Product-Focused Software Process Improvement*, pp. 478–494, Springer, 2023.

[5] B. Penzenstadler, "Infusing green: Requirements engineering for green in and through software systems.," in *RE4SuSy@ RE*, pp. 44–53, 2014.

[6] B. Penzenstadler, "From requirements engineering to green requirements engineering," *Green in Software Engineering*, pp. 157–186, 2015.

[7] N. Condori-Fernandez, A. C. Bolos, and P. Lago, "Discovering requirements of behaviour change software systems from negative user experience," in *Proceedings of the 40th International Conference on Software Engineering: Companion Proceeedings*, pp. 222–223, 2018.

[8] N. Condori-Fernandez, J. Araujo, A. Catala, and P. Lago, "Towards a non-functional requirements discovery approach for persuasive systems," in *Proceedings of the 35th Annual ACM Symposium on Applied Computing*, pp. 1418–1420, 2020.

[9] B. Penzenstadler *et al.*, "Iterative sustainability impact assessment: When to propose?," in *2021 IEEE/ACM International Workshop on Body of Knowledge for Software Sustainability (BoKSS)*, pp. 5–6, 2021.

[10] M. Basmer, T. Kehrer, and B. Penzenstadler, "Susaf welcomes susapp: Tool support for the sustainability awareness framework," in *2021 IEEE 29th International Requirements Engineering Conference (RE)*, pp. 418–419, 2021.

[11] S. Lieu, A. Wong, and B. Penzenstadler, "The 'vattn'case: Analysing sustainability impacts in a software startup," in *2022 International Conference on ICT for Sustainability (ICT4S)*, pp. 150–159, IEEE, 2022.

[12] P. Bambazek, I. Groher, and N. Seyff, "Application of the sustainability awareness framework in agile software development," in *2023 IEEE 31st International Requirements Engineering Conference (RE)*, pp. 264–274, IEEE, 2023.

[13] L. Duboc, S. Betz, B. Penzenstadler, S. A. Kocak, R. Chitchyan, O. Leifler, J. Porras, N. Seyff, and C. C. Venters, "Do we really know what we are building? raising awareness of potential sustainability effects of software systems in requirements engineering," in *2019 IEEE 27th international requirements engineering conference (RE)*, pp. 6–16, IEEE, 2019.

[14] L. Duboc, B. Penzenstadler, J. Porras, S. Akinli Kocak, S. Betz, R. Chitchyan, O. Leifler, N. Seyff, and C. C. Venters, "Requirements engineering for sustainability: an awareness framework for designing software systems for a better tomorrow," *Requirements Engineering*, vol. 25, pp. 469–492, 2020.

[15] D. Méndez Fernández and B. Penzenstadler, "Artefact-based requirements engineering: the amdire approach," *Requirements Engineering*, vol. 20, pp. 405–434, 2015.

[16] T. R. D. Saputri and S.-W. Lee, "Integrated framework for incorporating sustainability design in software engineering life-cycle: An empirical study," *Information and Software Technology*, vol. 129, p. 106407, 2021.

[17] L. M. Hilty and B. Aebischer, "Ict for sustainability: An emerging research field," *ICT innovations for Sustainability*, pp. 3–36, 2015.

[18] P. Baxter, S. Jack, *et al.*, "Qualitative case study methodology: Study design and implementation for novice researchers," *The qualitative report*, vol. 13, no. 4, pp. 544–559, 2008.

[19] G. Kumar, P. Meena, and R. M. Difrancesco, "How do collaborative culture and capability improve sustainability?," *Journal of cleaner production*, vol. 291, p. 125824, 2021.

[20] T. Galpin, J. L. Whitttington, and G. Bell, "Is your sustainability strategy sustainable? creating a culture of sustainability," *Corporate Governance*, vol. 15, no. 1, pp. 1–17, 2015.

[21] C. Boletsis, A. Pultier, and O. Prillard, "The projection mapping situational layer: Tabletop projection mapping for visualisation of real-time geospatial data," in *Proceedings of the 16th International Conference on PErvasive Technologies Related to Assistive Environments*, pp. 245–246, 2023.

[22] C. Boletsis, "The gaia system: A tabletop projection mapping system for raising environmental awareness in islands and coastal areas," in *Proceedings of the 15th International Conference on PErvasive Technologies Related to Assistive Environments*, pp. 50–54, 2022.

[23] D. Chasanidou, J. Krogstie, and C. Boletsis, "Sustainability design in mobile augmented reality," in *Norsk IKT-konferanse for forskning og utdanning*, no. 2, 2023.

[24] C. Boletsis and D. Chasanidou, "Audio augmented reality in public transport for exploring tourist sites," in *Proceedings of the 10th Nordic Conference on Human-Computer Interaction*, pp. 721–725, 2018.

[25] C. Boletsis and D. Chasanidou, "Smart tourism in cities: Exploring urban destinations with audio augmented reality," in *Proceedings of the 11th PErvasive Technologies Related to Assistive Environments Conference*, pp. 515–521, 2018.

[26] C. Becker, S. Betz, R. Chitchyan, L. Duboc, S. M. Easterbrook, B. Penzenstadler, N. Seyff, and C. C. Venters, "Requirements: The key to sustainability," *IEEE Software*, vol. 33, no. 1, pp. 56–65, 2015.

[27] University of Oslo, "Privacy and data protection - for employees," 2024. https://www.uio.no/english/for-employees/support/privacy-dataprotection/index.html, Accessed: Jan. 27, 2024.

[28] Bibliotekutvikling, "Kunstig intelligens i biblioteket – prosjektbank," 2024. https://bibliotekutvikling.no/prosjektbank/prosjekt/kunstig-intelligens-i-biblioteket/, Accessed: Jan. 28, 2024.

[29] N. K. Arora and I. Mishra, "United nations sustainable development goals 2030 and environmental sustainability: race against time," *Environmental Sustainability*, vol. 2, no. 4, pp. 339–342, 2019.

[30] G. A. García-Mireles, M. Á. Moraga, F. García, C. Calero, and M. Piattini, "Interactions between environmental sustainability goals and software product quality: A mapping study," *Information and Software Technology*, vol. 95, pp. 108–129, 2018.

[31] C. C. Venters, R. Capilla, S. Betz, B. Penzenstadler, T. Crick, S. Crouch, E. Y. Nakagawa, C. Becker, and C. Carrillo, "Software sustainability: Research and practice from a software architecture viewpoint," *Journal of Systems and Software*, vol. 138, pp. 174–188, 2018.

[32] S. L. Star and J. R. Griesemer, "Institutional ecology,translations' and boundary objects: Amateurs and professionals in berkeley's museum of vertebrate zoology, 1907-39," *Social studies of science*, vol. 19, no. 3, pp. 387–420, 1989.

[33] D. Nicolini, J. Mengis, and J. Swan, "Understanding the role of objects in cross-disciplinary collaboration," *Organization science*, vol. 23, no. 3, pp. 612–629, 2012.

[34] C. Kimble, C. Grenier, and K. Goglio-Primard, "Innovation and knowledge sharing across professional boundaries: Political interplay between boundary objects and brokers," *International journal of information management*, vol. 30, no. 5, pp. 437–444, 2010.

[35] S. Betz, B. Penzenstadler, L. Duboc, R. Chitchyan, S. A. Kocak, I. Brooks, S. Oyedeji, J. Porras, N. Seyff, and C. C. Venters, "Lessons learned from developing a sustainability awareness framework for software engineering using design science," *ACM Transactions on Software Engineering and Methodology*, 2024.