"It should last long without harming the environment": Perspectives on sustainability in an environmental and historical IT-project

Dimitra Chasanidou[1][0000−0001−9605−1782], Costas Boletsis[2][0000−0003−2741−8127], and John Krogstie[1][0000−0003−4830−1876]

[1] Norwegian University of Science and Technology, 7491 Trondheim, Norway
{dimitra.chasanidou,john.krogstie}@ntnu.no
[2] SINTEF Digital, 0373 Oslo, Norway
konstantinos.boletsis@sintef.no

Abstract. This paper explores the role of sustainability into an environmental and historical IT-supported project, named Gaia Vesterålen. The project utilises spatial AR/projection mapping technology to promote environmental and cultural awareness. We applied a qualitative research approach to explore sustainability aspects of the project. Sustainability Analysis Framework (SusAF) is a widely used approach to sustainability design that revealed issues related to projection mapping technology. The results suggest that sustainability is a multifaceted concept, and the project aims to balance different dimensions of sustainability while delivering engaging, immersive experiences to a diverse museum audience. The complexities of integrating sustainability into technologically driven initiatives are carefully balanced with goals of environmental, social, and economic responsibility. The findings suggest that the Gaia Vesterålen project represents an aspiring attempt to integrate sustainability into a technology-driven exhibition.

Keywords: Augmented Reality · Projection Mapping · Sustainability Awareness Framework · Sustainability Design.

1 Introduction

Cultural heritage tourism sites are considered valuable for future generations, while damage to these sites would cause significant economic, cultural and social loss [11]. In addition, climate change and environmental sustainability require effective environmental awareness and promotion of such behaviour combined with enhanced tourist experiences[4]. Augmented Reality (AR) and its applications are considered one of the most promising immersive approaches to create enhanced, interactive, and unique experiences with the potential to contribute to future competitiveness and sustainability of tourist sites [11]. Immersive technologies offer an innovative approach to cultural and environmental awareness (for example [1]). However, despite increased recognition and a shift in focus toward more sustainable methods to develop and manage cultural heritage tourism, little research has explored sustainability aspects related to spatial AR systems. Sustainability considerations in AR applications can differ from other technologies in several ways. An example is in regard to their environmental impact, as AR applications often require more computational power and energy than traditional computing or mobile devices.

Developers can significantly impact and improve longevity and durability in software development through actions such as prioritising resource conservation, using renewable energy sources, and designing intuitive and culturally sensitive user interfaces while facilitating user needs, preferences, and experiences [20, 12, 19, 5]. At the same time, since spatial AR experiences are commonly accessed through various and quite diverse devices, such as mobile devices, smart glasses, headsets, and projectors, sustainability considerations arise from the manufacturing, life cycle management, and electronic waste aspects of these devices, and since their content delivery and real-time data processing often rely on cloud infrastructure and content delivery networks, the environmental impact of data centers and network infrastructure should also be considered [10].

This paper aims to take the first step towards investigating the sustainability issues of a spatial AR/projection mapping system. To do so, the Sustainability Awareness Framework (SusAF) [13] is applied to a use case of an AR projection mapping system in a museum. The contribution of this work lies in the enrichment of the existing literature on the sustainability issues of a spatial AR system and the application of a sustainability tool (SusAF) to highlight and structure-related sustainability issues.

The paper is organised as follows: Section 2 discusses related work, while in Section 3 the case of the Gaia Vesterålen project, focusing on the technological part, is presented. Section 4 introduces the method, followed by study results in Section 5. The paper ends with concluding remarks and a discussion of future work in Section 6.

2 Related work

As the world increasingly depends on software systems in all domains, the need to make these systems more sustainable has become a priority [15, 24]. Sustainable software engineering refers to the development of efficient and reliable software and the mitigation of negative impacts, such as the environmental footprint [2, 24]. Sustainable practices in this field focus on reducing energy consumption, promoting ethical considerations, and fostering longevity in software systems to ensure that they remain adaptable and resource efficient over time [25]. These practices have been adopted by domains such as AR. The existing literature on sustainability in AR technologies highlights various applications and the associated technological challenges in promoting sustainability [10]. In addition, the role of AR was explored in relation to sustainability contexts, such as to promote sustainable tourism development [11], to encourage users towards environmentally sustainable behaviours [22], and to examine how AR technology affects sustainability education [18] among other studies.

Various approaches have been developed and suggested by researchers to incorporate sustainability into software design. A recent review identified 29 different sustainability design approaches in software engineering [2]. A separate review, focused on social sustainability, compiled a list of recommended tools and practices for software development to take social aspects into account [23]. By integrating such approaches, developers try to ensure that the software is technically sustainable and socially responsible. Some of the most prominent frameworks that have gained attention include SusAF[13, 14], AMDiRE [17], and INSURE/ENSURE[21]. The Sustainability Awareness Framework (SusAF) is one of the most popular approaches in the software engineering literature, particularly to raise awareness among stakeholders about the sustainability impact of software systems [13, 2, 6]. SusAF has been applied in many cases both in industry and academia [16, 9].

Therefore, the existing literature would benefit from investigating the sustainability issues of spatial AR systems through applications of sustainability frameworks. More specifically, projection mapping is a spatial-AR application that is quite popular in cultural contexts and which carries inherent sustainability challenges due to its computational and energy needs and high financial cost of equipment, compared to the field's alternatives (e.g., mobile devices, smart glasses). The sustainability analysis of a cultural projection mapping system would make for an intriguing and, potentially, useful use case for the researchers and practitioners of the field.

3 Case study: The Gaia Vesterålen project

Gaia Vesterålen is an environmental and history project for the Vesterålen area in Sortland (Norway) [7, 8]. The project aims to contribute to the sustainable development of the local area through innovation, research and technological development. In the project, projection mapping technology is used in a museum setting (Sortland Museum) to visualise a 3D model of the Vesterålen district, informing visitors about the history of the area and demonstrate how the environment has changed over the years and how it can change in the future.

The target group of Gaia Vesterålen is 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.

In the Gaia Vesterålen project, tabletop projection mapping technology is implemented 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 (Fig. 1). The described system is called the "Gaia System" and visualises real-time geospatial data, such as sea vessel traffic and fishing facilities (implementing the Projection Mapping Situational Layer [8]), and static/historical data, such as road infrastructure, population settlements, waste

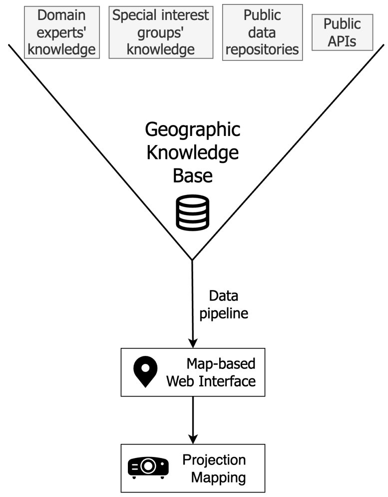

Fig. 1. A high-level description of the Gaia System architecture.

disposal sites, fauna and flora, and others[3]. The Gaia System uses nine 4K projectors that project the content (points, lines, polygons, animations) on a 3D printed physical-scale model of the Vesterålen area (dimensions 265 x 521 cm). The latest version of the Gaia System features multi-user interaction capabilities with different users interacting with the model, at the same time, through three touchscreens that are strategically placed close to the municipalities that comprise the Vesterålen region. That way, users get localised content – depending on the municipality of their vicinity – simultaneously and without visualisations overlapping. The touchscreen user interface, in addition to enabling or disabling projection mapping content, offers additional historical information about the projected content in the form of text, images, and videos.

Central to the project is the concept of sustainability across project objectives while an "environmental contract", that is, 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. However, sustainability, being a holistic practice, is relevant not only to the project goals but also to its content. Ensuring that the artifacts produced in the project, such as the Gaia System, are developed, maintained, and supported in a sustainable way, even after the end of the project, is an essential practice that further advances the project's sustainability value.

4 Method

This paper reports on an exploratory case study design [3]. The case applies an existing requirements engineering framework, named SusAF, in exploring

[3] Gaia System videos: https://xrlab.no/nokobit2024/videos.html

Fig. 2. One of the touchscreens and the physical model of the Gaia System, in the Gaia Vesterålen project.

sustainability issues in AR technology and connections with the museum ecosystem. The study was conducted at the end of 2023 when the technological part of the project was approaching its final development stage. 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.

4.1 Workshop: Applying the Sustainability Awareness Framework

The workshop was arranged as part of the project with the ultimate goal of delineating sustainability issues in relation to the technological system (projection mapping), as well as to envision the development of a sustainable project. Sustainability design takes a holistic perspective of the influential factors in the focal technological system to identify solutions that minimise negative impacts and maximise positive effects. For this purpose, a sustainability tool was applied. SusAF constitutes a popular tool in sustainability design for software products and services [13]. A printed version of the Sustainability Awareness Diagram (SusAD)[13] was used. Participants were informed beforehand about the workshop process and were familiar with the diagram. During the workshop, participants were asked to complete three tasks. First, participants worked on a mapping exercise to discuss sustainability issues in the five dimensions of SusAF. Second, participants worked on classification of identified issues into three levels of effects. Third, relations (chain of effects) within and across dimensions and issues were drawn, highlighting overlaps among issues and dimensions on the radar chart. Table 1 summarises the workshop process.

At the beginning, participants were delegated to five sustainability dimensions to work 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 project. In addition, participants with diverse educational background and project responsibilities that could correspond to the five sustainability dimensions were chosen. Five developers, having expertise in software engineering, user experience, virtual and augmented reality, and programming, participated in the workshop. Supplementary material, such as SusAD printouts, templates for taking notes, pens in different colours, and sticky notes, were used. The workshop lasted two hours, followed by additional discussions and clarifications on the findings. To efficiently manage both the process and the discussions, driving questions were asked. Hereafter, examples of driving questions per dimension are presented:

– **Driving questions on social issues:** How can the technology change the trust between the users and the museum? What effects can it have on users with different backgrounds, age groups, education levels, or other differences?
– **Driving questions on user issues:** What kind of knowledge or physical properties are required to use the technology and how can this affect different types of users? How can the user interface (UI) of the technology be made more accessible? Does technology promote social inclusivity? Is it adaptable to changing user needs?
– **Driving questions on environmental issues:** 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? How can technology affect the need for energy production? What about the use of energy? Does the hardware run on renewable energy?
– **Driving questions on economic issues:** How can technology affect the relationship between the museum and its visitors? How can it enable co-creation or co-destruction of value? How can changes in (parts of) the technology affect the financial situation?
– **Driving questions on technical issues:** How are the operating system and runtime environment expected to change and what does that require from maintainers of this system? What are the vulnerabilities of the system? How can the technology support changes in workload?

4.2 Interviews and Participant observations

After the workshops, individual interviews were conducted to allow the researchers to learn more about the experiences and views of the participants on sustainability, in relation to the identified issues, the technology and the project, as well as experiences with SusAF. Semi-structured interviews were conducted using an interview guide with mainly open-ended questions. The interviews were recorded and lasted around 30-40 minutes each. The verbal transcripts of individual interviews were used as the basis for the coding and analysis of the data. In data analysis, thematic analysis and open coding methods were used. This process helped to 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.

In addition, participant observations complemented the workshop data. In participant observations, an author participated in workshops and documented interactions among participants. Observations were made on communication styles and collaborative efforts to understand sustainability issues related to technological and cultural issues, discussion topics on sustainability issues, use of the tool, and challenges. Observations allowed the researchers to identify emerging patterns in discussions, prioritization, and negotiation of issues according to the process, the dynamics of interaction, and idea development among participants. The involvement of the researchers was instrumental in ensuring the smooth progression of the workshop and in addressing any ambiguities that arose.

5 Results and Discussion

5.1 Defining Sustainability

The results illustrate that projection mapping technology not only serves its purpose in the short-term sustainability, but also needs to be aligned with broader sustainability goals of all dimensions to serve the long-term goals of the project. Sustainability in the context of the Gaia Vesterålen project was broadly defined by interviewees as the commitment to ensure that the project lasts as long as possible over time with minimal harm to different aspects of the environment, society and economy. Sustainability's focus was on making the project accessible and safe for all user types, while minimising environmental impact such as carbon footprint and environmental pollution.

Table 1. SusAF workshop design

Workshop process	**Description**
Introduction	Short introduction of the process, SusAF and role delegation
Task 1: Mapping exercise	Identification of the most relevant sustainability issues in the five dimensions - Individual/ group work
Task 2: Levels of effects	Classification of sustainability issues into the three levels of effects (immediate, enabling and structural effects) - Individual/ group work
Task 3: Chain of effects	Drawing connections among sustainability issues and description of the connections - Group work
Sum-up	Summary, conclusions and next steps
Identified issues	Social issues, Individual issues, Environmental issues, Economic issues, Technical issues
Roles	5 roles - One participant per dimension

"I associate sustainability with sustainable development goals. So in Gaia, I feel sustainability is very much aligned with these goals. We need to focus more on the environment and perhaps also to think about infrastructure, data presentation and such..." Interviewee 1

"Sustainability in the Gaia Vesterålen project means that it should last as long as possible with less harm to the different aspects. Mostly, I think the environment, but it should last long without harming other sustainability goals, defined by United Nations, although not all of them are relevant here." Interviewee 5

The environmental aspect was discussed in the interviews as the main concern, with efforts focused on reducing the carbon footprint of the project through energy-efficient technologies and materials. For example, the project aimed to use low-energy lighting and sustainable materials, ensuring that its operational and maintenance phases would have minimal negative impact on the environment. However, these definitions of sustainability go beyond environmental concerns by embracing a holistic approach that includes other aspects of the SDGs.

In addition, social equity and economic viability were discussed during workshops and interviews. Social sustainability was a key dimension of the project in terms of inclusion and accessibility. The project aimed to create an inclusive environment in which all visitors, regardless of physical ability or background, could engage with the project content in the museum. The interviewees emphasised the importance of accessibility, ensuring that the project should be enjoyed by all visitors, including those with disabilities. This involved considerations of physical accessibility features, such as audio settings and tactile elements, as well as the creation of inclusive content that would resonate with a diverse audience. Social sustainability was extended to engage the local community, ensuring that

Fig. 3. Workshop results with SusAF in the Gaia Vesterålen project. The participants identified and classified issues into three levels of effects.

the project not only served tourists, but also enriched the lives of local residents by highlighting cultural heritage and promoting environmental awareness.

Economic sustainability, while considered slightly less critical than environmental and social aspects, was nonetheless important. The project was designed to be financially viable in the long term, considering cost-effective maintenance and potential revenue streams, such as the reuse of the equipment and educational programs. The economic dimension also included considering how the project could contribute to the local economy by attracting visitors and promoting local businesses. The sustainability approach of the project appears to be multifaceted, aiming to balance environmental preservation, social inclusion, and economic viability in a way that would ensure the longevity and relevance of the project.

5.2 Sustainability dimensions

The project aimed to reduce its environmental footprint by incorporating energy-efficient technologies, such as LED lighting and low-power audio systems, and using sustainable materials in its construction. This focus on environmental sustainability was not only on minimising harm to the environment but also on educating the public on environmental issues. Education on climate change and conservation, through the content and design of the project, constitutes a long-term goal. Although interviews identified environmental sustainability as the most critical dimension for the Gaia Vesterålen project, other sustainability aspects have a direct impact on the overall sustainability of the project. Specifically, the main issues related to the technology and beyond are discussed as follows:

- **Environmental Sustainability:** The use of projection mapping technology was highlighted as a tool to raise awareness about environmental issues, such as sea-level rise and temperature changes. This was done by projecting visual data that show the effects of these environmental challenges in real time or future projections, making the impact more tangible and engaging for the audience. The main discussion focused on how sustainable practices could be integrated into the technological infrastructure, such as using renewable energy sources for equipment and ensuring that the projection mapping system itself has a minimal environmental footprint.
- **Social Sustainability:** The social aspects of sustainability were considered in terms of community involvement and education. The project aimed to engage local communities using technology to visualise their cultural heritage, thus strengthening community identity and encouraging a deeper connection to the local community. The importance of making the technology accessible to all visitors, including those with disabilities, was mentioned, ensuring that the educational benefits are inclusive.
- **Economic Sustainability:** This dimension was addressed in terms of the long-term viability of the projection mapping system. This includes considerations such as the cost of maintaining the system, the potential to reuse or sell old equipment, and the economic benefits that the system could bring

to museums by attracting more visitors or by being adaptable for use in other contexts, such as schools. The discussion also covered how economic benefits could be maximised by promoting the system as a product for other institutions, thereby creating a new revenue stream.

- **Technical Sustainability:** This relates to concerns about the adaptability and maintenance of the projection mapping system. Issues such as the longevity of the equipment, the energy efficiency of the high-resolution projectors, and the potential for system failures due to environmental factors such as temperature changes were debated. The importance of creating a flexible and modular system that could be easily updated or repaired by the technical support team in the future was emphasised as crucial to the long-term sustainability of the project.

5.3 The role of technology in achieving sustainability goals

Technology played a central role in the Gaia Vesterålen project, particularly in achieving its sustainability goals in environmental, social, and economic dimensions. The use of advanced technologies allowed the project to reduce its environmental impact, improve accessibility, and create an engaging and educational experience for visitors. The interview participants believe that key technological components of the project include energy-efficient lighting, projection systems, and interactive digital displays. These technologies were selected not only for their ability to deliver high-quality visual and auditory experiences, but also for their low energy consumption and minimal environmental footprint.

One of the primary ways technology contributed to sustainability in the Gaia Vesterålen project was through the use of energy efficient equipment. LED lighting and low-power projectors were used to create immersive visual experiences while minimising electricity use. This was critical to reducing the overall carbon footprint of the project and aligning with the larger environmental goals of sustainability. Additionally, the use of digital technologies allowed the creation of dynamic content that could be easily updated or modified without the need for significant physical resources, further reducing waste. In social sustainability, technology played an important role in making the project more accessible and inclusive. Interactive digital displays and assistive technologies were implemented to ensure that the content is accessible to all visitors, including those with disabilities. Typically, museum visitors are a diverse audience group, and interactive digital displays allow for the creation of an inclusive environment where visitors could engage with the museum content, thus promoting social equity and broadening the impact of the project.

5.4 Metrics and indicators for measuring sustainability

Measurement of the sustainability of the Gaia Vesterålen project requires the development of specific metrics and indicators that could assess significant aspects of environmental, social and economic impacts. One of the key metrics discussed in the interviews was energy consumption, particularly in relation to the lighting and audio systems of the project. By monitoring energy use, the project team could assess the efficiency of their technologies and identify areas for improvement. This metric was particularly important to ensure that the project minimised its carbon footprint and aligned with broader environmental goals.

"I think in energy usage we apply metrics. In Norway, especially in the north, electricity and energy is low in CO2. But still it's good to think about it when you buy for instance a new computer. There's a lot of things that you need to consider and measure, but it's difficult in practice. For me, metrics in the environmental impact in terms of energy use and waste management." Interviewee 3

Another important metric was the carbon footprint of the materials and processes applied in the development and operation of the project. This included evaluating the environmental impact of sourcing, transporting, and installing materials, as well as the ongoing emissions associated with the maintenance of the project. By tracking these metrics, the project team could identify opportunities to reduce emissions and adopt more sustainable practices.

User feedback was also highlighted as a critical indicator. This included collecting data on visitor satisfaction, accessibility, and inclusion to ensure that the project met the needs of a diverse audience. User feedback with disabilities, in particular, was essential for evaluating the effectiveness of accessibility features. Economic metrics, such as cost effectiveness and revenue generation, were also important in evaluating financial sustainability. These metrics were discussed as significant in ensuring project viability and could provide value to the community in the long term.

5.5 Challenges and ethical considerations

Challenges and ethical considerations play a critical role in shaping the ability of the project to achieve its sustainability goals. Although technology and resource limitations pose practical obstacles, ethical concerns about privacy, transparency, and sharing of knowledge create deeper moral questions about the project's approach. On the one hand, the project faces several key challenges in three dimensions. In terms of environmental aspect, AR and projection mapping technologies, while effective for immersive experiences, are resource-intensive technologies. The project team should find a way to navigate among the complexities of reducing energy consumption during the development and operational phases. In addition, balancing technological innovation with sustainability goals is not without challenges, since these innovations often require significant energy consumption, which could lead to a higher carbon footprint. Related challenges in regards with technology lifecycle were discussed, as responsible disposal or recycling of outdated technology, as well as upgrading systems with minimal waste, needs to be planned.

In terms of social aspect, designing the project space and content in a way that is universally accessible requires additional resources and planning. Technological innovation could add an additional layer of challenges in achieving social sustainability. Ensuring that all visitors can fully engage with the project, regardless of their physical abilities or background, can sometimes conflict with other sustainability objectives, such as minimising resource use.

However, related ethical considerations were discussed in relation to the sustainability goals of the project. Privacy concerns were discussed as an important ethical consideration, particularly in connection to the data used in the project. The project involved data collection and processing to improve the visitor experience to evaluate the impact of the project. This raised questions about how data would be collected, stored, and used and whether visitors would be adequately informed about these processes. Therefore, it was suggested that the project team need to ensure responsible data collection practices to protect visitors' privacy.

Another ethical issue relates to the contradictory messages about sustainability. Study participants debated whether the project promotes sustainability while failing to adhere to sustainable practices in its design, development, and/or implementation. For example, if certain materials or technologies were not as sustainable as the project team would have liked, they needed to communicate this openly and explain their decision-making process. Therefore, it was suggested that the project team should make a lot of effort to ensure that their practices are aligned with their sustainability goals and to communicate any challenges or compromises they face. Lastly, the economical aspect is related to technology. Although sustainable technologies and practices often lead to long-term savings, they require a significant initial investment. AR and projection mapping technologies are known as expensive technology. Balancing the costs of sustainable materials and technologies with the need to remain economically viable is a debated challenge for the project team.

Furthermore, the ethical responsibility to share the technology and findings of the Gaia Vester ålen project with other museums and stakeholders was highlighted as important. The sharing of knowledge was seen as a way to maximise the positive impact of the project and to contribute to the global/national sustainability movement. The suggestion here relates to the dissemination of their knowledge and experiences in various communities and to support other institutions' efforts to adopt sustainable practices. Lastly, during the interviews, ethical considerations highlighted the importance of transparency, responsibility, and collaboration in achieving the sustainability goals of the project.

6 Conclusion

The Gaia Vesterålen project represents an aspiring attempt to integrate sustainability into a technology-driven exhibition, combining AR and projection mapping to enhance cultural and environmental education. Technology plays a key role in the promotion of sustainability in the Gaia Vesterålen project through user engagement and educational experiences. Tools such as AR and projection mapping offer immersive learning opportunities and present flexible ways to update content, reducing the need for physical materials and minimising waste.

Furthermore, the use of energy-efficient technologies, such as LED lighting and low-power projection systems, aligns with the project's sustainability objectives by reducing its overall energy consumption.

The project offers several avenues for future development and research. First, exploring resource alternatives, for example, use of renewable energy sources, such as solar power, to offset the energy consumption of AR and projection mapping technologies. In addition, continued advances in energy-efficient hardware and software design could further reduce the environmental impact of such installations. Another promising direction is the development of more comprehensive sustainability metrics to assess the project's impact. In conclusion, while the project achieved notable success in promoting sustainability through innovative technologies, it also highlighted the complex challenges inherent in balancing environmental, social, and economic considerations. Continuing, future projects can build on the achievements of the Gaia Vesterålen project, fostering a more sustainable approach to technology-driven educational and cultural initiatives.

Acknowledgements

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.

References

1. Alrowaily, M.A., Kavakli, M.: Mobile augmented reality for environmental awareness: A technology acceptance study. In: Proc. of ICCAE. pp. 36–43 (2018)
2. Bambazek, P., Groher, I., Seyff, N.: Requirements engineering for sustainable software systems: a systematic mapping study. Requir. Eng. pp. 1–25 (2023)
3. Baxter, P., Jack, S., et al.: Qualitative case study methodology: Study design and implementation for novice researchers. Qual. Rep. **13**(4), 544–559 (2008)
4. Bec, A., Moyle, B., Schaffer, V., et al.: Virtual reality and mixed reality for second chance tourism. Tour. Manag. **83**, 104256 (2021)
5. Becker, C., Betz, S., Chitchyan, R., et al.: Requirements: The key to sustainability. IEEE Softw. **33**(1), 56–65 (2015)
6. Betz, S., Penzenstadler, B., Duboc, L., et al.: Lessons learned from developing a sustainability awareness framework for software engineering using design science. ACM Trans. Softw. Eng. Methodol. **33**(5), 1–39 (2024)
7. Boletsis, C.: The Gaia System: A Tabletop Projection Mapping System for Raising Environmental Awareness in Islands and Coastal Areas. In: Proc. of PETRA. pp. 50–54 (2022)
8. Boletsis, C., Pultier, A., Prillard, O.: The projection mapping situational layer: Tabletop projection mapping for visualisation of real-time geospatial data. In: Proc. of PETRA. pp. 245–246 (2023)
9. Chasanidou, D., Krogstie, J., Boletsis, C., et al.: Sustainability design in industry and academia. In: Proc. of ICT4S. vol. to appear, pp. 1–10 (2024)

10. Chasanidou, D., Krogstie, J., Boletsis, C.: Sustainability design in mobile augmented reality. NIKT **2**, 1–15 (2023)
11. Cranmer, E.E., Tom Dieck, M., Jung, T.: The role of augmented reality for sustainable development: Evidence from cultural heritage tourism. Tour. Manag. Perspect. **49**, 101196 (2023)
12. Dick, M., Naumann, S.: Enhancing software engineering processes towards sustainable software product design. In: Proc. of EnviroInfo. pp. 706–715 (2010)
13. Duboc, L., Betz, S., Penzenstadler, B., et al.: Do we really know what we are building? raising awareness of potential sustainability effects of software systems in requirements engineering. In: Proc. of IEEE RE. pp. 6–16 (2019)
14. Duboc, L., Penzenstadler, B., Porras, J., et al.: Requirements engineering for sustainability: an awareness framework for designing software systems for a better tomorrow. Requir. Eng. **25**, 469–492 (2020)
15. Heldal, R., Nguyen, N.T., Moreira, A., et al.: Sustainability competencies and skills in software engineering: An industry perspective. J. Syst. Softw. **211**, 111978 (2024)
16. Krogstie, J.R., Chasanidou, D., Krogstie, B.: Social sustainability by design: Experiences with the sustainable awareness framework. In: REFSQ Workshops (2024)
17. Méndez Fernández, D., Penzenstadler, B.: Artefact-based requirements engineering: the amdire approach. Requir. Eng. **20**, 405–434 (2015)
18. Negi, S.K.: Exploring the impact of virtual reality and augmented reality technologies in sustainability education on green energy and sustainability behavioral change: A qualitative analysis. Procedia Comput. Sci. **236**, 550–557 (2024)
19. Oyedeji, S., Seffah, A., Penzenstadler, B.: A catalogue supporting software sustainability design. Sustainability **10**(7), 2296 (2018)
20. Rashid, N., Khan, S.U.: Agile practices for global software development vendors in the development of green and sustainable software. J. Softw. Evol. Process. **30**(10), e1964 (2018)
21. Saputri, T.R.D., Lee, S.W.: Integrated framework for incorporating sustainability design in software engineering life-cycle: An empirical study. Inf. Softw. Technol. **129**, 106407 (2021)
22. Sitompul, T.A., Wallmyr, M.: Augmented reality for encouraging environmentally sustainable behaviors: a survey. In: Proc. of ILA (2018)
23. Moises de Souza, A.C., Soares Cruzes, D., Jaccheri, L., et al.: Social sustainability approaches for software development: A systematic literature review. In: Proc. of PROFES. pp. 478–494. Springer (2023)
24. Venters, C.C., Capilla, R., Betz, S., et al.: Software sustainability: Research and practice from a software architecture viewpoint. J. Syst. Softw. **138**, 174–188 (2018)
25. Venters, C.C., Capilla, R., Nakagawa, E.Y., et al.: Sustainable software engineering: Reflections on advances in research and practice. Inf. Softw. Technol. p. 107316 (2023)