SustHack: A hackathon approach for engaging citizens and fostering a sustainability mindset

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Abstract

Hackathons and code camps have been used over the years to ideate, collaborate and develop innovative solutions to address sustainability challenges with citizens. However, there is less research on how hackathon products can drive citizens' behavioral changes via engagement in sustainable activities to improve sustainability awareness in society. In this study, we evaluate the potential of the hackathon to address local sustainability issues and develop innovative solutions to engage and stimulate citizens and hackathon participants for sustainable activities and awareness. Our approach involves the implementation of two hackathons, Living Lab Hack and SustHack. The result from the two hackathons shows that citizen engagement in hackathons brings a new dimension that facilitates inclusiveness in designing sustainability solutions and increases citizen sustainability awareness. Furthermore, the hackathon served as a reawakening call to action for the students and the citizens about the sustainability impacts of their activities.

Keywords

sustainability, local actions, hackathons, code camp, citizens' engagement

1. Introduction

Sustainability is a critical issue that impacts every aspect of our lives and the planet across various dimensions, covering environmental, social, and economic challenges. It is a complex issue that must be addressed to create a sustainable future. Becker et al. [1], through the Karlskrona Manifesto for Sustainability Design, described sustainability as a systemic concept and a conceptual framework built on five dimensions: the environmental, the economic, the technical, the social, and the individual dimensions. Addressing the challenges associated with each dimension calls for collective input from academicians, organizations, policymakers, and individuals. In addition, engaging and inspiring the next generation of leaders in sustainability is essential as part of the efforts to save the environment and mitigate the climate crisis. Higher education institutes (HEIs) are well-positioned to champion creative solutions that consolidate skills and competencies that address many sustainability issues like sustainable mobility choices, sustainable consumption, and sustainable lifestyles. However, engaging higher education students in sustainability issues, creating awareness, and stimulating their interest in sustainability can be challenging for academicians [2].

Although hackathons and code camps have existed over the years [3], especially in software engineering [4], [5], and have further become a practical and intensive approach to demonstrating fundamental practical skills and solving real-world problems with different objectives [6] and for encouraging innovation and collaboration, active learning, and creative thinking among diverse participants in various fields in an equally

supportive setting [7], [8]. Hackathons can have a different topical focus and domains, for example, to accelerate new scientific discoveries, collaboration, enriching social networks, and knowledge transfer [5], [9]; to improve education and strengthen curricula [6]. Furthermore, hackathons can focus on developing new digital solutions and business models to drive sustainable actions, circularity, and environmentally friendly initiatives [8], [10], [11]. Alternatively, the goal could be to develop civic digital interventions and design effective sustainability plans [12], to coproduce improved knowledge, and navigate complex climate adaptation governance [13].

Hackathons offer fast-paced, design-driven, and practical events where participants transform ideas into solutions for a specific problem or challenge, typically within a particular time frame [7]. It is a popular means of producing innovative prototypes and creative product ideas that extend impact beyond product innovation [5]. However, their potential to stimulate students' interest in sustainability and engage citizens in climate actions has not been fully harnessed. With the triple planetary crisis (climate change, pollution, and biodiversity loss) and its associated threat, there is a need to intensify actual actions to identify real-life issues at the community level while leveraging technology for environmental benefits. Hence, our study aims to fill this gap through sustainability-focused hackathons that include the engagement of citizens in sustainability actions to solve real-life environmental challenges and strengthening the UN's call for a 'Decade of Action'[14], particularly at the local and individual levels, raising awareness within communities to promote environmentally conscious behaviors.

Our study ignites a call to action to address local sustainability issues and highlight the perceived impacts of engaging citizens in sustainable activities through prototype design. Specifically, this study answers the following research questions.

- RQ1 How can hackathons be used to engage citizens and foster a sustainability mindset in their local environment?
- RQ2 What are the perceived impacts of such engagement among citizens and hackathon participants?

2. Background
2.1. Sustainability education in IT

Emphasizing sustainability education is essential to raise awareness and drive sustainable behavioral changes among academia, business organizations, government, and society to guarantee a more sustainable future. However, while many Higher education institutes (HEIs) continue to integrate sustainability teachings into their curriculum, the specific focus on IT sustainability courses is limited. For example, Genovese and Genovese [15] identified HEIs role in empowering young students to the awareness of environmental challenges. The study proposed integrating new values and skills that will trigger behavioral changes and facilitate a sustainable society through academic learning, to close the gap between student awareness and proactive environmental behavior. As a result, the young generations have been identified as beneficiaries of sustainable development goals and saddled with responsible behavior to safeguard the environment by maintaining a sustainable lifestyle [16], [17]. Therefore, every HEIs must be committed to equipping their students with such skills and values to awaken their environmental consciousness and increase their sustainability engagement. Such sustainability awareness embedded into IT learning can empower the students to develop innovative solutions triggered by the peculiarity of sustainability issues in their immediate Community and simultaneously bring about an opportunity to discuss sustainability activities among the residents.

2.2. Sustainability cultures

Lappeenranta is widely known for its sustainability culture and being among the Greenest cities in Europe and won the European Green Leaf Award 2021 [18]. In addition, the two Universities involved in this project are at the forefront of championing sustainability actions and sustainable education in their respective communities. Using hackathon events to tackle local sustainability issues is, therefore, culturally and academically aligned with the goals of the participating universities. Cultural diversity in sustainability is a binding force that shapes human perception, understanding, behavior, and relationship with evolving environmental reality [19], [20].

Recognizing the importance of Culture in human decision-making and sustainability can bring the economic, social, and environmental aspects closer [19]. Therefore, hackathons can leverage cultural diversity's crucial role in team composition, ideating, and solution development to bring a multicultural experience and background to finding solutions to local environmental issues.

2.3. Sustainability hackathons

Hackathons are implemented to drive innovative, practical solutions in different formats and structures, participation criteria, and intended outcomes. Unfortunately, research that combines sustainability, citizen engagement, and hackathons is limited. Nevertheless, we found a few studies that have explored the potential of hackathons as a tool for promoting sustainability. For example, Zapico et al. [21] use the concept of a green hackathon event to bring end users (in ad-hoc) and technical experts together to discuss sustainability issues and encourage more reflective practices. The result shows that a mix of competencies (technical, communication, design, creativity, programmers, and non-programmers) facilitates interdisciplinary collaboration and helps to promote sustainability. A related study conducted as an innovation contest to foster civic engagement and citizens' participation [22] led to a reawakening of citizens' and other stakeholders' awareness and involvement in tackling environmental challenges.

Furthermore, a study on citizen empowerment with civic technologies [23] uses hackathons to connect citizens and empower them to embrace broader community participation. The result is an increase in the involvement of the local neighborhood that brings diversity in evaluating the prototype solution in addition to the expert evaluation. A related study by Taylor et al. [24] uses a gamified hackathon to tackle the socio-environmental problems of residual and discarded items. The result found that hackathons offer a robust means of awakening the consciousness of sustainability issues and promoting cross-disciplinary collaboration and creativity that students are unlikely to experience under a traditional curriculum. Finally, the hackathon has been identified as an innovative strategy to foster collaboration between academia and corporate organizations [11] to drive sustainability, circularity, and lower environmental impact with technology solutions.

A study by Szymanska et al. [25] revealed how hackathons provide opportunities for students to explore, learn, and apply new, cutting-edge technologies and trends, allowing instructors to adapt to the student's needs and provide guidance rather than simply lecturing. This approach also allows the introduction of real-world scenarios and environmental issues that can be tested with new technological solutions.

There is still room to explore the suitability of hackathons in the sustainability and citizen engagement domains to deliver on the critical value of promoting sustainability awareness, offering innovative fast-track solutions, and providing support for enhancing citizens' engagement. Nevertheless, this study contributed to novel knowledge of exploring the capability of hackathons to drive and foster a sustainability mindset and engage citizens for sustainable lifestyles and behavioral changes.

3. SustHack methodology

The approach involves the implementation of two hackathons - The Living Lab and SustHack, organized as part of the project titled 'Synchronizing sustainable development actions between Finland and Malaysia - the Hackathon approach.' The project connected two universities with a strong sustainability focus: LUT University in Finland and Sunway University in Malaysia. The project aimed to develop sustainability education in both countries through hackathons to solve real, local challenges while engaging the citizens. This paper focuses on two hackathons delivered in Finland.

3.1. Living Lab hackathon

The Living Lab hack was a five-day local hackathon (between 25th April and 29th April 2022). The first in the series to find solutions to empower citizens and business owners for the common good. The participants were required to develop actionable solutions or services in the form of a prototype of innovative ideas that ensure the engagement of various stakeholders. While the theme is tagged "Local Sustainability Issue," each team was tasked to conduct a preliminary assessment by meeting with small business owners (SMEs), targeted customers, and general citizens within their immediate environment (the

University and the Community) for interactions to identify local sustainability issues. The identified local issues are then presented for review, adoption, and initial feedback from the organizers. Finally, each team developed a suitable prototype solution to tackle the challenges identified. There were three participating teams consisting of four members each. The best two teams qualify for the final SustHack (Engagement hackathon). The prototype is enhanced, tested, and the approach is discussed in a real-time environment by engaging the relevant stakeholders (citizens and business owners) in partnership with the visiting Malaysian students.

All the participating members in this phase are M.Sc students of Software Engineering (SE) at LUT University, Finland, with varying prior hackathon experiences and a strong interest in sustainability education. The demography details of the participants are in Table 1.

Table 1

Living lab hack participating team

Team	Gender	Background	Hackathon experience	Cultural diversity	Role distribution
Titan	1M x 3F	SE	Yes = 4	Asian and African	Project manager, Req. Engineer, Full stack developer, UI Designer
Binary	3M x 1F	SE	Yes = 3 No = 1	Asian, African, and European	Product manager, Req. Engineer, Front-end developer, Back-end developer
SustMine	2M x 2F	SE	Yes = 1 No = 3	Asian, African, and European	Req. Engineer, Product manager, Full stack developer, Designer

The juries were from LUT University, Finland, and Sunway University, Malaysia, with expertise in software engineering, sustainability, citizen engagement, and digital innovation. Table 2 details the jury's research interest distribution.

Table 2

Living lab and SustHack jury

Number of juries	Research Interest
3	Software sustainability, Requirement engineering.
2	Ubiquitous computing sustainability, persuasive tech, citizens' engagement.
3	GreenIT, Sustainability, Digital innovation.

The solutions were evaluated on six focus areas: (1) sustainability issues; (2) technically implementable; (3) innovation; (4) citizen focus; (5) economic viability; and (6) pitching of the solution. At the end of the presentations and evaluation, Team Titan and Team BinaryBin emerged as the best two winning teams, and Team SustMine 2nd runner-up, respectively.

3.2. SustHack Hackathon

Unlike the traditional hackathons reported in the literature, we adopted a robust citizen engagement approach in the SustHack supported by a sustainable action-oriented that goes beyond the technical aspect of problem-solving to include users' validation to spur climate actions. The SustHack hackathon was held in a five-day (between 23rd May and 27th May 2022) intensive event at LUT University, Finland, to take the winning solutions from the best two teams of the Living Lab hackathon (Teams Titan and BinaryBin) to the public and engage with relevant stakeholders. In addition, two additional members from Sunway University, Malaysia, with computer science (CE) and Artificial intelligence (AI) backgrounds, joined the teams to make the group a six-members each. This addition improved the teams' diversity and perspectives as they went head-to-head to perfect their solutions and engage with the citizens.

The SustHack Hackathon phase was used to enhance and work more on the solutions and includes technical implementation of the sustainability solutions with a citizens' engagement and validation approach that covers direct engagement with targeted stakeholders to receive feedback and validate the suitability and value of the proposed solutions to solving the sustainability issues that was identified and discussed in the first phase. Table 3 provides information about the SustHack participant's distributions.

Table 3
SustHack participating team

Team	Gender distribution	Background	Hackathon experience	Education level	Role distribution
Titan	3M x 3F	SE = 4 CS =2	5 Yes 1 No	5 master's students 1 bachelor student	Project manager, Req. Engineer, Full stack developer, UI/UX Designer
Binary	5M x 1F	SE =4 CS =1 AI =1	4 Yes 2 No	5 master's students 1 bachelor student	Product manager, Req. Engineer, Front-end developer, Back-end developer

The SustHack approach (see Figure 1) covered the following vital aspects; planning, presentations, further brainstorming on the sustainability issues, ideation and design, codings and implementation, market research and citizen engagement, pitching, and jury evaluation. In addition, the mentorship was provided by a group of 6 Ph.D. students throughout the hackathons processes. Figure 1 provides an overview of the SustHack process.

two products to the local Community. In addition, adequate time was allocated for debriefing sessions to evaluate sustainability ideas, engagement approach, patterns of teamwork, and an implementation plan for turning the winning solutions into actual projects that will last beyond the participants.

Data were collected through surveys, interviews, and observation methods.
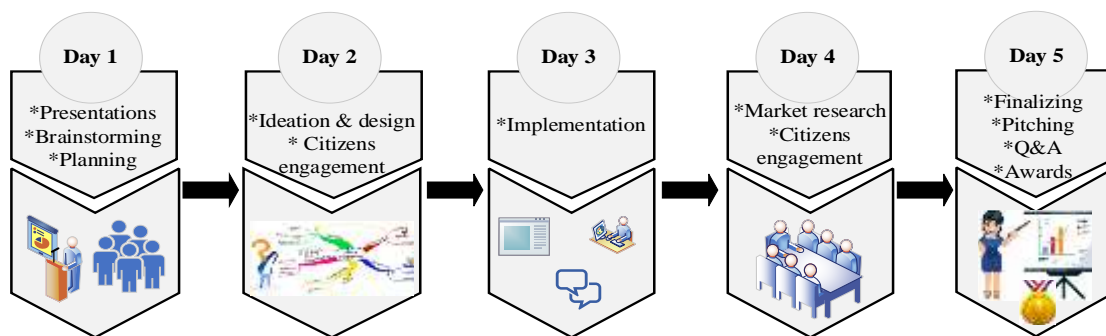
Figure 1: Phases of the SustHack Hackathon

3.3. Resources and data collection

The LUT University's Linux Lab provides the participants with all the tools and resources for ideating, designing, implementing, and presenting their ideas throughout the hackathons. The first hackathon was organized following the methodology reported by Happonen et al. [26] and covered the pre-hackathon, hackathon, and post-hackathon stages. However, we modified the pre-hackathon stage to include 'initial engagement' with citizens on sustainability issues. Furthermore, we introduced a new approach in the second phase of the hackathon, wherein the two winning teams considered the business feasibility and actual engagement with the citizens to capture their feedback and validate the relevancy of the

- Surveys: The team conducted a random stakeholder engagement survey before the Living Lab hackathon and a validated survey with their proposed solutions for the SustHack hackathon. The approach allowed the teams to identify a suitable method to engage their targeted users and highlight the proposed solution's suitability for the identified sustainability issues.

The survey participants include SMEs and citizens. They were recruited in two stages. First, by random approach within the University and the city area and asking questions about their understanding of sustainability, their businesses, challenges, suggestions, customer experience, reality, expectations, background, and willingness to test and review the proposed solution in the

second phase. The outcome of the engagement survey was used to arrive at the decisions on which issues to address and which stakeholder groups to engage further in the later part of the hackathon.

Secondly, the stakeholders willing to participate in the second phase were approached with a prototype solution developed in the SustHack stage for evaluation and feedback. Finally, new and interested participants (likely end users) were also included to test and answer a short survey about the developed prototype.

- Interview: We interviewed all the participants from both Living Lab and SustHack hackathons (16 in total) following the completion of the hackathon to gather in-depth information about participants' experiences, perceptions, challenges, engagement approach, and learning outcomes. The interview protocol included questions about participants' motivations for the hackathon, perceptions of the event organizations, challenges, areas of improvement, skills used and newly developed, and general feedback.
- Observation: We observed both hackathon events to gather data on the team selection and organization, design and implementation, participants' interactions, and collaborative activities during the event to balance the response from interviewing.

The teams presented their findings from the engagement activities and survey conducted as part of their solution presentations on the fifth day. The findings from the engagement stage are discussed in section 5, respectively. We employ the narrative analysis method and guidelines [27] to uncover and interpret the nature of the participant's experiences and challenges. Through this method, we built on each participant's story and behavior to arrive at generalizations of thoughts and meanings from the interview conducted for the participants.

4. Result

The result presentation is based on the information from the team's presentations, their pre-hackathon and hackathon engagement surveys, and the post-hackathon interview and observations conducted by the researchers. Even though an international traveling prize was attached to the winning solution, all the teams cordially conducted themselves. They demonstrated their knowledge of sustainability education accordingly in a friendly mood throughout the event. Furthermore, good collaboration in and across the teams without negative competing behavior was observed as the team used their dedicated writing boards to ideate and collaborate. For example, we observed how Team BinaryBin openly requested the integration of an API key at a point from the Tarvary Team, which was gladly provided.

4.1. Participants' motivation

We asked the teams about their motivation for participating in the event, and their responses showed a voluntary interest, building on previous experience, interest in solving common sustainability issues, eagerness to experience new learning, and eyes on the final prize. The summary of the keywords of their response was presented in Figure 2 as a word cloud.

Figure 2: Participants' motivation

4.2. Impact on participants' skills

From the participant's responses concerning the perceived improved skills during the event, the two hackathons revealed the essential skills, competencies, and current knowledge of sustainability that helped each team navigate the events' entire processes. The most cited improved skills identified from their verbatim responses during the interview include communication, teamwork, technical competency, stress management, knowledge of sustainability, and project management.

The participants also reported that the hackathon was an engaging and stimulating experience that helped them think critically about sustainability issues, gain new skills, develop innovative solutions, improve self-confidence and consider various approaches to engaging their

targeted users. The findings align with previous authors' work [9] on student, technology, and civic action hackathons.

4.3. Citizens' engagement strategy

Participants relied on the first briefing of the event organizer, their understanding of previously completed sustainability courses, and their team's communication skills to recruit their targeted citizens and formulate an engagement strategy to be adopted. The fact that the LUT University community is mainly known for its strong commitment to promoting sustainability within and outside the University empowered the targeted group within the community with a reasonable understanding of sustainability. There is evidence of many sustainability activities and calls to action in and around the University campus. The participants reported dividing their coverage area into 3: the University community, Prisma and its environs, and the City Centre. The engagement strategy is grouped into five (education and communication; empowerment; calls to action; ownership; and feedback); the description is presented in Table 4.

Table 4

Engagement approaches and strategies

Approaches	Description	Outcome
Education and communication	Discuss and understand challenges, supported with credible evidence and narration.	Reimagining sustainability issues that were previously neglected.
Empowerment	Provide platform and alternative options to ensure participation in addressing common needs.	Empowering citizens to champion sustainable behavioral changes.
Calls to action	Provide a clear, attractive, and well-communicated call to action to trigger a sustainable behavioral change.	Broadening community participation, inclusiveness, and ownership.
Ownership	Highlight the importance of taking ownership and commitment to a sustainable environment.	Demonstrations of sustainability knowledge and community support.
Feedback	Feedback system that shows the impact of one's action and promotes positive reinforcement for behavioral changes.	Continuous feedback and reminders about the impact of one's actions on the environment.

Some existing calls to action and sustainable activity points identified within the University community and the city include waste drop points, waste separation guides, plastics and bottles recycling points, sustainable food consumption points, e-biking spots, bicycle lanes, public transport adverts, sustainable energy usage, and second-hand shops in different locations. Starting from the University, the teams reach out to the SME owners on campus, their customers, university staff, and students. This was followed by Prisma and City center area, where random SME owners and citizens were engaged. An excerpt from the teams is quoted below:

"The first stage started with the discussion on their awareness and experience about University's sustainable activities. The discussion opened up new ideas and challenges. However, most new students and staff (especially Non-EU) express low knowledge about sustainable activities… The same approach was used at the Prisma area and the City center".

4.4. Hackathon solutions

Three prototype solutions emerged from the LivingLab to the SustHack hackathons. However, only the best two prototypes made it to the SustHack, where the winner emerged. The overall winner demonstrated the best engagement plan, reached out to the highest number of citizens, and presented the most convincing pitch with their prototype app (TarvaryMoves) that focuses on the engagement of the SMEs to promote the sustainable movement of goods and facilitate citizens' commitment to reducing CO_2 emissions, encourage social engagement and interaction, and boost sharing economy. The developed solutions promise not just to save the environment but also to contribute to the socio-economic empowerment of citizens and instigate individual actions toward achieving sustainable lifestyles. The description and ranking of each team's solution are presented in Table 5.

Table 5
Hackathon solutions and ranking

Team	Value proposition	Sustainability dimension	Living lab (1st hackathon)	SustHack Hackathon (2nd hackathon)
Titan	**TarvaryMoves** - commuting of goods, - CO_2 emission - social engagement and interaction - sharing economy	Environmental, social, economic, and individual	**Winner** Local issue Potential for start-up and mentorship	**Winner** Best engagement plan Number of citizens engaged (87) Excellent business plan *To participate in the #SustFood Hackathon in Malaysia.*
Binary	**NeatPoll** - online survey - data analytics - reduced paper - timely decision	Environmental, social, economic, and individual	**1st runner-up** Local issue Potential for start-up mentoring	First runner-up Number of citizens engaged (70) *To participate in the Slush start-up event*
SustMine	**ShopDock** - online SMEs for recycled products - facilitate reuse, reduce, and recycle	Environmental, social, economic, and individual	**2nd runner-up** Local issue Potential for start-up and mentorship	

5. Discussion and findings

5.1. Pre-hackathon

The cooperation of all the participants in abiding by the rules and following the instructions is commendable. In addition, their common educational background aided the participants' team formation. Quoting from the teams.

"Actually, we have all worked together as a group previously in the Software Architecture course during our time in Italy. We all had experience participating in hackathons before now, and we consider this event an opportunity to demonstrate our understanding of courses on sustainability to solve real-life sustainability issues in our immediate environment". - Titan Team

"We have some coding activities we do as we just code together. We shared a common interest in coding previously, and when the hackathons came up, we all embraced it and decided to work together again" - Binary Team

"Three of us have never participated in a hackathon before, and we are very excited about participating in this one" – SustMine Team

We discovered that all the participants were motivated by the ultimate prize of international traveling and competition. They were also motivated to demonstrate their understanding of sustainability-related courses and previous experiences and learn new ones, working as a team to build products and services to reawake civic actions for sustainability among the citizens and do something good for the community.

5.2. Hackathon

- Skills and collaboration: The event helped the participants to demonstrate several skills and competencies more practically. It also improved soft and hard skills, as the organizers emphasized this through several short presentations and mentorship. The teams were allowed to seek assistance from each other and were gladly provided. The participant also appreciated the importance of short punctuation during the event, as it helps to ensure feedback, mentoring, and fun. Additionally, they reported that working in a time-limited and goal-oriented environment motivated them to think more deeply about their immediate environmental issues and how the users of the solution perceived the significance of the developed solutions.

- Citizen recruitment and engagement: The fact that the LUT University community is known for its strong commitment to promoting sustainability within and outside the University empowered the Community with a reasonable understanding of sustainability. The initial engagement's outcome helped the participant finalize a specific local issue to address.

All citizens who willingly participated in the engagement phases have varying reasons for participation. They do so out of their interest to contribute to sustainability actions around them and as an opportunity to suggest their ideas, raise their challenges and work with the students in their learning pursuits.

Overall, the impact of the citizens' engagement includes reawakening and discussion of sustainability with the citizens, validation of the existence of local sustainability issues, and relevance of the proposed solutions to solving them. Additionally, it helps to identify factors (rewards, incentives, ease of use, availability, and prior awareness) that motivate citizens' adoption of the solution and strengthen the participant's sustainability knowledge and entrepreneurship plan.

- Hackathon solution and ranking: The team with the most coverage, the most significant number of feedback, and the best pitching emerged as the winner. The prototype solution comes with web and mobile apps. It utilizes persuasive strategies like rewards, incentives, and leaderboards to encourage environmentally-friendly behavior and foster a sustainable mindset among the citizens.

Furthermore, the event helped the team to strengthen their teamwork, problem-solving, and critical thinking skills and develop a sense of personal responsibility for addressing sustainability challenges, as reported in [28].

5.3. Post-hackathon - the outcome

There were a few challenges identified before and during the hackathon. Firstly, students reported challenges in getting the willingness of the engagement participants (especially those outside the University environment) to cooperate with the student in the pre-hackathon stage. This is primarily due to the language barrier among SME owners. At one point, all the teams worked together to share the knowledge of the two Finnish speakers on the team. Secondly, the visiting team member from Malaysia had an initial cultural shock and issue understanding the motivation behind the proposed solution. Finally, the participants' group expressed the challenges in convincing others to join their team and discussed the hackathon requirements before registration.

Another important finding is that the participants believed that community engagement and education were crucial to the success of sustainability initiatives. The stakeholder engagement brings a new dynamism to the entire process, as participants were able to validate that their solutions address one of the numerous sustainability issues facing the citizens. All three teams hope the prototype will outlive the hackathon event.

The importance of post-hackathon activities and further implementation after the event must be emphasized. However, the assertions of previous authors [18], [29], [30] focus only on such continuation being pushed by the participants rather than by the organizers. Nevertheless, it is crucial to ensure that the solutions created during the hackathon have a lasting impact beyond the participants [31]. Such gains might be short live, except the organizer considers the prototype's scalability to ensure its continued improvement by building a community around the solution. Furthermore, continuous tracking and measuring of the solution's impact can demonstrate its value to the immediate Community and attract additional support to sustain the solution in the long term as the need arises.

We answered RQ1 by demonstrating the potential of the hackathon to engage citizens to foster a sustainability mindset through real-world solutions that have citizens' input in the design and a lasting impact on society. The hackathon opens up discussions between the participant and the citizens about their immediate sustainability issues, activities, what could be changed, how it could change, and their commitment to an eco-friendly environment through their behavior and actions.

We uncovered the impact of citizens' engagement on both the participants and the citizens (RQ2); the participants shared that their engagement with targeted users provided valuable insights into actual sustainability issues. They reported gaining a deeper understanding of the challenges and opportunities in the field through engagement activities, which helped the team to identify needed features and changes in the potential solutions. In addition, they highlighted that the hackathon approach was unique and a valuable learning experience that allowed them to go out and meet real users for ideas and engage them in problem-solving to understand users' dynamics. Another finding is the importance of exposure to diverse perspectives and experiences

in the hackathon setting. They noted that this exposure helped them to broaden their thinking and approach to sustainability issues, understand market/user needs, and validate their ideas. As a result, they felt better equipped to make a positive impact on sustainability education.

6. Threat to validity

Our research is subject to several threats to validity, including internal, external, and conclusion validity. The threats to the study's validity and mitigation [32] are discussed for completeness.

Internal validity relates to a causal relationship. Because hackathon participants were recruited via a well-advertised method, they were motivated to participate due to their awareness about sustainability, knowledge, and skills without being coarse. Thus, their choice of sustainability issues as community residents may differ from what the majority consider a sustainability issue. However, they validated the issues' existence while engaging with the citizens.

External validity relates to the generalization of our findings. This means that the result of adopting citizens' engagement guarantees assurance with a hackathon. The engaged citizens ranged from individual city residents to relevant business owners, who all agreed with the existence of sustainability issues and were willing to embrace sustainable behavioral changes.

Conclusion validity relates to the degree to which conclusions drawn from the relationships in data are reasonable. The participants in the final SustHack are 12 in total, with each team presenting its engagement outcome. The post-hackathon interview for the participants was open-ended to learn about their motivation, experience, lessons learned and the perceived impact of the SustHack approach in fostering sustainable actions.

7. Conclusion

We highlighted how hackathons could motivate the participants and citizens and reawaken a sustainability mindset through friendly discussion, highlighting the impact of one's actions and activities on the environment. Through the engagement, we uncovered local sustainability issues and developed prototype solutions emphasizing behavioral changes and adopting an eco-friendly commitment to tackling local sustainability issues.

Additionally, the perceived impact of engagement during the hackathons was unraveled. The participants in the hackathon were motivated by their previously completed ICT (software and systems) sustainability courses. They demonstrated their knowledge to solve real-life challenges by offering the citizens a voice in solving local issues.

Beyond the usual potential and value of hackathons, we have proven the possibility of hackathons to contribute to learning and foster sustainability awareness, citizens' engagement, and eco-friendly behavioral changes within and outside the HEIs. The citizens' engagement approach is promising and would bring about positive impacts of the hackathon and the sustainability of developed solutions beyond the hackathon itself. Additionally, the research gap suggests limited adoption of the general citizens' engagement in the previous hackathons for sustainability and evidence of their input in validating the outcome.

The engagement approach in the sustainability hackathon poses an exciting research direction for technology-driven sustainability research and needs further exploration. This study provides a unique means of empowering and engaging software engineering students and citizens in sustainability education and awareness. It is a valuable starting point for demonstrating positive actions toward a sustainable lifestyle. The findings from the study are an excellent pointer to creating awareness and reawakening local and people's actions toward achieving sustainable development goals. We recommend the inclusion of locals and fluent speakers of the local language in future team formation to reduce language and culture barriers.

Further research on the sustainability hackathons with citizens' engagement approach across different sustainability issues will help shed more light on the benefits and perceived impact on the citizens, the participants, and the sustainability of the developed solutions beyond the hackathon event. In addition, a post-hackathon sustainability plan will help keep the developed solutions alive and suitable for general usage.

8. Acknowledgments

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