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Sustaining human health: A requirements engineering perspective☆

Meira Levy [a,b,*], Eduard C. Groen [c,d], Kuldar Taveter [e], Daniel Amyot [f,g], Eric Yu [h], Lin Liu [i], Ita Richardson [j,k], Maria Spichkova [l], Alexandra Jussli [m], Sébastien Mosser [n,o]

[a] School of Industrial Engineering and Management, Shenkar, the College of Engineering Design and Art, Ramat-Gan, Israel
[b] Department of Information Systems, University of Haifa, Haifa, 52526, Israel
[c] Fraunhofer Institute for Experimental Software Engineering IESE, 67663 Kaiserslautern, Germany
[d] Department of Information and Computing Sciences, Utrecht University, 3584 CC Utrecht, The Netherlands
[e] Institute of Computer Science, University of Tartu, Tartu, 51009, Estonia
[f] School of Electrical Engineering and Computer Science, University of Ottawa, Ottawa, K1N 6N5, Canada
[g] LIFE Research Institute, University of Ottawa, Ottawa, K1N 6N5, Canada
[h] Faculty of Information, University of Toronto, Toronto, M5S 3G6, Canada
[i] School of Software, Tsinghua University, Beijing, 100084, China
[j] Department of Computer Science and Information Systems, University of Limerick, Limerick, V94 T9PX, Ireland
[k] Lero, the Science Foundation Ireland Research Centre for Software, Limerick, V94 NYD3, Ireland
[l] School of Computing Technologies, RMIT University, Melbourne, 3000, Australia
[m] Faculty of Information Management, Neu-Ulm University of Applied Sciences, 89231 Neu-Ulm, Germany
[n] Department of Computing and Software, McMaster University, Hamilton, Ontario, L8S 3L8, Canada
[o] McMaster Centre for Software Certification, Hamilton, Ontario, L8S 4K1, Canada

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ABSTRACT

In our current day and age, Earth suffers under the human ecological footprint, which influences our health and well-being. Technological solutions, including software-related ones, may help tackle these concerns for humanity. However, the development of such solutions requires special attention and effort to overcome human, public, and social barriers that might prevent them from being effective. The Requirements Engineering for Well-Being, Aging, and Health (REWBAH) workshop gathering in 2021 focused on addressing the challenge of how Requirements Engineering (RE) knowledge and practices can be applied to the development of information systems that support and promote long-lasting, sustained, and healthier behavior and choices by individuals. An interactive discussion among subject matter experts and practitioners participating in the REWBAH'21 revolved around several questions. In a subsequent qualitative analysis, the emerging themes were arranged in the sustainable-health RE (SusHeRE) framework to describe RE processes that address both sustainability and health goals. In this vision paper, we present our framework, which includes four main SusHeRE goals defined according to the changes in RE that we deem necessary for achieving a positive contribution of RE on sustainability and health. These goals involve improved **RE Techniques, Multidisciplinary Expertise, Education Agenda, and Public and Social Ecology**.

1. Introduction

Well-being (WB) has been recognized by the World Health Organization (WHO) as a key stage concept in fighting the modern-life challenges of tension and stress, as well as undesired behaviors, such as consuming unhealthy food and insufficient practice of physical activity.[1] The United Nations' 17 Sustainable Development Goals (SDGs) serve as a shared blueprint for peace and prosperity for people and the planet, now and in the future.[2] Sustainable development is a broad term to describe policies, projects and investments that provide benefits today without sacrificing environmental, social, and personal health in the future. These policies are often described as green because they focus on limiting the impact of development on the environment. However, the benefits of sustainable development are also felt across a wide cross section of human health and well-being, including reductions in pollution- and environment-related diseases, improved health outcomes, and decreased stress.[3] Specifically, SDG

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* Corresponding author at: School of Industrial Engineering and Management, Shenkar, the College of Engineering Design and Art, Ramat-Gan, Israel.
E-mail address: lmeira@shenkar.ac.il (M. Levy).

[1] https://www.who.int/about/what-we-do.

[2] https://www.raeng.org.uk/global/sustainable-development-goals.

[3] https://www.who.int/health-topics/sustainable-development#tab=tab_1.

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0164-1212/

3 addresses the goal of good health and WB for all, and posits that good health and WB are directly related to sustainable development.[4] The focus is on promoting health and WB by fighting infectious diseases, and other emerging clinical challenges, while considering economic and social inequalities, rapid urbanization, as well as threats to the climate and the environment. This goal addresses the ecological and social determinants of health (Hancock, 2019; Parkes et al., 2019; Friedman and Banegas, 2018) that go beyond clinical and technological aspects.

One of the recommendations for reducing the overall human footprint is to reduce meat consumption and replace it with fruits, vegetables, nuts, and legumes. This recommendation is also in line with the EAT-Lancet Commission report.[5] Another recommendation from an ecological perspective calls for the reduction of transportation air-pollution by promoting public transportation options over private ones, which resembles the health-related recommendations that foster physical activity, reduce stress, and improve community, family connections, and WB.[6] Thus, these apparent links between ecological concerns and health concerns can help bring ecological and health co-benefits, which is termed as the Ecological Determinants of Health (Parkes et al., 2019; Li, 2017).

Over the last decades, the lifestyle in many countries has trended towards becoming less healthy and less sustainable: there is an increase in sedentary activity, higher concentration of fast-food outlets, and an increase in portion sizes as well as in convenience foods, high in saturated fat, sugar, and salt. One of the factors of the increase in sedentary recreational behavior is the characteristics of the built environments and an access to the active recreation facilities (Sallis and Glanz, 2006) but the other factors often include a lack of awareness. Eating behaviors are influenced by similar factors, and altogether they also contribute to a negative impact on the ecological footprint. Hence, our society faces an increasingly important challenge, namely: How can we reduce the human ecological footprint while meeting basic population needs and ensuring high levels of societal development and good health for all human beings (Hancock, 2019)?

The Brundtland report (Visser and Brundtland, 2013) calls for sustainable development that, on the one hand, addresses people's aspiration for a better life, and, on the other hand, considers the limited resources of our planet. In this vision paper, we tackle this challenge with a specific focus on how, through requirements analysis, we can connect the dots, make critical tradeoffs, raise the awareness of involved parties, and take political, economic, environmental, and societal factors into consideration. As the authors' collaboration focuses on human health and WB, with a particular attention to the aging population, this paper concentrates more on these aspects.

There are several initiatives in the public health domain to solve the challenge of increasing sustainability while safeguarding health and WB. One of these promotes the provision of healthier food options for people eating in city restaurants and schools in an urban domain in Lima, Peru.[7] Another initiative by the Dublin City Council (Ireland) involves conducting accessibility and safety audits, with the goal of transforming the street and sidewalks to become more pedestrian-friendly.[8] In addition, the government of the Australian state of Victoria introduced an initiative to improve access to water and healthy drinks options in local sports and recreation facilities.[9] There is a call to thematize sustainability goals in higher education (Antó et al., 2021), to make developers aware of sustainability challenges (Duboc et al., 2020), and to create specific ontologies that can foster interoperability of systems for enhanced and sustainable processes (Howell et al., 2021).

The responsibility of contributing to a better world places a burden on every individual and every domain. Information technology, as an important enabler, compels Software Engineering (SE) to play a central role in providing novel solutions from a technological perspective (Penzenstadler, 2013). For example, technology can be used to monitor the environment, optimize, and sometimes even enable more sustainable processes, and change the behavior of individuals or groups.

As a sub-discipline of SE, with a strong focus on the human factor and its interface to software systems, Requirements Engineering (RE) is perhaps among the most prominent fields to promote health and sustainability. Indeed, RE has become increasingly self-aware of its responsibility to do its part in bringing about a sustainable world (see Section 2).

In our society, where innovation and change are fundamental, we greatly depend on digital technology. This makes it essential for the software industry to have the necessary tools to accelerate production and evolution of applications that promote health and sustainability, without constraining the creative process. Moreover, it is crucial for citizens to easily access these tools to optimally exploit the digital solutions designed for them. Senior citizens are a good example of a target group because of the gradual onset and progression of cognitive, motor, visual, and auditory impairments. A crucial challenge is that technological innovations should not be detrimental to access to applications by special needs groups, but rather provide greater accessibility. The matter becomes even more difficult because, as with digital innovations, societal innovations continuously modify the contexts of use. However, an accessible application is an application that has been designed together with the targeted people—the stakeholders—and benefits from their feedback. Therefore, RE techniques need to consider the effect of applications that promote health and sustainability over time.

The annual IEEE International Requirements Engineering Conference brings together academic experts who deal with advanced methodologies and have expertise related to requirements elicitation and representation during Information and Communication Technology (ICT) development. At this conference, the Requirements Engineering for Well-Being, Aging, and Health (REWBAH)[10] community fosters discussions related to RE resulting from the need to build software systems that support healthcare, promote WB, encourage patients and the general population to follow healthy lifestyle recommendations, and address the specific needs of an aging population. Because of the growing importance of sustainability aspects, in the online gathering held on September 20, 2021, experts in this community started a discussion regarding the role of RE in addressing sustainability requirements for developing healthcare (including health-related) software systems. This exchange resulted in a new term being coined, *sustainable-health RE* (SusHeRE), which refers to RE processes and strategies that address both sustainable and health goals, and lead to requirements of a sustainable health system, which is designed to assist the user in adopting healthier and

4 https://unfoundation.org/what-we-do/issues/sustainable-development-goals.

5 https://www.thersa.org/blog/2019/01/the-eat-lancet-commission-report-my-favourite-eight-take-aways.

6 https://www.who.int/teams/social-determinants-of-health/urban-health.

7 https://cities4health.org/city-stories/lima-peru.

8 https://www.who.int/news/item/19-08-2021-bucharest-cairo-c%C3%B3rdoba-dublin-greater-manchester-and-warsaw-join-bloomberg-philanthropies-partnership-for-healthy-cities.

9 https://www.vichealth.vic.gov.au/media-and-resources/publications/removingsugarydrinks.

10 https://sites.google.com/view/rewbah2022.

more sustainable habits. The exchange on this subject revolved around the following research question:

In what ways can RE, and particularly SusHeRE, foster sustainability regarding software system development in the health and WB domain?

In this vision paper, we introduce our joint vision regarding the way RE should address sustainability and health-related requirements. This challenge consists of two aspects: (1) Whether healthcare software systems cause any sustainability hazards (e.g., undue power consumption), and (2) In what way these systems promote a healthy life and sustainable goals. The paper is organized as follows: Section 2 presents the background regarding RE in the sustainability, health, and sustainable-health domains. Next, Section 3 presents the research method, and in Section 4, we discuss the various aspects of SusHeRE's goals as envisioned by domain experts. Section 5 accumulates the experts' thoughts into the SusHeRE framework, followed in Section 6 by a discussion of an example of how the framework is applied in research. Lastly, in Section 7, we conclude and suggest future research directions based on the developed framework.

2. Background

The role of RE in promoting sustainable-health goals is an emerging field, and current research efforts often address these topics only indirectly or in isolation. To our knowledge, there is no concerted effort within RE to tackle threats to health and sustainability in an integrative perspective. However, the examples of initiatives and research directions within RE demonstrate a growing attention for its impact on important humanitarian themes. For example, starting in 2018, the *RE Cares* series of hackathons developed technologies that improve the resilience of local communities (Dekhtyar et al., 2020, 2019). Its idealistic roots were born of the observation that RE serves the purpose of supporting humanity through technology. Consequently, it aims to give back to the community of the area where the RE conference is held by providing RE expertise to make a meaningful change to a local initiative.

Furthermore, a growing number of publications illustrate the increased focus on societal, anthropological, and psychological matters within the RE community. These address "softer" themes related to SE, such as ethics (Marcos, 2020), emotional impacts on WB (Stade et al., 2019), emotional requirements (Miller et al., 2015; Taveter et al., 2019; Iqbal et al., 2022), law & data privacy (Polst and Feth, 2020), human values (Perera et al., 2020), explainability (Chazette et al., 2021; Khalid and Qureshi, 2021), RE for AI (Ahmad et al., 2021; Paca and Aristote, 2020), inclusivity (Ko, 2021), social injustices such as digital discrimination (Tushev et al., 2020), and green software strategies (Horkoff, 2021; Condori Fernandez and Lago, 2018; Anwar and Pfahl, 2017; Penzenstadler, 2014). In the software engineering community at large, the International Workshop on Green and Sustainable Software (GREENS)[11] particularly is a venue that focuses on green software, and promotes building systems that are energy-aware, considering cost–benefit analysis during design, and balancing its energy consumption with its value proposition. Although this is not entirely incompatible with software that promotes sustainable health behavior, it is more of a back-end perspective on a system. Similarly, much of the work presented at the International Conference on ICT for Sustainability (ICT4S)[12] also addresses the aspect of sustainability, along with improvements to make SE processes more sustainable.

The *SuSoftPro* tool (Alharthi et al., 2018) analyzes the impact of requirements on system sustainability, but works under the assumption that all requirements have already been elicited, making it primarily of use to the analysis phase of RE processes. There have also been several attempts at covering sustainability requirements for systems within particular domains, e.g., the analysis of e-Learning systems (Alharthi et al., 2019) or the use of digitalization in rural areas (Ferrari et al., 2022). However, few studies or models explicitly explore how the SDGs pertain to RE and SE, or how software systems pertain to SDGs, even though this is an important line of research (Seyff et al., 2022). This paper explores exactly this interaction, specifically for SDG 3 on health and sustainability, in the domain of RE.

2.1. Sustainability and RE

The RE domain has been familiar with the term "sustainability" for many years, which is especially reflected in the series of the International Workshop on Requirements Engineering for Sustainable Systems (RE4SuSy),[13] held since 2012 until its tenth edition in 2021. RE4SuSy led to, among other things, the Karlskrona Manifesto for Sustainability Design in 2015 (Becker et al., 2015). Over the years, a growing interest for RE in sustainability can be observed (Penzenstadler, 2014; Venters et al., 2017; Oyedeji and Penzenstadler, 2018; Oyedeji et al., 2019).

Penzenstadler (Penzenstadler, 2013) suggested that sustainability can be approached from at least two viewpoints:

- "Sustainable software" is concerned with the principles, practices, and processes that contribute to software endurance. This includes considering technical sustainability as a leading non-functional or quality requirement, which is a composite of qualities such as maintainability, extensibility, and usability aspects (Venters et al., 2021). It also covers sustainable software development to ensure that the development process is upheld at the optimal pace (Tate, 2005). These are aspects of sustainability we explicitly do not cover in this paper.
- "Software Engineering for sustainability" (SE4S) focuses on the effect of software systems on sustainability, which is not concerned with issues of the software system itself, or its development. This includes software to support meeting sustainability goals in line with the ISO 14 001[14] standard on environmental management, and other kinds of impacts on ecological, biopsychosocial, and economic structures. This perspective is perfectly aligned with the focus of this paper.

Venters et al. (2017) expanded this dichotomy of sustainability in RE, inspired by the triple bottom line,[15] to five dimensions, which subsequently formed the core structure of the Sustainability Awareness Framework (SusAF) (Duboc et al., 2020):

1. Environmental sustainability: The responsible use and stewardship of natural resources.
2. Economic sustainability: Assets, capital and added value, which includes wealth creation, prosperity, profitability, capital investment, income, etc.
3. Individual sustainability: Individual freedom and agency.
4. Social sustainability: Societal communities (groups of people, organizations) and the factors that erode trust in society.
5. Technical sustainability: The ability to maintain and evolve artificial systems over time.

11 https://greensworkshop.github.io/.
12 https://conf.researchr.org/series/ict4s.
13 http://birgit.penzenstadler.de/re4susy/.
14 https://www.iso.org/standard/60857.html.
15 https://en.wikipedia.org/wiki/Triple_bottom_line.

Seyff et al. (2022) mapped the SusAF onto the SDGs. They identified various interlinks among the SDGs, both positive and negative. Specifically for SDG 3, they found that it mainly relates to individual sustainability (health; lifelong learning), environmental sustainability (biodiversity; waste & pollution) and economic sustainability (governance; CRM; innovation; supply chain), but less so with technical or social sustainability. This mapping fosters awareness of the impact software systems have on the SDGs.

The works mentioned above establish the linkage between sustainability, health, and WB. However, they focus on the system's behavior and the way the system impacts sustainability. For example, Oyedeji et al. (2019) present sustainability goals like "Design for sustainable efficiency, reusability" and "Increase sustainability awareness among users". In RE, there currently is no consensus as to whether sustainability is a system goal, a stakeholder goal, a system quality, an overarching quality, a system constraint, or something else altogether. We mainly address SusHeRE goals from the human perspective for achieving better engagement and behavioral change in the long run. For example, Levy et al. (2022) addressed combined health and sustainability goals in an urban environment focusing on the prevention of type-2 diabetes health concerns. We argue, however, that social sustainability is a major contributing factor to WB. Specifically, we believe that health and WB are predominantly achieved through improvements in individual, social, and environmental sustainability constructs (cf. Penzenstadler, 2013).

2.2. Health and RE

Health-related system development has been studied by RE scholars for many years (Fricker et al., 2015). It has been acknowledged that the health domain is a complex domain with many concerns beyond purely technological ones, such as public and legal constraints (Cysneiros, 2002) and human barriers (Levy et al., 2021a) that have to be taken into account.

Realizing that healthcare systems are often large-scale and complex, and involve many kinds of uncertainties that pose considerable problems for RE (Sutcliffe et al., 2020), the REWBAH workshop series was initiated in 2020 to address the complex nature of developing healthcare software systems (Levy et al., 2021b). In the first workshop, the participants collaboratively identified the challenges REWBAH research should address (Levy et al., 2021b), including:

- Balancing user needs with technical limitations and costs.
- Properly considering the high number of adjacent domains, ranging from medicine (to ensure medical validity) and design to interaction and healthcare.
- Social determinants of health, i.e., specific social factors such as culture, addiction, and inequalities.
- Communicating with specialized (and busy) domain experts and other stakeholders as well as finding suitable tradeoffs among their conflicting goals.
- Merging the considerable knowledge and work from multiple disciplines related to WB, aging, and health (WBAH).
- Communicating WBAH user needs and domain knowledge to software engineers.
- Considering ethical and legal aspects in this increasingly regulated domain.
- Developing multi stakeholder platforms across the boundaries of institutes and private homes, as we are moving from point-of-care towards continuum-of-care systems.

2.3. Sustainable-health and RE

There are papers that address sustainability and health in regard to software development (Ouhbi et al., 2018; García-Berná et al., 2021; Brooks, 2020), which focus on sustainable requirements a system should address, ranging from engaging people to reducing the system's energy consumption. Searching the RE literature shows that there is a large body of publications regarding RE related to health systems and a growing body of papers regarding RE and sustainability. For example, in the Requirements Engineering Journal, we found 99 articles and 21 articles for these two topics, respectively. Even using a simple search query on Scopus,[16] we have not found any conference or journal paper that connects health and sustainability requirements in the way that combines both domains in a holistic manner to propose joint goals. Moreover, there are no known RE methodologies for assuring that the right sustainability requirements are elicited and defined, which would allow people to realize the mutual influence of sustainability and health.

3. Research method

In the REWBAH'21 workshop, the organizers (four of this paper's authors) initiated discussions about the way RE can promote sustainability and health and leverage the connection between them. This was performed through an on-line discussion between approximately 30 domain experts, predominantly scholars in the domains of RE and healthcare. The workshop organizers prepared five guiding and triggering questions that dealt with major aspects of RE on sustainable and health topics, to spark the discussion and to encourage participants to contribute further questions of their own, resulting in four additional guiding questions, for a total of nine questions. The discussion was recorded in Google Docs, a collaborative online rich text editor, by all the participants of the workshop. The participants who expressed an interest in making contributions beyond the workshop were invited to partake in elaborating and refining the answers. The phase of collecting, discussing, and refining the responses lasted 10 weeks. The discussion was closed once no further contributions were made. Following, we applied a qualitative analysis approach (Strauss and Corbin, 1997) in which the answers of each question were open coded followed by axial coding. This grouped the main emerging themes into two logical categories that are visualized in Section 4.3. Following this analysis, we grouped the emerging themes into four blocks by their goals, which together make up our SusHeRE framework, presented in Section 5. Further iterations and improvements were triggered by comments received during the peer-review process of this paper.

4. Discussion themes

In the following, we present the questions and the summary of the highlights provided by the participating domain experts, with the guiding questions grouped into two logical categories:

1. *RE techniques* for elicitation and validation (Section 4.1) address the relevance and suitability of RE methods for eliciting requirements.
2. *Interfaces of RE* to society, domains and disciplines necessary to achieve improved health and sustainability (Section 4.2). The interfaces include educating and engaging people with inclusivity-, health-, and sustainability-promoting systems; influencing policymakers; educating RE students and experts and learning from other disciplines while becoming self-aware about the sustainable-health challenges and behavioral impact.

[16] `TITLE-ABS-KEY ("requirements engineering" AND health* AND sustainability)`.

4.1. RE techniques

4.1.1. Which RE techniques can be useful for eliciting requirements for software systems that engage people to adopt healthy and sustainable habits*?*

Existing RE techniques such as agent-oriented goal models (Yu et al., 2011; Horkoff and Yu, 2014; Miller et al., 2014; Mooses and Taveter, 2021; Sterling Leon and Taveter, 2009), user stories (Dalpiaz and Brinkkemper, 2018; Tenso et al., 2017), or combined goal and process modeling (Amyot et al., 2022; Sulis and Taveter, 2022) can be applied to the design and development of healthcare software systems. Goal-based techniques (Horkoff et al., 2019; Chung et al., 2000) can be particularly useful for uncovering conflicting goals and competing stakeholder interests and for analyzing trade-offs, such as among personal lifestyle preferences, community well-being, and sustainability concerns. However, to address the behavioral-change focus of such systems, RE techniques should further take advantage of cognitive psychology theories. For example the Health Action Process Approach (HAPA) (Schwarzer, 2008) predicts engagement in health behavior, based on pre- and post-intention measures that are mediated by factors like self-efficiency, planning, and social support, and has been validated across a variety of preventative health behaviors, including physical exercise (Paech et al., 2016; Scholz et al., 2008), nutrition (Schwarzer and Renner, 2000), and cancer screening (Luszczynska and Schwarzer, 2010). Similarly, the Health Belief Model (Champion and Skinner, 2008) guides specifying design principles for altering or breaking habits and promoting preventive practices (Chung et al., 2021). The influence of the intersection of health and sustainability[17] in RE on these cognitive theory-based models should be assessed.

Successful healthcare software systems can only be achieved if the requirements for promoting health and sustainability are aligned with the people's stages of behavior, states of mind (e.g., emotions, mood, personality), biases, and the effects of misinformation. Qualitative methods can be incorporated in RE methods and education for realizing people's conceptions and attitudes. Design Thinking can also help to elicit the requirements about the current processes and create new ideas for addressing existing needs (Hehn and Uebernickel, 2018; Levy and Huli, 2019). An example of a requirements elicitation approach inspired by Design Thinking is the do/be/feel method of co-design (Lorca et al., 2018), which has been successfully applied in several health-related case studies, e.g., Miller et al. (2015), Taveter et al. (2019) and Mooses and Taveter (2021), as well as the PHArA-ON research project (Mooses et al., 2022). Such approaches function as frameworks for efficiently incorporating qualitative, experimental, and other methods into the requirements elicitation. As we addressed in Section 2.1, however, the question is whether sustainability is a high-level non-functional or quality requirement, a quality characteristic, another interest, or even a constraint when we design a new system (see, e.g., Venters et al., 2017). This can have a significant impact on how these frameworks are interpreted for and applied to eliciting sustainability requirements.

Another important consideration is whether we should *reinvent* or *reuse* sustainable-health systems. For example, can healthcare software systems be duplicated easily in different cultures? To answer this question, RE should consider emotional requirements as first-class citizens (Miller et al., 2015; Taveter et al., 2019), in concordance with the latest theories of emotion, such as the theory of (socially and culturally) constructed emotion (Iqbal et al., 2022; Taveter and Iqbal, 2021; Barrett, 2017; Boiger and Mesquita, 2012; Skains et al., 2021).

It is also important to note that requirements related to WB evolve over time, considering the health status of the user. A senior citizen who has difficulty walking might require dedicated transportation, preventing them from using public transportation without judgment or shame. It is necessary to take into account multi-objective criteria to ensure that the proposed elicitation is inclusive.

Mixed method studies offer both objective and subjective evaluation of the software systems and need to be encouraged as an academic best practice.

While we put forward several techniques that can be used or be adapted to deal with both sustainability and health goals, any other techniques that address social and psychological determinants during the development of software systems in engaging people to adopt healthy and sustainable habits, can be applicable as well. Any technique can be applied as long as it is aligned with ethical concerns.

4.1.2. Which RE techniques can be useful for eliciting requirements for software systems that educate people *about issues related to health and sustainability?*

The educational aspects regarding health and sustainability are not necessarily related to RE techniques, but rather to training students or requirements engineers. Students show great interest in sustainability and health issues, but guidance on how to assess and integrate such aspects in RE projects and practice is lacking (Watson et al., 2013). This requires developing reference case studies, leveraging social media, podcasts, YouTube videos, Interactive Digital Narratives (IDNs) (Skains et al., 2021; Perkis and Taveter, 2022) or bite-size learning to educate and encourage people to adopt sustainable and healthy habits. The challenge for RE in this regard is how to apply RE techniques in the new technological era, particularly in the educational context towards leveraging sustainability and healthy habits. This aim requires especially the adaptation of specific methods—such as Design Thinking (Hehn and Uebernickel, 2018; Levy et al., 2022)—in an integrative way, which allows the participation of all relevant user groups. Recent literature highlights that fostering diversity in RE projects is of central concern to social cohesion, representing a major challenge for sustainability (Wohlrab et al., 2020). Existing RE techniques (see Section 4.1.1) can be learned, but a focus should be placed on those that address social and psychological determinants during the development of software systems that engage people to adopt healthy and sustainable habits.

To increase guidance for students while avoiding biases, the above-mentioned case studies must be peer-reviewed by instructors and packaged in a way that makes them reusable. As ethical considerations are not embedded automatically in RE techniques (Salehnia and Pournaghshband, 2011), a real effort is needed to provide success stories as well as failure descriptions to students and fellow instructors addressing inequalities that may influence acceptance and engagement of sustainable-health systems.

4.1.3. Which RE techniques can be useful for eliciting requirements for software systems that help policymakers decide on policies *that promote health and sustainability?*

RE professionals and policymakers need effective communication means by creating better infographics and briefs to communicate research findings and knowledge in an actionable way. Different approaches that are used in empirical SE research, like surveys and interviews, can gather and deliver data to decision-makers for better data-driven decision-making, demonstrating these decisions' rationale and impact. Policymakers can also benefit from decision-support systems that use agent-based simulations to decide on sustainability and health-related issues;

[17] https://unfoundation.org/what-we-do/issues/sustainable-development-goals/.

dedicated RE techniques are needed to elicit and represent the requirement for such systems (Miller et al., 2014; Sulis and Taveter, 2022). The presentation of data can also facilitate educating policymakers and raise awareness of the cost vs. improvement assessments of sustainable and health promotion programs, including the communication of the rationale to the public, forcing restrictions on sustainability and health-related hazards, and promoting technology means, such as adopting the use of specific applications.

Communication first requires a common vocabulary. It would be helpful to create open-source documentation that should include a glossary for use by RE practitioners in different fields covering the jargon used by both policy experts and RE practitioners, followed by templates for executive summaries, detailed reports, and infographics. The awareness and appreciation of policymakers' priorities and limitations in understanding technical jargon will help produce better documents.

A search on the literature in RE shows that there is a theoretical gap regarding the way RE influences policymakers (Bergman et al., 2002), and as a result we call for understanding the political ecology in RE in general, and in the sustainable-health context in particular, taking a broader perspective of public and social ecology as suggested by Berkes et al. (2003) and Lang and Rayner (2012).

While we described several RE techniques that can be used during the RE process to better engage policymakers in adopting sustainable-health goals, other RE techniques may be used if they facilitate discussions and collaboration, such as those based on Design Thinking (see Section 4.1.2).

4.1.4. Which RE techniques can be useful for eliciting requirements for analyzing usage and stakeholder engagement *of software systems that promote health and sustainability?*

Qualitative research methods such as in-depth interviews, observations, workshops, and focus groups, conducted by researchers with good listening skills, followed by qualitative analysis, can teach us about the usage of devices or applications or user behaviors. Quantitative research methods, like Data-driven RE (Maalej et al., 2019) and Crowd-based RE (Groen et al., 2017b) can be helpful to look at (a) behavior, (b) contributions to health/sustainability, and (c) improvement potential towards better health and sustainability; either by technological improvements or through behavioral change. This requires the definition of objective measurements for health and sustainability. In particular, the realization of personal and population measurements as well as measures of the impact of various interventions to improve health and behavior are crucial inputs for defining requirements for software systems that promote health and sustainability. Following an 'action research' approach might furthermore support the generation of authentic insights, as researchers and practitioners work together on vital questions (Sein and Rossi, 2018). The rigorous application of such paradigms opens new challenges for requirements engineers in fundamentally understanding the users.

More than most other subdomains in SE, RE needs to closely align with practice-based theory rather than pure theory and empiricism, because software systems are used in real-world settings, while lab environments are far from being representative for those settings.

4.1.5. What RE techniques can be useful for validating requirements *related to health and sustainability?*

With sustainability and health goals comprising rather soft goals, it is often difficult to objectively validate them. However, it is important during the RE process to formalize the analysis of usage data for health and sustainability. There are cases where even the style in which the requirements are written plays a role, for example, user stories vs. traditional requirements, and visualization techniques for requirements.

Sustainable development goals are big-picture goals. As we break down SDG 3 to the level of an individual, these become behavioral change goals. Change management at individual and institutional levels are the biggest barriers to attaining SDG 3 goals. Citizenship science, civic participation, and stakeholder inclusion should be skills in which every requirements engineer is trained. However, because SDG 3 is contextual, what is healthy or health-promoting in one region is not necessarily possible or valid in another. Hence, RE techniques that can better extract the context, such as the use of personas to describe typical individuals or social contexts (Groen et al., 2017a) or applying the methods of co-design, e.g., in stakeholder workshop (Lorca et al., 2018; Mooses et al., 2022), could also be very helpful and useful in a context setting.

4.2. RE interfaces

4.2.1. How can RE respond to the needs of all segments of society *(including various age groups as they progress through life stages) as they face health and WB challenges arising from climate and ecological change?*

The RE domain should gain an understanding of practice-based knowledge and impacts of different opinions from non-academic literature that often does not pass peer review, such as podcasts and publications from health and WB organizations. RE guidelines for using and embracing such literature in the form of tutorials and working materials are required, based on existing empirical work on conducting gray literature reviews (Garousi et al., 2019) that can prepare RE practitioners for the societal challenges with health and sustainability (Doerr et al., 2018). Further RE guidelines should address the way other domains can influence the RE domain, practice, and tools. This preparation of resources should be personal or organization-oriented, depending on the situation and ability to contribute positively to climate and ecological change.

RE techniques should be complemented with inclusivity methods to ensure that all relevant segments of a society are considered during requirements elicitation. One of the solutions to this problem might be to enforce taking inclusivity into account already at the stage of identification of the stakeholders. As different stakeholders might have different needs and expectations from the system, it is especially important to consider inclusivity already at this stage, before the actual RE techniques are applied. Thus, qualitative approaches from empirical studies and empirical SE[18] can help, as well as HCI methods. These methods can help characterize the best practices and/or workarounds to guide development, systematize the capitalization on information acquired through experimentation with the user and their environment or ecosystem, and support agile developers with systematically considering the capabilities of people in interactions with their solution, particularly during the evolution of applications. We may, for example, when employing a Design Thinking methodology, create a minimum viable product (MVP) during the prototyping stage, to be validated by diverse stakeholders before entering into full-scale development.

4.2.2. How can RE respond to the needs of different domains *that develop solutions for a healthy and sustainable world where software systems play an important contribution?*

RE is never an end in itself but serves the design and development of (software) products, systems, and services. As a result, RE

[18] https://github.com/acmsigsoft/EmpiricalStandards.

not only contributes to making SE more sustainable, i.e., technical sustainability, but it also contributes to other domains that seek to achieve greater individual, social, environmental, and economic sustainability through (software) solutions (Duboc et al., 2020).

For example, Ncube and Lim (2018) propose a research agenda to assure the ability of RE to handle increasingly complex cyber–physical systems that address societal needs longitudinally. These include social sustainability aspects such as the water–energy–food–ecosystem nexus and population demographics, and societal impacts on environmental sustainability aspects such as global climate and integrated transport. Similarly, Doerr et al. (2018) propose a framework that classifies social contexts and RE methods for sustainable living in both urban and remote areas—i.e., smart cities and smart rural areas—with their focus being in particular on addressing mobility and economic needs. This not only serves convenience needs, but is directly associated with improved health and well-being, such as reduced emissions in cities through smart mobility solutions, and the ability of villagers to keep on living in their familiar community even when local services like the bakery and post office have closed.

In biology and agriculture, efforts to make natural environments and food production more sustainable with fewer resources or a more responsible choice of foodstuffs also see a growing need for support through software systems. For example, Penzenstadler et al. (2018) designed a sensor-based system for resilient smart gardens, while in Penzenstadler (2014), she demonstrates a practical instantiation of the Green RE framework, a comprehensive design process for engineering green solutions with appropriate activities and RE artifacts to document the requirements. Even for grassroots sustainable agriculture initiatives such as permaculture, information systems play an important role in guiding the design of such agroecosystems (Norton, 2019). This promotes further greening of the surroundings, which can be linked to improved air quality and greater happiness and stimulates the (self-sufficient) production of healthy foods.

To make meaningful contributions in promoting technological solutions for a sustainable and healthy society, RE must form collaborations with the above-mentioned initiatives and other non-SE-domains. A prominent contribution for which RE can provide expertise is leveraging speed development sessions that facilitate a safe space for cross-pollination of ideas, like hackathons, break-out rooms, or think tanks—a successful demonstration of this paradigm can be found in RE Cares (Dekhtyar et al., 2020) (see Section 2). In the ensuing elaboration of the design, RE can advise experts from other domains on the choice of appropriate digital solutions. Following this, RE can assist by measuring the effectiveness and efficiency of digital solutions (even prototypes) in a community of early adopters which exhibits different advocacy groups (e.g., regular and senior citizens, patients, practitioners) to validate the requirements or elicit further innovative requirements.

To fully consider sustainability goals in any domain, rather than just developing or introducing a software system, it is important for RE to target designing and developing sociotechnical systems (van Eijnatten et al., 2008; Sommerville, 2015; Sterling Leon and Taveter, 2009; Norta et al., 2014), which consist of interacting humans and technical components. Requirements for a sociotechnical system should be elicited and represented from the complementary perspective, where the elicited requirements are represented by, for example, role models and an organizational model for the business perspective, a domain knowledge model for the informational perspective, and goal models for the functional perspective. This approach is conceptual and therefore does not depend on a particular RE methodology (Sterling Leon and Taveter, 2009).

To establish cross-domain connections and assist other domains in their search for improving their impact on sustainability and health, RE will need to appeal to these fields by demonstrating the benefits it can bring when designing technology. One way to do this is by communicating its success stories more clearly. Another strategy is to identify pain points in those disciplines and target potential solutions to domain experts, which can then be elaborated together. For example, RE can relate experiences with digital ecosystems — e.g., Norta et al. (2014), Naab et al. (2018) and Hess et al. (2015) — to biology, where sustainable controlled ecosystems under development might struggle with similar problems often seen in SE, such as overly optimistic expectations regarding the lead time and break-even point, or a lack of monitoring potential preventing the ecosystem from becoming self-sustainable and profitable.

Furthermore, the RE community needs to become more accessible to non-RE experts and emphasize more on open-source software and resources. Every individual is a RE expert for themselves. If, like with Wikipedia, RE education, information, or projects are made freely available, they could over time become an engaging two-way open-source endeavor to solve complex world problems.

4.2.3. What are the specifics of RE of sustainability *in the health and WB domains?*

Health and WB are abstract concepts to many decision-makers, especially in commercial organizations. RE efforts should focus on developing measurements that are related to health and WB and can help with ranking different communities including organizations and cities (e.g., according to the Ease of Living Index[19] or the Perma-Profiler (Butler and Kern, 2016)). Within for-profit organizations, demonstrating which relationships between abstract health concepts and productivity are measurable can persuade decision-makers to incorporate those measurements in their management practices (Vänni et al., 2012) (see also Section 4.1.4).

At an organizational level, RE should ideally align with business goals, which determine the allocation and movement of the available funds. For example, in a health setting, it is relevant to identify which impact indicators will influence the budget or reimbursement, and how these can be better captured. RE should satisfy the needs of the stakeholders using the system that operates at multiple levels, and there is also an opportunity to see where organizational goals and stakeholder interests align with the requirements, and when they diverge. RE in general requires alignment with business goals and funds allocation; however, when developing software systems that foster engagement in achieving sustainable-health goals, a special emphasis is needed since it often involves several organizations that may have conflict of interests and funding priorities.

At an individual level, thinking towards a behavioral digital twin and helping to build the digital thread of a person could be helpful. This digital thread is not just the aggregate of a person's health parameters but can also be expressed by behavioral aspects and decisions, such as screen time, spending habits, or the choice of cooking versus ordering out. RE today can bridge the social determinants of health with individual health goals. Previously, this was just a policy-level task, but with today's ubiquitous and sophisticated data capturing, RE can look at ways to educate people about themselves based on the information captured about them, so that they are empowered to make the best decisions for themselves. One part of the problem lies in capturing the right requirements and considering privacy matters, while the second part lies in the tangible behavioral change

[19] https://currentaffairs.adda247.com/ease-of-living-index-2020-released/.

required from the user as found in behavioral change theory and the cyclical nature of behavioral change needs. This makes RE an iterative process instead of a linear one. Here, incorporating machine learning to capture selected user parameters to continuously update their requirements and align them with the health and sustainable goals will be revolutionary and helpful.

4.2.4. What education - specifically interdisciplinary education - *is needed to train requirements engineers to work in this domain, and to teach RE to subject matter experts in the domain, so that they can be the bridge between engineering and end-users?*

Data collection techniques, such as focus groups and in-depth interviews, require special skills and training that are typically not taught at engineering faculties. This can cause a mismatch with the emphasis on soft skills typically expected from an RE practitioner (Herrmann et al., 2020). A universal problem in RE, that was identified during the Open RE track at the REFSQ conference in 2021, is that the ability to teach RE is severely limited because the curriculum typically only covers one course on RE (Condori Fernandez and Lago, 2018). This leaves little time for students to acquire these much-needed soft skills in addition to learning the basics in RE. As a result, additionally having the social science faculty offer a qualitative research course to engineering would be a good starting point for engineering education innovation. Making this qualitative research course mandatory for undergraduate and/or graduate education would help to achieve the needed mindset shift in how requirements can or should be elicited for health and WB.

Partnering with existing online education platforms and continuous learning forums, RE education should be easily accessible. There needs to be some social marketing of the domain, analogous to how coding became to be perceived as a 'cool thing'. One can code but cannot make anything if the requirements of the system are not understood. Targeting middle school education and holding requirements camps in conjunction with coding camps, will truly start making the needed shift in the mindset and develop more awareness of RE. In the same way that problem-solving is a desired skill in education and business, requirements elicitation also needs to be a basic skill being taught. Nuances can be left for experts, but the basics and fundamentals can be democratized through proper education.

RE should be taught in interdisciplinary teams, applying methods that originated in social and behavioral sciences that aim to reduce the impact of one's own biases (e.g., Grounded Theory Strauss and Corbin, 1997). Domain experts need to be actively involved in the curriculum-building for the area that is addressed, both from the people perspective (e.g., psychologists, therapists) and from the application domain (e.g., agricultural experts, medical experts). However, the ethical side of sustainability builds the foundation for a broadly shared mindset that incorporates sustainability goals naturally in terms of understanding social and ecological aspects as 'resources' that should be protected (Aydemir and Dalpiaz, 2018).

There is also a need for a mindset shift in higher education. Engineering students often only learn about how to solve a problem, without clearly understanding the problem and without learning the skills necessary to get to the root of the problem. As a result, engineering students tend to remain focused on the problem, without properly being equipped with the tools and strategies to analyze the problem space before arriving at the appropriate solution. They elicit what can possibly be done, rather than what exactly needs to be done. To improve the situation, undergraduate education needs basic courses in climate and health, management, and basics of (human- and sustainability-centered) RE in all faculties. A solid understanding of RE concepts will generally not only benefit software engineers and IT professionals, but also students from other disciplines in the following ways:

- SE and IT students need this knowledge to follow the proper process and to be able to create high-quality RE artifacts.
- Students from other disciplines need this knowledge because they are the future stakeholders for software development projects, which will benefit from them understanding the process and the importance of their role and contributions.

To ensure that the future generations of software developers and stakeholders care about human-centered and sustainability aspects as they develop and adopt new systems, we need to start early and provide corresponding training (at least) at the undergraduate level. If we omit the human and sustainability aspects when teaching RE (i.e., if we limit teaching RE to teaching the core processes, tools, and artifacts), it might be too optimistic to expect future generations of software developers and stakeholders to have sufficient awareness about the potential issues that need to be addressed, for example in making sure that new systems are truly sustainable.

Technology today is a commodity, and businesses in all domains are being digitally transformed. Thus, there is a big gap between what education offers and what practice needs. RE needs to support domain experts by providing continuous education on eliciting requirements when they work with IT teams, and by bringing the basics of the domain knowledge into these teams. It is not just a 'nice-to-have' practice, but a 'must-have' requirement to build teams with the empathy and patience to understand each other's mindset. Only through education can we foster mutual curiosity and respect among disciplines.

A promising option is to add corresponding interdisciplinary courses to the study curriculum. For example, RMIT University in Melbourne, Australia, introduced a new course called "STEM for sustainable development" in 2022. It provides cross-disciplinary programs within the STEM (Science, Technology, Engineering, and Mathematics) college. This course aims to provide students with knowledge on sustainability as applied in STEM, including "consideration of sustainable development goals, priorities, and future sustainability trends in relation to STEM and health".[20]

In cases where an RE course is taught only at the postgraduate level in a given institution, special project-based courses for undergraduates could be developed that involve real stakeholders, as suggested in the Discussion (Section 6). Alternatively, courses covering project management or introduction to IT/CS/SE might be redeveloped or expanded to cover at least the core elements of RE and provide students with a better understanding of requirements elicitation and analysis.

4.3. Derivation of expert themes in societal and RE contexts

In order to structure our findings, we grouped them into logical topics, from which two main themes emerged: society and RE. These were further visualized. Themes belonging to the societal context (Fig. 1) show how the RE experts develop software systems that impact sustainability and health. Also included are both the interfaces required for realizing diverse cultures and needs of various groups of stakeholders. Additionally, we identified the RE process that may facilitate the interaction between the software developers and stakeholders during the software system development (Fig. 2).

5. The sustainable-health RE (SusHeRE) framework

To highlight the essence of the discussion in Section 4 regarding the role of RE in promoting sustainable-health software

[20] http://www1.rmit.edu.au/browse/; ID = 054465heparta;STATUS = A.

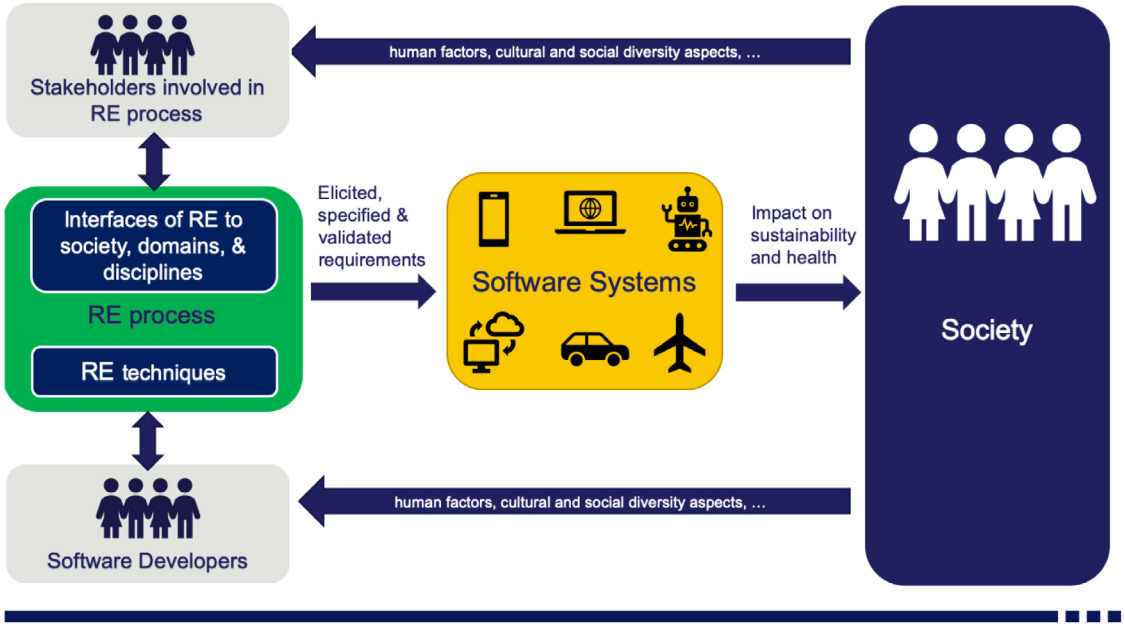

Fig. 1. Emerged themes related to society.

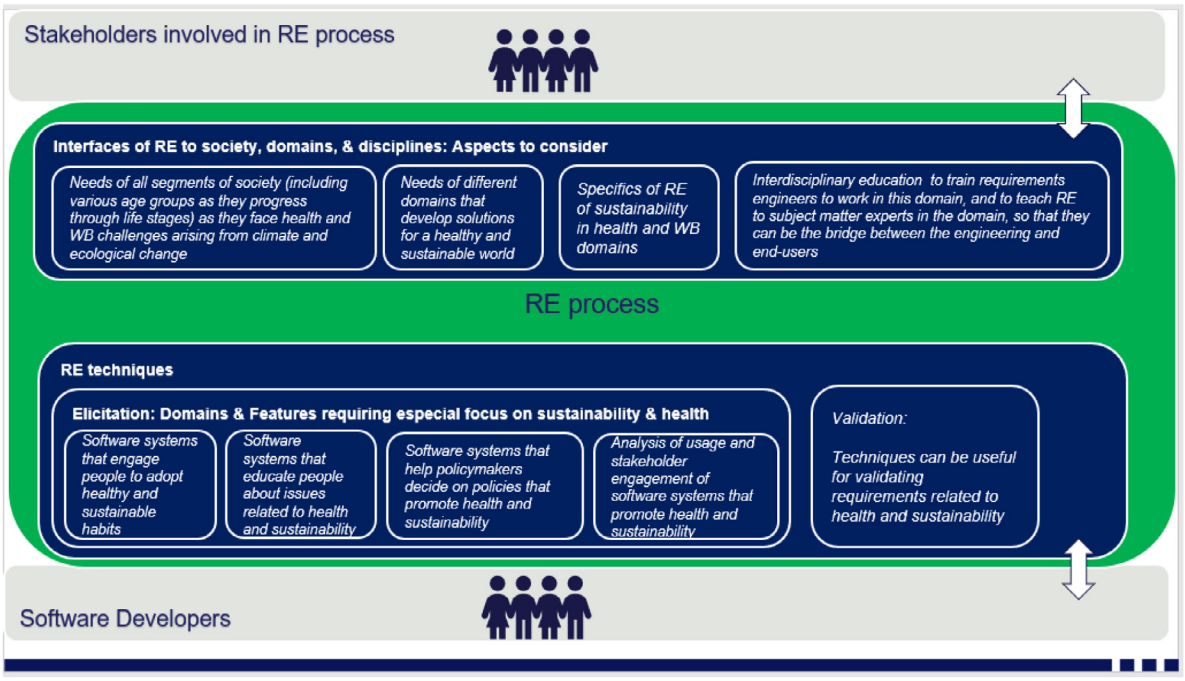

Fig. 2. Themes related to the RE process.

development, we converged it into a sustainable-health RE framework by grouping the cross-cutting topics of these discussions, thus identifying four main RE goals for sustainability and health. We define these according to the changes in RE we believe are necessary, and how these changes should promote sustainability and health through RE. Fig. 3 presents the overall structure of the framework, and the identified strategies for each goal.

- **RE Techniques:** RE must practice human-centered approaches for eliciting diverse requirements, so that we better realize human needs and capacity for sustainability and health change behavior. To support these approaches, the following techniques might be used: user stories; goal modeling; Human-Centered Design (e.g., Design Thinking); co-design (e.g., stakeholder workshops); engineering emotional requirements; qualitative techniques; quantitative approaches (e.g., Data-driven RE, Crowd-based RE); mixed methods' studies; practice-based research; longitudinal evaluations; inclusive methods; objective measurements of health and sustainability; agile approaches; and self-monitoring while retaining privacy. This RE goal was predominantly based on Sections 4.1.1 and 4.2.4, and in part on Section 4.2.1.

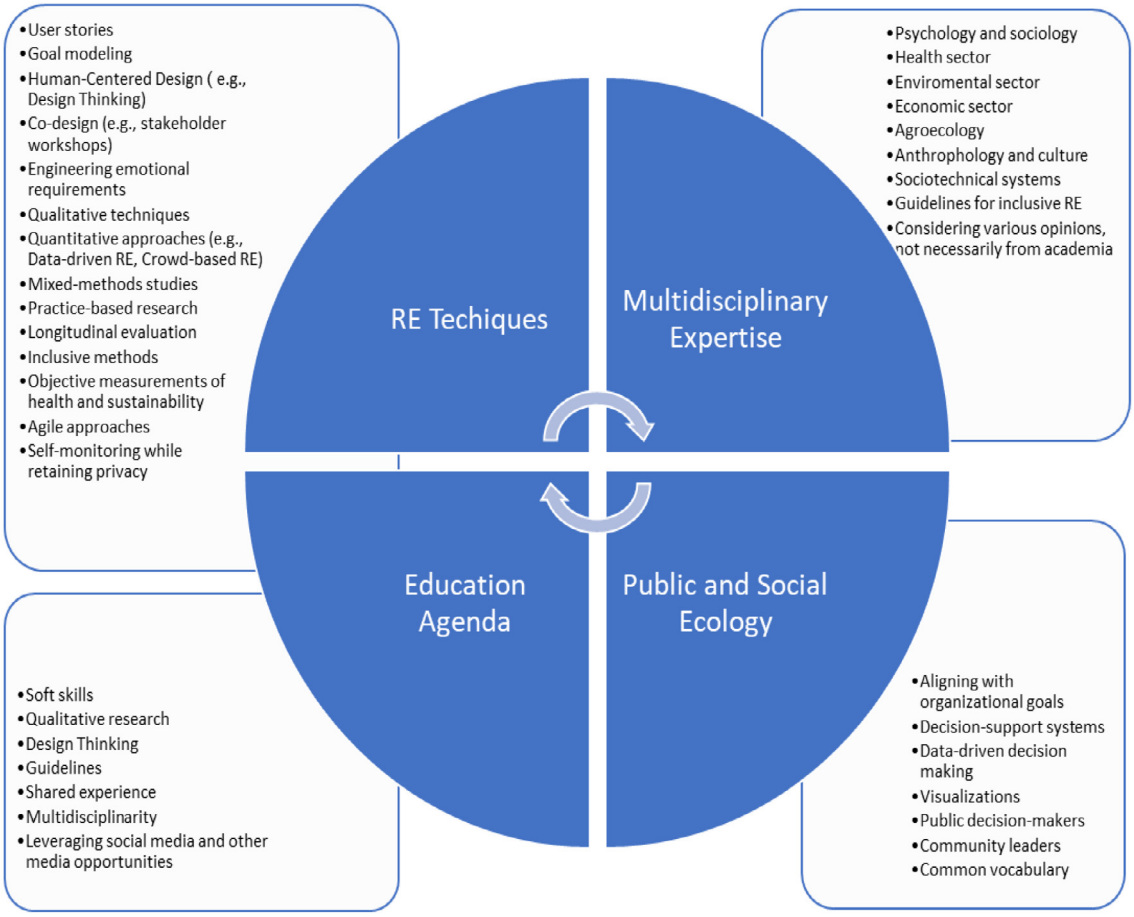

Fig. 3. The sustainable-health requirements engineering (SusHeRE) Framework.

- **Multidisciplinary Expertise:** RE must integrate knowledge and concerns from diverse perspectives and various disciplines/domains, so that we create solutions for sustainability and health that are inclusive and engage people for longitude behavioral change. The potential knowledge domains can be psychology and sociology; the health sector; the environmental sector; the economic sector; agroecology; anthropology and culture; sociotechnical systems; guidelines for inclusive RE; and considering various opinions, not necessarily from academia. This RE goal was predominantly based on Section 4.2.2, and in part on Sections 4.1.1 and 4.2.4.
- **Education Agenda:** Soft skills and interdisciplinary methods must be taught in RE, so that we are equipped with the necessary abilities to design for sustainability and health and can make sure that the resulting systems are effective. Several capabilities and shared knowledge should be embedded in the academic curricula, for example: soft skills; qualitative research; Design Thinking; guidelines; shared experience; multidisciplinary approach; and leveraging social media and other media opportunities. This RE goal was predominantly based on Sections 4.2.2 and 4.2.4, and in part on Sections 4.1.1, 4.1.2, and 4.2.3.
- **Public and Social Ecology:** RE experts must be better skilled in how to communicate to policymakers using data-driven visualization, so that we can influence policy to provide the appropriate constraints to facilitate sustainability and health solutions. The RE experts should be aware of and consider alignment with organizational goals; decision-support systems; data-driven decision making; visualizations; public decision-makers; community leaders; and a common vocabulary. This RE goal was predominantly based on Sections 4.1.3 and 4.2.3.

6. Discussion

In the 2021 IEEE/ACM International Workshop on the Body of Knowledge for Software Sustainability (BoKSS), Venters et al. (2021) posit that while sustainability should be addressed from technical perspectives such as maintainability and extensibility, further research is required by the SE community for studying its direct and indirect negative impacts on different dimensions of sustainability that result from the development, deployment, and continued use of software systems. The SusHeRE framework follows their call, combining health and sustainable goals for better engagement and behavioral change that will lead to healthier and sustained habits.

Levy et al. (2022) presented an example of how tackling a health challenge from health and sustainable perspectives can develop solutions that address sustainable-health goals. In their study, the challenge of preventing type-2 diabetes was addressed by developing a Municipal-Environmental-Social-Health (MESH) platform, which offers services that promote healthy and sustainable habits. The research was conducted in the multicultural city of Shfar'am, Israel, which is comprised of Christian, Druze, and Muslim residents. While there is some awareness about the promotion of a healthier lifestyle, the Arab culture, religious holidays and ceremonies, and culinary habits within families together constitute major challenges in preventing type-2 diabetes. The stakeholders for MESH were the head of the project, the project's designated coordinator in Shfar'am, Shfar'am municipality's health promoter, teachers and pupils in the local

high school, primary care physicians and nurses who treat and manage patients with diabetes, nurses who treat and manage pregnant women who were diagnosed with gestational diabetes, and the director of the Israel Diabetes Association branch that treats people with diabetes. The study took place in a multidisciplinary academic setting, involving engineering, design and medical students that practiced Design Thinking and service design methodologies. They employed various qualitative research means such as interviews and observations to gather data about potential users of the MESH platform. The students also studied cultural aspects and relevant medical guidelines that applied to their challenges that were provided by the different stakeholders. The research effort produced creative solutions, as part of which sustainable-health requirements were defined. Example of such requirements included promoting the use of solar energy in a sports field's lighting system with a software application that maps sports fields and enables reserving them for sporting activities and turning on/off the lights. Addressing the health challenge from broader perspectives of WB and sustainability may motivate people to engage in sports activities more often and take responsibility for sustainability, which may in turn lead to better health habits.

This research experience is a compelling example for how the SusHeRE framework is applicable even to the first phases of system development, which resulted in conceptual solutions. To propose solutions, students had to employ human-centered RE techniques, work in multidisciplinary teams that bring diverse perspectives and knowledge, drive an educational agenda that fosters soft skills and performing qualitative research, and finally, consider a multitude of institutional and public forces that may promote or hinder the solution implementation and acceptance.

The SusHeRE framework encompasses various aspects that we suggest should be taken into consideration when sustainable-health goals need to be achieved. Each project can tailor the relevant components from this framework to the desired project. In doing so, the framework supports researchers and practitioners by considering a wider range of applicable aspects and goals, helps preventing important aspects to be overlooked, and suggests a choice of suitable research methods and disciplines to involve.

7. Conclusions and future research

In this paper, we sought to elaborate on the research question: "In what ways can RE, and particularly SusHeRE, foster sustainability regarding software system development in the health and WB domain?" We narrowed down our treatment of this question to the area of "SE for sustainability", focusing on the effect of software systems on promoting sustainability in healthcare and WB, and particularly the role that RE can play in this context. Based on the discussion themes that originated from the REWBAH'21 workshop, we addressed two overarching topics: (1) *RE techniques* appropriate for elicitation and validation, and (2) *interfaces of RE* to society, domains, and disciplines necessary to achieve improved health, WB, and sustainability.

The cross-cutting topics of our discussion converged into the SusHeRE framework. This framework comprises four main RE goals for sustainability and health: (1) *RE techniques* that can be applied for enhancing sustainability in healthcare and WB; (2) *Multidisciplinary expertise* to properly address the interdisciplinary nature of sustainability in healthcare and WB and the relevance of taking a sociotechnical systems approach in this area; (3) An *education agenda* that emphasizes the importance of teaching soft skills and interdisciplinary methods in RE, and (4) *Public and social ecology* regarding the need to support public and communal decision-makers by providing appropriate simulations and data visualizations. Although we can observe a gradual shift in RE (see Section 2), concerted efforts into the four directions of our framework are crucial if RE and SE are to make a substantial contribution to SDG 3 by developing software solutions that sustainably promote good health and well-being.

7.1. Threats to validity

We identified several important threats to the validity of our work. In terms of internal validity, despite the large diversity of backgrounds and expertise of the workshop participants and co-authors of this paper, there is a risk of bias towards conventional RE and educational techniques from the SE community in our framework. One way to mitigate this threat would be to invite additional experts and educators from the disciplines identified in the right half of Fig. 3 to comment on and validate the proposed framework in various contexts and challenges, and provide enhancements to the framework with advanced solutions that promote health and sustainability. In terms of external validity, our framework is currently focused on just one of the 17 SDGs and cannot be generalized easily to the others at this time, because this would entail new collaborative efforts among varying sets of experts to be performed. In addition, the SusHeRE framework envisioned in this paper has yet to be empirically validated in practice. In terms of construct and content validity, our framework is a vision framework that is based on RE scholars' knowledge and experience as well as on a review of the literature, but not on grounded research. We believe that we incorporated important and relevant knowledge in our framework but acknowledge that it can be further modified and enhanced based on follow-up research and experience. Other types of validity, such as face or criterion validity, are less relevant to a vision paper that does not report on specific research.

7.2. Future research

Through our paper, we wish to inspire more collectives like ours to form, who will analyze the contribution SE can make to significantly impact the other SDGs. There is much potential to extend this framework for other SDGs. Moreover, the concept of sustainability spans different SDGs. For example, SDG 11 on "Sustainable cities and communities" and SDG 12 on "Responsible consumption and production" can benefit health and WB, and vice versa, so we did indirectly touch on those (e.g., in Section 4.2.2). We therefore encourage alignment between these efforts to mutually inspire frameworks, and efforts to safeguard sustainability and health, and other cross-cutting topics.

The increased complexity of systems through the digital transformation and the rise of sociotechnical systems compels RE to adapt its set of techniques to consider a wider variety of requirements in a broader context (Villela et al., 2018). The contribution of RE to designing such systems and steering innovation will only increase in coming purport that the SusHeRE framework comes at a time where it can directly be applied in the design of new software-driven solutions. For example, a recent cross-domain expert survey on dynamic systems of systems revealed that sustainability and health are key drivers that motivate and provide a rationale to developing such sociotechnical systems (Groen et al., 2022). Smart mobility solutions not only seek to improve infrastructural efficiency, but also to lower emissions and promote sustainable models of transportation like carsharing, multimodal public transport, and combined transportation of goods to competing shops in the same street. Smart city solutions include innovative approaches to the blue and green infrastructure with better use of natural resources like rainwater harvesting and improving the inner-city climate through mobile trees to provide

shade and filtering the air with moss walls. Smart farming solutions use artificial intelligence to make fine-grained decisions on plant needs, lowering the use and emissions of fertilizers and crop-protection products, while stimulating the use of natural pest control. Similar findings were also presented for smart manufacturing, smart healthcare, and smart energy. The role of RE in all these scenarios is crucial, and because the SusHeRE framework provides a domain-agnostic tool for RE, it adds to the body of new tools available to RE for handling the growing system complexity in all these contexts. Requirements engineers and domain experts are encouraged to use this framework as a basis for discussion to design sustainability- and health-driven solutions for each respective application area, and report on their experience. Furthermore, our vision paper can influence the RE community to foster sustainability and health goals through new joint research opportunities that collaborate with other domains for achieving these goals.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data

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Meira Levy is a senior lecturer at the School of Industrial Engineering and Management, Shenkar College of Engineering and Design, and a research fellow at the University of Haifa, Israel. Levy's research focuses on combining technology and design for promoting wellbeing, health, learning processes, decision-making, knowledge management, software development processes, organizational processes, and service design. Levy has published papers in international journals and conferences (e.g., in JKM, DSS, JISE, REJ, IEEE Software, Information Technology & People), and served as an organizer and PC member in conferences (e.g., CHASE, SEKE, ECIS, CENTERIS, CrowdRE and COGNISE, REWBAH).

Eduard C. (Eddy) Groen is a Senior Requirements Engineer and Project Manager at Fraunhofer IESE in Kaiserslautern (Germany). He is a cross-domain Digital Designer of software ecosystems, leads the development of Crowd-based Requirements Engineering (CrowdRE), and will coordinate Fraunhofer IESE's research program on Digital Sustainability. He holds a master's degree in Psychology and pursues a Ph.D. in Computer Science on CrowdRE at Utrecht University (the Netherlands) with Prof. Sjaak Brinkkemper. He co-chaired the Posters & Tools track at REFSQ'20, is a steering committee member for AIRE and CrowdRE, and received the Best Reviewer Award at REFSQ'23.

Kuldar Taveter is heading the Chair of Software Engineering at the Institute of Computer Science of the University of Tartu. He has co-authored a methodology for designing human-centric information systems, which is described in a monograph by MIT Press from 2009 and other publications. He has participated in several projects concerned with digital economy and proactive electronic public services. He coordinated the requirements engineering activities in the EU project Pharaon (2019–2024) on supporting older adults and their caregivers with information technology solutions. He has worked for longer periods in Finland, Australia, USA, and China.

Daniel Amyot is Professor at the School of Electrical Engineering and Computer Science of the University of Ottawa, Canada. He received a Ph.D. degree in Computer Science (uOttawa) in 2002. His research interests include requirements engineering, goal and process modeling, regulatory compliance, smart contracts, and healthcare informatics. Daniel led the standardization of the User Requirements Notation at the International Telecommunication Union from 2002 to 2013. Daniel was general chair of the IEEE International Requirements Engineering Conference in 2015 and program co-chair in 2018. He is also on the editorial boards of SoSyM and the Requirements Engineering Journal.

Eric Yu is Professor Emeritus at the Faculty of Information and Department of Computer Science at the University of Toronto. His research interests include software requirements engineering, conceptual modeling, information systems engineering, knowledge management, and enterprise modeling. He was the originator of the i* agent- and goal-oriented modeling framework, which brings social and organizational modeling into information and software systems analysis and design. A version of i* is part of an international standard. He received the Peter P. Chen Award in 2019 and the ER Fellow Award in 2022.

Lin Liu is Associate Professor at the School of Software, Tsinghua University, China. She currently leads the Tsinghua-China Life Industrial Safety Big Data Research Laboratory. Her research interests are in the areas of requirements engineering, Big Data Software, Smart Services for Safety and Health. Her research emphasizes concepts and modeling techniques for systematically analyzing software systems requirements, design methods and patterns for big data and intelligence applications. She serves on the Editorial Board of Requirements Engineering Journal, and Co-Editors for Recent Special Issues on Big Data Software Requirements, XAI Requirements, Generative AI for Software Engineering with Chinese Journal of Computer Research and Development.

Ita Richardson is Professor of Software Quality in the Department of Computer Science and Information Systems, University of Limerick, a Co-Principal Investigator in Lero – the Science Foundation Ireland (SFI) Research Centre for Software, and a Principal Investigator in the Aging Research Centre. She publishes and supervises students on research into Connected Health, Global Software Engineering, and Gender issues in STEM. This has been funded by a variety of agencies including SFI, Irish Research Council and European Union. Her collaborators have included Ocuco, Johnson & Johnson, University Hospital Limerick Group and the Irish Health Service Executive.

Maria Spichkova is a Senior Lecturer at the RMIT University, Australia. Her research interests are related to software engineering, HCI, Human-oriented software development, computing education as well as formal modeling, testing, and verification. Maria received her Ph.D. in 2007 from the Technical University of Munich, Germany, where she worked between 2003 and 2013, before joining RMIT in June 2013.

Alexandra Jussli is a doctoral student and research assistant at the chair of leadership and organizational behavior at the University of the Armed Forces Munich. Her work deals with the role of identities and global human needs in the changing world of work and new wort settings, such as digitalized workplaces, remote working, and agile teams.

Sébastien Mosser is an Associate Professor of Software Engineering at McMaster University and a member of McMaster Centre for Software Certification (McSCert) and McMaster Institute for Research in Aging (MIRA). He is an expert in software modeling, domain-specific languages, and language-based approaches. He started working on software engineering applied to the aging population in 2014 and has led several related projects.