Safeguarding Human Health: A Requirements Engineering Perspective

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Abstract

In our current day and age, the world suffers under the human ecological footprint, which influences our health and well-being. Technological solutions may help tackle these concerns for humanity. However, the development of such solutions requires special attention and effort in order to overcome human, political 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 workshop revolved around several questions prepared by the workshop co-organizers, plus several topics brought in by the experts. In a subsequent qualitative analysis, the emerging themes were arranged in a comprehensive sustainable-health RE framework. We present our framework, which includes four main sustainable-health RE 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

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are: **RE Techniques, Multidisciplinary Expertise, Education Agenda, and Political Ecology**. The sustainable-health RE framework supports the development of technological solutions that advance health and sustainability through these four goals, and provides a roadmap of development areas for the domain of RE. It emphasizes the complexity of developing sustainable-health solutions, the need for considering soft requirements such as emotional and social ones, as well as political considerations that may hinder implementation and stakeholder engagement. The framework also includes an educational agenda that can help requirements engineers acquire the range of capabilities that is necessary to effectively resolve the technological challenges concerning sustainability and health that lie ahead.

Keywords: Requirements engineering; Health; Well-being; Sustainability

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[†]. 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[‡]. Specifically, SDG 3 addresses the goal of good health and WB for all, and posits that good health and WB is directly related to sustainable development[§]. 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 in line with the EAT–Lancet Commission report[**] 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 fosters physical activity, reduces stress, and improves community, family connections, and WB[††]. 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).

Hence, our society faces a new challenge: 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)?

There are several initiatives in the public health domain aiming at this challenge. For example, one of such initiatives in the urban domain of Lima, Peru, which promotes the provision of healthier food options for people eating in city restaurants and schools[‡‡]. Another initiative by the Dublin City Council involves conducting accessibility and safety audits, with the goal of transforming the street and sidewalks to be more pedestrian-

† https://www.who.int/about/what-we-do

‡ https://www.raeng.org.uk/global/sustainable-development-goals

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

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

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

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

friendly[§§]. There is a call to thematizing sustainability goals in higher education (Antó et al. 2021), to make developers aware of sustainable challenges (Duboc et al. 2020), and create specific ontologies that can foster interoperability of systems for enhanced and sustainable processes (Howell, Beach, and Rezgui 2021).

The responsibility of contributing to a better world burdens every individual in all domains. Information technology, as an important enabler, makes Software Engineering 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 discipline 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 the 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 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. Seniors 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 technology innovations should not deteriorate access to applications by special needs groups, but rather provide greater accessibility. The matter becomes all the more difficult because, as well as 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 learn the effect of applications that promote health and sustainability over time.

The annually held IEEE International Requirements Engineering Conference (RE) 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. The Requirements Engineering for the Well-Being, Aging, and Health (REWBAH)[***] community fosters discussions related to RE resulting from the need to build software systems that not only support healthcare, but also promote well-being (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 latest online gathering on September 20, 2021, experts in this community started a discussion regarding the role of RE in addressing sustainability requirements for developing healthcare software systems. This exchange revolved around the following research question:

In what ways can RE foster sustainability with regard to software system development in the health and WB domains through *sustainable-health RE*?

In this 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 the developed system promotes a healthy life and sustainable goals. The paper is organized as follows: Section 2 presents the background regarding RE in the sustainable, health, and sustainable-health domains. Next, Section 3 presents the various aspects of sustainable-health RE goals as envisioned by domain experts. Section 4 accumulates the experts'

[§§] 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

[***] https://sites.google.com/view/rewbah2022

thoughts into a comprehensive sustainable-health RE framework. Lastly, in Section 5, 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, while 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)(Dekhtyar et al. 2019). Its idealistic roots were born from 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 software engineering, such as ethics (Marcos 2020), emotional impacts on WB (Stade et al. 2019), emotional requirements (Miller et al. 2015)(Taveter et al. 2019)(Taveter and Iqbal 2021), law & data privacy (Polst and Feth 2020), values (Perera et al. 2020), explainability (Chazette, Brunotte, and Speith 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, Ebrahimi, and Mahmoud 2020), and green software strategies (Horkoff 2021)(Condori Fernandez and Lago 2018)(Anwar and Pfahl 2017). The *SuSoftPro* tool (Alharthi, Spichkova, and Hamilton 2018) analyzes the requirements' impact on system sustainability, but works under the assumption that all requirements have been already elicited, making it primarily of use to the analysis phase of RE process. There were also some attempts to cover sustainability requirements for systems within particular domains, e.g., the analysis for e-Learning systems (Alharthi, Spichkova, and Hamilton 2019) or on digitalization in rural areas (Ferrari et al. 2022). However, few studies or models explicitly explore how the SDGs pertain to RE and software engineering, or how software systems pertain to SDGs, even though this is an important line of research (Seyff and Lammert 2020). 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), held since 2012 until its tenth edition in 2021, which among other things led to the Karlskrona Manifesto for Sustainability Design in 2015 (Becker et al. 2015). Over the years, a growing interest of RE in sustainability can be observed (Venters et al. 2017).

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 ISO 14001 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. (Venters et al. 2017) expanded this dichotomy of sustainability in RE, inspired by the triple bottom line[†††], 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.

A recent mapping of SusAF and its categories onto the SDGs identified that SDG 3 specifically 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 (Seyff and Lammert 2020). We argue, however, that social sustainability is a major contributing factor to well-being. Specifically, we believe health and WB are predominantly achieved through improvements in individual, social, and environmental sustainability constructs.

2.2. Health and RE

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

Realizing that healthcare systems are often large-scale, complex, and involve many kinds of uncertain knowledge 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, Liu, et al. 2021). In the first workshop, the participants collaboratively identified the challenges REWBAH research should address (Levy, Liu, et al. 2021), including:

- Balancing user needs with technical limitations and costs;
- Properly considering the high number of adjacent domains, ranging from medicine (to ensure medical validity), design, 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;

[†††] https://en.wikipedia.org/wiki/Triple_bottom_line

- Developing multi stakeholder platforms across the boundaries of institutes and private homes, as we are moving from point-of-care toward continuum-of-care systems.

2.3. Sustainable-Health and RE

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. There are papers that address sustainability and health in regard to software development (Ouhbi et al. 2018)(García-Berná et al. 2021), focusing on sustainable requirements that the system should address ranging from engaging people to use the system to reducing the energy consumption of the system. Even using a simple search query on Scopus[‡‡‡], we have not found any conference or journal paper that connects together health and sustainability requirements in the way that combines both domains in a holistic manner for joint goals. Moreover, there are no known RE methodologies for defining these requirements simultaneously, which would allow people to realize the mutual influence of sustainability and health.

3. Discussion themes

In the REWBAH'21 workshop, we initiated discussions about the way RE can promote sustainability and health and leverage the connection between them. The discussions were performed in Google Docs, a collaborative online rich text editor that could be accessed by all of the workshop's participants; approximately 30 domain experts, predominantly scholars in the domains of RE and healthcare. The workshop organizers prepared five guiding questions to spark the discussion and encouraged participants to contribute further questions of their own, resulting in four additional guiding questions for a total of nine. Following the workshop, the participants who expressed an interest in making further contributions were invited to partake in elaborating and refining the answers further. 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. appropriate *RE techniques* for elicitation and validation (Section 3.1) address the relevance of RE methods for eliciting requirements, and
2. the necessary *interfaces of RE* to society, domains and disciplines to achieve improved health and sustainability (Section 3.2), which relate to educating and engaging people with inclusivity-, health-, and sustainability-promoting systems; influencing policymakers; educating RE students and experts; and learning from other domains while becoming self-aware about the health-sustainable challenges and behavioral impact.

3.1. RE Techniques

3.1.1. 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 multi-agent goal models (Horkoff and Yu 2014)(Miller et al. 2014)(Mooses and Taveter 2021), user stories (Dalpiaz and Brinkkemper 2018)(Tenso et al. 2017), or combined goal/process modeling (Amyot et al. 2022) can be applied to the design and development of healthcare software systems. However, to address the behavioral change focus of such systems, RE techniques should take advantage of

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

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 it has been validated across a variety of preventative health behaviors, including physical exercise (Paech, Luszczynska, and Lippke 2016)(Scholz et al. 2008), nutrition (Schwarzer R and Renner B 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[§§§] 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 (DT) can also help to elicit the requirements about the current processes and create new ideas and the way to limit existing needs (Hehn and Uebernickel 2018). An example of a requirements elicitation approach inspired by DT is the do/be/feel™ method of co-design (Lorca, Burrows, and Sterling 2018), which has been successfully applied in several health-related case studies, e.g., (Miller et al. 2015)(Taveter et al. 2019)(Mooses and Taveter 2021), as well as the PHArA-ON research project[****] (Mooses et al. 2022). Such approaches function as frameworks to efficiently incorporate qualitative, experimental, and other methods into the requirements elicitation. 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)).

Another important consideration is whether we should reinvent the wheel or reuse sustainable-health systems. For example, can healthcare software systems be duplicated easily in different cultures? To find an answer to 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 (culturally) constructed emotion (Taveter and Iqbal 2021)(Barrett 2017)(Boiger and Mesquita 2012).

It is also important to note that requirements related to WB evolve over time, considering the health status of the user. A senior citizen with 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-methods studies offer both objective and subjective evaluation of the software systems, and need to be encouraged as an academic best practice.

3.1.2. 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 for how to assess and integrate such aspects in RE projects and practice is lacking (Watson, Noyes, and Rodgers 2013). This requires developing reference case studies, leveraging social media, podcasts and YouTube videos, or bite-size learning to educate and encourage people to adopt sustainable and healthy habits. The challenge to 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 DT – in an integrative way, which allows the

§§§ https://unfoundation.org/what-we-do/issues/sustainable-development-goals/
**** https://www.pharaon.eu/

participation of all relevant user groups. Recent literature highlights that fostering diversity in RE projects is a main issue for social cohesion, representing a major challenge for sustainability (Wohlrab, Knauss, and Pelliccione 2020).

To increase guidance for students while avoiding biases, the aforementioned case studies must be peer-reviewed by instructors, and packaged in a way that makes them reusable. Not all RE techniques are created equal, and a real effort is needed to provide success stories as well as failures descriptions to students and fellow instructors.

3.1.3. 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 software engineering 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 issues; 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 particular applications.

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

Searching the literature of RE shows that there is a theoretical gap regarding the way RE influences policymakers (Bergman, King, and Lyytinen 2002), and as a result we call for understanding the political ecology in RE in general, and in the sustainable-health context in particular.

3.1.4. 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 like 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, Nayebi, and Ruhe 2019) and Crowd-based RE (Groen, Seyff, et al. 2017) 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 software engineering, 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 representing those settings.

3.1.5. 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 that even the style in which the requirements are written might play 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, they 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. 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, Groen, et al. 2017) 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.

3.2. RE Interfaces

3.2.1. 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, like podcasts and publications by 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 grey literature reviews (Garousi, Felderer, and Mäntylä 2019), that can prepare RE practitioners for the societal challenges with health and sustainability. 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 were taken into account during requirements elicitation. Qualitative approaches from empirical studies and empirical software engineering[††††] can help, as well as HCI methods. These methods can help characterize the best practices and/or workarounds to guide development, systematize the capitalization of information acquired through experimentation with the user and their ecosystem, and support agile developers to systematically consider the capabilities of people in interactions with their solution, in particular during the evolution of applications.

3.2.2. 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 and services. As a result, RE not only contributes to making software engineering more sustainable, i.e., technical sustainability, 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 (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

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

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. (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 particular 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 through the use of fewer resources or a more responsible choice of foodstuffs also have a growing need for support through software systems. For example, Penzenstadler et al. (Penzenstadler et al. 2018) designed a sensor-based system for resilient smart gardens, while in (Penzenstadler 2015), Penzenstadler 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 aforementioned 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, Shani, and Leary 2008)(Sommerville 2015)(Sterling and Tavares 2009)(Norta et al. 2014), which consist of interacting humans and technical components that operate within an organization. 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 organization model for the organizational 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 that is used (Sterling and Tavares 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 translate experiences with digital ecosystems – e.g., (Norta et al. 2014)(Naab, Rost, and Knodel 2018)(Hess et al. 2015) – to biology, where sustainable controlled ecosystems under development might struggle with similar overly optimistic expectations regarding the lead time and break-even point, or where a lack of monitoring potential prevents 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 an RE expert for themselves. If, like Wikipedia, RE education, information or projects are made freely available, it could over time become an engaging two-way open-source project to solve complex world problems.

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

Health and WB are abstract concepts to many decision-makers (especially in for-profit 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[‡‡‡‡]). 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 3.1.4).

At an organizational level, RE should ideally align with the 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.

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, for example, screen time, spending habits, choice of cooking versus ordering out. RE today has the opportunity to 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 required from the user as found in behavior 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 (ML) to capture some user parameters to continuously update their requirements and align them with the health and sustainable goals will be revolutionary and helpful.

3.2.4. 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 the 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.

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

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 known. 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 with an origin in social and behavioral sciences that are aimed at reducing 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, healthcare or environment sciences students tend to remain focused on the problem, without really being equipped with the right 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. 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:

- SE/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 enough awareness about the potential issues that need to be addressed, for example in making sure that the new systems are truly sustainable.

Technology today is a commodity, and all businesses are being digitally transformed. Thus, there is a big gap between what education offers and what practice needs. RE needs to help domain experts by providing continuous education on eliciting requirements when they work with IT teams, as well as 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. Education alone can foster mutual curiosity and respect among disciplines.

4. A Comprehensive Sustainable- Health RE Framework

To highlight the essence of the discussion in Section 3 regarding the role of RE in promoting sustainable-health software development, we converged it into a comprehensive sustainable health RE framework by

grouping together the cross-cutting topics of these discussions. This framework includes four main RE goals for sustainability and health, which we define according to the change in RE we believe is necessary, and how this should positively affect sustainability and health.

- **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 modelling; 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 keeping privacy. This RE goal was predominantly based on Sections 3.1 and 3.2.4, and in part on Section 3.2.1.
- **Multidisciplinary Expertise:** RE must integrate knowledge and concerns from diverse perspectives and disciplinary domains, so that we will 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; health sector; environmental sector; economic sector; agroecology; anthropology and culture; sociotechnical systems; guidelines for inclusive RE; and realizing various opinions, not necessarily from academia. This RE goal was predominantly based on Section 3.2.2, and in part on Sections 3.1.1 and 3.2.4.
- **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 curriculums, for example: soft skills; qualitative research; design thinking; guidelines; shared experience; multidisciplinarity; and leveraging social media and other media opportunities. This RE goal was predominantly based on Sections 3.2.2 and 3.2.4, and in part on Sections 3.1.1, 3.1.2, and 3.2.3.
- **Political Ecology:** RE experts must be skilled in communicating 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; visualization; public decision-maker; community leaders; and common vocabulary. This RE goal was predominantly based on Sections 3.1.3 and 3.2.3.

Error! Reference source not found. presents the overall structure of the framework, providing identified strategies for each goal.

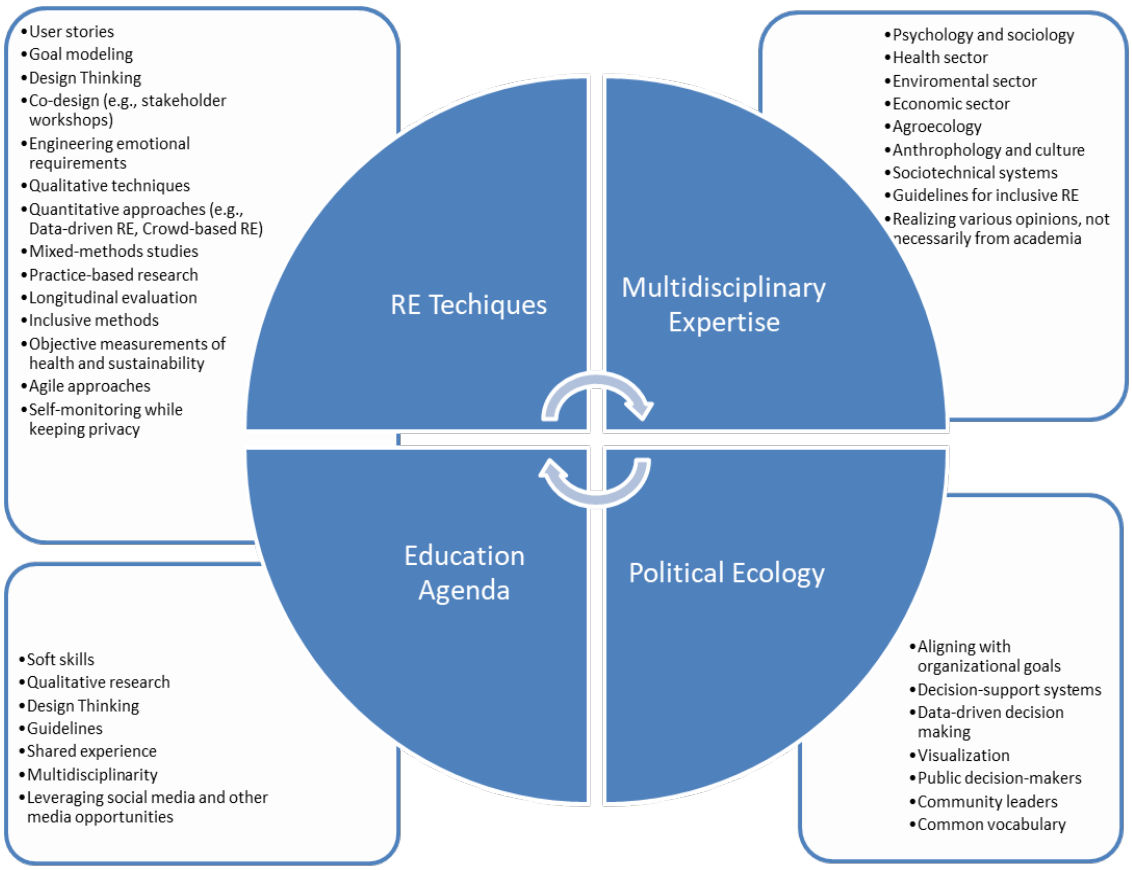

Figure 1: A Comprehensive Sustainable-Health RE Framework

5. Conclusions and Future Work

In this paper, we sought to elaborate on the research question: "In what ways can RE foster sustainability with regard to the UN SDG 3 and to software system development in the health and WB domains?" We narrowed down our treatment of this question to the area of "software engineering 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 originating from the REWBAH'21 workshop, we addressed two overarching topics: 1) appropriate *RE techniques* for elicitation and validation, and 2) the necessary *interfaces of RE* to society, domains and disciplines to achieve improved health, WB and sustainability.

The cross-cutting topics of our discussion converged into a comprehensive sustainable-health RE 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) the interdisciplinary nature of sustainability in healthcare and WB and the relevance of sociotechnical systems' approach in this area; 3) the importance of teaching soft skills and interdisciplinary methods in RE, and 4) the need to support public and communal decision-makers by 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 software

engineering are to make a substantial contribution to SDG 3 by developing software solutions that sustainably promote good health and WB.

There are several threats to the validity of our work that can help identify future research directions. In terms of internal validity, and despite the 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 software engineering 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 **Error! Reference source not found.** to comment and to validate the proposed framework in various contexts and challenges, while reporting on requirements elicited for 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, although there is much potential to do so. We are especially aware that the construct of sustainability is highly interrelated. 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 that we did indirectly touch on those (e.g., in Section 3.2.2).

Through our paper, we wish to inspire more collectives like ours to form, who will analyze the contribution software engineering can make to significantly impact the other SDGs. We also encourage alignment between these efforts to mutually inspire frameworks, roadmaps and efforts to safeguarding sustainability.

Acknowledgements

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