Sustainability Design in Requirements Engineering: State of Practice

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ABSTRACT

Sustainability is now a major concern in society, but there is little understanding of how it is perceived by software engineering professionals and how sustainability design can become an embedded part of software engineering process. This paper presents the results of a qualitative study exploring requirements engineering practitioners' perceptions and attitudes towards sustainability. It identifies obstacles and mitigation strategies regarding the application of sustainability design principles in daily work life. The results of this study reveal several factors that can prevent sustainability design from becoming a first class citizen in software engineering: software practitioners tend to have a narrow understanding of the concept of sustainability; organizations show limited awareness of its potential opportunities and benefits; and the norms in the discipline are not conducive to sustainable outcomes. These findings suggest the need for focused efforts in sustainability education, but also a need to rethink professional norms and practices.

Categories and Subject Descriptors

D.2.8 [**Software Engineering**]: Requirements/Specification

Keywords

Sustainability, Requirements Engineering, Perceptions, Sustainability Design, Obstacles

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1. INTRODUCTION

As software systems are increasingly embedded in the social and technical fabric of our society, the role of software engineering (SE) is shifting [1]. From a narrow technical profession that builds software systems, software engineers are emerging as change agents as software technology is increasingly acknowledged as a transformative force in society [2, 3]. The importance of understanding the wider socio-technical systems in which software is embedded has been emphasized in the past decade, foremost in areas such as safety and security [4] [5]. But there is more to it than that in a highly connected world: It is suggested that every line of code has not just financial and technical implications, but also moral and ethical consequences, as software services shape and inform human behaviour [6].

In daily SE practice, decisions are made that directly affect the functional behaviour and system qualities of specific software systems. These decisions have direct and indirect effects on the socio-technical systems into which these software systems are integrated; as well as far-reaching systemic effects accumulated through their longer-term continuous usage. Such effects have been recognized by some of the Codes of Ethics for the software engineering profession, which emphasize the significant opportunity that the developers of these technologies have to do (and influence) good or harm [7].

Sustainability is generally defined as the capacity to endure [8]. This concept interrelates five dimensions [9]: environmental, economic, social, individual, and technical. The *environmental* dimension refers to the responsible use of natural resources. The *economic* focuses on assets, capital and added value, which includes wealth creation, prosperity, profitability, capital investment, income, etc. The *social* one is concerned with societal communities (groups of people, organizations) and the factors that erode trust in society. The *individual* dimension covers individual freedom and agency. Finally, the *technical* relates to the endurance of artificial systems.

A rising concern for sustainability has brought the effects of software systems in these dimensions into the spotlight [9, 10, 3]. With this comes increasing questions about how to understand and consider them as part of software engineering. *Sustainability design* refers to the commitment to treat sustainability as a first-class concern in SE. As a fundamental precondition for the continued existence of a system and a factor that is influencing many system goals. This begins with Requirements Engineering (RE) [3, 11]. However, the adoption of sustainability design practice is under-investigated in the field of SE. It is not yet clear what motivates practitioners to engage in this topic and what holds them back. But if SE as a discipline is to arrive at a new understanding of its role in society, we should start with an investigation into its own perceptions, and how these perceptions influence SE practice.

This paper characterizes the current understanding of sustainability in SE through a qualitative interview study with requirements engineers. We aim to answer two closely related questions: (1) What are the current perceptions and practices of sustainability design in RE practice? (2) What are the challenges perceived by RE practitioners for engaging in sustainability design? We take this as a starting point to identify promising leverage points - effective places of change in the software profession - that would facilitate adoption of sustainability. The focus of our analysis begins with RE, since it has the greatest influence on the sustainability of software systems [11].

In Section 2, we discuss related work to examine why useful SE practices are not adopted. Section 3 presents the design of our interview study. Section 4 presents key findings, and Section 5 examines obstacles to sustainability design and possible interventions. Section 6 discusses limitations of the study. The paper concludes, in Section 7, with a set of research priorities that highlight the interdisciplinary nature of the challenges the discipline is facing.

2. RELATED WORK

Useful practices are often not adopted even when organizations recognize the value of adopting them [12, 13]. In order to draw parallels on the adoption of sustainability design, we examined the SE literature so as to identify why existing good practices are often overlooked and ignored.

It has been recognized that there is a general mismatch between the theory on what should be practiced and the actual practice [14, 15, 16]. However, there is no consensus regarding the underlying reasons as to why such practices have not been widely adopted by the SE community[1].

Evidence suggests that at the *level of an individual*, poor adoption is often due to the lack of education and experience. For example, Regev et. al., [18] state that use of good RE practices in industry is hampered by a poor understanding of these practices and their benefits. To address this, they suggest that teaching RE at university level is essential. Similarly, Bull and Whittle [19] argue that SE is a creative process that is fundamentally about designing solutions to problems that require reflection. However, reflective practice is rarely taught explicitly in software engineering education. Moreno et. al., [20] found that the knowledge required to successfully integrate good practices into SE tasks was beyond the classical technical knowledge taught in most undergraduate and graduate SE programs.

Others see the reason of why practices are not widely adopted more as a fault at the side of the researchers. Glass [14] argues that *researchers simply do not have the required experience to make their theories the solution of choice.* Additionally, Beecham et. al., [15] found that with regards to the Global Software Engineering practices, practitioners perceive the input provided by researchers as potentially useful, but do not read research articles because of their inaccessibility. Moreover, they suggest that a *leap of faith is required to apply a theory that has not been proven in practice first.* Similarly, the personality of the individual software engineer can hamper the adoption of practices. Riemenschneider et. al., [12] highlight that while many organizations attempt to deploy methodologies intended to improve software development processes there is *resistance by individual software developers* against using such methodologies, which often obstructs their successful deployment. Toma, Auruma and Vidgena [21] suggest that the mismatch between academia and industry concerning the nature of technical debt increases the risk that intuitively attractive but sub-optimal heuristics may be adopted out of necessity by practitioners. Their study revealed precedents of technical debt to include pragmatism, prioritization, attitudes, ignorance and oversight. However, these precedents are not mutually exclusive and would be expected to manifest in various combinations and weights in different situations.

On the *level of professional environment*, it is the organizational culture that is believed to strongly influence the adoption of practices. For example, Ahmed et. al., [22] argue that when institutionalizing software product lines within an organization, organizational behavior plays an important role. Additionally, *extra costs are named as one of the reasons* why certain best practices are not implemented [23]. Lavallee and Robillard [24] also highlight how organizational factors such as structure and culture have an impact on the working conditions of developers. Their preliminary results show that many decisions are made under the pressure of certain organizational factors, which negatively affected software quality.

Finally, on the *level of norms in professional practice*, it is suggested that there is a need not only to understand the properties and behavior of software, but also the behavior of software engineers, development teams, and organizations [25].

In summary, the literature identifies several levels at which adoption of "proven" useful practices can be hampered. Researchers, practitioners, teams, organizations, and professional practice regulators could all be responsible to a certain degree. But which of these potential forces are relevant in the case of the adoption of sustainability design practices in RE?

3. INTERVIEW STUDY DESIGN

As part of a broader investigation into sustainability design, this paper reports the results of an exploratory qualitative interview study on the current understanding of sustainability and its related practices in the requirements engineering profession. The study design is described below.

[1]We do not review work on technology adoption (e.g., [17]) since we treat sustainaibltiy as a design concern, not technology by itself.

1) At the *Planning* stage, the interview questions[2] were designed collaboratively by all authors. The study was piloted with one interviewee to validate clarity of questions and the interview structure. Given that no major changes were required, this interview was also considered in the analysis following the guidelines in [26].

The first stage of the interview centered on background information, finding out how requirements engineering professionals define sustainability, and on relevant activities they undertake in their daily personal and professional lives. The participants were then asked to read through a brief document outlining principles of sustainability design [27]. The second part of the interview focused on eliciting feedback on if and how the practitioners would conceive to use these principles in their work life and what would be the expected difficulties in their adoption.

2) The *Data Collection* was undertaken both through in-person interviews and via an online-conferencing software. We interviewed 13 requirements practitioners from 8 countries (Austria, Brazil, Germany, Spain, Switzerland, Turkey, UK, and the USA). All interviewees work in companies, spend at least a third of their time on RE activities, and have a minimum experience of one year full-time or two years part-time in RE. Additionally, the interviewees fulfilied other roles in their companies such as project managers, product managers, and developers. The interviewees (8 male, 5 female) had a mix of educational background (3 PhD, 7 graduate and 3 undergraduate degrees). Their ages ranged between 25 and 59, with 6 interviewees in the 30-39 age bracket. The mix of businesses covered in the study included 3 small (1-49 employees), 6 medium (50-999), 2 large (over 1000 employees), and 2 Enterprise companies (over 5000 employees). The business domains varied from e-Voting to Enterprise Resource Planning, Software as a Service, security, embedded systems, hardware distributors, civil aviation, and energy.

10 of 13 interviews were held in English, 3 in Spanish. All participants were native or fluent in the language of the interview. All interviews were recorded and transcribed in their original language. Spanish transcripts were translated into English for analysis.

3) For *Data Analysis*, we used the qualitative content analysis method [28] to extract views and perceptions on sustainability from these interview transcripts. A minimum of two analysts read each of the interviews and coded the text with conceptual categories relevant to sustainability perceptions, as well as peer-reviewed each other's work. An initial set of codes were created by the first coder and was updated with each following coding activity. The initial codebook, as well as the updates, were discussed and agreed upon by all co-authors of this paper, who are also the researchers that worked on the coding task. A web-based text analysis tool [29] was used to support the coding and review process. Within the framework of qualitative content analysis, we used a mixed approach of inductive category development and deductive category application [28, 30].

Key findings of this interview study fall into three sections, as summarized in Table 1, and are discussed in the following sections. We reference the individual interviewees by fictitious names to ensure anonymity.

[2]The questions and the codebook for this study can be found at http://sustainabilitydesign.org/2015-interview-study.

Table 1: Key areas of findings on 3 levels.

Category	Finding
Individual findings	Sustainability as environmental or financial
	Sustainability as separate from SE
	Sustainability as a nice-to-have quality
The professional environment	Lack of methodological support
	Need for mentality change
	Assumed costs as barrier
	Concerns of small companies
	The role of the customer
	Companies lack time
	Engineers lack management support for it
	Doubts about benefits for business
	Perception of trade-offs and risks
Norms in SE practice	Project success assessed at delivery only
	Poor communication of sustainability values
	Regulations are drivers for sustainability

4. STUDY FINDINGS

4.1 Individual Findings

What is sustainability about? We observed that only 3 out of 13 interviewees (Ray, Liz, Sam) relate sustainability to its systemic and broad context. Ray noted that sustainability is about allowing humans to "thrive". Liz - similar to Sam - stated that sustainability is "a general, wide-reaching goal of making human life non-damaging to the planet", and that this is relevant for the present and the future as well as for individuals and societies. These 3 individuals view sustainability as comprising of environmental, social, individual, and organisational concerns.

In contrast, the perceptions on what sustainability comprises are much more *narrow and segmented* among the rest of the interviewees, with each of them focusing on one or a few specific topics.

Typically, interviewees perceived sustainability as an issue of *natural resources availability and waste reduction*. For them, sustainability is about making "the use of non-renewable resources efficient" (Amy) so that the society "can still go on like thousands of years without running out of the resources" (Eve).

Business and its process continuity is seen as another major issue in sustainability. A number of interviewees (Cat, Eve, Pat, Ray) refer to the need for business to be continued in the long run.

Another topic closely related to quality is that of *support for change in software*, which was the key notion of sustainability for Max. To him sustainability is about "[...] supportability, reusability, maintaining and updating [...]" or in short about "Agility to update.".

Is sustainability separate from SE? Several interviewees (Ben, Pat, Eve, Jen) explicitly *saw sustainability as a separate field from that of Software Engineering*. Eve stated, "I am surprised that you are addressing this sustainability issue in the context of SE." This stems from their notion of sustainability as only "[...] limited to natural resources [...]" (Ben), and the view that things related to sustainability are "[...] perceived as being onerous and it's not benefiting us as a business [...]" (Pat).

Is sustainability an optional quality? Three interviewees (Jen, Eve, Pat) saw sustainability as a unique selling

point of the software development process, and the software system itself. However, they suggested that sustainability should be considered once other priorities have been established. For instance, Jen stated "right now, when we are developing the software we only consider the performance of the system [...] but on top of it, probably the energy consumption and sustainability requirements might be added." She then added that "at the end, when it comes to developing the software, you are bound to a paying customer and they should be willing to participate in such an activity [...]". Ian thought that sustainability would be in competition with other non-functional requirements (NFRs), stating that "if you want to be more sustainable, most of the time you have higher costs, and maybe most of the times other NFR may be less beneficial". Pat, working in a startup, felt that being sustainable was out of his hands as he rented the office space, so "energy management, waste and stuff like that, is influenced by [...] the policies they [space owners] have in place". He further noted that as the company grows "hopefully, in the future, we can start doing things in a more sustainable way, from the green perspective". Thus, sustainability is mostly seen as only an environmental issue which has little to do with the work of software development in the first place. Yet, some think it would be "nice" to consider sustainability as an NFR, if everything else has been addressed.

These misperceptions of sustainability focus purely on the environment and disassociate sustainability from SE. This corresponds to the responses provided on how interviewees address sustainability in their daily private and work lives.

Actions on Sustainability. – So what do RE practitioners do to support sustainability in their daily private and work lives? The vast majority of the responses on private life actions were about recycling and/or reuse, saving energy by switching off when not in use, reducing water usage, and using public transport or cyclying for travel. Max noted the long-term reuse of personal knowledge, and Sam considered issues of community and individual life quality. Ben and Eve reported doing nothing related to sustainability at all.

Similar responses on actions related to sustainability were reported on within the work sphere including reduction of paper use (Jen, Kim, Cat, Liz), reduction of energy use by switching off unused devices, moving to more energy efficient hardware (Jen, Ian, Dan, Liz), use of public transport for work travel (Pat), and reduction of waste from printers (Eve). Two individuals discussed social aspects of sustainability at work, with respect to sustainable work schedule management (Sam) and employee disaster care (Ray). Only Max related sustainability to engineering practice in terms of reusing knowledge for change support and evolution in software.

Two more individuals noted that their organizations pursue sustainability-related certification, either directly (Kim) or through work with clients (Ian). However, they knew very little about the actual implications of this certification, as this had no or little effect on their daily work as requirements engineers.

Personal Responsibilities. Some interviewees denied responsibility for sustainability or acknowledged only a very small share in it. For example, Ian stated: "I am trying at least not to be wasteful. I try to avoid too much plastic [...] when it is easily possible.". Cat pointed out that the customer was responsible for the final decisions: "maybe, I can do something that I think is super sustainable and that will go well and such, but if he [the customer] doesn't have the vision that this is important, [...] it would never be done".

Several interviewees believe that the decision regarding sustainability should be made by higher management such as executives and project managers (Cat, Ben, Ian). Ian, for example, stated that "[...] it is really a political discussion that should happen on the executive level and it is difficult for a requirements engineer to have an impact there". Others think it is the customer who needs to request a sustainable system (Eve, Pat). Jen believes the requirements engineer and the software architects (designers) do have the power to actually design sustainability into systems. However, she argues that currently they often only focus on technical aspects. Eve thought that because of limited design possibilities in hand, none of the roles has the capability to make changes for sustainability at the company: "[...] I think we are very limited in our possibilities to change anything". This also indicated a low sense of personal responsibility in professional life.

4.2 The Professional Environment

Our interviewees reported that there are a number of factors in their professional environment that hold them back from engaging in sustainability design.

Lack of Methodological Support. Several interviewees (Jen, Amy, Liz, Eve) suggested that they *cannot practice sustainability design as it is not supported by the methodologies* used in their companies. For instance, Jen says that her company uses a waterfall methodology, but she cannot apply sustainability to her work as "the waterfall lifecycle does not contain any concepts of sustainability." This is echoed by Amy who stated that "we work with quite clear methodologies in each phase of the project. [...] if it [sustainability] isn't justified by the methodology, it is difficult to incorporate".

They further note that there is a general lack of such methodologies in SE. For example, Eve suggested that "there must be much, much more information and techniques and methods available in order to help the developers, REs, project managers and usability engineers".

Need for Change of Mentality. One of the major difficulties in adoption of sustainability design is that it would be difficult to convince people they work with to *change their way of thinking*. Pat says that "convincing them and getting them to change their way of thinking" will be the key challenge in adopting sustainability in his company. This difficulty is related to the *inherent unwillingness to change*. Sam and Ray anticipate reactions such as "if we have ever done it in this way, why would we change? " and "how am I going to be reviewed on this?", respectively. But it also comes from the *already excessively fast-paced markets*. Sam notes that "we are moving forward already at a really fast and maybe even unsustainable speed [...]. And so, asking people to [...] think about doing things differently while they still have day-to-day goals can be pretty challenging."

Another compounding factor here is (as per Ray, Liz, Cat, Eve) the *number of parties* involved that need to agree to a change. Liz notes that it is not only about RE professionals, but also about the whole "industries and policy people who have a hard time thinking in those [sustainability] terms ".

Moreover, Ray notes the need to "have people to truly agree on a *shared vision* of sustainability and work towards it". This point is confirmed by Kim and Ben, with Ben stating that "the *commitment of all the team* is necessary for practicing sustainability design in an organization". Eve highlights that "such a commitment would require awareness by all roles", which according to her, "is a major obstacle".

Economic Constraints and Short-term vs Long-term Trade-off. An unsurprising factor that made several interviewees reluctant to practice sustainability design concerns the *assumed costs of doing* so (Ray, Eve, Ian, Amy, Ben and Kim). There is a general underlying assumption that practicing *sustainability requires extra work*, which inevitably means extra costs. Kim, for example, believes that money will need to be spent in "making people understand and getting the stakeholder involved", while Amy expects "the extra costs to be incurred in the system analysis or implementation". Interestingly, Amy believes that "the cost would not be a problem if it was justified by the methodology". Similarly, Eve is concerned with the extra costs and risks when "you add some *functionality only for sustainability* purposes", which suggests that sustainability itself is not a good enough reason for the extra work.

Even when interviewees see the potential gain from sustainability engineering, they may still feel unable to commit to it due to *additional initial investment needs*. Thus, Ben notes that "what one is looking for is to make the most money in the shortest time possible [...]. If we want to implement or adopt sustainability in our company [...] we have to make an initial effort, or we have to invest time, resources and money to later collect the rewards". He then suggests that "this requires agreement from many actors within the company, which is not an easy thing to achieve".

Small Company Concerns: Client's Satisfaction and Costs. Pat, Max and Ian work in small companies with under 50 employees. They highlighted that the key priorities in their work life are focused on good relationships with their clients. This means that the companies are very responsive to the customer requests, in terms of *delivery time, acceptance of customer viewpoints, and costs*. For instance, Pat notes that his company is "[...] based on being reactive, it's about building a relationship with these clients and customers and it's in a way is... you know [...] impressing them ". While Ian and Max agree that though sustainability is a worthwhile cause, they would rather leave it up to the customer to prioritize it. As stated by Max, "you've got to shy off pushing this too much by becoming an evangelist if you're pushing against an emotively held big belief of the customer because you would just never make a sale." Moreover, all three interviewees were concerned about the potential loss of clients due to costs. Ian states, "it would cost more and it might be cheaper, for our customers, to switch to another partner, who is not in this topic and don't care about sustainability, but just doing their job in the cheapest way".

Limited resource availability is another issue raised by the small companies. Pat, for example, stated that sustainability design "would require us to do extra things which we do not have resources for". This point is closely related to the cost argument, but considered from the manpower and skill availability perspective - small companies do not have access to either on short notices.

Stakeholder for Sustainability Requirements. Possibly as a consequence of the importance of customer satisfaction to companies, some interviewees (Cat, Eve, Ian and Jen) clearly indicated that sustainability design must be either driven or approved by the customer. Ian, for example, states that "his company likes to work in a sustainable way, but asks "whether their customers also put a high priority on sustainability".

This belief comes partially from the underlying assumption that the customer will have to pay extra for sustainability design (Eve, Ian, Jen). Eve, for example, stated that "addressing this issue requires extra work and this extra work has to be paid by someone – the customer".

Several of the interviewees (Cat, Eve and Jen) think that if the customer is not interested in sustainability then the company is left with no choice but to avoid it. This is clearly stated by Cat who said that "the customer is asking me this, I know it will not be sustainable, but *I have to deliver this now because it's what he wants*". Ian, on the other hand, believes that his company has "the power to make the customer aware that sustainability is important for him and the corporate business image", and therefore worth pursuing.

Lack of Time in Companies. Some interviewees (Ben, Cat, Pat, Amy) commented on lack of time as a key factor preventing them from practicing sustainability design. This issue is clearly voiced by Cat, "*as there is no time, you do what you can*. And perhaps this [sustainability design] is pushed down" and "it gets forgotten there in a corner". This same interviewee states that when the customer asks for something unsustainable, the company cannot waste time in reasoning about it, but will simply implement it and "yit is the customer's problem". "Deep down everyone wants to do well, but there is no time", says Cat. Amy agrees, "it is not intentional, it is because of specific needs of projects that, unfortunately, [engineers] do not usually have this [time]".

Lack of Management Support. Organizations are typically structured in hierarchies, which can make individuals in lower levels feel unable to make bigger changes without management approval. This view was very clear in several of our interviews (Amy, Ben, Cat, Dan, Eve, Jen). Cat noted that if her manager does not share her ideology, her sustainability ideas might never be prioritized and implemented. Amy agrees that sustainability needs to "be supported from above [the directive layers] so that this is *understood as part of the company*". However, convincing the high management of the need for sustainability is a tough challenge and cannot be done without proof of extra financial resources (Ben, Dan, Jen). Ben, for example, says he "would need a deeper study of both the situation and of the benefits [...] to talk to my managers", while Jen states humorously "if it brings more customers or it brings more money, it would be easy. Like always".

Doubts about the benefits for business. Three interviewees were skeptical about the benefits that sustainability could bring to businesses. Pat compares sustainability design with form filling and says "it's *not benefiting us as a business*". Jen fully agrees. Similarly, Kim believes that even though "software can do a lot to bring more sustainability, [...] *some software just don't have anything to do with sustainability*".

Requirements Trade-offs and Risks. Finally, some interviewees had implementation concerns with respect to sustainability. Ian believed that *sustainability competes with other requirements*. He exemplifies that redundancy is needed

for safety, but it also requires more resources and power.

Eve and Kim thought that sustainability may impose risks. Eve notes that "when you add some functionality only for sustainability purpose, of course, there is [...] *extra risk for an error somewhere in the system*". Kim, on the other hand, took the viewpoint of the customer, reasoning that a system change driven by sustainability could not be implemented if it had a negative effect on the customer.

Typical beliefs at the organizational level are summarized in Table 2.

Table 2: Needs in Professional Environment

Sustainability needs...	**So organizations need...**
to be part of SE methodology	to adopt new methodologies
a change of mentality	to invest into vision building and training
investment	to commit resources
to be considered for all software	stakeholders to ask for it
be considered beneficial	demonstrated business benefits
time commitment	time saving alternatives
management support	proof of utility to management

4.3 Norms in Professional Practice

We observe a clear influence that the current professional practice guidelines and norms[3] have on the practice of sustainability amongst the RE practitioners. The influence of these norms and guidelines transpires through a number of avenues, some of which are discussed below:

Fixed Point in Assessment of Project Success. Many of the presently practiced software engineering methodologies advocate for a clear project completion point. If the project is delivered on time, within budget, and is accepted by the client - the project is deemed to be a complete success. As stated by Ben "once this solution has been delivered and executed, we stop having influence on how the client will use it or as the client wants to take it". In other words, at this point the interviewee feels convinced that his job is well done and completed; the responsibility of the software developing organization is considered to be discharged.

This point is also observed by Ian. He comments in the second stage of the interview: "I think it is upfront sometimes difficult to forecast how sustainable something really is and over time once [...] everything is deployed, there will be more concrete data available, which can then, in turn, be very useful for fine tuning and optimizing and maybe even correcting some of the requirements. And that of course could, along with awareness, also have a positive impact on sustainability."

Poor Communication of Sustainability and Certification Values. The comments of our interviewees suggest that in many companies, there is little awareness of the systemic nature of sustainability values, little communication across professional boundaries, and little assistance provided to software engineers to support their understanding of sustainability issues. Although several companies promote reduction of waste, recycling, paperless operations, use of public transport for travel and alike, these sustainability-supporting behaviors remain external and disjointed from the daily core work of software engineering. Even though Kim is employed in a company which is sustainability certified and Ian is employed in a company that is working towards such certification, neither of them quite know what such certification is about (except for switching off and no paper printing policies). The certification has no effect on their own professional practice.

External Standards and Regulations. Investors requirements and enforced regulations and legislations drive organizations to engage with sustainability. For instance, Pat notes that, despite his company's priorities on economic growth, they have to account for their environmental (CO2 emissions) and social impact (job creation) due to investors driven by the EU regulations.

Table 3 exemplifies some of the interviewees beliefs about organization norms.

Table 3: Professional Norms

Norms need to ...	**because sustainability needs to...**
promote long-term reassessment and re-evaluation practice	be evaluated over time
define tasks and obligations in each SE role	have an advocate
promote responsibility	be regulated

5. OBSTACLES AND INTERVENTIONS

When asked if they would personally support sustainability design in their institutions, all thirteen interviewees were unanimously fully supportive. Yet, each noted a number of areas which, in their perspective, would make sustainability design adoption difficult. It is interesting to note that some of the issues raised by our interviewees have indeed been identified and observed in previous research work on new practice adoption studies (see section 2). This study did not attempt to introduce real change into software engineering practice, but instead invited practicing requirements engineers to consider obstacles to adoption of sustainability design. The stimulative findings and analysis results from this study are summarized in Table 4 and discussed in the following sub-sections.

5.1 Individual Resistance, Lack of Education

An innate human characteristic is *resistance* to uninvited change; it is previously noted to cause difficulties in adoption of new practices in software engineering [31]. Our interviewees explicitly and implicitly noted a number of areas where such resistance to change could be expected.

The issue of individual resistance to change was explicitly noted by Ray and Sam, who say that individuals: (i) **do not like to change** their habitual practice if they do not see an urgent need to do so, and (ii) **are already too stressed** and will be concerned about implications of change on their

[3]We interpret "norm" as general agreement within the SE profession on what a software professional should be obliged, permitted, or expected to do

Table 4: Obstacles and Intervention Strategies

Level	*Obstacle*	*Mitigation Strategy*
Individual	Lack of Knowledge	Education
	Lack of Experience	Training
	Lack of Methodology and Tool Support	Demonstrators of current methodology and tool applicability; New tool and methodology development
	Resistance to Change	Education on need for Change; Motivation for change adoption
	Fear of Unknown due to Change	Clear evaluation and assessment timelines, criteria, and support provision
Professional Environment	Lack of Higher Management Support	Education, Demonstrators of benefits of Sustainability Design
	Reliance on Customer for Sustainability Requests	Demonstrators of benefits from Software Engineering leadership
	Tradeoffs: Sustainability vs. NFRs	Demonstrators of win-win solutions
	Risk due to change	Stepwise transition support for risk reduction; A roadman with strategies, methodologies, sample case studies
	Fear of client and income loss	Demonstrators of win-win solutions, Experience of past success
	Unavailable Time and Resource	sustainable design into current practice within the available resources; Stepwise transition plans
	Short-termism and income focus	Education, Demonstration of past success
	Poor Communication of Sustainability Values	Embedding sustainability into key values throughout organization, rewarding sustainability inductive practice and innovation
Norms in Professional Practice	Lack of responsibility for long term consequence of software, Sustainability as fundamental ground for software acceptance, Integration of sustainability requirements into SE guidance and practice standards	Review of and integration of sustainability principles within the professional standards, guidance, and accreditation criteria

own performance and work-load. Since all thirteen interviewees also agreed that sustainability will require extra (unwelcome) work, to some degree, they also all implicitly resisted the idea of change. Some also explicitly **passed the responsibility** over to others (e.g., managers, companies, policy makers), rather than expressing willingness to take it upon themselves. Furthermore, several interviewees noted that to ensure success of this endeavour, a substantial commitment into consensus building and **world-view change** is required across team members, various teams, stakeholders, and management. While each interviewee was personally supportive, they implied that such an endeavor, clearly, was not a job for a single requirements engineer or even their small team.

We observe a clear relationship between the **knowledge sources** on sustainability used along with the work experience of those interviewed for this study, and the depth and breadth of their perception on sustainability. Those interviewees whose knowledge sources are limited to news (Amy, Ben, Cat) or news and some discussion (Dan) have a rather narrow perception of sustainability, limiting it mostly to the topic of environmental impact and resource use. Indeed, the environmental topics of sustainability are the ones most often discussed in news, while social, ethical, and individual topics are most often neglected. A limited set of sources of knowledge on a subject also reflects the low interest of these interviewees in this subject. Similarly, we note a clear trend that individuals who use more knowledge sources on sustainability (Ray, Sam, Max, Ian, Liz) are more likely to have deeper, and broader understanding of sustainability and have more interest and engagement with this topic both in personal and professional lives.

Unsurprisingly, those with a broader perception of sustainability are more likely to be engaged into sustainability-related practices in their private and work life. There, most sustainability-related activities discussed by our interviewees have a strong environmental focus such as reducing waste and recycling.

Many of those interviewed say that they are unable to practice Sustainability Design within Software Engineering due to the **lack of methodology and tool support** (see Section 4.2). While it has been demonstrated [32] that in many cases sustainability can be supported through use of the present RE techniques and tools, the interviewed RE practitioners did not show any awareness of this. Thus, it is not only the absence of tools and techniques that hampers the practice, but the **lack of knowledge** about what sustainability is and how to support it within the current RE practice methodologies and tools.

Indeed, before the second stage of this interview study, we requested that the interviewees read a short document on sustainability [27] and then reflect on how they could integrate the notions of sustainability from the document into their practice. The reading of this two-page document was sufficient for most of the interviewees to form a broader, more inclusive view of sustainability as a subject, and to conceive practical steps for integrating sustainability design into their professional practice. In short, our findings confirm the proposition (see Section 2) that **lack of education and experience regarding a discipline can have a negative effect on the actual practice**. Therefore, it is necessary to educate RE practitioners on the subject of sustainability design through formal education (e.g., university degrees), practice guidelines, demonstrative examples/case studies, and alike.

5.2 Professional Environment: Organizational Culture

The findings from our study corroborate previous work that identified organizational culture as a key factor in the adoption of good practice. The most obvious example for this is the uniform response from the small business rep-

resentatives (Pat, Max, Ian as discussed in 4.2). All three thought that sustainability-related practices are unsuitable for small businesses, as they must be **reactive and immediately responsive to the customer** needs and have **no time or resources** to spare. This is mirrored by a recent survey that concluded, "Given the narrow view that people have of sustainability, it is not surprising to hear such opinions. Gladly, corporate mentality towards sustainability is changing and CEOs are increasingly recognizing the importance of sustainability to the success of their business [33]".

This clearly is a matter of culture within software start-ups. Data from new start-up businesses suggests that those with a social enterprise and community benefit focus are more resilient, and more likely to survive than those without [34]. For instance, Pat, who represents a start-up that works on market analysis, would be able to demonstrate the opportunities for the increased customer base through appeal to increasingly environmentally aware customers or competitiveness of the client's business through engagement with sustainability. Yet, to Pat, this has not been requested by the client and so is not worth pursuing. Interestingly, Pat also admits that other good practice guidelines that have proven long-term benefit to the software companies, such as adequate documentation and change management, are lacking in this start-up due to the same focus on reactiveness and short-term survival.

Software organizations have a strong focus on **satisfying customer requirements** (see Section 4.2). All that is engineered within the software must be requested by and paid for by the customer. Indeed, the customer has to agree on what software they are paying for. However, it is also well recognized that often the customer is not clear on their real requirements [35]; it is the responsibility of the requirements engineer to help identify, clarify, and agree upon the actual requirements with the customer. Should the methodology adopted by an organization insist on requirements analyst identifying and discussing sustainability requirements with the customer, it is very likely that (at least some) such requirements will make into the list of what the customer asks. This, in turn, would require for an organization to either have a clear priority for its own sustainability values, or be forced to prioritize these through external standards and regulations.

The majority of the interviewees bluntly stated that implementing sustainability design requires **extra costs**, which the companies are not able or willing to pay. This corroborates the findings from the related work on good practice adoption (Section 2) that extra costs hamper implementation of good practices in industry.

Our interviewees name several reasons explaining as to why the companies are unwilling to undertake these extra costs. First, they fear that the **client will not pay** extra for sustainability (if they have not asked for it) and will instead choose another, cheaper vendor. Thus, not only extra costs will be incurred, but the client will also be lost. Secondly, they note that the companies do not have the **time and resources** to commit to sustainability design since sustainability is often considered an optional extra property, rather than a basic foundation of software operation. Furthermore, even if one could see the potential of some future gains from investing into sustainability, such future-focus is not commonly valued, the companies want to make the **most money in return for their resource investments in the shortest time**. Finally, adoption of sustainability design is likely to require substantial organizational change with costs associated with staff training and education, and building a shared vision and practice amongst all members of development teams as well as management and policy makers.

While the risks and the costs of this new practice are commonly perceived to be very real and present, the potential gains from it seem still unproven and removed in time.

5.3 Norms and Practices, Regulations and Responsibilities

The current **standards and regulations** for software professional practice do little to promote sustainability practice within software organisations, focusing only on avoiding intentional and immediate harm [36] through software design. Software effects often do not manifest until a period of continuous use (e.g. effects of Facebook or Twitter). Thus, it has to be recognized that the software development organizations are responsible for the longer-term effect that their software delivered to their user communities.

Yet, today the focus is clearly singly on the immediate impact. If the project is delivered on time, within budget, and with the quality accepted by the customer, the work of the developing company is often considered to be completed and the responsibility delegated to the customer. But, if the **success or failure of a software project is measured at a fixed point in time** (i.e., handover date in the current practice), the indirect and systemic effects of the software systems will be externalized by the developer companies to the responsibility of the customer. The responsibility for some of these indirect effects can be passed back to the developer companies if the longer term adaptive maintenance contract is linked to the initial system delivery cost, or if the software use is provided as a service by the software company.

It is also not surprising that a substantial shift from owning to leasing software services is already under way as more customers move to Software/Platform as a Service business models. However, so far it has mainly been driven by economic and usability factors. The explicit focus on environmental and social concerns that materialize in indirect and systemic effects of software systems are still largely overlooked [11]. Yet, the SE profession must assume responsibility for the **longer-term results** of their developments.

To contrast the software industry practice, the UK Standard for Professional Engineering Competence [37], for instance, defines specific sustainability-focused competencies and commitments for each role of a professional engineer. Here a professional needs to "undertake engineering activities in a way that contributes to sustainable development", including the "ability to [...] progress environmental, social and economic outcomes simultaneously" [37]. Such explicit commitment to sustainability, as well as resumption of longer term responsibility for one's work is presently amiss within software organizations and their regulating and guiding bodies.

6. LIMITATIONS

In this section, we discuss four threats to validity: construct validity, internal validity, external validity, and reliability.

Reactive bias to the presence of a researcher can cause

a threat to the **construct validity**, which can be exacerbated by different researchers conducting the interviews. To reduce that threat, interviewees have been assured their anonymity and we use open questions in the interviews as a way to reduce interviewer bias [38]. Similarly, an interview guideline had been agreed upon by all interviewers and followed after the first pilot interview. A relevant threat to construct validity is that interviewees may not understand the questions, and the interviewer may misinterpret data. To mitigate this threat, we ensured that the interviewees had sufficient prior experience in RE; further on, to provide a context for the questions, we asked the interviewees to read a brief document on sustainability design before the second stage of the interview started[4]. In addition, we piloted the interview to make sure that the questions were clearly stated. Furthermore, the interviews were taped allowing the researchers to listen to the interviews again to limit misinterpretation. Transcripts were passed to the interviewees for comments and corrections, and no corrections or changes were suggested by interviewees. Coding of the first interview was conducted with all of the core coding group participating. The following coding was then conducted pairwise with always at least one member of the core coding group taking part.

Confounding factors influencing the analysis are a major threat to **internal validity**. To mitigate this threat we applied qualitative analysis techniques. Additionally, we do not claim that we collected any other data but that for practitioners perceptions and attitudes related to sustainability, and how these may shift when sustainability design is considered. Also, to allow for future comparison across studies, all selected practitioners had a defined level of experience in RE. Nevertheless, treat of the confounding factors cannot be ruled out completely.

Considering **external validity**, the cases presented here are not *statistically* representative and should not be taken as such; this is a qualitative study, and statistical generalization is not our goal. Instead, we are concerned with analytical generalization [38]. Our explorative, qualitative study was designed to help us identify current perceived obstacles and possible mitigation strategies to enable sustainability design. By selecting people with a sufficient amount of experience in requirements engineering, different application domains, countries and company sizes, we focused on the collection of a rich set of data.

To mitigate threats to **reliability** due to interpretation in qualitative analysis, coding was done first in a team and then pairwise. Any mapping disagreements were discussed until consensus was reached.

7. CONCLUSIONS

This paper reported on a study of the current state of sustainability in RE practice. We investigated current perceptions and attitudes on sustainability in RE practice and assessed whether they reflect the full scope of Sustainability Design. We identified barriers to the engagement with Sustainability Design in RE practice and identified possible interventions. Finally, we compared this to non-adoption of good practices discussed in our literature review.

On an individual level, we found a lack of knowledge and understanding, on the professional environment level there was a lack of support, and in the norms on professional practice there is a lack of responsibility. These key aspects are shown in more detail in Table 4. These obstacles direct us to the interventions points of education (on every level), integration of sustainability principles (on every level), and the need for success stories to demonstrate win-win solutions. For the latter, we need longitudinal case studies with a common design, to be replicated across different application domains. A simple design would be "apply sustainability principles in real projects and see how this is reflected in existent success measures". The lack of a control group of course makes it challenging to draw firm conclusions. A shared knowledge base would contribute to increasing the visibility of the opportunities.

If we take seriously that "every line of code has a moral and ethical implication" [6], we accept that designers of systems are at least partially responsible for their effects on societies and on the environment. Education presents a key avenue for improvement. We need to include sustainability principles in software engineering courses, educate software customers about sustainability within requirements elicitation, and educate software users about the choices they are making.

In addition, we have identified a number of *research priorities* that highlight the interdisciplinary nature of the challenges the SE discipline is facing. These research priorities are an integration of sustainability design principles with requirements engineering and software design, a common case study design replication across different domains, and a rework of the ethics standard for software engineering to include the responsibility for sustainability including towards society and the environment.

Significant barriers remain to overcome before Software Engineering can claim to routinely advance not just technical and economic, but also social, individual and environmental needs simultaneously. Critical reflection is needed at the individual, organizational and community level to advance the profession's ability and commitment to do so.

[4]As the first stage was focused on own perception elicitation, the reading request was post-first stage.

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