

SUSTAINABLE SOFTWARE ENGINEERING EDUCATION CURRICULA DEVELOPMENT

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Abstract: Climate change risk and environmental degradation are the most critical issues of our society. Our technology influenced daily life style involves many software and apps which are used by large society and their use is increasing than ever before. Sustainability is a significant topic for future professionals and more so for Information Technology (IT) professionals and software engineers due to its impact on the society. It is significant to motivate and raise concern among students and faculty members regarding sustainability by including it into Software Engineering curriculum.

Key words: Sustainability, Sustainable Software Engineering, Curricula, Software Engineering.

1. INTRODUCTION

Presently software has become an integral part of our everyday life and gradually impacting human being and society. Therefore, environmental concerns should be addressed in its development, implementation and operation. Sustainable software engineering (SSE) is based on the foundation of designing and developing software by taking into consideration various dimensions of sustainability which are economic, environmental, individual, social and technical ones [5, 32]. Brooks et al. [7] found three dimensions to sustainability: environmental, economic and social. These are interrelated and these should be selected in such way towards optimum arrangement and alliance. A number of recent studies were performed to find out how sustainability is identified and included in software engineering process towards sustainable software development [41] which can reduce its environmental impact on society. Global absorption of CO₂ in atmosphere in December 2016 was 405.25

parts per million (ppm), the highest in documented past record which is matter of concern towards climate change.

A recent survey by Manotas et al. [24] of 3860 software professionals from Google, ABB, IBM and Microsoft reveal that present higher educational programs do not prepare these professionals to undertake sustainability, although they are inclined to learn about it [24]. Also in their survey they noticed extensive significance of greenability and sustainability. Another study on teaching sustainability in software engineering also supports that sustainability is not included in the software engineering (SE) courses and the present focal point is on energy efficiency issues [19, 31, 34]. Scientists have recently recognized that issue related to green and sustainability software engineering should be part of the discipline towards future of human beings. In many research studies, sustainability and energy efficiency are observed as crucial expertise for future software engineers [19, 20, 31, 34]

Sustainability management is one of the upcoming movements in the 21st century but, until now, it could not get as much attention as it should be by SE. In this respect, the contribution of ICTs for energy and environmental sustainability has attracted attention of both researchers and professionals [8] as software contributes significantly to every aspect of our lives. Yet, the current industrial growth and adoption of ICT more and more threaten the future of sustainability and cause environmental issues [8, 39]. Sustainability is becoming a crucial concern in information technology and software towards our future. Software engineers presently perform many tasks that may ensure sustainability, for instance, Agarwal et al. [1] consider the capabilities and gain of green software and suggested more efficient algorithms will take less time to execute and it leads to sustainability. For now, apart from cost, factors such as environment, social and human sustainability are required to be considered in any planning, implementation and running initiative related to software systems [36]. Organizations are now beginning to understand that not only cost efficiency, but also long-term and continued prosperity can be gained from sustainability. Therefore, apart from factors like cost, time, and quality, sustainability has also become one of the significant objectives to achieve when developing, configuring, operating and working software systems. Therefore, there is a need to support the transition to sustainability and incorporate it into software systems and other underlying business processes [6].

Green and Sustainable Software Engineering (GSSE) is the art of developing green and sustainable processes [23]. Sustainable software process takes care its objectives and impact on human beings, society, economy, and environment that derive from its solution and deployment [4]. According to Erdelyi [15], green software causes little e-waste during its operation and development. Presently, the effect of IT on sustainable advancement – in particular, on software - is an emerging issue due to global concern on climate change. Education sector has to contribute significant role in ensuring future software engineers understand sustainability dimensions and integrate it into SE curriculum.

The rest of the paper is organized as follows: In Section 2 related work with sustainable and sustainable software engineering is presented. Section 3 describes sustainability and software quality. Section 4 illustrates sustainable software and sustainable software engineering. Afterwards, section 6 introduces curricula development on sustainable software engineering. Section 6 includes points of discussion. Finally, it concludes along with a brief viewpoint for future direction.

2. RELATED WORK

Sustainable or green software engineering is getting limelight among professionals and researchers [20, 29]. Researchers have noted that sustainability is under-represented in the curricula [41], hence the need to include the concept of sustainability in the university curriculum of computer science, software engineering and information systems. Mann et al. [25] presented a framework for educators to design sustainability-centred education while Sammalisto and Lindhqvist [40] observed on the integration of sustainability in higher education based on different sustainability dimensions like environmental, economic, social and technical. Gibson et al. [16] studied requirements engineering significance in ensuring sustainability in software development in UK. Groher and Weinreich [17] studied how sustainability is perceived by software professionals in projects and found that professionals mainly linked it with maintainability and extensibility of software. Renzel et al. [37] contributed a detailed strategy of projects for sustainable software engineering. Chitchyan et al. [11] reviewed sustainability related with Software Product Line Engineering (SPLE) and suggested main focus on technical and social sustainability issues along with social sustainability related to organization. Lutz et al. [22] also specified characteristics of sustainability in SPLE. Mohhankumar and Anand Kumar [28] proposed green based model for sustainable software engineering. Recently Penzenstadler et al. [33] proposed a blueprint for a course on software engineering for sustainability. Gibson et al. [16] suggested educational sector has an important part to play towards future software professionals who can understand sustainability issues in software development. Therefore there is need to integrate it in Software Engineering discipline curricula. Gibson et al. [16] further observed that it is mentioned just once even in ACM/IEEE guidelines and twice in SWEBOK in respect to software economics area. They argued in current scenario there is need of sustainable software engineering education guidelines and components required in such curricula for future software engineers. Therefore, this paper advances effort in this direction.

3. SUSTAINABILITY AND SOFTWARE QUALITY

Software quality is a significant issue therefore it is important to ensure that sustainable software development should take care of it. Sustainability is usually referred as a non-functional requirement in software systems while in business processes it is part of, for instance, e-waste, and network bandwidth [6]. Non-

functional requirements lead to quality in software product. Interestingly organizations have recognized sustainability in quality issues, for instance, maintainability, usability, agility to update but could not include it due to time and budget constraints in software project management [12]. Betz and Caporale [6] argued to integrate sustainability aspects into the software development process as: requirement specification, architecture, design and construction, testing, and software evolution. Requirements are the key interface between the business process and software systems. The requirements specification is the main input for the design of software systems. Requirements management represents the interface between the life cycles of business processes and software systems. Therefore, requirements and their changes have an impact on sustainability via business process [6]. Business process helps in getting functional requirements of any system. Thus, to analyze sustainable requirements, specific objectives and goals need to be defined using the available risk analysis techniques [6]. Sustainability ought to be taken care of in requirements selection decision making while developing the software. Furthermore, according to vom Brocke et al. [42] and Penzenstadler [32], sustainability is not sufficiently integrated into traditional software system engineering and business process management, also argued that the trend is usually not notably explained in the relevant business process models and also not considered in planning, developing, configuring, and operating software systems [32, 42].

Amri and Bellamine Ben Saoud [3] proposed Generic Sustainable Software Star Model (GS3M) to examine sustainable software and noticed some studies consider sustainability as a part of quality, while others observe quality and sustainability as different concepts and use quality attributes to support sustainability. Calero et al. [9] and Calero [10] applied the hypothesis that sustainability is a factor of the software quality, thus, unified it as a quality characteristic with three other sub-characteristics: energy consumption, resource optimization and perdurability. Calero [9] also noticed that operationalization in this way includes introducing some modifications in the ISO quality standard ISO/IEC 25010 to support sustainability as a quality component. Albertao et al. [2] and Kern et al. [18] also identified quality attributes to define sustainability. Interestingly, Albertao et al. [2] formulated software project sustainability characteristics into development-related features (modifiability, reusability, portability, and supportability), usage-related attributes (performance, dependability, usability, and accessibility) and process-related attributes (predictability, efficiency, and project's footprint). While Kern et al. [18] endorsed a quality model for green and sustainable software which construct sustainability criteria into three categories: common quality criteria which are well-known and standardized issues (such as efficiency, reusability, modifiability and usability); directly-related benchmark (such as energy efficiency, framework entropy, functional types, hardware obsolescence, adaptability, feasibility, accessibility, usability and organization's sustainability); and indirectly-related yardstick that demonstrate effects of software on other

products and services and cover the effects of use as well as systemic effects such as the fit for aim, elegance and reflectivity.

4. SUSTAINABLE SOFTWARE AND SUSTAINABLE SOFTWARE ENGINEERING

Sustainable software is defined as the software whose direct and indirect negative influence on economy, society, human beings, and environment that result from development, implementation and usage of the software are minimum [29]. Sustainability is considered as an additional feature in many software projects as software engineers are tied by time-to-market pressure and are often less inclined to administer sustainable methods and techniques [14]. Dick et al. [13] proposed first definitions for sustainable software and sustainable software engineering in 2010 which has become the foundation for later explanation. Sustainable software engineering is developing software through a sustainable software engineering process which meets sustainability purpose in considering human beings, society, and environment from software implementation and operations. According to Ray et al. [35], the term 'sustainable' applies to both the longer life and greener aspects of software. Green software generates the minimum amount of e-waste during its operation and development [15]. Furthermore, ICT has a major role in sustainable development, specifically in software and green computing [1].

5. SUSTAINABLE SOFTWARE ENGINEERING CURRICULA OUTLINE

The program should include the following units in the curricula so that students can get sufficient exposure to different components of sustainability issues in software development life cycle.

Sustainability Theory: Understanding the concept of sustainability and green software and its various parts, so as to be applied to different stages of software development and deployment and operations stages in the organization.

Requirements Engineering for Sustainability: Sustainability inclusion in requirements elicitation and analysis process, understanding of sustainability to apply in requirements elicitation process which includes stakeholder modelling, goal modelling, process modelling, and system modelling.

Sustainability Analysis: Understanding of rigorous analyses of sustainability issues in software development, from cost estimation to project management, software maintenance and evolution. It should include, in general, software systems to be developed from a comprehensive perspective to sustainability and long-term consequences on the environment and the society.

Sustainability issues in Software Architecture and Design: How to apply sustainability in different kinds of software architecture and design issues, for

instance database, human computer interaction, and modules interconnection, and in software architecture development.

Sustainable System Modelling: Stakeholders requirements modelling towards understanding how to incorporate sustainability issues into the scenarios of requirements with the help of UML diagrams. It also includes trade-offs, conflict resolving in the requirements of different stakeholders, and system modelling by using available tools from sustainability perspective for complex software systems.

Sustainability Engineering Process: Software process improvement should include sustainable software engineering and Agile approaches. Also knowledge of applicable tools, methods and technologies to facilitate the sustainable software engineering process. Energy and resource utilization are the main components that impact sustainability and, therefore, should be determine from the initiation of the process.

Sustainability in Testing and Quality Assurance: An optimized approach in ensuring sustainability in software engineering process including testing, quality and operation of the software product. Knowledge of standards of eco-design (ISO 14006, ISO 14062).

Sustainability Management Process: It includes planning phase, controlling phase, of sustainability activities along with sustainability policies to ensure an efficient process. Eco-design of digital services towards ensuring reducing environmental impacts to develop digital services that are more sustainable consume less resources and energy and produce less waste.

Advanced Applications: Parallel computer architectures, clusters and grids: how to maintain sustainability while handling their affairs.

Capstone Projects: Projects involving sustainability in software engineering during summer internships or such mini projects as part of the course.

Tools for sustainability: Tools must be introduced to assist different stages of software development (requirements, design, testing, configuration management etc.) towards ensuring sustainability. This can be a part of a sustainable or green software engineering laboratory program.

6. DISCUSSION

Sustainable software engineering is an emerging paradigm and significant for the society in terms of the environment. The present industrial production and more and more use of ICT bring endanger the prospective sustainability and lead to environmental problems [39, 8]. In a recent study, Salam and Khan [38] classify 20 success elements towards the evolution of green and sustainable software. Out of these, green software design and efficient coding is the most significant factor (71%) and power-saving software methods (70%).

The purpose of SSE is to curtail the power footprint of computers as well as minimize other environmental impacts related with software systems. Software is now a pervasive part of the society as even mobile phone and social media users are in billions. It is the responsibility of software engineering educators to prepare the SE professionals by providing them with skills to meet the expectations of the software industry [26]. Therefore, it is significant to include sustainability in courses for future software engineers so that it can be achieved while developing, deploying and maintaining all kinds of software in the future. SE ethics and professional practices should be included in the SE curriculum [27] and professional practices can include sustainability component. Moreover, sustainability has the potential to attract more students to SE discipline area due to its indispensable significance for future [30]. The proposed curriculum development can be easily customized and introduced as part of an undergraduate- or graduate-level software engineering curriculum. Since only a limited number of undergraduate and graduate programs on sustainability have been introduced in the last decade in certain institutions, the curricula proposed here can be a useful contribution to the body of knowledge for software engineering educators. As requirement specifications are the base input for software architecture and design therefore requirements have an impact on sustainability. With increasing global concern regarding our climate, the time has come to include “Sustainability” as a non-functional requirement towards quality software for future generations.

7. CONCLUSION AND OUTLOOK

Due to climate change in last decade and proliferation of information technology, software and apps in daily life in society, there is crucial need to develop and deploy green software. Therefore, there is need to provide training to future software engineers in such a manner that they will be able to include sustainability in each stage of software development life cycle. Software engineering undergraduate and graduate programs should include at least one such course in their curriculum. Here important units of sustainable software engineering curricula have been described along with literature review on sustainable/green software engineering approaches, concepts and tools. This work can be extended by a survey and interviewing software engineering professionals to know in more detailed manner how SSE course can be developed and improved in future towards more practical-oriented approach so that future software engineers will be able to produce eco and sustainable software.

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