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Conference Paper · August 2014

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A Systematic Literature Review on Sustainability Studies in Software Engineering

Ruzita Ahmad[1], Fauziah Baharom[2], and Azham Hussain[3]

[1]*Universiti Utara Malaysia, Sintok Kedah, rita_azura08@yahoo.com*
[2]*Universiti Utara Malaysia, Sintok Kedah, fauziah@uum.edu.my*
[3]*Universiti Utara Malaysia, Sintok Kedah, azham.h@uum.edu.my*

ABSTRACT

The existing literatures on sustainable development in software engineering have moved towards new paradigms of research and it is claimed as still immature in the sustainable development community. However, the sustainability study in software engineering is a new research field and has received a noteworthy attention lately in the year 2010. Therefore, this paper aimed to contribute a Systematic Literature Review (SLR) in this field to provide an overview of sustainability development in software engineering discipline with observe the research activity and related topics, limitation, approaches, methods, and available studies.The applied method is an SLR standard protocol produced by Kitchenham et al. (2007). The investigation is based on the 3059 articles in the first iteration searching query. Currently, almost 600 of related publications are selected and only 175 as relevant for our research questions. Consequently, too few studies in the literatures pertaining to sustainability in software engineering are published, whilst it is quite active in other disciplines. So, this research will be supported the limitation in the literatures with contributes the new paradigm in sustainability software engineering.

Keywords: Sustainability, sustainable development, systematic literature review (SLR).

I INTRODUCTION

Sustainability is defined as the development that can meet the needs at the present until to the future generations as to satisfy their own needs (Bruntland Comission, 1987). In the sustainable software engineering discipline, the term of sustainability is defined as the development of the software product for long living systems that can meet the needs of the present to the future generations with the integration of the three pillars sustainability concept i.e. (environment, economic, social) as to fulfill the requirements in a timely basis.

Several researchers have defined sustainability development with their own understanding, views and perspectives. For example, Mahaux et al. (2011) is focused on element IT changes behavior that will be affected to the society and environment towards sustainability. Nauman et al. (2011) used the ideas produced by Mahaux et al. (2011) and enhanced with the element positive and negative impact on sustainable development. Then, Penzenstadler et al. (2013) attached the elements of responsible use of ecological, human and financial resources towards sustainability. Next, Calero et al. (2013) contributed that the consumption of resources can improve the performance of energy used in producing the software product towards sustainability.

Earliest, Argawal et al. (2012) examined that the performance of the software system in long living software towards sustainability depending on the utilization of the resource usage to the maximum level. Later, Venters et al. (2013) take into account the composite and non-functional requirement which is used in software quality standard to identify the characteristics that will used as indicators to evaluate the sustainability in software products. This idea is agreed by Calero et al. (2013) in touch the element of quality attributes to the software sustainability evaluation. All of these ideas have been used by the researchers to create their own definition and their understanding of sustainability in software engineering with the integration of the original aimed of sustainability in which to meet their own needs at the present until to the future generations.

The significant of this study is to investigate some of the research activities related to sustainability in software engineering with focused on the approach and method used, and find out the limitation of the existing works. Thus, these issues can contribute to our study in achieving the objective in this study.

A. Overview

The word of sustainability means to be a sustainable action by highlighting on the concept, dimension, and practices towards sustainability development. Sustainability development has been

introduced by Bruntland Commission in 1987 with aimed to improve the quality of life for all of the Earth's citizens with the use of natural resources beyond the capacity of the environment without prejudice. In order to fulfill the sustainability definition itself in which requirement to meet the needs at the present until to the future generations, and the need to find the innovative way in changing the institutional structures that is indirectly influenced individual behavior. This means taking the action to change the policy and practice at all levels from individual to the international level is highlighted. The progress in developing the concepts of sustainable development has been rapid since the 1980's and there are tightly focused on three pillars dimension which are Environment, Social and Economic. Sustainable development is not a new idea and it has been practiced in the development of the country in the various fields such as in manufacturing, construction, restoration of natural disasters, soil and erosion, ecosystems and biodiversity, and so forth.

Recently, sustainability in software engineering just began in early 2010 and has been recognized as a relevant topic in software engineering (Penzenstadler et al. 2013). Initially, the sustainability concepts have been applied in the software development and the usage of software systems began in the new era of the development. Most of the software products and processes are developed with an economic benefit and the existing software systems developments are commonly not intended to serve the economic purposes (Penzenstadler et al. 2013 and Koziolek et al. (2011). Besides, the development of software products and processes focus on social benefit and they are also ignoring the environmental purposes (Penzenstadler et al. 2013 and Coral et al. 2013). These development trends are some reasons for sustainable development is needed in software engineering to address the problem occurred in order to integrate all dimensions of sustainability as united collaboration (Penzenstadler et al. 2013; Koziolek et al. 2011, Penzenstadler et al. 2010).

B. Sustainability in Software Engineering

In the literatures, there are several publications in the form of systematic literature reviews on different topics in software engineering including sustainability relation to software engineering. This research aims to provide the literature review based on sustainability in software engineering, which covers research on sustainable development activities, the limitation in the existing work, the method and approaches being used and the available case studies. The investigation will focus on the kind of sustainable development that has been developed in software engineering since it has been introduced in this discipline.

As the results, the exploration has found that several researchers have established their own ideas towards sustainable development in software engineering in various types of contributions such as strategy models, framework model, requirements engineering techniques, method and goal modeling. Naumann et al. (2011) contributed a framework for sustainable software engineering that promoted a method to guide the development of products and processes towards sustainability. Gu et al. (2012) proposed a green strategy model that provides decision makers in the business strategy. The researcher contributed a broader view on sustainable software engineering. Stefan et al. (2011) used the theoretical idea proposed by Cabot et al. (2009) who is involved in the business organization, discipline related to the quantitative goal modeling techniques. The proposed ideas have been used by Stefan et al. (2011) in managing the environmental sustainability in software engineering.

Earliest, Mahaux et al. (2011) recommended the requirements engineering techniques towards sustainability in software engineering. They provided a model for integrating sustainability into the software development process. Latest, Penzenstadler et al. (2013) continued the ideas by Mahaux et al. (2011) in contributing the requirements engineering for sustainable systems. The research highlighted that the requirements engineering extremely important impact on the potential software systems and hardware that need to be carefully written in guiding with the new ways of living systems are more sustainable.

Penzenstadler et al. (2013) contributed to the other publication pertaining to support environmental sustainability by requirements engineering. In their latest publication, the researcher has proposed a guideline in detail pertaining to the sustainability environmental to support the development of ICT systems with an adequate requirements engineering approach that integrates the knowledge of environmental informatics. While, Johann et al. (2013) has continued the goal to propose a guideline in the social sustainability in requirements engineering in detail. The researcher proposed the ideas based on the social impacts of software systems which involve many fields of interest either directly or indirectly linked to social sustainability. However, there are no publications contributed to economic sustainability.

As findings, most of the studies focused on development and management in software sustainability. However, there are too few

publications are contributed in software sustainability evaluation. None of them has investigate closely to the metric evaluation for each identified characteristics and sub-characteristics in measuring sustainability standard. Therefore, the idea to require and justify the foundation of software sustainability evaluation will be investigated in the next future work in the form of SLR.

C. Research Question

The research objective of this study is to develop a body of knowledge on sustainability studies in software engineering. In order to ensure the main objective is achieved, several questions have been developed. This is further detailed in the following research questions:

RQ1 How much research activity in sustainability in the last 20 years?

RQ2 How many research publications in sustainability for software engineering in the last 5 years?

RQ3 What are the limitations in the existing works?

RQ4 What are the approaches and methods been used for sustainability in software engineering?

D. Review Method

This section reports the details about each step of the systematic literature review (SLR) adapted from Kitchenham et al. (2007). The steps involved planning the review which contents identification of the need for a review, develop and validate review protocol. Next, the second step is conducting the review with identifying the primary studies, select primary study, assess the quality of primary studies, extract data and synthesis data. Finally, reporting the results is concluded the finding.

II SEARCH DESIGN AND PROCESS

The search design and process guideline is adapted from Kitchenham et al. 2007). The research question in Section I-D is used in the search process in this study based on the following digital libraries such as IEEE Digital Library, ACM Digital Library, SpringerLink, ScienceDirect / Scopus, Web of Science, Taylor & Francis, and Wiley Inter Science.

A. Search Strategy

The search process is based on "sustainability" term in general and focused in the context of software engineering from the digital libraries including the journal, and conference proceeding listed above. The searching process is moved to the other term such as "sustainability in software engineering" together with the following keywords: limitation in software sustainability, approach in software sustainability and method in software sustainability.

B. Inclusion Criteria and Exclusion Criteria

The 3059 articles have been reviewed in this study pertaining to the term of sustainability. In stage 1, identification of search topic will be executed on each database. None related articles will be excluded and the related articles will be included in the next stage. Next, in stage 2 the exclusion of the articles based on titles, abstracts and conclusions will be done and the relevant articles will be included in the next stage. Then, in stage 3 will exclude the articles without approach and method component and finally, the rest of related articles will be included in this research. Consequently, the critically appraisal studies will be analyzed in this research with 175 most relevant articles are included.

C. Data Analysis

The articles finding from the digital library database will be classified according to the research type facets and knowledge area (Kitchenham et al. 2007). The term will be distributed according to the topics, methods, frameworks, tools, case studies, and application domain as listed below.

- Metadata: Authors, Year of publication, title, source, keywords, research topic and institution.
- Knowledge area: Flood management, SOA adoption and implementation, software engineering models and methods, software engineering metric evaluation, software engineering process, software quality, sustainability in flood management, sustainability in SOA, sustainability in software engineering, sustainability modeling, sustainability concept, software sustainability evaluation, and sustainability standard.
- Research type facets: Philosophical, Exploratory, Solution, Validation, Evaluation, Opinion and Experience.
- Domain: Management of watershed plan, management of storm water infrastructure, flood management, urban water management, green software application, integrated impact assessment, software metric evaluation
- Method: Footprints, Well-being index, Genuine progress indicator (GPI), Index sustainable economic welfare (ISEW), Life cycle assessment (LCA), Delphi approach,

Analytical Hierarchy process (AHP), Normalization and combination process.

III RESULTS

The findings of search articles in the digital library database are provided in Table 1 below.

Table 1. Findings results per database

Database	Mapping Date	Results
IEEE Xplore	Sept 2013 – Mac 2014	600
ACM Digital Library	Sept 2013 – Mac 2014	600
SpringerLink	Sept 2013 – Mac 2014	600
ScienceDirect / Scopus	Sept 2013 – Mac 2014	600
Web of Science	Sept 2013 – Mac 2014	500
Taylor & Francis	Sept 2013 – Mac 2014	80
Wiley InterScience	Sept 2013 – Mac 2014	79
Total articles downloaded		3059

All related results were ordered in the database and each database is considered to download almost 600 articles in the first iteration of the study. According to the Section III shows the finding results per database. The articles will be categorized according to the research questions in SLR as to ensure the objective of the research study is achieved. The next section will discuss further the systematic review based on the SLR research questions.

RQ1: How much research activity in sustainability in the last 20 years?

As to answer the first research question in this SLR paper, the 2409 articles related to sustainability activities in any discipline is listed as the first collection in SLR according to the type of search database.

In the last 20 years ago, the sustainability in other disciplines was significantly raised during the time. There are several studies in the literatures pertaining to the sustainability in multiple ways and fields. For example the sustainable development in building, ecosystems and biodiversity, soil and erosion, earth disaster such as flood hazard, earthquakes, tsunamis, storm or storm surges and so forth. The action in developing the sustainability concepts by focusing on the three pillars dimension was aimed to improve the quality of life for the citizens in the country. These are the issues that frequently been discussed in the publications. However, the other goal in developing the country becomes sustainable are to promote efficient use of resources, environmental harmony, and equitable social order for every level of class of the citizens by upgrading their wealth, welfare, security, policies for the household, community, and company or organization are also mostly discussed.

Consequently, the sustainable development most established in every angle of human life through research activities and practices.

RQ2: How many research publications on sustainability for software engineering in the last 5 years?

In the last four years starting in 2010, there was increased in the number of publications in sustainability for software engineering in many domains. The research on sustainability in software engineering has began ended 2009 according to the idea and theory proposed by Cabot et al. (2009) in business organization discipline according to their proposed modeling techniques that has been used by Stefan et al. (2011) in developing the environmental sustainability in software engineering. Almost 650 articles are discussing on the sustainability in software engineering. The search queries in late December 2010 have provided a few publications in sustainable informatics with involved the types of research domains. The investigation is moved to classify the articles based on sustainability systems or knowledge, education, disciplines, technologies or methods, application and implementation.

As the result, we only received a few articles that can be referred and relatively that could be used for building up a body of knowledge, including sustainability concept are 30 results, sustainability in software engineering are 32 results, sustainability application domain are 60 results, sustainability software solution are 33 results and sustainability hardware solution are 5 results. Table 2, 3, 4, 5, and 6 below are presented a few of included articles that very closely related to this study are presented below according to the databases searching query.

Table 2. Included results from IEEE Xplore

Author	Type	Topic	Domain
Venters et al. (2013)	framework	The blind man and the elephant: towards software sustainability architectural evaluation framework	sustainability architecture
Durdik et al. (2012)	model	Sustainability guidelines for long living software system	Sustainability design

Penzenstadler (2013)	Method and tool	Supporting sustainability aspects in SE	Sustainability evaluation
Shenoy et al. (2011)	approach	Green software development model: an approach towards sustainable software	Green software
Rachuri et al. (2009)	Metric / standard	Metric standard and industry best practices for sustainable manufacturing system	Sustainability standard
Koziolek et al. (2013)	Metric evaluation	Measuring architecture sustainability	Architecture sustainability

Table 3. Included results from ACM

Author	Type	Topic	Domain
Koziolek (2011)	Metrics evaluation	Sustainability evaluation of software architecture	Software Architecture
Calero et al. (2013)	review	Sustainability and quality	Definition
Penzenstadler (2013)	review	Towards a definition of sustainability in and for SE	Definition
Penzenstadler (2013)	review	Requirement engineering for sustainable system	Sustainability concept
Penzenstadler et al. (2013)	Model/ method	A generic model for sustainability with process and product specific stances	Environmental sustainable assessment
Weiss et al. (2012)	Metric evaluation	Preseverence in sustainable software architecting	Sustainability methods
Jansen et al. (2011)	method	A method for assessing technology sustainability	Sustainability method

Table 4. Included results from SpringerLink

Author and reference	Type	Topic	Domain
Naumann et al. (2011)	model	The greensoft model: a reference model for green and sustainable software	Green software
Mahaux et al. (2011)	Assessment	Discovering sustainability requirement: an experience report	Green software
Penzenstadler et al. (2013)	review	Support environmental sustainability by requirement engineering	Environmental sustainable software
Mahaux et al. (2013)	Perspective views	Integrating the complexity of sustainability in requirements engineering	Green software
Bouwers et al. (2013)	Metric / method	Evaluating usefulness of software metrics	Software metrics evaluation

Table 5. Included results from ScienceDirect

Author and reference	Type	Topic	Domain
Kocak (2012)	Model and Metric	Green software development and design for environmental sustainability	Green software
Tate (2005)	review	Sustainable software development: an agile perspective	Agile sustainability
Johan et al. (2011)	approach	Sustainable development, sustainable software, sustainable SE: an integrated approach	Green software
Hornbaek (2006)	metric	Current practice in measuring usability	Metric evaluation for usability characteristic
Afgan (2010)	Method and tool	Sustainable paradigm: Intelligent energy system	Sustainability assessment

Table 6. Included results from Web of Science

Author/reference	Type	Topic	Domain
Johan et al. (2013)	review	Social dimension of sustainability	Social sustainable software
Finkbeiner et al. (2012)	Method and tool	Towards life cycle assessment	Sustainability evaluation
Calero et al. (2012)	model	Sustainability Model	Sustainable characteristics
Koziolek et al. (2013)	approach	A lightweight method	Sustainability evaluation (MORPHOSIS Method)
Koziolek et al. (2010)	review	Quality of Service Oriented software system	Service Oriented architecture method

RQ3 What are the limitations in the existing works?

The limitation in the existing works is classified according to the research domain from general to the specific. The sustainable development in the last 20 years in various disciplines has fully established according to the development process, management and evaluation technique. Some of limitations occurred by the time basis has closely improved by the responsible party with their own standard of procedure and the action taken. In the context of software engineering, the sustainable development

is a new issue that is necessary to be closely searched and improved from time to time according to the development process, management and evaluation.

According to the famous researcher of sustainability in SE such as Mahaux et al. (2011), Koziolek et al. (2011), Kocak (2011), Durdik (2012), Penzenstadler (2013), Penzenstadler et al. (2013), Venters et al. (2013), Johann et al. (2013) and etc. has been investigating the issues related to sustainability in software engineering. Some limitations occurred in the current works has been improved by the researcher with their own idea, theory, perspective views and experiences. The articles reviewed according to the sustainability in SE are almost 32 publications had supported us to find out the new limitations that need to be catered in this research.

RQ4 What are the approaches and methods been used for sustainability in software engineering?

From the SLR, the investigation found that 13 articles have been reporting on the approaches and methods of sustainability in software engineering. Some of the paper has applied the same method and approach such as the life cycle assessment approach, multi-criteria approach, Delphi approach and etc. However, most of the publication proposed their own method and approach such as Koziolek et al. (2013) proposed their own method for sustainability in SE namely MORPHOSIS method.

IV CONCLUSION

This SLR is expected to gather more results to be classified as sustainability in software engineering with more case studies, review, discussion and etc to find out more existing limitations, methods and approaches. The investigation of sustainability in software engineering will further examine on the new issues and elements towards software sustainability based on the existing gap and limitation in flood sustainability and Service Oriented Architecture (SOA) sustainability. The integration of these three elements hopefully will contribute to the technique of evaluation in software sustainability. The future work is moved to investigate the assessment technique towards sustainability in a form of SLR.

ACKNOWLEDGEMENT

We would like to thank the Malaysian Ministry of Higher Education for providing the funding for this research through LRGS entitled “A new Holistic Service Oriented model for wireless and sustainable flood management: From monitoring to emergency response”.

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