International Journal of Electrical and Computer Engineering (IJECE)
Vol. 14, No. 3, June 2024, pp. 2868~2874
ISSN: 2088-8708, DOI: 10.11591/ijece.v14i3.pp2868-2874

Integrating green computing into rational unified process for sustainable development goals: a comprehensive approach

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Article Info

Article history:

Received Oct 18, 2023
Revised Feb 7, 2024
Accepted Mar 9, 2024

Keywords:

Artifact
Eco-friendly software
Green computing
Rational unified process
Sustainable development goals

ABSTRACT

This research explores the incorporation of green computing variables into the rational unified process (RUP) methodology, specifically focusing on sustainable development goal (SDGs) 12-responsible consumption and production. Supported by three additional papers using the preferred reporting items for systematic reviews and meta-analyses (PRISMA) method. Our study aims to promote eco-friendly software development practices and tools (artifacts) aligned with green computing principles to support SDGs throughout RUP development phases. We conducted a matrix thorough analysis of existing green computing adaptability within RUP, yielding key findings: a system charter for inception, system requirement specification for elaboration, software development result for construction, and software test report/user acceptance test for transition. As a result, we've compiled comprehensive phase-specific documents, emphasizing the need for educational initiatives to foster green computing adoption among developers. This study advocates for cross-disciplinary collaboration to ensure successful implementation of eco-friendly software development processes.

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1. INTRODUCTION

Recently, sustainable development goals (SDGs) have become a major topic of reference for research topics. This research will determine which artifacts are in accordance with green computing rules that support SDGs for use in the software development process. A search was conducted to determine the methods to be discussed in this research, so that a topic that contributes to the SDGs was obtained. The first step taken in this research is to determine the model or methodology in the software development life cycle (SDLC) that will be used in this research by identifying related topics in the Google Scholar academic database which is presented in Figure 1.

Based on the search results presented above, selected rational unified process (RUP) to continue in this research. This is intended to increase contributions to science related to the types of artifacts that can be used in RUP to support SDGs with green computing principles. Software development in the context of digitization is being carried out, one of the software development methodologies is RUP which is used by [1] in 2023. Retrieved from [2] RUP is a software development methodology using an iterative approach, which is suitable for software development with a large scope because with this method, it breaks down the development process into smaller parts. Parviainen *et al*. [3] said in his journal, as a contribution to the reduction of CO_2 emissions, industries are currently implementing digitalization. Digitalization is key to

supporting internal efficiency within an organization or supporting external opportunities. Tiwari [4] in his journal said digitalization can be done in several ways such as the use of information systems which help to reduce community mobility with vehicles, as well as information systems based on green computing. This is also a program of the United Nations [5] that is SDGs, one of the 17 goals of the SDGs is the 12th goal on "Responsible Consumption and Production" whose targets focus on reducing the use of resources that have an impact on the environment. The main cause of environmental impacts is humans and their irresponsible and harmful behaviors. As an example, for such behaviors are the large amount of CO_2 emissions from industries and vehicles, the cutting down of trees, and the excessive use of resources by technology [6].

The things done in this research include mapping the output documents from the implementation of the RUP software development method into green computing criteria. The findings are a framework in the form of a matrix mapping between the process stages provided in the software development methodology and green computing criteria. This framework can be a reference and guide for software developers in carrying out software development in accordance with the ideals of green computing. Of course, this is in line with the SDGs program initiated by the United Nations in taking steps to ensure sustainable consumption and production patterns.

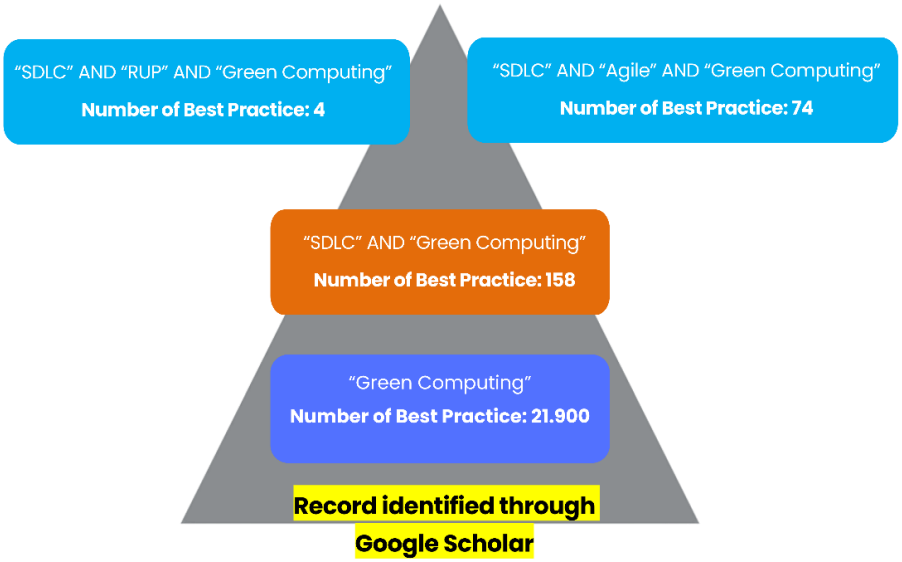

Figure 1. Related topic record identified

2. METHOD

Retrieved from [7], one of the software development methodologies is the SDLC which is a process for developing or changing a software system using models and methodologies that people have used to develop previous software systems based on best prices or proven methods. The same journal also describes the models that can be used in developing software with SDLC. This research generalizes the output of the stages of software development method which is integrated with the principles of green computing in addition to producing software that helps work, the software development process from analysis to implementation is also friendly to the environment we live in.

Based on Figure 2, we use preferred reporting items for systematic reviews and meta-analyses (PRISMA) approach to perform systematic literature review (SLR) to reduce bias in the search for literature that can support the data in this study. In the planning phase of the review according to the introduction, it has been stated that this research will determine artifacts that are in accordance with the rules of green computing and support SDGs 12. In the next phase, our search strategy using google scholar is used in searching journals because according to [8], google scholar has successfully indexed articles from many professional scientific publishers and Gusenbauer [9] concluded that Google Scholar is the most comprehensive academic search engine today. The manual search used the following keywords in Table 1.

Tabel 2 is a list of inclusion and exclusion criteria, indicating that the papers used for the review are those published in English. To be considered in this category, the selected papers must meet the requirements outlined in Table 2. All filtered papers underwent a synthesis analysis, and the results are presented in Table 3. The overall outcomes of the performed SLR can be depicted in Figure 3.

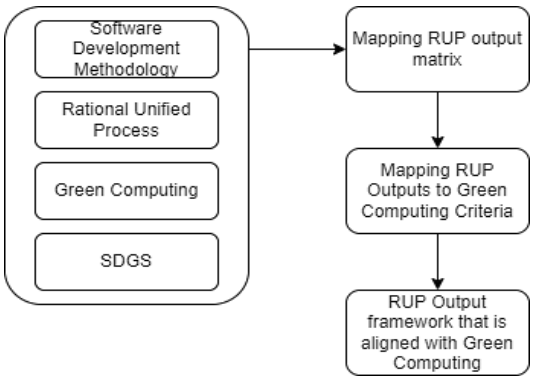

Figure 2. Design of research method

Table 1. Search keyword and best practices number

Keyword	Number of Best Practice
"Software Development Life Cycle" AND "Rational Unified Process" AND "Green Computing"	4 Result
"Software Development Life Cycle" AND "Agile" AND "Green Computing"	74 Result

Table 2. Inclusion-exclusion criteria

No	Quality Criteria	Outcome
1	Does the research discussed contribute to SDG?	Yes: Explain that the results of the research contribute to SDG No: Contribute to other programs
2	Is the research indexed in internationally reputable journals?	Yes: The research was indexed in an internationally reputable journal No: Indexed in other journals

Table 3. Result article synthesis

Study	Data Source	SDLC	SDG Used	Challenge/Limitations
Software Development Methodologies: Analysis and Classification [10]	*https://doi.org/10.1109/REEPE57272.2023.10086852*	Extreme Programming, SCRUM, RUP, RAD	9	Complexity of Methodology Selection
Green Scrum Model: Implementation of Scrum in Green and Sustainable Software Engineering [11]	International Research Journal of Engineering and Technology (IRJET)	Agile, SCRUM	13	Unclear Enrichment Method, Integration with Existing Process
Integrating Sustainable Development Goals into Project-Based Learning and Design Thinking for the Instructional Design of a Virtual Reality Course [12]	*https://doi.org/10.3390/engproc2023055078*	RUP	4	Generalization of Findings, Sustainability Contains, Limited Methodological Details

Another journal from [2] discusses a software development approach that is carried out iteratively as an application development cycle model, this method breaks down the software development process into smaller sub-processes so that detailed development can be carried out, and this method is called RUP. Retrieved from international business machines corporation (IBM) [13] in its implementation, software development using the RUP goes through 4 phases, which are inception phase, elaboration, construction and transition.

In addition to IBM, the RUP stages are also used by [2], [14]–[19] and also [1]. In its implementation, each stage of software development using RUP will produce an output document which will be used as a reference for the next stage and of course this output document will be used as the basis in this research to produce a mapping of output documents from each stage of the environmentally friendly RUP. The implementation of green computing in supporting the United Nations program, namely the SDGs, is also discussed in a journal from Jha [20] which highlights how green computing approaches to information and communication technology (ICT).

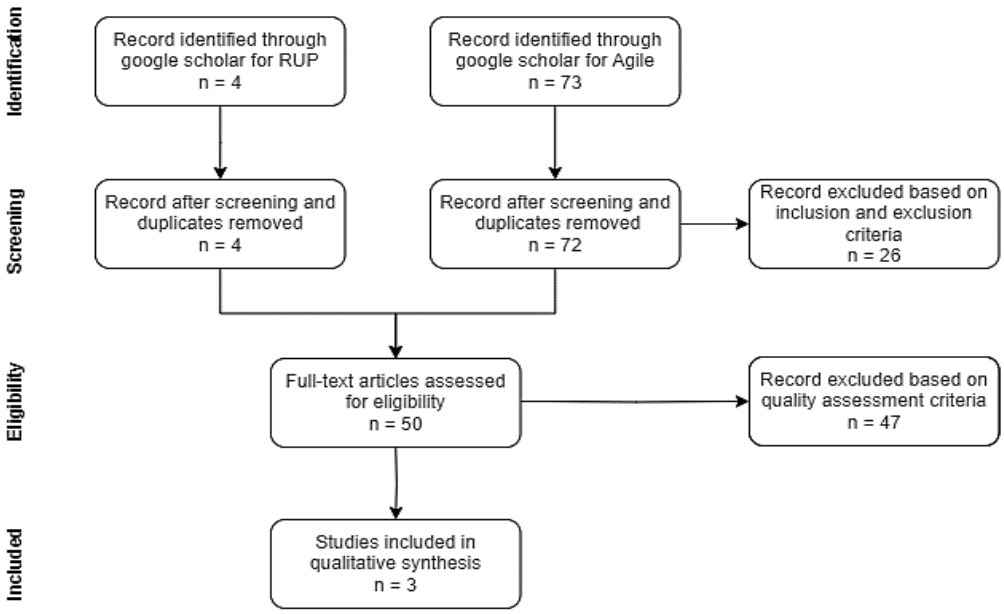

Figure 3. Prisma flow diagram

In the aim of making software that has minimal impact on environmental damage, the implementation of green computing principles at each stage of the RUP is carried out so that the output documents from each stage have implemented green computing principles. Journal from [21] details criteria related to formal approaches in contributing to sustainable computing, involving green computing criteria such as green management, design, recycling and disposal, manufacturing, purchasing, and green use. The criteria of green computing are also discussed in several related journals as discussed by study [22]–[26] which all have six criteria that can be grouped into general criteria as mentioned earlier. In his journal, Raza *et al.* [21] said that green manufacturing does focus on green product development. While Saha [25] analyze various issues related to green computing such as the relationship between environment and information technology, green information technology advantages, adoption of green computing, eco-friendly practices, green computer design, green information technology standards and regulations about industry association. Kharchenko *et al*. [27] explain the definition and classification of Green Information and Technology implementation by analyzing the main principles of development, implementation, indicators and values of green computing. Mesaad *et al*. [28] provide an analysis of current green computing initiatives and an overall comparison of them to show their efficiency and also discusses the development and challenges of green computing. Kern [29] discusses awareness and approaches to creating awareness about green computing. Nanath *et al*. [30] discusses the impact of Green Information System on innovation where the Company gets better performance than competitors because of better performance from green innovations.

This research mapped the output document from the implementation of the software development method into the green computing criteria. The findings are a framework in the form of a matrix mapping between the process stages provided in the software development methodology and green computing criteria. Which will help software developers contribute to the United Nations program, namely SDGs at point 12 through the implementation of green computing in developing software using RUP. This is done by the author with the hope that in the future, software development carried out from the analysis stage to implementation is always in line with the ideals of green computing for a better living environment in accordance with the SDGs promoted by the United Nations.

3. RESULTS AND DISCUSSION

This research begins a discussion of existing literature related to the implementation of the RUP software development methodology and the outcomes provided from the literature. Retrieved from [31], in his journal, the implementation of RUP through 4 phases produces outputs at each phase. In this discussion, it also launches from other sources related to the implementation of the RUP software development methodology and the outputs generated from each stage of the RUP. Each author makes the results of each stage different depending on their needs, Table 4 presents the output documents from each RUP stage implemented by several previous researchers with topics related to this research.

Table 4. Output table of RUP stages

Writer	RUP Phases			
	Inception	Elaboration	Construction	Transition
[31]	Observations and Analysis of the problem	Flowchart, UCD, menu structure, display mockup	Hardware and software requirements, code output or display	Application test results using blackbox test
[14]	A System Charter, or guiding document outlines the purpose, scope, resources, constraints	Unified modelling language (UML)	software development result (SDR)	Software test description (STD) dan software test report (STR)
[15]	Business Modeling (BM Canvas), Requirement (Flowchart of current system & Requirement of system), Analysis & design (UCD)	UCD, activity diagram, entity relationship diagram (ERD), interface design	Code implementation and display results, Blackbox testing results	Installation and deployment (results), system maintenance design
[32]	Use Case Diagram (UCD)	UML	Code implementation and display results	User acceptance test (UAT)
[16]	UCD, Activity Diagram	Sequence Diagram, Class Diagram	Code implementation and display results	Configuration and UAT results

In supporting the SDGs carried out by the United Nations, this journal will formulate the stages of RUP software development that contribute to this. This research will do in this case is to map the output of each RUP stage into the green computing criteria, the result is a matrix that gives us an overview of what outputs from the RUP stages can contribute to green computing. This will provide an overview of software developers who use the RUP method in carrying out their development, to consider the output of the RUP stages that help their institutions contribute to green computing. In Table 5, the implementation of green computing principles is carried out on documents generated from each stage of the RUP carried out by previous research so that the output documents that best meet all green computing criteria are obtained. Even these outputs can be clear guidelines on what developers should do when implementing RUP in accordance with the ideals of green computing which is presented in Table 6.

Based on Table 6, the RUP outputs that fit the green computing criteria, a mapping of the most suitable outputs and the framework used to create them can be made. Table 7 contains the output documents from the RUP stages that represent green computing and are expected to be a contribution for software developers to the SDGs program.

From Table 7 presented, it can be determined what documents can be the output of the RUP stage which is in line with the principles of green computing. At the Inception stage, the output is in the form of a system charter which contains an analysis of the current system and the proposed system design in the form of a pdf document with digital signatures of related parties. At the elaboration stage, the output is a system requirement specification which is a pdf document and contains UML and display design. The output of the construction stage is in the form of a software development result which contains a software development report along with the source code, development log and display of the software created. While the output of the Transition stage is in the form of a software test report which contains the results of software testing carried out by the development team and a User Acceptance Test which contains the results of software testing by users, both of these documents are pdf.

Table 5. Output matrix of RUP stages against green computing criteria

RUP Phases / Green Computing	Inception	Elaboration	Construction	Transition
Green Design	[14], [15], [16], [31], [32]	[14], [15], [16], [31], [32]	-	-
Green Manufacturing	[14], [15], [16], [31], [32]	[14], [15], [16], [31], [32]	[14], [15], [16], [31], [32]	[14], [15], [16], [31], [32]
Green Management	[14], [15]	[14], [15], [31], [32]	[14], [31]	[14], [16], [32]
Green Purchasing	[14], [15]	-	-	-
Green Use	[14], [15], [16], [32]	[14], [15], [16], [31], [32]	[15], [16], [31], [32]	[14], [16], [31], [32]
Green Recycling and Disposal	[14], [15]	-	[15], [16], [32]	-

Table 6. New table of RUP outputs according to green computing criteria

RUP Phases			
Inception	Elaboration	Construction	Transition
[14], [15]	[14], [15], [31], [32]	[16], [31], [32]	[14], [16], [32]

Table 7. Table of RUP output documents

RUP Phases			
Inception	Elaboration	Construction	Transition
System charter	Software requirement specification	Software development result	Software test report and user acceptance test

4. CONCLUSION

This study has retrieved the incorporation of green computing principles into RUP methodology, with a specific emphasis on supporting SDGs 12 – Responsible Consumption and Production. As result green computing seamlessly fits into RUP's structured software development approach which is presented in Table 5. A significant outcome of this research as presented in Table 7 is the compilation of five comprehensive documents. It can serve as artifact in each phase of RUP, culminating in a detailed report which is system charter as result for inception, system requirement specification as result for elaboration, software development result as result for construction, software test report and user acceptance test as result for transition. This research is limited to how RUP aligned with green computing can support the SDGs program. In this case, it applies from the analysis phases to software implementation, of course we all try to keep the earth where we live always good to live in.

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