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

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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.

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

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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 CO₂ 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 CO2 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.

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.

Table 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.
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).
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.

Integrating green computing into rational unified process for sustainable development... (Filan Firmansyah)
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 result or display output or display results, and the framework used to create them can be made. Table 6 contains the output documents from the RUP stages that help their institutions contribute to green computing and are expected to be a contribution for software developers to the SDGs program.

### Table 4. Output table of RUP stages

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

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

<table>
<thead>
<tr>
<th>Green Computing</th>
<th>Inception</th>
<th>Elaboration</th>
<th>Construction</th>
<th>Transition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Design</td>
<td>[14], [15], [16], [31], [32]</td>
<td>[14], [15], [16], [31]</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Green Manufacturing</td>
<td>[14], [15], [16], [31], [32]</td>
<td>[14], [15], [16], [31]</td>
<td>[14], [15], [16]</td>
<td>[14], [15], [16]</td>
</tr>
<tr>
<td>Green Management</td>
<td>[14], [15]</td>
<td>[14], [15], [31], [32]</td>
<td>[14], [31]</td>
<td>[14], [16], [32]</td>
</tr>
<tr>
<td>Green Purchasing</td>
<td>[14], [15]</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Green Use</td>
<td>[14], [15], [16], [32]</td>
<td>[14], [15], [16], [31], [32]</td>
<td>[15], [16], [31], [32]</td>
<td>[14], [16], [31], [32]</td>
</tr>
<tr>
<td>Green Recycling and Disposal</td>
<td>[14], [15]</td>
<td>-</td>
<td>[15], [16], [32]</td>
<td>-</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Writer</th>
<th>Inception</th>
<th>Elaboration</th>
<th>Construction</th>
<th>Transition</th>
</tr>
</thead>
<tbody>
<tr>
<td>[14], [15]</td>
<td>[14], [15], [31], [32]</td>
<td>[16], [31], [32]</td>
<td>[14], [16], [32]</td>
<td></td>
</tr>
</tbody>
</table>

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 an 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 so 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.

REFERENCES


**BIOGRAPHIES OF AUTHORS**

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