Integrated-Software Sustainability Evaluation Model (i-SSEM) Development

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***Abstract*—An *integrated*-Software Sustainability Evaluation Model (*i*-SSEM) presents the holistic evaluation criteria of software sustainability with performed the systematic measurement by using Goal Question Metric (GQM) approach. The required of the holistic evaluation in software sustainability is to address the limitations of the previous studies in which the needs to integrate all evaluation criterion into sustainability dimension such as environment, economic and social. The evaluation criteria are supported by references standards such as standard organization of product quality, sustainability development principal introduced by Bruntland Commission Report and the best practices from individual and organization in software sustainability evaluation (SSE). In order to provide the holistic SSE with integrated all sustainability dimensions, the proposed characteristic and sub-characteristic is evaluated based on "what, who, when, why, where" and "how" to measure the criteria. The proposed evaluation criteria consist nine (9) characteristics and thirty-two (32) sub-characteristics with nineteen (19) metrics. Embedded of GQM contributes in defining the measurement goals by determining the purposes, perspectives, point of views in the following context of environment with respect to achieve software sustainability.**

***Index Terms*—Software sustainability evaluation, sustainability dimension, evaluation criteria, goal question metric (GQM).**

I. INTRODUCTION

The Brundland Commission Report has defined sustainability as meeting the needs of the present generation without compromising the ability of future generations to meet their own needs [1]. Sustainability has been practiced in the various fields such as in manufacturing, construction, restoration of natural disasters, soils and erosions and ecosystems and biodiversity. Sustainability in software engineering is just began ended 2009 in which the issue has been recognized as an important topic that is needed to be highlighted in software development [2],[3],[5],[6].

Sustainability is strongly related to long living software in which the regardless to highlight sustainability in software development will be influenced to the system with poor quality. This scenario will be reflected into the strategies of efficiency to achieve profitability and also reliability with the aimed to improve and recover the risks of the system failures and errors in the future [9]. Unfortunately, the systems architectures today are claimed as poor quality in handling the changes and transformation process to meet the goal in sustainability impacts [8]. For instances, the software systems are lacking consistency between the system and user in which the software architectures do not supporting the users action in handling the changes in the environment. As the results, the complexity of software systems is increased in term of the cost of maintenance because of the system is damaged and failure will be reflected to the business process and having difficulties to be maintained [4],[8],[10]. In order to master all changes within the software development towards long living systems, the continuously of evaluation process in software sustainability is significantly to lead the achievement of sustainability [4],[8]. Therefore, this study proposed an *integrated*-Software Sustainability Evaluation Metric Model (*i*-SSEM) to cater the problem.

II. LITERATURE REVIEW

Several studies on sustainability characteristic performed more supported ideas in bringing the information and guideline or framework in identifying the sustainability characteristic in the various domains especially in software engineering. The best known practices models and guideline or frameworks in the literatures such as software model proposed by [3],[5],[11],[12], and several studies had produced a framework or guideline towards sustainable software such as [2],[7] and [13].

Based on the investigation of a systematic review in [14] and [15] investigated more results based on characteristic and sub-characteristic of software development towards long living software. Several characteristics in the previous studies are adopted from the standard quality model of ISO/IEC 25010 – System and Software Quality Requirements and Evaluation (SQuaRE) which are functional suitability, performance efficiency, compatibility, operability, reliability, security, maintainability, and transferability. They claimed the selection of this standard quality model as a benchmark due to it quality in emphasizing the important of features in use for a software product.

Most important elements such as the integration of environment, economic and social dimensions towards software sustainability are highlighted in the previous works. Though, most of them did not observe the sustainability paradigm with clearly defining the goal in terms of purposes, perspective in the specific environment context. In [2] focuses on natural environmental in which they are proposed a framework as sustainability taxonomy for modeling the software system where the decisions have potential impacts on sustainability. They claimed covers all dimensions in sustainability, however the guidelines to develop the taxonomy is unclear, limited and too generalized.

According to [13] focuses on sustainability of software from an environmental perspective which is the way of software product and process should be focused to aim at dematerializing production and consumption processes to

save the natural resources. The researchers connected all sustainability dimensions in their model and directly focused on environmental perspectives because they described the environmental dimension have most efforts and its relation to the other dimensions indirectly.

In [7] assesses software sustainability through their generic sustainability model framework. The issue of human is debated in their framework that software is developed to support the human work on good communication, helps companies to set up rules for positive, open and efficient communication and the elements pointed can support the company culture builds on the above-named values. The values are created to focus on business social that are central to values of tolerance, trust, fairness and culture. Even so, this framework did not clearly define the goal, purposes, perspectives, and highlights the context of criteria that need to be achieved.

Overall, the models are regardless to show the systematic measurement process which only focuses on what need to be measured instead of who, when, where, why, and how to measure. Besides that, the goal of evaluation criteria did not well-defined for each proposed characteristic with presented an effective goal measurement and the evaluation mechanism did not well presented the holistic sustainability criteria. Therefore, this study intends to improve the limitations of previous works in defining the goals for the proposed features of software sustainability evaluation by using Goal Question Metric (GQM) with focuses on holistic evaluation criteria in environment, economic and social dimension.

III. INTEGRATED - SOFTWARE SUSTAINABILITY EVALUATION MODEL DEVELOPMENT

The proposed *i*-SSEM is performed the holistic evaluation criteria of software sustainability with presented the systematic measurement by using GQM approach. The required of the holistic evaluation in software sustainability is to address the limitation of the previous studies in which the needs to integrate all evaluation criteria of sustainability dimension. The sustainability dimensions are environment, economic and social. Thus, *i*-SSEM is introduced to support the constraint. An *i*-SSEM is constructed using GQM method that contributes in defining the measurement goals by determining the purposes, perspectives, point of views in the following context of environment with respect to achieve software sustainability. As indicated in [14] and [15] performed by Systematic Literature Review (SLR) method were gathered several characteristics and sub-characteristics to be identified as characteristic of software development towards developing software sustainability. All characteristics are collected from several sources such as:

i) **Secured based software development** such as ISO/IEC 25023 Measurement System and Software Product Quality, ISO/IEC 25022 System and Software Quality Requirement and Evaluation – Measurement of quality in use, ISO/IEC 25010 Software Standards Quality Model, and ISO/IEC 15504 Software Process Improvement and Capability Determination.

ii) **Sustainability development in other domain** such as Brundtland Commission Report, Energy Sustainability Index (ESI), Environmental Sustainability Index (ESI), Environmental Performance Index (EPI), Index of Sustainable Society (ISS), and Weighted Index of Social Progress (WISP) and,

iii) **The important characteristics of individual** who involve in software sustainability development are obtained from the best practices in literature such as [3],[4],[5],[6],[7],[8],[11],[12],[16] and [17].

Figure 1 illustrates the hierarchical structure of evaluation criteria of *i*-SSEM and following by the organization of characteristic into sustainability dimension. Next section is discussing the enhancement of measurement criteria through the proposed characteristic.

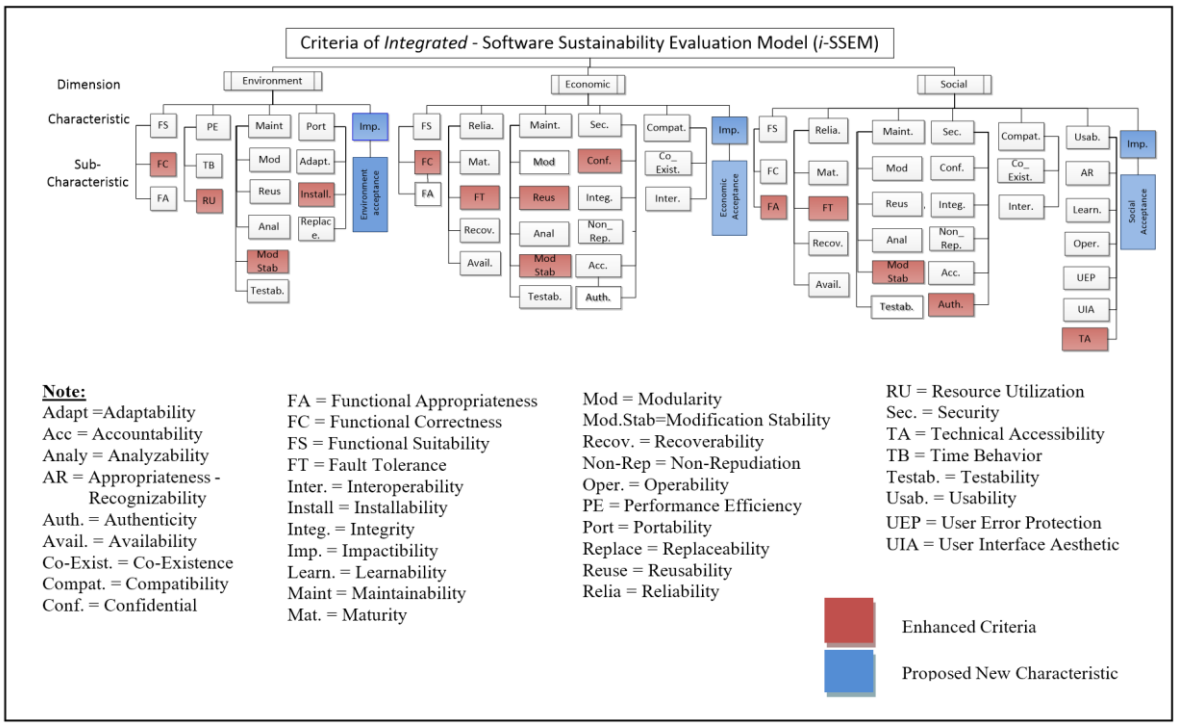

Figure 1: Hierarchical structure of evaluation criteria of integrated-software sustainability evaluation model (*i*-SSEM

A. Organization of Characteristic and Sub-Characteristic into Sustainability Dimension

The identified characteristic and sub-characteristic is organized into environment, economic and social dimension of sustainability. The organization of characteristic and sub-characteristic of software sustainability metric in this study is followed the theory, experiences, skill and opinion from the best practices in the literature and also the standard organization recommended by International and Organizational Standards such as ISO/IEC 25023 for characteristic and sub-characteristic in software quality. The verification process is used to verify the proposed characteristic and sub-characteristic of software development towards software sustainability. The purpose at this verification stage is to ensure the identified and organized characteristic and sub-characteristic for software sustainability are completeness, correctness and understandable. The elements of completeness is important to describe for the inclusion of all required characteristic and sub-characteristic, process, tasks, technique and method are comprehensive to achieve the objectives in this study. While, correctness is to look for the accuracy of the model based on the usable results, cost-effective, the adequate of characteristic and sub-characteristic towards software sustainability, and also the consistency of the model structure and components. In addition, understandable is to look for the model structure and component should be clear, usefulness, appropriate for audience, ease to use, ease to implement, and unambiguous. Thus, all the elements are to support and analyze the data collection pertaining to the characteristic and sub-characteristic involved are built significantly to achieve software sustainability.

The verification stage is performed using expert review approach, which is easier to use and faster to collect the data from expert in order to support the improvement and modification related to the requirements that have been developed. The organized characteristics for each dimension are discussed below.

a. Environment Dimension

Four (4) characteristics have been organized into environment dimension of software sustainability. There are functional suitability, performance efficiency, maintainability, and portability. The descriptions are as follows:

i) **Functional Suitability** - This characteristic is important to create a software system and product with minimal impact to the environment in which the functions provided are performed the accurate results towards user intended objectives. The results performed are achievable in order to get a better understanding of the actual impact on user's intended usage [1],[18],[19] and [20].

ii) **Performance Efficiency** - This characteristic is important to provide software with features towards green software in which the energy efficiency need to be predicted and environment [1],[5],[7],[18],[19] and [20].

iii) **Maintainability** - This characteristic is important to support software system to be effectively and efficiently to perform the task and function that can support to achieve the sustainable energy efficiency that can reflect to the environmental context [1],[5],[7],[18],[19] and [20].

iv) **Portability** - This characteristic is important to support software system to be effectively and efficiently in which a system, product or component can be transferred from one hardware, software or other operational from one environment to another [1],[5],[7],[18],[19] and [20].

b. Economic Dimension

Five (5) characteristics have been organized into economic dimension of software sustainability. There are functional suitability, reliability, maintainability, security, and compatibility. The descriptions are as follows:

i) **Functional Suitability** - This characteristic important to provide the correct function to meet stated and implied needs of software requirement. The effective function to perform the correct result to achieve the intended objective will minimize the cost development [3],[4],[5],[6] and [7].

ii) **Reliability** - This characteristic is important to predict the completed system or software product will satisfy prescribed reliability needs during the development of the system or software product. The behavioral of the system need to be predicted due to its quite related to the cost of development [7],[8],[17],[18],[19] and [20].

iii) **Maintainability** - This characteristic is important to predict and control the software in providing the effectiveness and efficiency with which a software system is reused, modified, changed and tested with the lower of cost development, maintenance and minimum impact to the cost of failure and risks [7],[8] and [17].

iv) **Securit**y - This characteristic is important to provide agility of software system in which the protection of information and data, so that person or other product or system have the degree of data accessibility appropriately to their types and level of authorization. This characteristic can support to reduce cost of development and risks of capital value in long term profit [18],[19] and [20].

v) **Compatibility** - This characteristic is important to provide software as flexibility in which system or component can exchange information with other product, system or component and also sharing the same hardware or software environment. The flexibility can reduce cost investment, risks and sharing the benefits to low cost of development [7],[8] and [17].

c. Social Dimension

Six (6) characteristics have been organized into social dimension of software sustainability. There are functional suitability, reliability, maintainability, security, compatibility and usability. The descriptions are as follows:

i) **Functional Suitability** - This characteristic is important to provide the suitable and reasonable results in order to achieve the specified usage objective. The functional of software is more accurately to gain user accessibility and interaction in using software [1],[18],[19] and [20].

ii) **Reliability** - This characteristic is important to provide human satisfaction especially in using the system or software product in term of the operational behavioral and accessible function when required for use [1],[5],[7],[18],[19] and [20].

iii) **Maintainability** - This characteristic is important to predict the software system can provide the task or function are valuable to achieve the user objective and expectation [1],[5],[7],[18],[19] and [20].
iv) **Security** - This characteristic is important to provide protection requirements for software of system from the case of a standalone system to the case of a system connected to the internet. The determinations of the required security functions and the assurance of their effectiveness need to be highlighted towards secured accessibility, participation and communication with the users [1],[5],[7],[18],[19] and [20].
v) **Compatibility** - This characteristic is important to operate successfully by communicating and exchanging information due to an interoperable system can support easier in exchanging and reusing the information internally and externally [7],[8] and [17].
vi) **Usability** - This characteristic is important to enable user participation, accessibility and interaction in operating and controlling the software. This characteristic provides suitability of the software for the task, self descriptiveness of the software, controllability of the software, conformity of the software with user expectation and also suitability of the software for individualization [7],[8] and [17].

B. Enhancement of Measurement Criteria of Software Sustainability Evaluation Model

The organized characteristics and sub-characteristics are enhanced in term of the measurement criteria to achieve software sustainability. Seven (7) characteristics and twelve (12) sub-characteristics have been enhanced and organized into sustainability dimension. The GQM approach is used to develop goal, questions and metrics. The metric development can be classified into two major group which are testing and predictive.

The testing metrics are used to collect data in order to measure the actual use of working application and user satisfaction as well as identifying problem encountered. Therefore, it requires fully functional application. This testing metric is further divided into preference metrics (measure actual user satisfaction) which refers to as subjective metrics and performance metrics (measure actual performance of the system when conducting a task or application performance) which regarded as objective metrics. Therefore, the metrics defined in this study are basically for testing metrics for both preference (subjective metrics) and performance (objective metrics). Next section discusses the enhancement criteria for each dimension.

a. Enhancement of Measurement Criteria for Environment Dimension

The enhancement of measurement criteria in environmental dimension is referred to green software which is the property is influenced by two aspects such as energy consumption and resources consumption. The energy consumption is related to the efficiency of the systems by using the energy efficiency such as runtime efficiency, CPU intensity, memory usage, peripheral intensity, idleness and algorithmic efficiency [21]. In conjunction, the resources consumption aspects are related to the software products that containing the software and hardware configuration, materials used such i.e. print paper, storage media, ink toner and coverage will be influenced the level of sustainability in environment dimension [8]. Both environmental dimension aspects are needed to be measured as to evaluate the level of sustainability achievement in the software development.

According to the [1], the environment dimension is focused on the development that preserves the diversity of biological species which is quite related to the essential ecosystems and ecological processes. The particular environmental sustainability is focused to the human well-being as to improve the human welfare by protecting the natural resources. These include the element such are water, land, air, mineral and ecosystems services. In addition, the elements will be contributed to the consumptions of sources of raw materials used for human needs that centered to the human wastes are under controlled [22] and [23].

b. Enhancement of Measurement Criteria for Economic Dimension

In order to achieve the economic sustainability dimension, the three aspects are needed to be highlighted in the software development. There are software process evolving intellectual capital with broken down into sub-aspect i.e. (customer capital value, human capital value, and structural capital value), low cost of software process with decomposed into sub-aspect i.e. (market requirement value, and physical value), and long term of profitable software by taken into consideration of sub-aspect i.e. (innovation value for market, and differential value). For instance, the software development is developed with the low of cost processing in which the process can assist to evolve the Intellectual Capital (IC) with a long-term profit [21].

Furthermore, economic dimension refers to the development that aims at maintaining the assets such as the capital and value added [23]. The economic dimension is focused on the financial and closely related to the profit and non-profit value. This element is required to define the income as the amount during the activity has started until at the end of the period of activities [1]. Generally, the economic sustainability is proposed in maintaining the financial value involved as the capital in the activities in order to make sure the activities are achieved the profit until at the end of the project. This phenomenon can imagine that the economic sustainability is applied in optimizing the value to the company or organizations.

c. Enhancement of Measurement Criteria for Social Dimension

Social dimension is referred to the development that preserves the community especially in maintaining the close social relationships in communities [1]. The social sustainability is related to the development in maintaining the social capital and societal communities in the harmony situation without compromising to the government and any other party. This element is related to the social capital as an investments and services that can create to the basic framework for society [23]. In the context of software engineering, the social sustainability dimension is referred to the technique on how the software development is built to enhance the social capital value [21]. There are two aspects that are needed to be highlighted in the social sustainability dimension such as the technical community and the user community. For instance, the social dimension in software sustainability is assessed the values for technical community such as enabling the participation, communication, and interaction. Besides, the value for user community is related

to the accessibility of the software system that had been developed.

IV. RESULTS AND DISCUSSION

The measurement goal is defined by adapting the templates as proposed by [24]. The templates consisting of Purposes i.e. (to characterize, evaluate, predict, motivate and etc) that is pointed out to the object under study i.e. (process, product, model and etc) in order to clarify the object under study i.e. (to understand, assess, manage, engineer, learn, improve, and etc). The second element is Perspective that related to the specific issues or features that is needed to be examined i.e. (cost, effectiveness, correctness, defects, changes, product metrics, reliability, and etc), from the point of views of the i.e. (user, developer, manager, customer, corporate perspective and etc). Next, the third element is Environment focuses on the context of i.e. (process factor, people factors, problem factors, method, tool, constraint and etc) [16]. Results of GQM are shown in the Figure 2, 3 and 4.

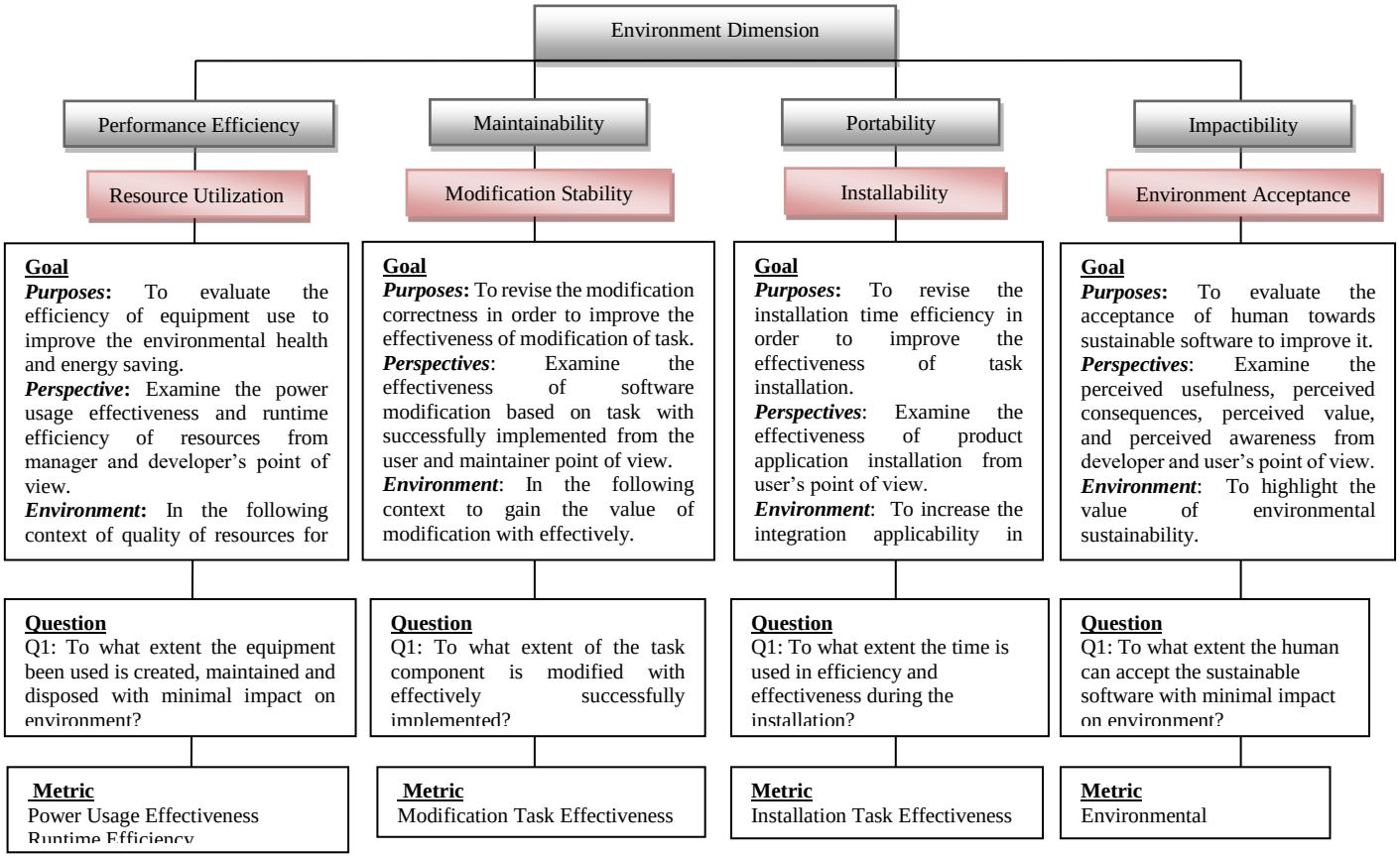

Figure 2: Hierarchical structure of GQM for environment dimension

Several characteristic and sub-characteristics that have been organized into environment dimension is enhanced in terms of what, who, when, why, where and how to measure the criteria that have been focused. The enhanced characteristics and sub-characteristics that are related to the environment dimension is performance efficiency through the resource utilization sub-characteristic, maintainability through the modification stability sub-characteristic, portability via the installability sub-characteristic and new proposed characteristic is *Impactibility* with environment acceptance. The measurement criteria for the characteristic organized into environment dimension is enhanced based on the way of software is created, used, maintained and disposed with minimal impact on environment.

Furthermore, the enhancement of characteristic and sub-characteristic in economic dimension are functional suitability through functional accuracy sub-characteristic, reliability through fault tolerance, maintainability via three sub-characteristics such as modularity, reusability and modification stability, security via the confidential sub-characteristic and new proposed characteristic is *Impactibility* with economic acceptance. The measurement criteria for the characteristic organized into economic dimension is enhanced based on the way of software is created with the lower of economic risks for the capital value, low cost of software development with long term profits.

Thus, the enhancement of characteristic and sub-characteristic in social dimension such as functional suitability through the functional appropriateness, reliability through fault tolerance sub-characteristic, maintainability through testability sub-characteristic, security via authenticity sub-characteristic and usability through the technical accessibility sub-characteristic. The concept of human is vital in socially software development due to all works in software development is performed by people who are called knowledge workers and will be reflected to human towards the end. The knowledge workers are defined as the people who are involved and responsible in the software development such as manager, developer team, maintainer team, and users. The acknowledgment of the social approach in sustainable software can ensure the success of interaction between human and application. The reason to gain the satisfaction of human towards software performance provided by software process or product is potentially a

significant role in gaining the success-ability of the software development. Consequently, neglecting the importance of human factors in developing software process and product can leave a huge impact on the integration concept of sustainability dimension in software sustainability.

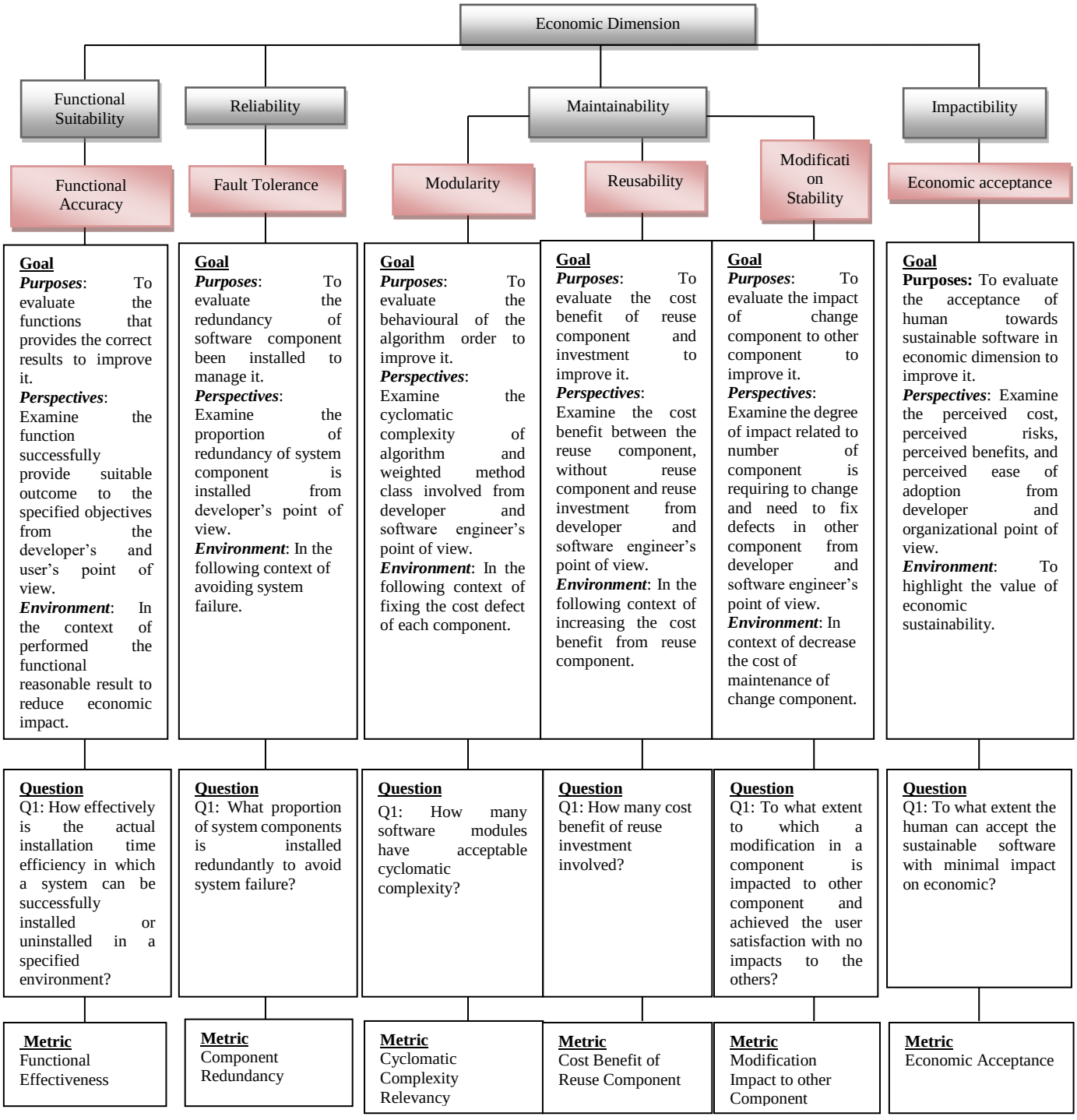

Figure 3: Hierarchical structure of GQM for economic dimension

Impactibility in sustainable software is defined as a degree of human acceptance of the software towards software sustainability in terms of environment, economic and social. *Impactibility* characteristic is needed to be highlighted in sustainable software features due to the limitation of previous studies in highlighting the impact of software is developed towards environment, economic and social perspective directly in the sustainable software model. Dealing to sustainable software, the relationship between software and the impact provided by the software is required to be optimized in order to achieve the integration of sustainable software. The software is quite related to the human because the software is developed with highlighted the environment impact in which focuses on the way of software is created, used, maintained and disposed with minimal impact on environment. The issue of resources computing is significantly to be addressed in terms of impact provided by the system from the start of implementation until to the future generation. Thus, this characteristic is important for ability of software to provide the user environment acceptance of computing resources to be extended use. Another issue is the cost investment spending by software organization in

developing software with minimal impact of cost of software construction, maintenance, and management for survivability. Thus, *Impactibility* characteristic is the issue of user acceptance in developing and maintaining software with economically friendly in which the software is created with positive impact to low cost of software development, maintenance and management to be survived are required to be highlighted. Therefore, the *Impactibility* characteristic is broken down into environment acceptance, economic acceptance and social acceptance to support the previous limitations.

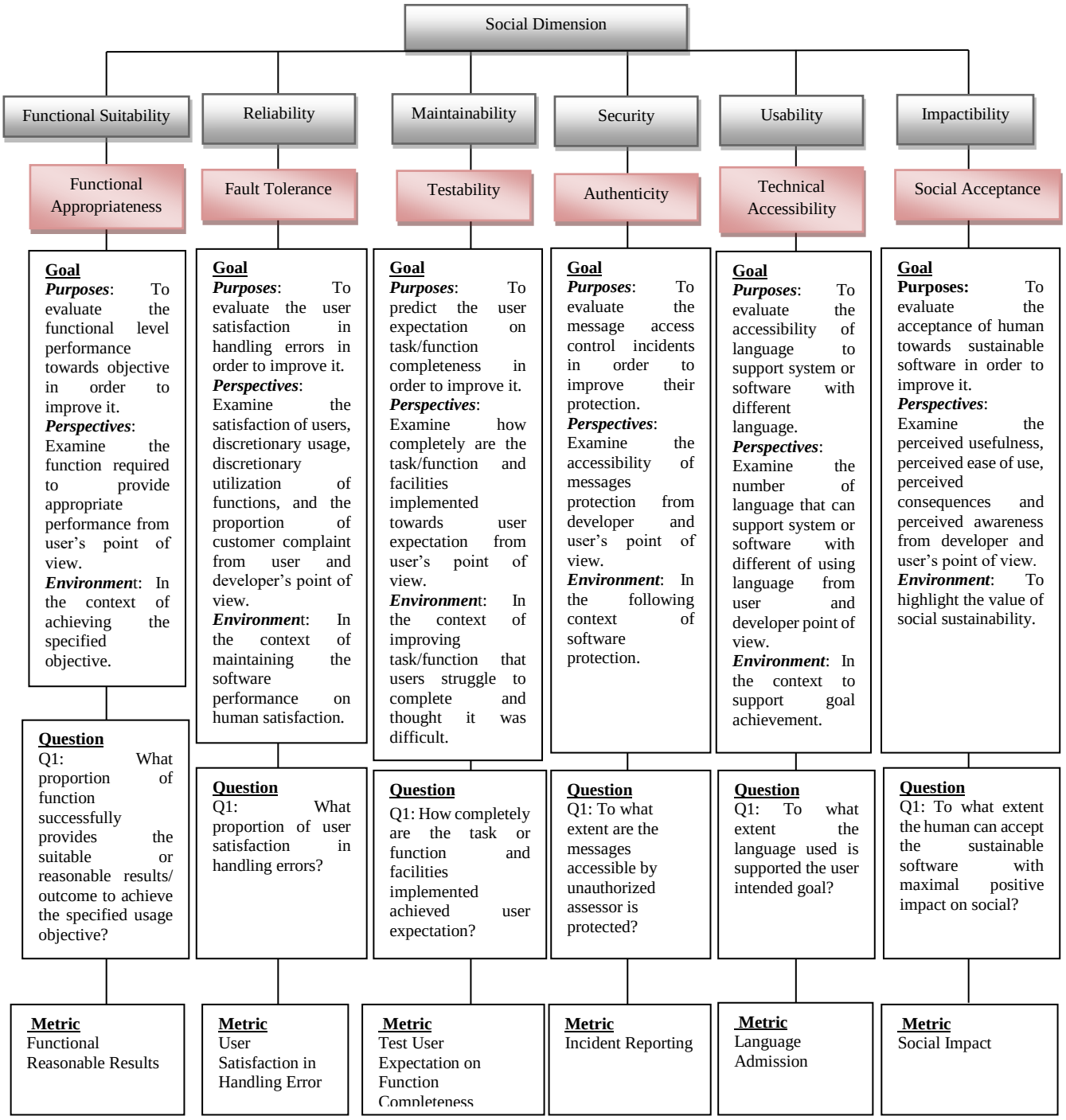

Figure 4: Hierarchical structure of GQM for social dimension

Environment acceptance sub-characteristic is defined as ability of software to provide the user environment acceptance of computing resources to be extended use. This sub-characteristic will support to measure acceptance of human towards sustainable software with environmental friendly in which software is created, used, maintained and disposed with minimal impact on environment [27]. Next, economic acceptance is defined as ability of software to provide the user economic acceptance to low cost of software development to be survived. This sub-characteristic will support to measure acceptance of human towards sustainable software with economical friendly in which the software is created with positive impact to low cost of development and management to be survived. Lastly, social acceptance sub-characteristic is defined as ability of software to provide the user social acceptance to sustainable social connectedness. This sub-characteristic is to measure acceptance of human towards sustainable software with social friendly in which the software

is developed with the impact of human connectedness to the software function.

V. CONCLUSION

The investigation of a systematic review in the previous works investigates more results based on characteristic and sub-characteristic and measurement mechanism of software development towards long living software. The characteristics are known as functional suitability, performance efficiency, compatibility, operability, reliability, security, maintainability, usability and *Impactibility*. The comprehensive specification and evaluation of the significant characteristic is highlighted in this software sustainability model by defining the appropriate characteristic and taking into account of the purpose of usage of the software product, organization into sustainability dimension, enhancement of measurement criteria towards software sustainability and presented using GQM approach. The application of GQM is recently used in business-driven quality improvement approach very well in many domains. However, this approach currently beneficial to the researcher in developing evaluation metric for software and merely very helpful in defining the goals that need to be achieved towards software sustainability. GQM has much assists in defining the accurate goal for each characteristic and sub-characteristic in this study respectively with fully descriptions on the purposes, perspectives, the point of views, and the context of the environment, economic and social perspective that are needed to be highlighted.

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