A Sustainable Engineering Infrastructure Model for the 21st Century

Bassey Okon†1 , Sunday Ekpo*2 and Dr Taha Elhag†3

Abstract— **Advancements in interdisciplinary fields respecting systems and subsystems, devices and components and technologies and architectures have resulted in complex infrastructural developments requiring sustainability. This paper presents a sustainable engineering infrastructure (SEI) model that is expected to serve as a planning, design, development, implementation and management platform for the engineering community. Starting from the preconceptual design phase, a step by step algorithm and system-level SEI model has been developed. The SEI model analyses the project lifecycle with an allowance for on- and offsite recycling processes. All aspects of conceptual design, procurement, materials handling, construction, renovation, disposal, decommissioning, hazardous materials, demolition and recycling are addressed. Appropriate metrics for the engineering project lifecycle are incorporated in the developed SEI model functions. Issues bordering on project viability, reliability, performance, deliverability, maintenance, environmental impact assessment and return-on-investment amongst others are integrated into a common design and analysis pool function. The SEI model is expected to offer an unprecedented design and management leverage for project engineers and managers involved in all kinds of projects and infrastructural developments. Energy, maintenance and the external factors characteristics gained severity indices of 70 – 80% and water resources management, infrastructure design characteristics and the project characteristics have 48 – 74% in managing infrastructure systems. A sustainability index of 0.45 was obtained for the case study reported in this paper. The results of this study indicate that the proposed novel SEI model and sustainability index function promise to transform engineering projects management.**

Index Terms— project lifecycle cost algorithm, project metrics, sustainable engineering infrastructure model, sustainable indicators framework.

I. INTRODUCTION

One of the greatest challenges of the 21st century has been the issue of sustainable development and the vast implications of this concept on human activities. Therefore, a widely accepted definition of sustainability is addressing the needs of the present without compromising the ability of future generations to meet their own needs [1]. However, the concept of sustainability concentrates on three factors viz: the social, economic and environmental values for its success. These trio factors reveal a balance within the sustainability development model.

The World Commission on Environment and Development (WCED)'s report titled "Our Common Future" focused on enhancing quality of life therefore, allowing people to live in a healthy environment and improve social, economic and environmental conditions for the present and future generations [1]. Conversely, [2] indicates that sustainable development at all times should be viewed with the five guiding equity central principles; physical, social, political, economical, and environmental values for the present and the future generations.

Fig. 1 indicates the relationship between the trio sustainability values within any healthy environment.

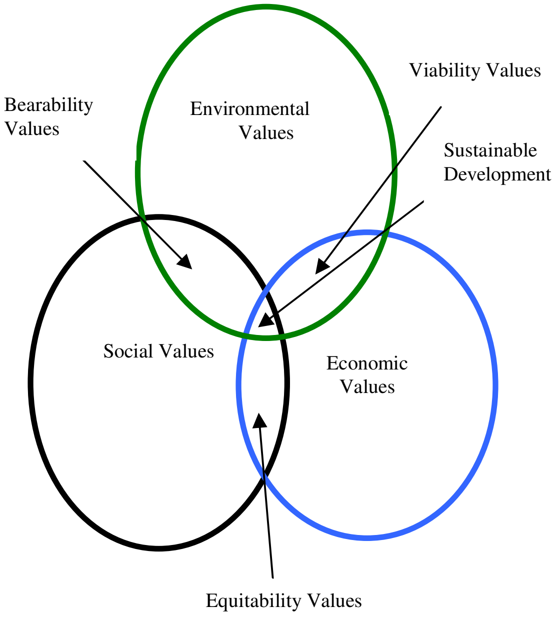

Fig.1 The three themes of sustainable development

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[1] Bassey Okon, PhD Student with the School of Construction and Project Management UCL Bartlett Faculty of the Built Environment London, WC1H 0QB, United Kingdom; email: b.okon@ucl.ac.uk
[2] Sunday.Ekpo, PhD Student with the School of Electrical & Electronic Engineering, The University of Manchester, M60 1QD, United Kingdom; email: Sunday.Ekpo@postgrad.manchester.ac.uk
[3] Dr.T.S.M.Elhag, Senior Lecturer with the School of Construction and Project Management UCL Bartlett Faculty of the Built Environment London, WC1H 0QB, United Kingdom; email: t.elhag@ucl.ac.uk

Nevertheless, [3 – 4] explain that the concept of sustainability to be used in the corporate community is by developing the principle of “triple bottom line”. The triple bottom line within this context refers to the three themes of social, environmental and economic (financial) performances, which are directly tied to the concept and goal of sustainable development. They are highly interrelated and are of equal importance. It is a term that is increasingly acceptable worldwide within the corporate community and as a framework for corporate reporting practices in sustainable development.

Basically, the set of environmental values are natural resources utilization, environmental management drive, pollution prevention and controls- (air, land waste and water resources). On the other hand, social set focuses on the standards of living, equal opportunity, community, governance, institutions, consultations, inclusion and empowerment of citizenry. The economic set outlines cost savings, profits research and development, economic growth, efficiency and stability.

Nonetheless, within the sustainability model, the spheres of sustainability intersect (socio-environmental) yielding a new set of SEI model values. The products of these are: environmental justice, natural resources, stewardship, local and globally. Moreover, the sustainability intersection between economic and social values promotes the equitability values of business ethics, fair trades and workers right. Similarly, the intersection between environmental and economics values supports the viability values of energy efficiency, subsidies and incentives for the use of natural resources [5].

II. THE SEI MODEL

The sustainable engineering infrastructure (SEI) model is developed from Fig.1 for the interdisciplinary fields respecting systems and subsystems, devices and components application, technologies and architectures and infrastructure have been resulted in complex infrastructural developments requiring sustainability. However, SEI model is expected to serve as a design, development, implementation and management platform for the sustainable engineering community.

The SEI model presents the economic, social and environmental values (as sets of system goals) for the sustainability values attainment. The sub-sets are equitability, viability and bearability values. In the SEI model, the following definitions as used in this paper apply. Where:

S_{ov} – Social values,
E_{qv} – Equitability values,
E_{nv} – Environmental values,
E_{cv} – Economic values,
V_v – Viability values,
B_v – Bearability values and
S_{uv} – Sustainability values.

The Venn diagram of Fig. 1 is translated into a mathematical model called the SEI model.

$$n(E_{cv})\ \mathrm{U}\ n(E_{nv})\ \mathrm{U}\ n(S_{ov}) = n(E_{cv}) + n(E_{nv}) + n(S_{ov}) - n(E_{cv} \cap E_{nv}) - n(E_{cv} \cap S_{ov}) - n(E_{nv} \cap S_{ov}) + n(E_{cv} \cap E_{nv} \cap S_{ov}) \quad (1)$$

But,

$$\left.\begin{aligned} n(E_{cv} \cap E_{nv}) &= n(V_v) \\ n(E_{nv} \cap S_{ov}) &= n(B_v) \\ n(E_{cv} \cap S_{ov}) &= n(E_{qv}) \\ n(E_{cv} \cap E_{nv} \cap S_{ov}) &= n(S_{uv}) \end{aligned}\right\} \quad (2)$$

Therefore, substituting Eqn. 2 into 1 yields

$$n(E_{cv})\ \mathrm{U}\ n(E_{nv})\ \mathrm{U}\ n(S_{ov}) = n(E_{cv}) + n(E_{nv}) + n(S_{ov}) - n(V_v) - n(B_v) - n(E_{qv}) + n(E_{cv} \cap E_{nv} \cap S_{ov}) \quad (3)$$

$$\Rightarrow n(E_{cv})\ \mathrm{U}\ n(E_{nv})\ \mathrm{U}\ n(S_{ov}) = n(E_{cv}) + n(E_{nv}) + n(S_{ov}) - n(V_v) - n(B_v) - n(E_{qv}) + n(S_{uv}) \quad (4)$$

Eqn. 4 is the final mathematical representation of the sustainability model by the application of the set theory. It implies that for the sustainability goals of engineering projects to be attained, relevant indices and values of sustainability must be defined and modelled as a set of integrated systems parameters. Consequently, the sustainability engineering stand point should promote a rigorous interaction for a balance amongst the three themes of sustainability.

Fig. 2 presents a project life cycle framework starting from the preconceptual design phase through a step by step algorithm and system-level SEI model. The SEI model analyses the project lifecycle with allowance for on and offsite recycling processes, a design infrastructure concept from the cradle to grave.

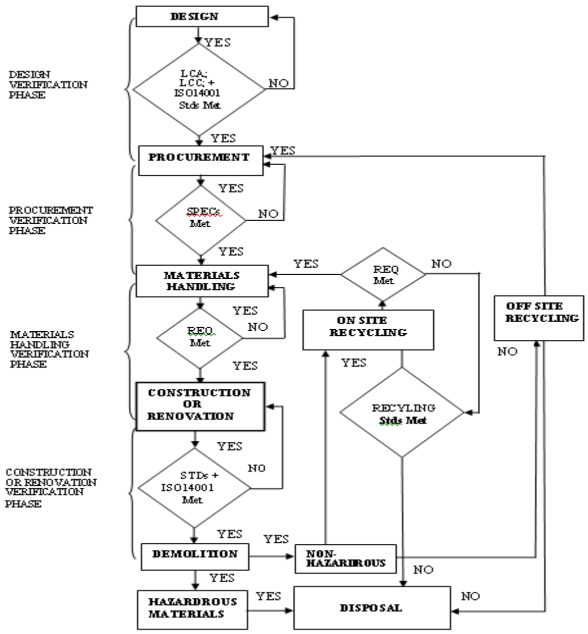

Fig. 2 Project lifecycle framework

The SEI model also addresses and normalizes sustainability to be within ranges of $0 \leq Suv \leq 1$ by applying the probability (P) and set theory concepts into sustainability.

Therefore, accurate and reliable indices of sustainability can be qualified and quantified. For an ideal project, the Suv is 1. But this is impracticable in real engineering projects. Hence, the proposed developed SEI model reported in this paper has defined and normalised Suv values to unity for engineering. An ideal engineering project management system would have a Suv of 1.

III. METHODOLOGY OF STUDY

The research employed a two-stage methodology: literature and questionnaire surveys. These were conducted with the maintenance and operation managers to discover factors affecting the proper and sustainable management of the infrastructure within Manchester City Centre Shopping Malls.

The literature review was aimed at identifying the lapses within the management practices and the service deliver within the infrastructure systems. However, [6] observes that the components of infrastructure systems includes facilities for water supplies, wastewater, energy and maintenance management of the entire system. It is regarded as the complex part of the overall infrastructure network. As s result, the surveys sought to determine the infrastructure management experts' views on the existing practices and better ways for proper management.

In the survey, 51 factors were accordingly selected and grouped into six different categories thus:

-energy resources management characteristics,
-water resources management characteristics,
-maintenance management practices,
-infrastructure design characteristics,
-infrastructure project characteristics,
-external factors affecting infrastructure management.

The employable methodology for the questionnaire surveys was to rank and evaluate these factors according to their influence and significance regarding the proper and sustainable management of the infrastructure within the shopping malls. Sixty-five copies of the surveys were administered as indicated in Table 1.

Table 1 Questionnaire Surveys Information

Questionnaire Survey	No. of Copies
Total No. of Surveys Produced	65
No. Administered	65
No. Received from Respondents'	21

A total of 65 copies of the questionnaire surveys were produced; 40 were mailed to the maintenance/ operations managers and 25 were administered by hand at the information desks within the shopping malls. From Table 1, out of the 21 respondents, 15 copies of the questionnaire surveys were completed by the maintenance/operations managers and six copies obtained from the information managers' desk. The response rate for the responded survey was 32%. However, this response rate came high above the normal rate of 20 – 30% for most posted and hand-administered surveys [7].

To calculate the degree of influence of each variable a three-point scale is used thus: [7]

1 = (not significant)
2 = (moderately significant)
3 = (highly significant)

IV. ANALYSIS AND RANKING OF DETERMINANT MANAGEMENT CHARACTERISTICS FACTORS

The factors were ranked according to their significance towards examining the proper delivery of sustainable projects. A severity index (SI) computation is used for ranking the associated factors according to their significance as stated in [7]. Mathematically, the SI is given by:

$$\mathrm{SI} = \left(\sum_{i=1}^{3} w_i x f_i \right) x \frac{100}{n} \qquad (5)$$

where i represents the ratings 1 – 3, fi, the frequency of the responses, n, the total number of responses and wi, the weights for each rating. However, the summary of findings regarding the statistical analysis for the severity index and analyses of the result are indicated in the subsequent headings of this report. This explains that 11 factors have less significant impacts on the services delivery within the context.

V. MEASURING RESPONDENTS' CONCORDANCE

This was targeted at determining the variation of responses for each factor. The coefficient of variance allows for the comparison of variables between two or more different variables. The characteristics factors for the coefficient of variation were determined by the application of Eqn. 6:

$$\mathrm{COV} = \frac{S}{\bar{X}} x 100\% \qquad (6)$$

where COV represent the coefficient of variation, S denotes the standard deviation and $\bar{X}$ the weighting mean sample [7].

The coefficient of variation (COV), in this case, expresses the standard deviation as a percentage of the mean and is useful in comparing the relative variability of different responses with values calculated using Eqn. 6 [7]. From the results, statistical analyses present variation responses on the survey regarding factors affecting proper delivery of sustainable projects. The analysis results are indicated in subsequent caption of this report. Conversely, [8] noted that with negative variation trends on the result, it would have signified random variable increases. Therefore, the factors would have been insignificant and of low effects in the direction of the service delivery within the infrastructure systems.

VI. DISCUSSIONS OF RESULTS

The statistical analyses from the questionnaire surveys are presented. Hence, *CR* denotes category ranking and *OR*, overall ranking.

A. ENERGY RESOURCES MANAGEMENT CHARACTERISTICS

This group identified 11 factors. The severity indices range is 45 – 87%. The result shows that these factors have relatively weighty degrees of influence on infrastructure management in terms of cost and service delivery. Furthermore, 87% of the respondents strongly agreed with the use of efficient and energy saving fixtures in building infrastructure for cost savings. The class maintained coefficients of variation of 18 – 48% which are relatively low and indicate a good concordance level between respondents. Also, the category ranking range is 1st – 11th. As a result, it indicates a strong agreement on "the use of efficient and energy saving fixtures" factor while the employment of solar panels is ranked least in the overall scale. However, their overall ranking ranges between 2nd – 21st. There are exceptions of five variables perceived by most respondents as not being highly significant in this investigation.

B. WATER RESOURCES MANAGEMENT CHARACTERISTICS

This category includes 10 factors. Six of these factors achieved severity indices within the range of 60 – 74%. This shows that these variables have higher degrees of influence and they are considered to be of top priority in water resources management delivery. The category maintained coefficient of variation between 24 – 47% which are relatively low, signifying a strong agreement level between respondents. One factor was recorded with a coefficient of variation ranked 53%, indicating that the factor is of less importance. In addition, the category ranking ranges are between 11st –11th. Therefore, it indicates a good level of concordance from the respondents stand point.

However, the overall ranking category contains two of the top 10 factors. The top two ranked factors within this group are: the prevention of water wastages/losses through leakages and installation of accessories, dual flush toilet and wireless urinals.

C. MAINTENANCE MANAGEMENT PRACTICES

The question consists of 7 factors. In this category, 3 factors achieved severity indices ranges of 83 – 88%. This presents a relatively high degree of influence of these factors on the maintenance management practices. The other four factors are within the severity indices range of 64 – 75%. There are indications from the respondents that these four factors are equally of significance. Nevertheless, in this category the coefficient of variation range of 6 factors are between 18 – 37%. This explains that the factors are relatively low and indicate a strong agreement level between respondents in the ranking of these factors. Therefore, these factors are very crucial in enabling proper maintenance practices.

On the top of category ranking is the employment of technical or skilful expertise in addressing maintenance culture and is ranked 1st. It demonstrates a strong agreement amongst the respondents on the influence and its importance towards this factor. Furthermore, team working approach between the maintenance personnel and preventive maintenance factors were ranked 2nd – 3rd respectively. The other factors were considered more subjective with less influence in this category. The top ranked factor in this group still remains the employment of technical /skilful expertise in infrastructure management. The remaining factors in this category do not gain strong degree of influence within this group.

D. INFRASTRUCTURE DESIGN CHARACTERISTICS

The category has 6 factors. Two of these factors attained severity indices between 60 – 68%. This displays that these variables have high degree of influence towards decision making in infrastructure design characteristics. Moreover, the remaining four factors severity indices are ranging between 55 – 56% it explains the fact that their levels of influence are strong within this background. However, they should not be discarded from the respondents view points. The coefficient of variation is between 32 – 40%. The significant observation in this group is that the effect of these factors is low. The implication for a proper infrastructure design characteristics are that it enhances effective service delivery and just-in - time maintenance culture. In the category ranking, the top ranked factors within this group include inspection/ testing and commissioning. Also, feasibility of the design framework and the design quality/ specification ranked 1st – 3rd, these factors are regarded to be of high importance. In the overall ranking, this category came low. Consequently, this study explains that the factors are considered to be expensive, time consuming and harder for proper implementation.

E. INFRASTRUCTURE PROJECT CHARACTERISTIC

Ten factors were outlined. The severity indices range is between 58 – 66%. Also, over 60% and above of the respondents' strongly agreed with the need to tackle these factors. It is only one factor that records 58% as severity index. The result shows that these factors have relatively substantial degree of influence on infrastructure project characteristics in terms of time, materials, cost and service delivery.

However, in this category the coefficient of variation range of all factors is 33 – 40%. Therefore, these factors are fairly essential within this context. The category ranking ranges are 1st – 7th. It indicates a good level of concordance on the influencing factors regarding the sustainable infrastructure projects characteristics. The category ranking contains two of the top 10 factors ranked 1st – 2nd. These factors are: the quality of finishing and construction method/technology. This indicates a strong concordance between the respondents in ranking of these factors. On the top of overall ranking scale expresses more concern on the influence of quality of finishing as it promotes aesthetics on the engineering and infrastructure projects delivery systems.

F. OTHER EXTERNAL FACTORS AFFECTING INFRASTRUCTURE MANAGEMENT

The questions in this category contained 7 factors. This group demonstrates effectively high severity indices of 67 – 72%. This explains that these variables have extensive degree of influence after the commissioning, operation and maintenance of infrastructure systems delivery. The topmost severity index factor of 72% ranked 1st in this group, is the quality of equipment and installation. In addition, the remaining six factors' severity indices are 67 – 71%, meaning that their levels of influence are relatively very strong. Observably, four of these factors have severity indices of 71% overlapping each other. This signifies a strong correlation between their significant influences towards the infrastructure management from the respondents' point of view.

In the coefficient of variation ranking, the top ranked factors are the weather condition and government policies came 1st and 2nd respectively. Similarly, this group category ranking is 1st – 5th. Apart from quality of equipment and installation factor ranked 1st, four other factors have corresponding ranking of 2nd – 3rd. The remaining two factors are within the rank of 4th – 5th, indicating a strong degree of concordance and their significant impacts within this group.

Furthermore, on the overall ranking list within this category is the quality of equipment and installation ranked 1st. Two other factors overlapped within the ranking of 2nd – 3rd; these are the government polices and sustainability of the building. This indicates their significant impacts towards the standard practices and safety of the infrastructure system.

CONCLUSION

The study reviews different factors against the proper implementation of sustainable infrastructure systems management within the shopping malls in Manchester City Centre. In this study, the achievable results of findings demonstrate variations in each case due to the associated aims and objectives within its scope. Additionally, this paper presented and discussed the aim of study, background literature and questionnaire surveys outcome on the infrastructure systems management within the shopping malls in the Manchester City Centre, United Kingdom. Consequently, from a thorough literature search and pilot interviews with some infrastructure management experts, 51 fundamental factors were identified and subsequently addressed.

In this report, the contributions from the economic, social and environmental values (in terms of system probability) yielded 3/4, 4/5 and 3/4 respectively; this gives a S_{uv} factor of 0.45. This is an acceptable sustainability index for the project under review and given the intervening factors of interest. Obviously, the indicated parameters will vary based on the infrastructure and the case study in focus.

On the whole, the result suggests that some factors appraised in this investigation do not tend to play a major role within the sustainable infrastructure management characteristics. This paper has identified some of these factors as being time consuming, expensive and harder approach for adoption. However, the analysis of this study will form the starting point to develop a proper assessment in efforts to implementing a sustainable infrastructure management system.

ACKNOWLEDGMENT

The authors hereby acknowledge the invaluable support and cooperation of the management and staff of the Manchester Arndale Centre during the course of this research. Also, the unalloyed supports of the private owners of the shopping malls within the Arndale Centre are equally acknowledged.

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