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A Taxonomy for Measuring Sustainability of Construction Projects

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Abstract
The property and construction sectors need tools to assess levels of waste, environmental damage, social costs, and the impact of civil engineering and infrastructure projects on the ecosystems. However, while most efforts focus on addressing sustainability at macro (institutional and organisational) levels, there is also a need to understand the various indicators and the interaction between them at the micro levels of construction and infrastructure management. This will facilitate evaluation of sustainability during the design, construction, operation, maintenance, and decommissioning stages of a project. This paper analyses the main indicators such as environmental, economic, health and safety, and resource utilization, for measuring sustainability of construction projects. It reviews current efforts, and discusses methodological and implementation issues in developing project-level indicators. It then discusses data and information requirements for measuring sustainability at the project-level, and identifies how user-friendly IT tools would facilitate integration of sustainability considerations into the decision-making processes at various interfaces in a project's life cycle. The paper concludes that robust frameworks, methodologies, and practical step-by-step implementation strategies at the micro level, are all essential for achieving sustainable environments in the property and construction sectors. Recommendations are also given for further research.

Keywords
Sustainability, Frameworks, Construction, Indicators, Information Technology

1. Introduction and Background to Work

The research reported in this paper grew out of the realization that the construction sector is under enormous pressure as it strives to fulfill its expected roles toward realizing the objective of achieving a sustainable construction environment. The pressures have been engendered by the need for new knowledge and work practices that are anchored in *designing for sustainability* in infrastructure engineering and project management. These pressures are further exacerbated by the fact that in the construction industry, sustainability is still widely seen as a novel concept with disparate and oftentimes conflicting definitions leading to difficulties in implementation at the operational level.

While the authors do not wish to be drawn into the epistemological arguments related to the definitions of sustainability, the paper acknowledges that a broader spectrum sustainability agenda has different trajectories and dimensions such as: environment, social, economic, transportation, resource utilization, and health and safety. Moreover, while some of the sustainability variables are best suited for consideration at the macro-levels of project investment appraisal (such as during feasibility studies), there are some indicators that are directly influenced by design decisions and are therefore better addressed by design engineers. What is required is therefore a clear classification, identification, and understanding of these indicators and the design decisions that impinge on them. This will facilitate the development of appropriate strategies to manage such indicators at the organizational level, through improved diffusion of sustainability knowledge to project teams across the construction supply chain (clients, architects, designers, quantity surveyors, contractors, sub-contractors, safety management personnel etc). The focus of the work reported in this paper, is to identify the sustainability factors that can be controlled by taking appropriate decisions at the design interface of the project cycle. Thus, one of the key objectives is to identify those sustainability indicators that designers can claim ownership of, and are therefore able to influence or control as appropriate. The focus here is on those design decisions that impinge on the identified sustainability variables, and how ICT can contribute in fusing together, and disseminating *sustainability design knowledge*. Such identification is a pre-requisite to entrenching knowledge management processes that would facilitate achieving sustainability goals. As Fell et al (2002) noted, "indicators are only useful if the aspect they are measuring is capable of being influenced by the owner of the indicator. Indicators should be directly related to policy objectives and targets". In the context of the focus of this paper, which is addressing sustainability issues at the micro project-specific levels, the requirements are: to identify these indicators, analyze and understand how they are influenced by design decisions; and then develop assessment tool(s) that would help designers to evaluate the impact of their decisions on the ecosystems. This should then lead to proactive measures and design decisions that mitigate against negative impacts of such designs and contribute to achieving sustainability objectives.

The outline of the paper is as follows: Section 2 discusses related work and current approaches to indicator evaluations. Section 3 gives a classification of sustainability indicators and describes the research approach adopted to identify the indicators for construction project. Section 4 describes the need/requirement for a decision support framework that would assist individuals and groups within the construction supply chain to make use of available knowledge on sustainability evaluation and interpret the impact of their design decisions on achieving the objectives of a sustainable construction environment. The emphases here are on indicator evaluation, and developing tools for use by design engineers. Section 5 gives a summary of the work while section 6 draws conclusions and gives recommendations for further work.

2. Related Work

In recognition of the global importance attached to sustainability, different research programmes have been initiated to investigate the problems and issues related to indicator development. In some cases, these have resulted in tools and systems for evaluating the sustainability of projects. These are discussed in the ensuing section:

The Building Research Establishment (BRE) UK developed a tool appropriately named Building Research Establishment Environmental Assessment Method (BREEAM) which is used for evaluating the environmental performance of buildings in the United Kingdom. BREEAM was conceived as a tool to stimulate demand for "green" buildings in the market place. It can be applied either at the design and refurbishment stages, or for existing buildings in operation. Further details can be found in (URL1).

The US Green Building Council instituted a priority program that led to the development of "Leadership in Energy and Environmental Design" (LEED). This is a voluntary, consensus-based, market-driven green building rating system based on existing proven technology. The system facilitates evaluation of environmental performance from a "whole building" perspective over a building's life cycle, by providing a definitive standard for what constitutes a "green building". It is essentially a self-assessing system designed for rating new and existing commercial, institutional, and high-rise residential buildings (URL2).

The National Institute of Standards and Technology (NIST) developed a window-based decision-support system - Building for Environmental and Economic Sustainability (BEES). The tool is used to measure the environmental performance of building products by using the life-cycle assessment approach specified in ISO 14000 standards (NIST 2003).

Similarly, the Hong Kong Special Administrative Region (HKSAR) China initiated some sustainability programmes and studies. Prominent among these is the well-publicised series of studies on environmental sustainability conducted by the Centre for Urban Planning and Environmental Management (CUPEM) in the University of Hong Kong (URL3). The focus of the CUPEM studies was on developing initial environmental sustainability indicators for use in the Pearl River Delta in China. The HKSAR Government also initiated the Sustainability Development for 21st century (SUSDEV 21) programme and commissioned a consultancy study in the autumn of 1997 (URL4). The study, which conducted some public consultations, identified key areas of concern in developing a sustainability agenda for the HKSAR. These include: Economy, Health, Natural Resources, Social Infrastructure, Biodiversity, Cultural Vibrancy, Environmental Quality and Mobility. Most of these issues clearly contribute to macro economic and strategic policy formulation and decision-making.

Also the HK-BEAM – Hong Kong Building Environmental Assessment Method is a private sector initiative in HKSAR under the direction of the Real Estate Developers Association of Hong. It provides voluntary, independent and credible recognition for enhanced environmental quality and performance in office and residential buildings. Results of the assessment are presented according to the total scores on the HK-BEAM certificate as a rating of fair, good etc. Also Ove Arup and Partners developed a Sustainability Project Appraisal Routine (SpeAR). This program allows the sustainability of a project, plan, product or organization to be measured and illustrated graphically at different stages. The assessment results and graphical interface is shown in the form of a ROSE diagram, such that particular weaknesses or strength of the project in terms of sustainability can be identified. SpeAR is an evolving tool, which Ove Arup continues to adapt in different project situations (URL5).

The above catalogue of projects and initiatives demonstrates increasing interests in sustainability. However, it also shows that while most of the current efforts focus on developing tools for assessing sustainability of buildings, there is a noticeable dearth of similar efforts devoted to appraising the sustainability of other civil infrastructure. This is rather paradoxical given the peculiar characteristics and heavy impacts of other built infrastructure in achieving the objectives of a sustainable construction environment. Construction activities consume significant resources such as materials and energy, leading to depletion of natural resources with significant implications on the ecosystems. There is therefore a need to (i) identify sustainable indicators that designers can specifically target and use in assessing their design proposals, (ii) develop specific tools that harness the knowledge and techniques of evaluating sustainability, and (iii) use enabling information and communication technology (ICT) to deploy and make those knowledge bases and tools available to designers. The work reported in this paper is part of the initial contributions towards addressing the existing gap and missing link.

3. Taxonomy of Construction Project Sustainability Indicators

This section provides a classification of sustainability design indicators. Such a structure would underpin and facilitate the efforts of practitioners and construction researchers in identifying key elements of a design in assessing the sustainability objectives. It would also facilitate organization and management of sustainability knowledge, and facilitate identification of commonalities and differences between design proposals.

The key elements of the taxonomy are derived from an extensive literature search of generic organizational systems of different types of sustainable design categories available (GCCP 2000, URL5). The core indicators include: Economic Indicators, Technical Indicators, Environmental Indicators and

Social Indicators. Figure 1 shows the broader classification showing sub-categories and components that can be controlled by taking appropriate project design decisions.

Figure 1: Classification of Sustainability Design Indicators for Construction Projects

In Figure 1, italicized elements define potential action points for sustainability evaluation at project level (i.e. during design stages). Others are perceived to be more appropriate for macro-level considerations.

3.1 Economy

The requirement here is that a sustainable infrastructure be affordable, provide reasonable return on investment (ROI) over the long term, and minimize future capital expenditure to the owners over the project life. Hence the economy is most appropriately measured using the whole life cost of the project. The subcategories that are directly influenced by design decisions include; initial cost, material cost, and life cycle cost. Normally, at the macro level, the major economic indicator is measured in terms of the gross domestic product (GDP), but at the project level design proposals are often compared and hence their economic sustainability is measured in terms of the life cycle cost.

3.2 Environmental

One specific type of assessment used to measure the influence of human activities including construction on the natural environment, is the pressure-state-response model - PSR (Fell et al 2002). It uses cause-effect approach to assess *pressures* that lead to a certain *state*, which in turn introduces certain *responses* (i.e. measures) to reduce the pressure on the ecosystem. As an illustration, a construction project such as a dam whose siting results in deforestation (pressure), can lead to loss of a total forest area (i.e. a certain state), which may as a necessity require reforestation (i.e. response measure) to contain the pressure. Sub-categories include land, water, and energy. Environmental impact assessment is normally undertaken at the macro level such as during the feasibility stages of the project (DETR 1998, URL6).

3.3 Society

This mostly relates to the social infrastructure consisting of wider issues such as housing, employment, services and other measures of the quality of life (e.g. education, mobility). Most of the indicator components are usually addressed at the macro-policy formulation levels and are not directly influenced by design decisions at the micro levels of project implementation. Additional subcategories include public perception and views, which generally relates to public views towards the project (such as whether residents in the hinterland will promote or object to the project depending on its final appeal and potential ripple effects e.g. on property prices). This can have far-reaching and oftentimes unforeseen impacts even after a facility has been constructed. As an illustration, a recent case was seen in HKSAR in 2002 when constructed noise barriers in Tolo Harbour Expressway were demolished due to public objection triggered by the appearance of the barriers. Public perception of the project as 'aesthetic nuisance' triggered some pressures and eventually won the argument, even though the project satisfied other sustainability requirements such as cost, environment, and society.

3.4 Resource Utilization

Construction activities consume large share of material resources including wood, minerals, water, and energy. This consumption in turn leads to depletion of natural resources in the eco-systems. However, such negative impacts can be controlled and minimized by taking proactive measures and decisions such as; proper siting and design of constructed facilities, efficient use of construction materials, re-use and recycling of materials at all stages of the project through the adoption of innovative construction techniques. Other examples of design decisions that impinge on the sustainable design indicators include decisions on whether to upgrade existing stock or opt for new project schemes, specification of construction materials that meet the objectives of durability design (Ugwu et al 2003), and general waste management anchored in designing out waste.

3.5 Health and Safety

This indicator addresses the general health of the ecosystem. The subcategories include weather, ecology, and public health as shown in Figure 1. It is also considered a measure of the social infrastructure. Its great importance is underpinned by the requirement that construction teams collaboratively address and be responsible for health and safety implications of their design decisions at their respective interfaces since such decisions impinge on construction of projects, and the operation of constructed facilities. The recent Severe Acute Respiratory Syndrome (SARS) epidemic in March 2003 and specific outbreak in residential areas such as the Amoy Gardens in the HKSAR, has also added new dimension to sustainability in the context of health and safety. The Government of HKSAR conducted a detailed investigation that covered environmental, building design and utilities amongst others. This revealed that environmental factors like leakages from sewage pipes might have propagated the SARS virus leading to vertical cross-infection amongst the residents (see URL1 for full report on the investigation). Consequently, this has led to some suggestions for a 'health and safety index' for public and private properties in HKSAR. This poses significant challenges to building services designers and public health engineers, not least in the context of evaluating the health and safety sustainability element.

4. ICT-enabled Decision-Support for Sustainability Evaluation

This section discusses how information and communications technology (ICT) would contribute in achieving sustainability objectives. ICT would underpin the development and implementation of decision support frameworks for use in *designing for sustainability*. Specific ICT roles include (a) information modeling, data and user requirements extraction (i.e. developing sustainability ontology), (b) persistent data and information storage using database management systems, (c) analytical tools for computational analysis and evaluation of the sustainability of design proposals, (d) system integration (i.e. data-, tasks- and process-level integrations) to enhance collaborative working and sustainability knowledge management in organizational contexts. The above proposed ICT-driven decision support framework is predicated on the use of object oriented modeling constructs to encapsulate sustainability knowledge chunks as objects. The knowledge mapping process can be expressed symbolically as follows:

["Sustainability Knowledge => Objects (where Object = Data + Methods)"].

In the above expression, objects correspond to the sustainability indicators identified, as represented in the conceptual level ontology in Figure 1. Data corresponds to granular sustainability related attributes and other features of these objects, while methods correspond to various processes including algorithmic computational methods that convert these attributes into measurable quantitative and qualitative values for use in sustainability assessment. The encapsulation of data within a sustainability object could be achieved using powerful features of object-oriented modeling and system development. These object-oriented concepts include abstraction, encapsulation, inheritance and polymorphism, which would help in requirements analysis, data and information modeling, system modeling and development.

5. Discussion and Further Work

Sustainability has remained a global issue following the protocol agenda 21 published at the end of 1992 Earth Summit in Rio de Janeiro and subsequent dedicated summits the most recent being in Johannesburg, South Africa in 2001. Various national governments have instituted programmes tailored to achieving sustainable environments. In the UK, the Sustainability Action Group of the Government Construction Clients' Panel (GCCP) in its publication (GCCP 2000), defined sustainable construction as "the set of processes by which a profitable and competitive industry delivers built assets (buildings, structures, supporting infrastructure and their immediate surroundings) which: (i) enhance the quality of life and offer customer satisfaction, (ii) offer flexibility and the potential to cater for user changes in future, (iii) provide and support desirable natural and social environments, (iv) maximize the efficient use of resources". GCCP recommended specific themes for action towards achieving sustainable environments. Design and construction processes directly impinge upon some of these. These include: (i) re-using existing built assets, (ii) designing for minimum waste, (iii) aiming for lean construction, (iv) minimizing energy both in construction and use, and (iv) conserving water resources.

However, it remains a major challenge to translate these programmes and initiatives from those of mere aspirations to practical realization. The construction industry has pivotal roles towards achieving these objectives in the context of ensuring sustainability of the built environment (Fell et al 2002, Ugwu 2003). The taxonomy presented in this paper and the ensuing discussions, show that sustainability is a multidisciplinary subject, and that there is a need for an interdisciplinary approach to developing and evaluating sustainability indicators. It also highlights the need for robust ICT frameworks and sound methodologies for system development and implementation. This classification is an initial contribution to such interdisciplinary requirements in quantifying the relevant sustainability indicators. Further work would investigate sustainability design attributes in greater detail. Such a sustainability knowledge mapping process would facilitate better understanding of interactions between these subcategories and design decisions.

6. Conclusion

This paper introduces an ongoing research investigation that is developing and mapping sustainability indicators for construction projects. The initial focus is on the Hong Kong construction industry. The paper presents a discourse on the need to identify the indicators applicable to construction projects as well investigate the interaction between the attributes of these indicators and design decisions. This is with a view to harnessing the knowledge associated with sustainability evaluation, and making such knowledge available to designers at the appropriate project interfaces within an organizational context. Further work will report on the validation and implementation of these indicators, for practical use in evaluating the sustainability of construction projects.

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