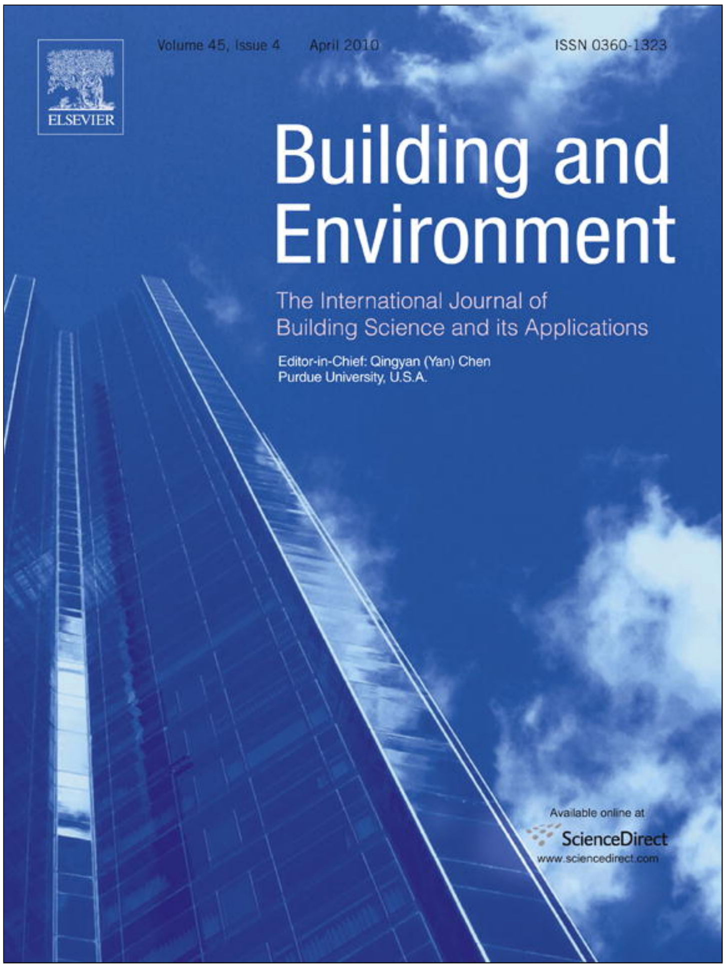
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Key performance indicators (KPIs) and priority setting in using the multi-attribute approach for assessing sustainable intelligent buildings

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ABSTRACT

The main objectives of this paper are to: firstly, identify key issues related to sustainable intelligent buildings (environmental, social, economic and technological factors); develop a conceptual model for the selection of the appropriate KPIs; secondly, test critically stakeholder's perceptions and values of selected KPIs intelligent buildings; and thirdly develop a new model for measuring the level of sustainability for sustainable intelligent buildings. This paper uses a consensus-based model (*Sustainable Built Environment Tool- SuBETool*), which is analysed using the analytical hierarchical process (AHP) for multi-criteria decision-making. The use of the multi-attribute model for priority setting in the sustainability assessment of intelligent buildings is introduced. The paper commences by reviewing the literature on sustainable intelligent buildings research and presents a pilot-study investigating the problems of complexity and subjectivity. This study is based upon a survey perceptions held by selected stakeholders and the value they attribute to selected KPIs. It is argued that the benefit of the new proposed model (SuBETool) is a 'tool' for 'comparative' rather than an absolute measurement. It has the potential to provide useful lessons from current sustainability assessment methods for strategic future of sustainable intelligent buildings in order to improve a building's performance and to deliver objective outcomes. Findings of this survey enrich the field of intelligent buildings in two ways. Firstly, it gives a detailed insight into the selection of sustainable building indicators, as well as their degree of importance. Secondly, it tesst critically stakeholder's perceptions and values of selected KPIs intelligent buildings. It is concluded that the priority levels for selected criteria is largely dependent on the integrated design team, which includes the client, architects, engineers and facilities managers.

1. Introduction

The recent decades have witnessed a maturing of concern and interest in building performance that is increasingly evidenced in building design. Sustainable or green design is not simply about attaining higher environmental performance standards or investing in new values; it is also about rethinking design 'intelligence' and how it is placed in buildings. The distinction between the notions "Green", "Intelligent" and "Sustainable" is critical in what underlies valid sustainable buildings. These concepts have no absolutes- these terms are more useful when thought of as a mindset- a goal to be sought, a process to follow [1]. Indeed, many of the concepts are pertaining to intelligent buildings have inherent relevance in sustainable building. 'Green' is part of being sustainable but tends to emphasise designs that considers the usefulness of applying solar energy, day-lighting and natural ventilation and reducing consumption, as well as treatment of any waste by recycling for example. However, sustainable building could be described as a "subset of sustainable development" which requires a continuous process of balancing all three systems environmental, social and economic sustainability [2] i.e sustain for future generations.

Implementing sustainable practices usually tends to raise the initial design costs, additional design services, commissioning, and certain green features may add as much as 2–7% (based on project nature and size) of total project cost [1], but operating costs can be reduced and healthier workplaces can lead to increased productivity thus whole life cost can be less. Meanwhile, 'intelligent buildings' should be sustainable, healthy, and technologically aware, meeting the needs of the occupants and business, and should be flexible and adaptable to deal with change. In other words, a sustainable intelligent building can be understood to be

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a complex system of inter-related three basic issues ***People*** (owners; occupants, users, etc.); ***Products*** (materials; fabric; structure; facilities; equipments; automation and controls; services); and ***Processes*** (maintenance; performance evaluation; facilities management) and the inter-relationships between these issues. These goals include all the phases of a building's life span, the environmentally friendly built environment with substantial safety, security, offering well being and convenience, a lower life cycle cost and long term flexibility, controllability and marketability. All this leads to achieving a building that has the best combination of environmental, social and economic values [3–6]. The differing emphasis of these and other definitions balances in various ways technological capacity, design value, and culturally perceived needs in the design of buildings. It is argued that "*intelligent buildings are not intelligent by themselves, but they can furnish the occupants with more intelligence and enable them to work more efficiently*"[7]. Holden [8] points "... *Intelligent buildings represent a key benefit that can reduce the initial capital outlay, as well as enabling a higher potential return on investment (ROI)*". From these definitions, technological innovation was not considered to be the main driver in the system selection. This finding reinforced the argument by Clements-Croome [4] that a true intelligent building is not necessarily a building with purely advanced technologies; instead it should be one with high values.

When aiming to reduce environmental impacts, yardsticks for measuring environmental performance are needed [9]. The term "*Building Performance*" is complex, since different criteria in the building sector have differing interests and requirements [10]. A problem has emerged associated with the scope to find objective or universal quality standards. The issue here is the lack of consensus on what constitutes excellence in building assessment performance, covering the overlapping dimensions of social, economic, environment and technological factors. Thus, sustainable assessment methods have emerged in recent years as a means to evaluate the performance of buildings across a broad range of sustainable considerations. The importance of such methods can be regarded firstly in terms of helping architects, engineers, planners and decision makers in what is defined as the principles of "*Selective Sustainable Design*" [11]. These methods are leading to pressure on industry to demonstrate how well (or how poorly) they are currently performing vis-à-vis "sustainability." In addition, the construction industry, are being confronted with a new set of regulatory practices and priorities, largely generated by the push for sustainability. However, the success of sustainable buildings is measured, in part, by how well they support the management from the inception of the design process, to the recycling of its materials at the end of their useful life [12]. A wide range of existing issues are available in terms of sustainable intelligent buildings, which can be used for the aim of developing a new model called the Sustainable Built Environment Tool (SuBETool) analysed using the analytical hierarchical process (AHP) for multi-criteria decision-making, in which "*multiple methods*" involve quantitative and qualitative approaches [13]. Since the field of key performance indicators is vast, this inspired the authors to develop a conceptual model for the selection of the most appropriate key performance indicators for intelligent buildings. To achieve this a tour study has been conducted to: firstly, Identify key issues related to sustainable intelligent buildings (environmental, social, economic and technological factors); develop a conceptual model for the selection of the appropriate KPIs; secondly, test critically stakeholder's perceptions and values of selected KPIs intelligent buildings; develop a new model for measuring the level of sustainability for intelligent buildings; thirdly, the main objective of the new model in this paper is to make it accessible to the developers, designers, occupiers and decision makers by providing practical benefits on how they can influence and select their own sustainability indicators, priority levels, benchmark comparison and building performance. The new tool explains how to analyse and interpret a broad range of data and feedback, and how to share results so that any lessons learnt can be put into practice. The paper will end with a discussion of the difficulties the proposed analytical framework would face in practice.

2. Methodology outline

In order to achieve the goal of this paper, the methodology is broken into 3 phases:

Phase 1; To develop general conceptual models that highlight the **critical selection factors and indicators**;

Before choosing a methodology, however, it is essential to decide how the data will be used. It is essential to design cohesive and coherent data management systems to a trusted format in order to ensure that the system performance is monitored properly, that reliability data is collected and that the relevant people are trained to analyse it for use by decision makers, designers and facilities managers [14]. It is advisable to think ahead so that data collected as part of a sustainability assessment can be reported as Key Performance Indicators (KPIs) [15]. The use of (KPIs) and benchmarking is fundamental to any improvement strategy. "*An indicator system should provide a measure of current performance, a clear statement of what might be achieved in terms of future performance targets and a yardstick for measurement of progress along the way*" [16]. The challenge in this case is to find effective indicators, requiring a clear conceptual basis. Hence, the selection of indicators will recognise the available data, resources and time, in addition to the interests and needs of the particular group involved in the selection of indicators [17]. The selected indicators must meet the following criteria [18–21]:

- Assist in informing choice in design decisions (Representative)
- Be usable by anyone- including professional designers and lay users (Reasonably simple)
- Allow participants to compare and contrast different options
- Be flexible, multipurpose and generic in nature, and useable on many different types of buildings (Sensitive to change).
- Comprehensive: Useable at different phases in a buildings life cycle: concept, design, construction and in use.
- Easy to use, with a simple and clear interface.
- Reflect specific issues that could have impacts on sustainable buildings for current and future developments.
- Be quantifiable and scientifically valid (quantitative criteria or qualitative converted to quantitative).
- Be cost effective but give value.
- Data accessibility should be made easy and not constrain the process [20].

The initial step is to choose the most appropriate criteria to formulate an '*indicators set*', which considers the building's performance in relation to the local environment, culture and economy, as well as business goals [22]. To test this approach, the search for appropriate indicators was conducted first by reviewing the literature and second by a survey with a number of professionals by inviting key people from each of the following disciplines to participate: architect, engineers, and facilities managers in order to investigate which KPIs were perceived as most relevant to intelligent buildings. Large samples of professionals are not always available so only a limited number of experts were identified for the surveys described here but the sample included design consultants and facilities managers. 20 stakeholders were presented with the proposed selection criteria, were invited to review the relevance, coherence and clarity of approximately 115 individual indicators identified as having a major influence on the overall perceived and operational quality of a building. They were also invited to add and refine new attributes to the indicators. The selected indicators were derived from reformulated sustainability assessment methods that are the most frequently used within the UK (*Building Research Environmental Assessment Method* 'BREEAM', *Design Quality Indicator* 'DQI', *Sustainable Project Appraisal Routine* 'SPeAR'…), supplemented with additional ones adapted from sustainability indicators used in tools developed by other countries, such as, (*Leadership in Environmental and Energy Design* 'LEED'; *Comprehensive Assessment System for Building Environmental Efficiency* 'CASBEE'; *Asian Institute of Intelligent Buildings* 'AIIB'; *Green Star*, *Sustainable Building Challenge* 'SBC' and *Hong Kong Building Environmental Assessment Method* 'HK-BEAM'…). Additional indicators related to health and well being and their effects on productivity and well being of users, as well as automation, intelligence and user control of the indoor environmental quality, air quality, temperature, daylighting and sound in buildings were considered. The SuBET system is designed to include consideration of regional conditions and values, but the calibration to local conditions does not destroy the value of a common structure and terminology. The system is therefore a very useful international benchmarking tool and one that provides clues to local industry on the state of performance in their region, while also providing absolute data to enable international comparisons [23].

Although most of the indicators are directly transferable from the UK to elsewhere, it should be noted that (depending on the country specific context) some indicators may require reformulation or new indicators may be needed to take into consideration the specificity of the local context in which they are applied. However, there should be a limited common number of indicators, which have standardised measurements and can be compared with targets, landmarks or other standards as appropriate. "*There is no limit on the number of indicators that can be used, although a greater number can limit comprehension and the relative importance of each indicator*" [13]. The selected stakeholders were invited to attach new attributes to the indicators and select ones based on their *relative importance* and potential *value* of each indicator on various building types (shopping centres, offices, schools…).. In order to facilitate the *selection process* and make it transparent and easy to follow, four hierarchical categories of indicators were introduced as follows (adapted from Design Quality Indicator framework) [24,21]:

1- **Pre-requisite (Mandatory) Indicators** (as articulated by demand side): These are being introduced to eliminate failures in meeting the minimum requirements in key issues and they are compliant with standards, regulations and quantified minimum targets.
2- **Desired Indicators**: Setting ideal targets for building performance beyond the minimum required by regulations and codes of practice to include the users vision.
3- **Inspired Indicators**: Inspiring goals and vision set by client: refers to long term mission and values.
4- **Non- active indicators or non- applicable indicators**: The scope of the project does not require these, or they cannot be achieved.

The table 1 (See Table 1) reveals the stakeholder's (in this case an architect) response to this survey, with reference to energy and natural resources sustainability indicators. The stakeholder's contribution in this study therefore is a response to the question "*Which sustainability issues are mandatory (pre-requisite) or desired more than other issues (non applicable or non active indicators)?*" based on their intensive knowledge, experience and preferences. We propose that finding answers to this question will be of benefit to the 'selection' of KPIs. However, it may not be possible to answer this question with absolute certainty by creating a credible and robust process to arrive at a consensus as to what are currently the most important issues for sustainable buildings [25,21]. It is notable that the stakeholder selected 6 out of 9 main indicators in terms of required and desired categories. Thus, the inspired and non applicable criteria could be marginalised at this stage. This may be the case if the indicator needs to be addressed, but is not relevant in the region or case study. Or the indicator is not applicable at this stage but might be over a period of time (i.e. five years). This might be considered as a wide approach, but conversely highlights one significant issue in customising a general assessment scale to regional application.

At the end of the survey, eleven respondents completed the questionnaire (from 4 architects, 4 engineers, and 3 sustainability assessors- an assessor is an expert has intensive knowledge in evaluating building performance). The stakeholders identified 16 main key categories relevant to sustainable intelligent buildings based on their influence on the whole life cycle of intelligent buildings, and categories under the four headings of *Environmental* (e.g. energy, CO_2 emissions, transport, land use, waste reduction….), *Socio-cultural* (user satisfaction, quality of space, safety at work, quality of services…), *Economic factors* (predictability, maintenances, life cycle costs…) and *Technological Factors* (intelligence, communications, controllability….). Within these categories, 57 indicators and sub indicators were identified within the scope of required and desired indicators.

The importance of the selected indicators can be considered in relation to the sustainability considerations varying from building components at the "**micro scale**" such as (water, energy and maintenance,), to urban and regional planning aspects on the "**meso scale**" (such as land use and site selection and planning considerations), to national and issues on the "**macro scale**" (such as greenhouse gas emissions from all energy used for building operation and transport) and issues on the **global scales** (such as climate change). The selection of sustainability indicators is based on a whole life model focusing on *People* (owners; occupants, customers, etc.); *Products* (building quality, materials; fabric; structure; facilities; equipment; services); and *Processes* (automation; control; systems; maintenance; performance evaluation) and the interrelationships between them in accordance with the following phases: design, construction, operation, maintenance, post-occupancy evaluation recycling and disposal [4,14,21]. However, due to the time constraints and data availability of this research dealing with a large set of sustainability indicators only those available indicators are chosen in this paper as follows (see Tables 2 and 3):

The main difficulties associated with the indicators' selection include the definition of typical, good and excellent practice in intelligent buildings, when no consensus has yet been reached by a wide variety of stakeholders. For example, some architects might be concerned that the functionality and quality of internal spaces are relegated to a secondary issue in comparison with the external appearance of their buildings. Meanwhile the facilities managers have concerns about the heating, the indoor environmental quality and energy consumption rather than with the functionality and external aesthetics. Architects have considerable information and ideas about what a product must achieve and do, but this is often different from that preferred by the environmental assessor, where the main interest is the environment and the use of renewable energy resources in buildings. Individual's attitudes and perspectives are established from the experience and reflection on interactions within social groups (see Table 3). Others may (or may not)

Table 1
An example of a stakeholder (one of the architects) perceptions selection process for proposed energy indicators based on relative impact and importance on the buildings Adapted from [21].

Proposed Sustainability Indicators			Minimum Request and the Compliance Requirements	Indicators Classification				Life Cycle Stage (Spatial Scale)			
Category	Credit No.	Indicator (KPIs)		Required Mandatory	Desired	Inspired	Non Applicable	D&P	M&OP	POE	R
Energy and natural resources	E1	Total life cycle primary non-renewable energy	To predict non-renewable primary energy used for building operations and greenhouse gas emissions	●	○	○	○	✓	✓	✓	
	E2	Lot orientation to maximise passive solar energy	To ensure that the project site plans provide for the location and orientation of building that will maximise passive solar potential	○	◉	○	○	✓	✓		
	E3	Total life cycle primary from renewable energy (renewable energy implications)	To encourage the use of sources that generates power by renewable energy means, e.g. 'green power'.	○	○	◯	○	✓	✓		
	E4	Use of Daylight in the primary areas (Daylight absorbability)	To ensure an adequate level of daylighting in all primary occupied spaces.	●	○	○	○	✓	✓		
	E5	Peak Energy Demand Reduction for building operations	To encourage and recognise projects that implement systems to reduce peak demand on energy supply infra-structure	○	◉	○	○	✓	✓		
	E6	Passive solar gain and cooling	To encourage using the natural movement of heat and air to maintain comfortable temperatures, operating with little or mechanical assistance	○	○	◯	○	✓			
	E7	Annual electrical energy conservation	To minimize the peak monthly electrical demand for building operations, especially where the grid is near peak capacity	○	○	◯	○	✓	✓		
	E8	Design features to maximise effectiveness of ventilation in naturally ventilated occupancies	To encourage and recognise the provision of natural ventilation system from the early design stage considering building orientation and wind directions	●	○	○	○	✓	✓	✓	
	E9……En	Maximise the effectiveness of operable windows (Glass structure encourage effectively natural air flow)	To ensure that the number, placement and type of windows or other openings in a naturally ventilated building are capable of providing a high level of air quality and ventilation	○	◉	○	○	✓	✓		

Key: (the degree of importance).
Highly Important and Required ■.
Desired and Important issue ■.
Inspired issue with less important than other issues ◉.
Non applicable or they can not be achieved ◯.

Key: (Life Cycle Stages).
Design and Post Construction (**D&P**).
Management and Operation (**M&OP**).
Post Occupancy Evaluation (**POE**).
Recycle, Reassemble and Reuse (**R**).

have quite different perspectives [26,27,21]. Such perspectives shape the reasons individuals hold for their decision-making. Separating the responsibility of the facilities managers from that for the functional and architectural design is then not the solution, but an easy pitfall. Additionally, it was seen that some team members had a hard time to keep their minds open for more than one option; immediately going for the less troublesome solution rather than first trying to identify the challenge to be met. This should be facilitated by whoever is selecting KPIs.

Phase 2; *To test and refine the general conceptual models developed in phase 1 by testing the level of importance of the selection criteria and indicators*;

There are no hard and fast rules about which techniques embodied in sustainability assessment should be used, because each study will be unique to the building location or prevailing situation. However, it is clear that adopting well-known and widely used techniques ensures that results are meaningful, that they can be repeated and therefore compared, and that the information can be benchmarked against other tools that have used the same methodology. With the possibility of not having scientifically derived weights, it is possible to use 'consensus-based' weighting for the different categories of indicators. In the SuBETool, the 11 selected stakeholders (from a sample of 20) ranked various factors, such as environmental issues, in terms of their relative importance or assigned weights in the process of design, construction and operation of intelligent buildings. Since people have different views and different levels of understanding about sustainability issues, a standardised production for assigning relative importance to different sustainability impacts is required if there is to be a consistent basis for decision-making. The relative importance has been derived using the analytical tool called the Analytical Hierarchy Process (AHP) [28], which uses a 9 point scale. In brief, the AHP approach can help to improve the decision-making process, and has been applied to numerous multi-criteria problems in the last few decades [28–32].

The AHP approach consists of several levels of hierarchies, but in this case five have been selected beginning with overall goals followed by dimensions, categories, indicators, and interrelationship between indicators. AHP enables the users to make effective decisions on complex issues by helping to order the factors involved in their decision-making processes. In addition, AHP helps to establish decision models through a process that contains both qualitative and quantitative components. Qualitatively, it helps to deconstruct a decision problem from the overall goal into a set of manageable categories, indicators and sub indicators. Quantitatively, it uses pair-wise comparison to assign weights to the elements at the indicator and sub indicator levels [31,33].

Sustainable intelligent buildings can be treated as a complex system and can best be understood by breaking the system down into their constituent elements and then structuring the elements hierarchically; by composing judgments on the relative importance of the elements at each level of the hierarchy into a set of overall priorities [24]. Each level in the hierarchy corresponds to the common characteristic of the elements in that level. For example, the aim of the stakeholder's

Table 2
The stakeholders identified 16 main key categories relevant to sustainable intelligent buildings based on their influence on the whole life cycle of buildings.

Key Performance Indicators (KPIs)	Identified indicators within the scope of prerequisite and desired indicators	Chosen Indicators in this paper (due to time constraint)
1- Environmental Indicators group (En-KPIs):	Energy and Natural Resources (E) Water and Water Conservation (W) Materials used, Durability and Waste (M) Land use and Site selection (L) Transport and Accessibility (T) Greenhouse Gas Emissions (Pollution) (GHG)	Energy and Natural Resources (E) Materials used, Durability and Waste (M)
2- Socio-Cultural Indicators group (So-KPIs):	Functionality, Usability and Aesthetic aspects (F) Indoor Environmental Quality (IEQ) - Health and Well being 1- Architectural considerations – cultural heritage integration and the compatibility with local heritage value (A) Innovation and design process (ID)	Functionality, Usability, and aesthetic aspects (F) Indoor Environmental Quality (IEQ) - Health and Well being 1- Innovation and design process (ID)
3- Economic Indicators group (Ec- KPIs):	Flexibility & Adaptability (FA) Economic performance and affordability (EP) Building Manageability (BM) Whole Life Value (V)	Flexibility & Adaptability (FA) Economic Performance and Affordability (EP)
4- Technological Indicators group (Tc- LPIs):	Intelligence and controllability (IC) Communications and mobility (C)	Intelligence and controllability (IC)

contribution in this study therefore is to ask the question "Which sustainability issues are of greatest importance? For example, is transportation and accessibility more important than say, energy and natural resources or water consumption and if it is, then how much more important?" The nominal-ratio scale of the priority levels (PL) among the categories was represented on a 1–10 point scale, with participants asked to judge the relative importance of one issue compared with another (pair-wise comparisons).

Taking Energy (E) as one of one of the categories in Environmental indicators groups illustrates seven main indicators (Sub-Categories). The evaluator determining the priority level attributed of each one. Each indicator in any category will be granted a value out of 10, where:

1–3 Low priority
4–6 Medium priority
7–10 High priority

E1: Total life cycle primary non-renewable energy: PL1 = 5
E2: Site orientation to maximise passive solar potential: PL2 = 4
E3: Total life cycle primary from renewable energy: PL3 = 4
E4: Use of Daylight in the primary areas: PL4 = 7
E5: Peak Energy Demand Reduction for building operations: PL5 = 5
E6: Annual electrical energy conservation: PL6 = 7.5
E7: Energy policy and audit: PL7 = 7 (These values are an example only and will vary from project to project).

Taking Environmental sustainability indicators (En, SIs) as one group illustrates two main categories. In this case, the evaluators, sustainability assessor, the architect and the building engineer, determine the priority level attributed to each one taking into account that each value for a category in one group will be granted a value out of 10 (See Figs, 1 and 2).

It is noted from Figs. 1 and 2 that, although each multiplier (Priority level) is identified on a scale of 1–10, the process of assessment is complex. A high degree of inconsistency between responses was apparent when comparing the summary results with the detailed results. The differing views of the assessor, the building architect and the building engineer on multiplier level lead to subjective results. When this method is applied in different geographical regions, the reference building types, climatic conditions and locations are different. Additionally, the differences in priority levels between stakeholders could result in major differences in sustainability assessment results. Also, according to the survey, the aggregated results illustrate that the different individuals of the same skill group (i.e. architects) have given different weightings scores based on their preferences and experiences of buildings. Even by taking the average between the architects, the building engineers and the assessors, the aggregated results have given different weightings which could skew the final assessment results. Also, it is clear from the aggregated results that, the priority levels expressed qualitatively and quantitatively are open to wide interpretation by the 11 assessors and therefore the assigning of scores can vary considerably depending on those making the assessment- even within the same system. Overall, the results show a surprising degree of inconsistency about the relative importance of different KPIs across a broad range of interest groups. These can also be very subjective leading to a distorted evaluation, as there has been no consensus in judging various sustainability indicators. Consequently, effective project value delivery requires an ongoing dialogue between all decision makers to negotiate appropriate compromises and balance stakeholder views. Also, the whole building team needs to work closely to develop strategies not only to meet regulatory requirements but also to meet the aspirational demand for exceptional energy and environmental performance ratings [34]. Hence, measuring and valuing the **quality** of design has therefore become a key issue confronting designers, planners, decision makers, construction practitioners and clients.

Phase 3; To develop a practical model for sustainable intelligent building systems assessment and performance;

A sustainability assessment methodology and tool has been developed called- the Sustainable Built Environment Tool (SuBETool). The aim of developing the system is to deliver the most objective measurement possible, by considering a range of vital issues. The SuBETool have been developed to deliver the best objective measurement possible. Such improvements rely on the accurate translation of an indicator value into a sustainability measure. The SuBETool was designed to comply with the following principles:

The system is a rating framework or toolbox and only becomes a rating tool after a third party (a range of stakeholders) calibrate it for their region and meet local area considerations by defining

Table 3
An example of selected stakeholders (11 from sample of 20) perceptions selection process for proposed KPIs based on relative importance and value on intelligent buildings. Adapted from [21].

Proposed Key Performance Indicators (KPIs)			Level of importance (value) attributed by different stakeholders											Life Cycle Stages Spatial scale			
Dimensions	Credit no.	Main Issues (Category)	Architect 1	Architect 2	Architect 3	Architect 4	Engineer 1 4	Engineer 2	Engineer 3	Engineer 4	Assessor 1	Assessor 2	Assessor 3	D & P	M & OP	POE	R
Environmental Indicators group	E	Energy and renewable Energy	D	D	I	D	R	I	D	R	R	D	D	✓	✓	✓	
	M	Material Used, Waste and Durability	I	I	I	D	I	D	D	I	D	D	I	✓			✓
	F	Functionality, Usability & aesthetic aspects	R	R	R	R	I	I	I	D	I	I	I	✓			
Socio-Cultural Indicators group	A	Architectural Considerations	R	D	R	R	I	N	N	I	N	I	N	✓			
	I	Indoor Environmental Quality	D	I	D	D	R	R	D	D	R	R	D	✓	✓	✓	
	D	Daylighting and Illumination	D	R	R	D	R	D	R	R	R	R	D	✓	✓		
	ID	Innovation & Design Process	R	D	R	D	D	R	R	R	D	D	D	✓			
Economic Indicators group	EP	Economic Performance & Affordability	I	I	D	D	R	R	R	R	D	I	I	✓	✓	✓	
	L	Flexibility & Adaptability (FA)	I	I	N	D	D	R	I	I	D	D	R	✓	✓		
	MI	Management, Intelligence and Controllability	D	I	I	D	R	R	R	D	R	D	D	✓	✓	✓	

Key: (the degree of importance).
Highly Important and Prerequisite (R).
Desired and Important issue (D).
Inspired issue with less importance than other issues (I).
Non applicable or they can not be achieved (N).

Key: (Life Cycle Stages).
Design and Post Construction (D&P).
Management and Operation (M&OP).
Post Occupancy Evaluation (POE).
Recycle, reassemble and Reuse (R).

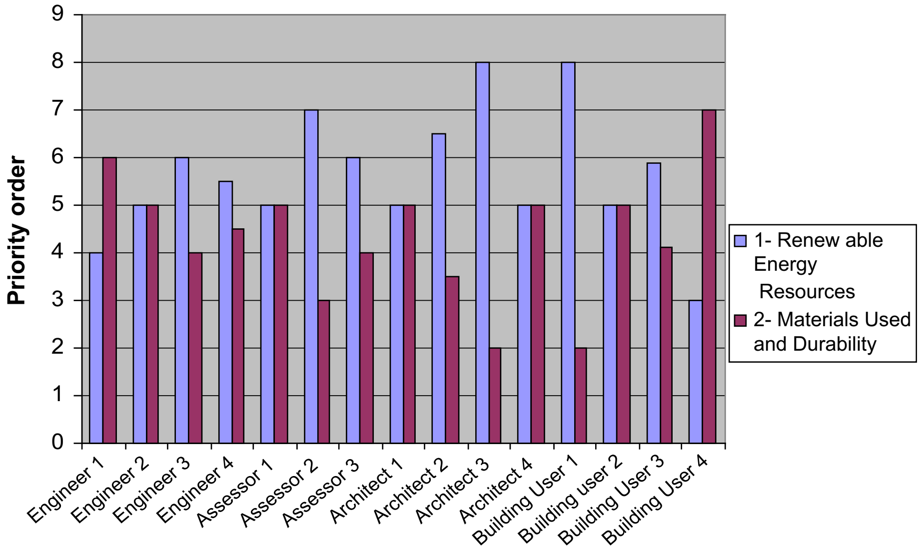

Fig. 1. The priority levels attributed to renewable energy resources and materials by different stakeholders.

selective criteria, priority levels and setting weights, context and performance benchmarks.

Negative implications are as valuable as positive ones, particularly for assessing existing buildings. Furthermore, a survey carried out by Lee & Burnett [35] revealed that 70% of the stakeholders agreed with the use of 'negative scoring'. The supporters of negative scoring considered that this would give an incentive to building owners, developers and decision makers to achieve higher sustainability scores. The rating system does not account for negative scoring to reflect unsustainable performance of buildings. Also, it would be better for such aspects to be penalised within the system to ensure that the most important aspects are included in the building's design. Hence, in the SuBETool, a negative scoring system should be adopted to downgrade non-performing buildings. In this model a linear ranking scale for the level of each criterion has been used. 'Priority level' and the value for each indicator can be translated into a numerical score. Moreover, the importance of this indicator is further modified by a weighting to represent its priority within the criteria group. To summarise, the value of the multipliers are based on the importance of each criterion which is weighted according to its importance in each case;

Apart from weighting issues, the arrangement of data has been categorized using the following equation to reflect the application of indicator performance in terms of positive and negative applications. Adapting the approach of Sustainable Building Challenge (SBC) [23] as follows

$$\text{Sustainability Score} = [\text{Level of Performance}(L) \times \text{Priority Level}]\ \text{Scn} = L \times PL(\text{judged by stakeholders})$$

L = -2 to +5, PL $\leq$10 (highest priority = 10)

Each category is further sub-divided into individual indicators and these are weighted according to their relative importance [17]. The actual value of each indicator is translated into a sustainability measure value in the range from +5 to -2 (Level of performance) as below:

$+4 \leq +5$ (demanding performance) represents best practice (**Excellent** performance);

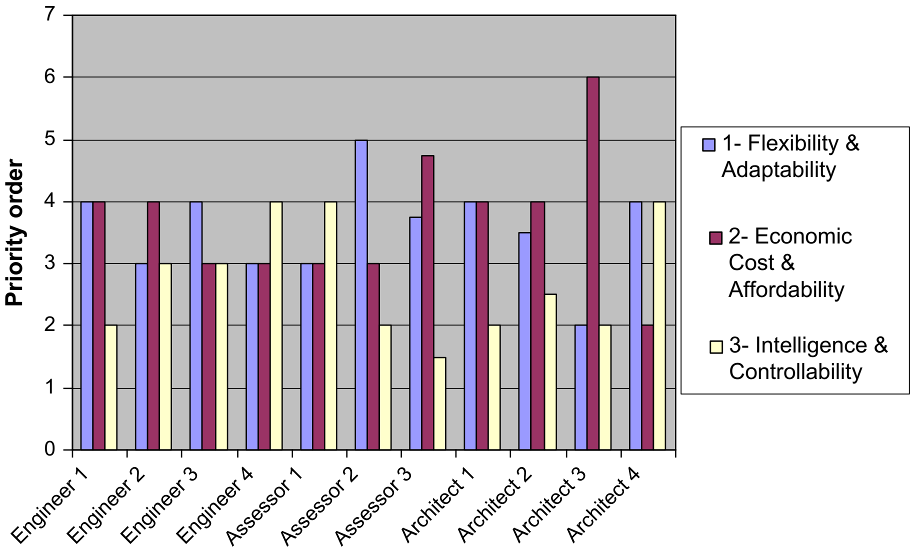

Fig. 2. The priority levels attributed for selected Economic categories by different stakeholders.

$+3 \leq +4$ represents very **good** practice reflecting stable conditions in terms of sustainability;
$1.5 \leq +3$ **Good** Performance
$0 \leq 1.5$ represents current **standard** (Minimum acceptable performance) or typical practice for the particular building type and region, or also due to the difficulty in obtaining data.
-1 to -2 represents **unsatisfactory** performance (Deficient) which is not likely to meet the accepted regulations, design criteria and industry norms, or the indicator performance gives a negative impact on the environment in social, economic and environmental terms.

One could ask why the level of performance of each indicator is allocated a value between -2 and +5 instead of -5 and +5? The main justification for this by the evaluators is to provide a scale where the focus in sustainability assessment is based on more positive than negative attributes. This is why the researchers did not use "0" as a middle terms in their assessment tool. This scale is designed to encourage those involved in sustainability projects to achieve better design results.

Each criterion is allocated a score from the data analysis. The score for a criterion is multiplied by the priority level for that area. The score for an indicator is, therefore, the total of the criteria scores under each category. Afterwards this value is multiplied by the priority levels provided for each indicator or sub indicator. The resulting number from this multiplication represents the weighted score for the indicator or sub indicator.

The authors found it may be easy to achieve a consensus between stakeholders for building performance on the SuBETool scale (-2–+5). For instance, if there is no evidence for renewable energy applications in buildings the performance level could be given the score -2. However, it seems more difficult to obtain this consensus when it is related to the relative important and priority level of each indicator. For instance, the four selected architects (from a sample of 11 selected stakeholders in this study) have revealed different priority levels with reference to renewable energy implication (1, 2, 3, and 2 respectively, see Table 4). The difference in priority level between stakeholders could have a much bigger impact on the final "Score" or outcome than all performance inputs into the system from "measured data" (See Table 4). Thus, weighting and expert weightings can skew results depending on who is carrying out the evaluation, and thus results in a subjective assessment even when the same indicators are applied.

3. Discussion

The overall results show remarkable differences in the level of sustainability despite the similarities in the performance value for the applied indicators between stakeholders. Values can be related to different phases, different stakeholders and different parameters, and can therefore have different meanings, although on the first sight they seem to be the same, because the same "word" is used. For instance, in the three figures, the non implication of renewable energy systems have greatly different levels of sustainability, equalling respectively −2 for Architect 1, −4 for Architect 2, −6 for Architect 3 and −4 for Architect 4 (see Table 4). In other words, the aggregated results can vary from expert to expert and sometimes can be skewed, which are not reliable in terms of the accuracy of the tool itself and make the results open to interpretation. The problem in fact of understanding requirements and transforming them into high quality indicators is a universal one that many stakeholders have struggled with [19,26]. It raises questions about the nature of good sustainable indicators in terms of priority levels and benchmarking. It is typically the case that different individuals or groups are responsible for different levels within building sectors, and they will have their own take on the narrative and its implications. For example, many developers are looking for a return on investment whereas quantity surveyors see sustainable intelligent buildings as being significantly more expensive from the outset. It is important that the added value gained by being sustainable is properly accounted for and that misunderstandings are not allowed to ruin the design [4], as well as developing more effective feedback systems, which can provide useful evidence for future designs and help to allay some of these perceptions. The design, construction and management teams need to reform to ensure that creative integration is allowed to take place and that there is shared view and brief in the project from the outset, in addition to setting performance targets. This will mean, for example, that there will be a balanced view of the technical and social inputs necessary to make the project truly sustainable; this will necessitate much more systems thinking and analysis than has been customary [4]. However, given different weightings and scores by each stakeholder, it would be meaningful to use trend analysis in real practice. For instance by taking the average between the four selected architects, it is possible to read the overall trends for each selected indicators from their judgments. Thus, by recognizing KPIs as a tool to reach consensus among stakeholders, it seems useful to discuss a procedure to do so as a future topic.

Although the research has generally achieved the specific objectives stated in the introduction, the research was not conducted without limitations. Firstly, the size of the sample was limited. Since the intelligent building industry is new and developing, a large sample of professionals was not available. Only a very limited number of experts were identified for the surveys. The major group of experts were the design consultants together with facilities managers. Secondly, the current framework is not complete, as it does not reflect how it can be used to aggregate all scores of key performance indicators used in this study.

The key point is that we believe that the developed framework and key criteria identified in this study will improve the understanding of practitioners, but in a way that allows comparison, discussion and learning. Also, the developed framework is able to consider different levels of information and structure all relevant issues in an ordered manner, helping decision makers to handle the multiplicity of the issues embodied in the concept of sustainability. The work established an approach which is adaptable for each project.

The results of the weighting exercise are inevitably subjective and are time- dependent (and will require regular updating). However, the method used has proved effective in impartially determining the inconsistency of views between various groups. The contribution of this survey gives a cogent insight into the priorities and expectations of different decision makers. This can help to inform our understanding of IBs. Research to measure social and economic sustainability is still in its infancy [36].

Table 4
Weighting process for renewable energy for four individuals (Architects) of the same skill group.

Energy and Natural Resources (E)	Weighting L1 × PL 1 = Scn	Weighting L2 × PL 2 = Scn	Weighting L3 × PL 3 = Scn	Weighting L4 × PL4 = Scn
E1: Use Renewable Energy Systems	-2 × 1 = -2	-2 × 2 = -4	-2 × 3 = -6	-2 × 2 = -4

L = -2 to +5 (Performance Level for applied indicators).
Priority Level attributed by Architect 1 PL1.
Priority Level attributed by Architect 2 PL2.
Priority Level attributed by Architect 3 PL3.
Priority Level attributed by Architect 4 PL4.

4. Conclusions

This paper presents the development of a conceptual model for the selection of KPIs for intelligent buildings, which aims at assisting the stakeholders to select the most appropriate indicators for buildings. The paper revealed that although the participation of all decision makers and stakeholders in the establishment of proper levels and weightings could facilitate the process of recognition and incorporation of regional diversities. The problem in this regard is in understanding the different perspectives of stakeholders on what constitutes good performance in buildings in order to reach a consensus about indicators and priorities. Also weightings can skew results dependent on who is carrying out the evaluation, and thus results in a subjective assessment. The main difficulties associated with benchmarks include the definition of typical, good and outstanding practice in intelligent buildings. In addition, subjectivity in sustainability is unavoidable and consensus needs to be reached by a wide variety of stakeholders. This should be facilitated by whoever is carrying out the sustainability assessment. Additionally, participation of stakeholders and decision makers in the establishment of benchmarks and weightings could significantly facilitate the process of recognition and incorporation of regional diversities [21,26].

Holistic decision-making requires a judgment about the relative importance of different impacts within the overall performance of options being considered. This approach has led to a very large and complex system, which requires large quantities of detailed information to be assembled and inputted, causing further difficulties and frustration. The research has been advanced into a working master planning tool in co-optation with Hilson Moran. However, the researchers contend that the SuBETool in its current form is most useful for discussion. It cannot provide an absolute measure of the design quality of an intelligent building but can be used to articulate the subjective qualities felt by different stakeholders in the design process and thereafter in the use of a building. The authors believe the data and findings are time- dependent and propose to renew them on a regular and planned basis. Additionally, it is generally believed that feeding more shared information to the model (or experts) would lead to better decisions. It is meaningful to discuss accuracy of assessment of each weight. In this problem, however, it seems that further discussion about the consistency of each rater's assessment and reliability of overall assessment should be carried out. Finally, significant work remains to be carried out in order to make the measurement less complex, less subjective, more reliable and the process of calculation more flexible and easier to follow. Also, greater integration across various stakeholders, urban policy makers, planners and designers needs to generate a consensus in various sustainable buildings issues [37,21,26].

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