Towards Key Performance Indicators for 'Environmental Building'

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ABSTRACT: Our society tries to balance it's activities with environmental problems like global warming, aiming for 'sustainability'. Over the years this term 'sustainability' has grown to incorporate environmental, economic and social issues. In the construction industry many different actors like researchers, policy makers and architects are dealing with the complex problem of realising a sustainable built environment. However, the all-embracing broadness of the term sustainability makes it hard to measure building performance in this field, and mingles value systems with objective analysis work. It renders communication across the board of building professionals difficult and risks to slow down research and technology development in this vital field. In order for the construction industry to move forward, a fundamental review of what exactly it is that comprises 'sustainable building' must be undertaken. This paper describes ongoing research efforts focussing on the one sustainability aspect of 'environmental friendliness'. These efforts aim to bring together a solid body of knowledge on all aspects that make up environmental building, on ways to measure building performance for each of these aspects by means of calculation and/or measurement, and on ways to enhance communication about these aspects throughout the building life cycle.

Keywords: sustainability, building performance, communication

1. INTRODUCTION

In an increasingly globalised world the construction industry, like most human undertakings, is having to deal with a range of serious environmental issues like global warming, biodiversity and resource (re)use, all within a context of striving for social equity and economic growth. Many different professions (e.g. architects, politicians, researchers) have addressed this issue and, especially over the last 35 years, have contributed to a broad range of efforts all aiming to balance human activities related to the built environment with these environmental issues. The buildings benefiting from these activities, as well as the disciplines involved, are increasingly gaining prestige and are becoming a more integrated part of the construction industry. However, the different streams making up the field are not yet clearly defined. Building labels like 'environmental', 'sustainable', 'ecological', 'low-energy' and 'green' seem to be quite interchangeable. While some basic definition of these terms is available (see text box,), their application in the construction industry seems to be overlapping and arbitrary. Actors in industry and academia all use these descriptors, without clear boundary lines. As an example, a highly influential book on the topic, Sue Roaf's Ecohouse 2 Design Guide, defines an EcoHouse as: 'buildings that are part of the larger ecology of the planet and are part of a living habitat' (Roaf et al, 2003). On the other end of the spectrum, the Building Research Establishment defines Eco-Houses as buildings that balance 'environmental performance' with the need for a high quality of life and a safe and healthy internal environ-

Dictionaries lfrom Oxford (2001) and Cambridge (2006) give the following definitions for some principal terms used in 'environmental building and construction':

- Environment (adj: environmental): 1. the surroundings or conditions in which a person, animal or plant lives and operates 2. the natural world, especially as affected by human activity
- Sustain (adj: sustainable: able to be sustained): 1. strenghten or support support physically or mentally 2. keep (something) going over time or continuously 3. suffer (something unpleasant) 4 uphold or confirm the justice or validity of.
- Ecology (adj: ecological): the branch of biology concerned with the relations of organisms to one another and to their physical surroundings
- Low-energy: Low: below average in amount, extent or intensity; Energy: 1. the strength and vitality required for sustained activity 2. power derived from physical or chemical resources to provide light and heat or to work machines 3. the property of matter and radiation which is manifest as a capacity to perform work
- Green (adj): 1. the colour between blue and yellow in the spectrum 2. covered with grass or vegetation 3. young, unripe, inexperienced or naïve 4. pale and sickly looking 5. concerned with or supporting protection of the environment as a political principle.

ment, taking into account energy, water, pollution, materials, transport, ecology and land use, and health and well-being (BRE, 2006a).

While some common understanding seems to be building up over the years (for instance it has become usual to take ‘sustainability’ to include environmental, economic and social aspects) the precise meanings remain rather open-ended and undefined.

The spirit of current times tends to favour the term ‘environmental building’ in a broad sense, resonating with the public opinion. The fact that some buildings have been designed and constructed while taking action to address some environmental issues is already frequently used as a marketing instrument, suggesting that these buildings gain an edge over more traditional constructions. Whilst this broad scope encompasses many different activities and products under the ‘environmental building’ banner, it also comes at a price. As soon as there is a choice to be made between the aspect of environmental friendliness and more traditional performance aspects like return on investment, structural stability or occupants comfort it is often the environmental aspect that looses out. Furthermore, there also is evidence of the environmental aspect being misused to further projects that do not really fit under the banner – examples are the development of ‘sustainable buildings’ in nature reserves, or the oxymoron of a ‘green’ airport design. The term ‘greenwash’ is now frequently used to describe buildings that pay lip service to the idea of environmental building, but do not really fit the bill.

In order for the construction industry to move forward and for ‘environmental building’ to become a more mature discipline, a fundamental review of what can be considered to be ‘environmental building’ needs to be undertaken. This review should include an in-depth reflection on the aspects that need to be addressed, and the way the building’s performance regarding each of these aspects can be measured. Ways of measuring ‘environmental friendliness’ must be compared to the way performance is measured in other domains of construction like for instance structural mechanics or economics, and must be brought to the same standards. This is not a trivial task, as can be exemplified by the many different ways in which a prime aspect like ‘energy efficiency’ can be expressed: in terms of energy end-use in GJ, as percentage of energy use of a reference building, in terms of consumption of fossil (or equivalent renewable) fuel, and even in terms of CO_2-emissions or exergy.

This paper describes the organisation and first results of a range of a new research initiatives at the University of Plymouth, School of Engineering, that aim to contribute towards the development of a concise definition of ‘environmental building’ along these lines, while concentrating upon the theme of building performance across the whole building life cycle.

Note that this research focusses on ‘environmental building’ only. Much of ongoing work on work on ‘sustainable building’ includes economic and social aspects. However, according to Hueting and Reijnders (2004) such an aggregation of different aspects tends to conceal difficult trade-offs and choices. Therefore the authors of this paper prefer to limit their scope to environmental issues for the moment, while the debate on ‘sustainabililty’ and its components continues.

2. PROBLEM ANALYSIS, GOALS AND OBJECTIVES

The problem of defining ‘environmental building’ is multifaceted. There are many different actors in the field, with each group having their own background terminology, and priorities. Value systems are often implicit, and might change over time. Part of the knowledge base needed to assess environmental friendliness is incomplete, as is obvious for instance from the lack of data needed to perform full life cycle assessments. At the same time there is a tendency to try to aggregate performance for the different aspects of environmental impact into one overall performance indicator. That environmental performance might even be bundled with economic performance and social performance to yield an overall sustainability performance.

Yet a more unambiguous definition of ‘environmental building’ will benefit different parties involved in the construction of buildings. It will provide a common basis for communication between architects, engineers, consultants, contractors, and building surveyors and their clients, thereby facilitating joint efforts and preventing conflicts originating from different interpretations. It will contribute towards a better positioning of the efforts of authorities, environmental action groups and industry in the field. And it will provide the academic community dealing with ‘environmental building’ with a much-needed foundation for further development of the field, moving it from a rather missionary activity towards a more scientific discipline.

The overall goal is to bring together a firm body of knowledge on the different aspects that are considered to make up ‘environmental building’ and ways to measure building performance in these fields, with the final aim of improving the understanding of, and communication about ‘environmental building’.

In order to attain this goal, the following research objectives will be pursued:

- Investigation of the different terminologies, value systems and priorities used by different actors and stakeholders in the building industry regarding environmental, sustainable, ecological, low-energy and green building;
- Comparison of the way environmental performance of buildings is expressed with existing key performance indicators in other fields

of construction, or possibly even with performance measurement in other disciplines;
- Development of a concise definition of 'environmental building', and the opening up of a dialogue on this definition with different national and international participants in the field, through the construction of a flexible framework for the different aspects that contribute towards 'environmental building performance';
- Development of a formal manner to deal with (subjective) values that are involved in 'environmental building performance' that can be changed to reflect differences in insight, scientific developments and political choices;
- Identification of missing knowledge in the appraisal of environmental friendliness of buildings, leading towards the development of dedicated research efforts to fill the knowledge gaps.

3. METHODOLOGY

The approach for bringing together a profound body of knowledge on 'environmental building' consists of the following activities:

1. In-depth literature review regarding the terminology on 'environmental building' and the closely-related terms in the most relevant disciplines. This review will clarify the current use of terms, and result in a good underpinning of overlaps, implicit assumptions, vaguenesses, and potential conflicts of opinion/interest.
2. Review of the definition of building performance in other branches of the construction industry, including at least structural mechanics and building economics. The outcomes will describe how 'building quality' is described in these 'competing' fields, and will help to provide a baseline for describing 'environmental performance'.
3. Analysis of existing performance rating schemes for 'environmental building' like LEED, BREEAM, EU and UK regulations, etc. This will provide a benchmark regarding the current state-of-the-art in measuring environmental building performance, as well as an insight into the value systems currently in use
4. Development of an overview (aspect tree) of all issues that relate to environmental building, mapping interrelationships between these aspects. The elements to be included in the aspect tree are to be gathered from literature and interviews with different actors and scientists in the field. Special attention will be needed to ensure that the overview is built in a neutral but flexible format, allowing future changes (eg when new knowledge becomes available) and ensuring that no implicit value system is included in the overview.
5. Investigation of different strategies for the application of preferences and priorities to the elements that make up environmental performance of buildings. Specific aspects to be addressed include the question of the possible existence of common value systems to similar groups, and the issue of aggregation of performance data into higher-level performance indicators, leading into the identification and definition of Key Performance Indicators (KPI's) for 'environmental building'.

4 FIRST RESULTS

The first results in this research effort have provided a number of important findings regarding the definition of 'environmental performance'. Findings are clustered on four levels: on defining performance in general, on defining environmental performance, on defining performance in buildings, and on environmental performance in buildings.

4.1. Performance

The importance of performance on different human endeavours has been around for almost half a century. A starting point is identified in the ideas presented by Herbert A. Simon in 'The Sciences of the Artificial' (Simon, 1969). This work introduces an outline for a science of developing products according to well-defined performance criteria. It discusses how probability theory and utility theory can be applied to judge the performance of different alternatives. Since then work in the fields of systems engineering (e.g. Blanchard and Fabrycky, 1998) and decision theory (e.g. Keeney and Raiffa, 1993; French, 1993) has been added to this framework. This body of knowledge is interdisciplinary and applies to all human-made systems. Some remarks on performance in two diffemt fields, being automobile engineering and health care, are presented below.

In the automobile industry, a solid framework is in place that defines performance and allows to compare the performance of individual cars against international benchmarks. As an example, the United Kingdom's Certificate of Conformity (Vehicle Certification Agency, 2006) requires that the following is known for every single car, amongst 50 data entries:

- Engine capacity (cc)
- Fuel consumption (pmg)
- Max Net Power (kW)
- Power/Weight ratio (-)
- CO emissions (g/km)
- CO_2 emissions (g/km)
- $HC+NO_x$ emissions (g/km)
- Particulates emissions (g/km)

Note that these data entries can all be obtained by putting an individual car on a testbench and performing measurements according to carefully defined experimental conditions.

Within health care, performance is measured in order to monitor baseline data and identify options for quality improvement. Typically three categories of performance indicators are used: fiscal/economic, service/satisfaction and clinical/health. A typical performance indicator (know as marker in this discipline) for 'service' for instance is appointment waiting time, which can be measured in minutes per appointment. Markers in the clinical field address many issues (safety, timeliness, effectiveness, efficiency, equity, and pacient-centredness) and include well-defined and clearcut indicators like total patient falls with injuries per quarter, antibiotics given within a time limit of x hours, or in-patient mortality rate (Ballard, 2003).

4.2. Environmental Performance

In engineering and science different performance aspects are taken into account when assessing environmental performance. A good, broad overview of different factors that need to be considered is given by Azapagic et al (2004), who discern resource depletion, global warming, ozone depletion, acidification, eutrophication, oxidants creation, and toxic waste creation as the main environmental issues.

Different disciplines all have their own metrics to measure performance related to these factors. By way of an example, in environmental marine science serious efforts are under way to develop scientifically robust indicators for the monitoring of environmental change. One example for such an indicator is a taxonomic distinctness indicator (Leonard et al, 2006). Typically the indicators in this field are much-further developed than those in the building industry, being expressed in probabilistic terms (means and 95% confidence intervals) instead of deterministic values, while reference points (a null-hypothesis for plotting indicator values) are discussed in quite some depth (Leonard et al, 2006).

On an aside, many performance indicators for sustainability include economic and social aspects. However, according to Hueting and Reijnders (2004) such an aggregation of different aspects tends to conceal difficult trade-offs and choices. Therefore the authors of this paper prefer to limit their scope to environmental issues for the moment, while the debate on 'sustainabililty' and its components continues.

4.3. Building Performance

An important milestone regarding performance of buildings is the report 'Working with the performance approach in building' by the International Council for Research and Innovation in Building and Construction (CIB, 1982), currently being brought forward and updated by the CIB Program on Performance-Based Building (PeBBu). This approach has now made it's mark in building regulations (Meacham et al, 2005), education (Loftness et al, 2005) and industry (Hammond et al, 2005). Yet while a lot of progress has been made all papers on this issue also demonstrate the complexity of connecting means and ends, key value driver ownership, the importance of negotiating processes, and, in general, a problem area around the exact definition and interpretation of building performance.

As a local example, in the UK the Design Quality Indicator (DQI) has been launched as an assessment tool for the evaluation of building quality (Gann et al., 2003, Whyte and Gann, 2003). DQI consists of three main elements: a conceptual framework, a data-gathering tool, and a weigthing mechanism. The conceptual framework represents the features of quality in design. The data-gathering tool sollicits an assessment of quality for each aspect from participants on basis of questionnaires. Finally, the weighting mechanism captures the quality perception against (subjective) priorities (Gann et al., 2003). DQI is currently going through a trailblazing scheme; a web based version has been developed (Whyte and Gann, 2003).

4.3. Environmental Building Performance

Within the building industry there have been different efforts to develop a system to measure environmental performance. These can either focus on the process of designing, constructing, and operating buildings, or focus on the building as a product. The efforts result in environmental labels, ratings and product declarations which are intended to provide customers with information that allows them to make purchases taking into account environmental factors (Crawley and Aho, 1999).

In the United Kingdom, the most significant method defining and assessing environmental building performance is BREEAM, the BRE Environmental Assessment Method (BRE 2006b). BREEAM uses a consensus based weighting system to aggregate performance into one overall score for a building, which is then rated on a scale ranging from pass, good, very good to excellent. Across the Atlantic, the main methodology used in the United States is LEED, the Leadership in Energy and Environmental Design Scheme by the US Green Building Council (USGB, 2006). This is a point-based system, similar to BREEAM, but resulting in buildings being awarded bronze, silver, gold or platinum status.

While these assessment methods steer the industry in an environmental friendly direction, there are still doubts about their full effect. For example, Curwell et al. (1999) note that many buildings use significantly more energy than predicted and that not all buildings achieve good standards of occupant satisfaction, and that this particularly affects the more highly-serviced and innovative concepts.

5. EXAMPLE: BUILDING PERFORMANCE REGARDING THE ASPECT OF 'ENERGY EFFICIENCY'

The point that environmental building performance is still in its infancy and needs further development can be made by a clear example: the measurement of energy efficiency of buildings.

Energy efficiency has had a lot of attention ever since the energy crisis of the 1970s. There is a multitude of handbooks and software tools available to support energy efficient design, and energy efficiency figures prominently in building regulations and assessment schemes like BREEAM and LEED.

Yet even for this prime factor in environmental performance of buildings there is not one standard way of expressing performance. Energy efficiency is given in all different ways – one can describe it by measuring (or calculating) energy end use in a building in GJ or MJ, and the percentage of savings made by introducing specific measures or systems; it can be related to the energy use of reference buildings of all sorts, giving a factor of performance to capture the relationship; it can be based on an approach that just looks at the system boundary of the building or one that includes the whole fuel supply chain, taking into account efficiencies along the way; it can be related to CO2 emissions or the amount of equivalent renewable fuel needed; or expressed by means of exergy, taking into account the quality and degrading of energy along the supply and use chain. Energy efficiency can even be measured in monetary values (Pounds Sterling, Euros or Dollars) by superimposing economic values over energy usage data.

Still, the BREEAM assessment method just awards points based on achievements calculated in $kWh/m^2/year$, without being more specific. LEED refers to ASHRAE or local energy calculation codes and awards points for percentages of energy saved when comparing to the 'prequisitive standard'. These different ways of expressing energy efficiency are hard to relate to each other, or to energy supply system readings and monitoring data, resulting in communication problems across the board.

In order to improve on this situation, there is a need to express performance in a more formal way. Such approaches can be found in the scientific literature. For instance Zeigler et al (2000) describe how a repeatable experiment or calculation can be conducted for predicting performance; this calls for a clear distinction of experimental set-up, experimental conditions, and observable results. The experiment will generate a set of observable states and output. From these a measure for how well the system performs its function can then be derived; undertaking this will result in the quantification of the performance of the system in a specified performance indicator. In such an experiment all observations are ordered according to a time base.

The authors of this paper suggest that there is an urgency to apply this fundamental approach to all environmental aspects of building, in order to get a better communication in the industry. For the example of energy efficiency this would require a clear definition of the experimental set-up (building with systems with a very clear and strict system boundary), experimental conditions (defining climate conditions, occupant behaviour, system control), observed states (temperature, kW or Joules in terms of end-use or fuel consumption), and data aggregation (summed to yearly values, peak demands etc).

6. RELATED RESEARCH EFFORTS UNDERWAY AT THE UNIVERSITY OF PLYMOUTH

The University of Plymouth, School of Engineering is focusing and intensifying its research activities on improving the understanding of 'environmental buildings'. To this end, a number of activities is being set in motion:

- The School of Engineering is participating in the Center of Excellence in Teaching and Learning focused on Education for Sustainable Development (CETL-ESD) at the University of Plymouth. The work on understanding of 'environmental building' will be brought into the CETL-ESD, and be put forward for feedback from the other disciplines involved in this Center for Excellence.
- Part of the research activities at the School of Engineering focuses on Post Occupancy Evaluation (POE). It is hoped that an increased scrutiny of 'environmental building' will help develop better approaches for measuring this aspect in POE's. The work on environmental friendliness in POE might also be expanded to include building commissioning, building operation and control, and even towards feedback on the building design process.
- Ongoing research at the School of Engineering already deals with missing information needed to carry out environmental appraisal of buildings, for instance through development of approaches to carry out in-situ measurements of thermal properties. This research will be lined-up with a broader look at environmental building as described in this white paper, allowing a reflection on the state-of-the-art in assessing building performance. Research partners involved, eg. the UK Carbon Trust and BRE, will be approached for feedback on the issue of defining 'environmental building'.
- The work will line up with efforts undertaken in the fields of building regulations and contract procedures. Ultimately this will lead to contributions towards the development of 'performance contracts' for environmental buildings.
- The development of a concise definition of 'environmental building' will connect to ongoing efforts to investigate personal value drivers, putting an emphasis on the motivation and need to change the building industry towards a more environmentally friendly undertaking.
- A better understanding of the elements defining 'environmental building' will directly link to project management and control, supplying the researchers at the University of Plymouth with a

firm knowledge base that can be implemented in work on the development of design criteria, technical performance measures, system specification, resource allocation, requirement analysis and trade-off studies.

5. DISCUSSION AND CONCLUSION

From the literature review it is clear that the definition of Key Performance Indicators for 'environmental building' is not an easy undertaking. Any definition needs to be specific in order to be useful and overcome the current vagueness and confusion in the discipline, yet at the same time the definition will need to be flexible enough to allow different professionals to tailor the indicators towards their specific interests. In terms of scientific experiments and definitions, this requires the definition of a number of well defined experiments that still have a few experimental parameters that can be varied to accommodate specific needs and context.

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