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From Green to Sustainability—Trends in the Assessment Methods of Green Buildings

Abstract This research investigates recent developments in assessment methods of green buildings and compares the differences in rating systems among the United Kingdom, USA, and Germany. There are indications that the rating systems are moving from green buildings to sustainable buildings. In order to understand the recent research in academic areas, we survey the recent Ph.D. dissertations and literature related to green building assessment. Discussion is provided on the major research areas of green buildings, which cover accountability of life cycle cost, methodology for balancing the three pillars, and government vision and public policy.

Keywords: green, sustainability, buildings, assessment, methods, rating systems

1 Introduction

The US Environmental Protection Agency (EPA) defines green building as the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building's life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction. Although the terms "green" and "sustainability" are often used interchangeably in common parlance, they are two different concepts. Table 1 summarizes the differences between green and sustainability.

Green is typically associated with individual products

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and processes, while sustainability is tied to an entire system, in which individual consumer products and other commercial materials are a part. In this sense, green products and processes are, at best, a subset of wider sustainable building, farming, or manufacturing processes, but not the reverse.

Going green distinguishes itself from sustainability in that conceptually it balances precariously on one leg (environmental health or economic vitality) of the sustainability tripod (economic vitality, environmental health, and social equity), while sustainability rests securely on all three legs of that tripod (or the "triple bottom line", another sustainability metaphor). Sustainability, at the very least, is built upon a core meaning that makes the pursuit of all three legs necessary and compelling.

Green is popular and easy to implement, because it connotes quick and inexpensive steps to make the world less unsustainable by deployment of tactics that reduce the environmental impact of human activity, agricultural and industrial production, and our built environment. In this case, un-sustainability of our system, as a set of social, cultural, and economic systems and practices, is never directly confronted. Sustainability, on the other hand, is radical (in the proverbial sense of "going to the roots") and involves systems thinking in undertaking the necessary changes in our economic, social, and urban processes to achieve a dynamic, virtuous, and balanced relationship with nature. In other words, green evokes small incremental improvements in social practices, modern technology, and human habitats; sustainability implies a revolution in organizing our personal and collective lives and inhabiting the planet.

2 Developments of rating systems for green buildings

The first rating system for environmental assessment of buildings was developed in the United Kingdom (UK) in 1990. *Figure 1* shows the Building Research Establishment's Environmental Assessment Methods (BREEAM) of the UK framework. The major content is the code for

Table 1*Differences: Green vs. Sustainability*

Aspects	Green	Sustainability
Relation to sustainability tripod	Only one pillar (environmental improvement)	All three pillars (environment health, economy vitality, social justice)
Focus	Individual components	Interplay of individual components and the whole system
Tactics/strategy	Tactical application of activities that involve “picking low-hanging fruit”; promoting individual changes and reforms to make world less unsustainable	Strategic discovery of the proper scale that will make successive policy steps and actions easier and less costly by designing and implementing a sustainable, self-balancing system
Political orientation	Conventional, “pragmatic realist”, reformist	Innovative, visionary, revolutionary (“going to the roots”)
Scale	Individual devices, products, indicators, practices, buildings as most tractable level for greening	Cities or regions as the level at which human and social disequilibriums and ecological insults can be dynamically rebalanced
Risks or excesses	Green washing	Utopian fantasizing or top-down authoritarian policy action
Definition of success	Infinite progress of incremental improvements	Reduction of ecological footprint to a city or region’s fair Earth-share

Figure 1. The framework agreement of BREEAM for the local green building evaluation process. Referred from <http://www.breeam.org/page.jsp?id=347>.

sustainable built environment which includes core process and technical standards, and framework agreement with local cultures. BREEAM offers flexibility of the assessment method for different local environments.

The U. S. Green Building Council (2009) established the Leadership in Energy and Environmental Design (LEED) rating system in 2000. LEED establishes 13 areas for rating

in five systems which include Building Design and Construction (BD + C), Interior Design and Construction (ID + C), Operation and Maintenance (O + M), Neighborhood Development (ND), and Homes. Table 2 illustrates the selected areas for each system of the newest LEED v. 4 and the possible points for each category. Figure 2 shows the distributions of the metrics in each system. With the

Table 2*LEED v. 4 Rating Systems and Possible Points*

	BD + C	ID + C	O + M	ND	Homes
Integrative process					2
Sustainable sites	10		10		7
Energy and atmosphere	33	38	38		38
Water efficiency	11	12	12		12
Indoor environmental quality	16	17	17		16
Materials and resources	13	13	8		10
Location and transportation	16	18	15		15
Regional priority	4	4	4		4
Innovation	6	6	6	6	6
Smart location and linkage				28	
Neighborhood pattern & design				41	
Green infrastructure and building				31	
Regional priority credits				4	

exception of the rating system for neighborhood development, energy and atmosphere is the major focus for LEED rating systems.

Comprehensive Assessment System for Built Environment Efficiency (CASBEE) stems from a joint industrial/academic/government project in Japan in 2001. The basis of assessment for this system is building environmental efficiency (BEE) by dividing the building environmental quality and performance by the building environmental loads. It is often regarded as the Japanese equivalent of

LEED. There are four fundamental assessment tools in CASBEE, namely, CASBEE for Pre-design, CASBEE for New Construction, CASBEE for Existing Building and CASBEE for Renovation. The tools serve the different stages of the design process. By April 2015, the total number of the CASBEE certified buildings is over 450 (mostly in Japan), while the first international CASBEE certified building is the TEDA MSD H2 Low Carbon Building, located in Tianjin, China.

China developed the Green Building Assessment System (GBAS) based on the Green Olympic Assessment System (GOBAS) in 2006. In 2007, the German Sustainable Building Council developed Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB) (German Sustainable Building Council, 2007). The major difference between DGNB and the other rating systems is that DGNB focuses more on social and functional quality. Table 3 shows the perspectives, items, and metrics of DGNB.

Table 4 shows the development of sustainable metrics in social and functional quality. It appears that only DGNB is approaching the definition of sustainable building rating systems from 1990 to 2007. Both BREEAM and LEED are the major references for the other sustainable building rating systems.

3 Sustainability thinking for green buildings

Sustainability thinking has a broader scope than merely a green buildings focus. Several historical definitions of sustainability are summarized as follows (Wang, Qiu, Chen

Figure 2. Distribution of the metrics of the rating systems of LEED.

Table 3*The Perspectives, and Number of Items, and Metrics of DGNB*

Perspectives	Items	Metrics
Environmental quality	6	13
Economical quality	3	11
Social and functional quality	13	47
Technical quality	6	23
Process quality	8	29
Site quality	4	18

& Chang, 2014):

1) Brundtland Commission (1987):

“Sustainable development is development that meets the needs of the present without comprising the ability of future generations to meet their own needs.”

2) Viederman, S. (1993):

“... to ensure to the degree possible that present and future generations can attain a high degree of economic security and achieve democracy while maintaining the integrity of the ecological systems upon which all life and production depend ...”

3) Alan Atkisson (1998):

“..., it is lofty goal whose perfect realization eludes us.”

The goal of a sustainable society includes three components. They are a flourishing economy, social health/social justice, and a sound environment. Construction of a sustainable society is based on a tradeoff process among economic, social, and environmental issues as illustrated in *Figure 3*.

Social sustainability combines design of the physical environment with a focus on how people live and use a space, relate to each other, and function as a community. It is enhanced by development which provides the right infrastructure to support a strong social and cultural life, opportunities for people to get involved, and scope for the place and the community to evolve (Wang, Chang, Williams, Koo, & Qu, 2015). Both the Social and Functional Quality emphasis of DGNB in Table 4 and Neighborhood Development of LEED in *Figure 4* illustrate new trends in rating systems incorporating social sustainability and a movement from green to sustainable building ratings.

4 Recent academic research issues for assessments of sustainable buildings

In order to understand recent academic research, related to green building assessment in the United States, the authors surveyed PhD dissertations and identified 99 published in 2014 on this topic. *Figure 5* shows the top three research areas of these 99 dissertations are applied science, social science, and sustainability. These research areas of the

evaluation of the green building would be related to humanity and human behavior.

Of the 99 dissertations, 12 (Abdallah, 2014; Arroyo, 2014; Attallah, 2014; Berghorn, 2014; Hogan, 2014; Johnson-Ferdinand, 2014; Karatas, 2014; Kwok, 2014; Langevin, 2014; Lin, 2014; Vanhoozer, 2014; Wao, 2014) were selected based on their relevance to our research topic. The major areas for the future research of the assessment of sustainable buildings are found and illustrated in the following.

4.1 Life cycle cost analysis

One of the major difficulties for quantitative analysis of sustainable buildings is obtaining adequate data for operation and maintenance costs of the buildings, verifying the accuracy of these data, and analyzing the buildings' life cycle costs. Attallah (2014) utilized agent-based modeling to simulate the diffusion of sustainability in a construction market. The research modeled selection of sustainability credits at the project level, based on feedback from industry professionals. Life cycle analysis was also introduced as an objective quantifiable tool to assess the potential reduced environmental impact associated with application of project sustainability credits as a result of targeting certification levels when specific sustainability policies are adopted. Berghorn (2014) developed a life cycle cost based risk model to improve project decision making with regard to risk control and reduction. The major contributions from the research included a consensus-based assessment of risk management; characterization of retrofit risks; an empirical evaluation of scenario failure mode and effects analysis and its application to this domain; and development and pilot application of a life cycle cost based risk model.

Also addressing life cycle analysis, Kwok (2014) established a framework of carbon emission modeling that includes modeling energy use, water consumption, energy efficient technology, material production, transportation, and end-of-life analysis of construction materials. This framework could establish the much-needed framework needed by industry to reliably estimate carbon emissions throughout a building lifecycle. Hogan (2014) analyzed the net savings of life cycle costs and cost effectiveness for a green building better than LEED. Low correlation was found between the earned points on energy and atmosphere (EA) and water efficiency (WE) credits and the initial incremental investment, but a relatively high correlation coefficient was found for energy-related points versus the initial incremental investment. The sustainable items that led to the increased initial construction costs were mainly related to energy savings, as anticipated.

4.2 Methodology for balancing the three pillars

Another area of emphasis in the dissertations was

Table 4*Development of Green Building Rating Systems from 1990 to 2007*

Year	Green building rating system	Country/ Area/organization	Referred system
1990	BREEAM	UK	Original
1993	IDP (Integrated Design Process)	Canada	Original
1996	BREEAM Canada	Canada	BREEAM
1996	HK BEAM (Hong Kong Building Environmental Assessment Model)	China's Hong Kong	BREEAM
1998	SB Tool (formerly known as GB Tool)	International standard	GB Tool
1999	Eko-Profile/Eco-Profile (Okoprofil)	NBI Norway	Ecoprofile + ercb
1999	EEWH (Ecology, Energy, Waste and Health)	China's Taiwan	LEED, CASBEE
1999	Green Leaf Eco-Rating System	Canada	LEED, Green Leaf
2000	BREEAM Green Leaf	Canada	LEED, Green Leaf
2000	LEED	US GBC (Green Star Communities)	
2000	TQ (Total Quality)	Austria	GB Tool
2002	CASBEE	Japan	Original
2002	GEM (Global Environmental Method) UK for Existing Buildings	UK	Green Globes Canada
2002	Green Leaf	ECD Energy and Environment Canada	BREEAM, Green Leaf
2003	Green Star Australia	Australia GBC	BREEAM, LEED
2005	Green Mark	Building & Construction Authority (BCA) Singapore	LEED, Green Star and others not disclosed
2005	Green Globes US	US	Green Globes Canada
2006	GBAS	China	GOBAS
2007	CEPAS (Comprehensive Environmental Performance Assessment Scheme)	China's Hong Kong	HK BEAM and existing standards
2007	Green Star New Zealand	New Zealand	Green Star
2007	TQ-B (Total Quality Building)	Austria	TQ
2007	DGNB, German Sustainable Building Council	Germany	Original

Figure 3. Domain of sustainability.

methodologies to balance economic, environmental, and social sustainability. Karatas (2014) developed an algorithm for optimizing the sustainability of single-family housing units in the US. Abdallah (2014) studied the methodology for optimizing the selection of sustainability

measures for existing buildings. Both of these dissertations included a social impact model with tradeoffs between the social quality of life for housing residents and the life cycle cost of housing, an environmental performance model for maximizing the environmental performance of housing units while minimizing their initial cost, and a multi-objective optimization model that provided the capability to generate optimal tradeoffs among three housing sustainability objectives of social quality-of-life, environmental performance, and life cycle cost. However, neither of the dissertations included a more comprehensive assessment of social sustainability, nor ecological impacts, thus failing to fully consider all metrics among the three sustainability pillars.

Arroyo (2014) explored multiple-criteria decision-making methods for sustainable design in commercial buildings. This research evaluated (1) goal-programming and multi-objective optimization methods, (2) value based methods (including Analytical Hierarchy Process (AHP) and Weighting Rating and Calculating (WRC)), (3) outranking methods, and (4) Choosing By Advantages (CBA). After comparing these methods, this research

Figure 4. Spans of the economic, environmental, and social sustainability for product lifestyle management.

Figure 5. The distribution of the research areas of 99 Ph.D. dissertations completed in 2014 in the United States addressing green building evaluations.

proposed CBA could be the better multiple-criteria decision-making method to creating transparency, building consensus, and continuous learning in the design process.

Lin (2014) presented the theoretical structure of an early stage designer-centered multidisciplinary design optimization framework, entitled Evolutionary Energy Performance Feedback for Design (EPPFD). EPPFD enabled by a customized genetic algorithm (GA)-based multi-objective optimization (MOO) approach can be used to provide energy performance feedback in assisting design decision-making.

Wao (2014) modified value engineering methodology to provide avenues that may be followed to achieve improved building sustainability outcomes. Vanhoozer (2014) developed new methods of post occupancy evaluation to the architectural field, established behavioral connections between workplace and home environments, and provided a framework for evaluating the implementation and

utilization of high performance buildings.

Wang, Chang, Williams, Koo, & Qu (2015) developed the balanced scorecard for the sustainable design centered manufacturing by using Structuring Equation Modeling. Balancing the three pillars of sustainable buildings has a room for future improvement.

4.3 Government vision and public policy

Demand for new sustainable buildings will grow in the next decades, especially in metropolitan areas with high population density. Besides the push from the market, the vision of local governments and their policies are important factors affecting the development of evaluation systems for sustainable buildings. Some research completed in 2014 suggesting public policies are described below.

Research conducted by Hogan (2014) analyzed the extent to which Energy Star (ES) certification is reflected in

commercial real estate tax appraised values in Texas. This body of green building appraisal research provided taxing authorities with a more comprehensive understanding of how green building certification influences property values. The study was intended to serve as a foundational document to aid in the development of a best practice methodology for tax professionals to accurately appraise the market value of ES properties prior to comparable market transactions.

Johnson-Ferdinand's research (2014) suggested that third party rating systems, coupled with dashboards, are an effective decision support tool that facilitates efficient decision-making for urban redevelopment. The present study investigated whether a prescriptive approach to urban development, a third party rating system, coupled with a Business Intelligence Dashboard as a data visualization tool to display the status of redevelopment, can provide feasible and intuitive integration of data in which to prioritize redevelopment. The study presents a new framework and key sustainability indicators, based on existing third party rating systems, to prioritize redevelopment. It introduces these assessments into a Spatial Decision Support System, utilizing a dashboard as an interactive tool to gather and consolidate data and to present an evaluative means for decision-makers. The aim of his research was to advance knowledge for new concepts for sustainable urban redevelopment projects using decision frameworks for selection among alternative Brownfield redevelopment projects.

Langevin (2014) developed the Human and Building Interaction Toolkit (HABIT), a framework for the integrated simulation of occupant thermal comfort, related adaptive behaviors, and building energy use as part of sustainable building design and operation. Results indicate that more efficient local heating/cooling options may be paired with wider set point ranges to yield up to 24% to 28% HVAC energy savings in Philadelphia's heating/cooling seasons while also reducing discomfort among occupants. However, it is shown that the source of energy being saved must be considered, as local heating options replace cheaper, more carbon-friendly gas heating with expensive, emissions-heavy plug load electricity.

4.4 City or urban scale

Without any doubt, buildings are one of the most important components of the built environment but a "built environment" is much more than an agglomeration of buildings. Buildings can be very "green" and efficient but hardly sustainable because sustainability is a broader concept that can only be implemented at a larger scale. For example, it is very hard to achieve the goal of net zero energy buildings without considering energy efficiency and clean energy production at the urban scale. The same applies to water, materials, food, and so forth. Therefore, the requirements for building sustainability assessment (BSA) have

expanded and nowadays it is not enough to evaluate building components or the building separately. It is necessary to consider the interaction between buildings and their surroundings in assessing these buildings, taking into account the life style of the surrounding population. Furthermore, the current population moves from rural to urban environments also stresses that green buildings have to be assessed at the city/urban scale.

The paradigm of sustainability assessment tools is changing from the building scale to the city/community environment scale. Currently more and more cities around the world are concerned with sustainable development, as well as its evolution. Additionally, the rapid growth of cities and the urban regeneration of degraded and/or abandoned areas are current concerns of authorities, both at international and local levels. This is reflected in the emphasis, in several of the dissertations we analyzed, on public policy and government vision. In tandem, a new generation of sustainability assessment tools are being developed to be used to guide and help cities and urban areas to become more sustainable, such as BREEAM Communities (BRE, 2012), LEEDND (Neighborhood Development) (The US Green Building Council, 2009), SCTool (IISBE, 2009; IISBE, 2013), CASBEE Urban Development (CASBEE, 2013), Earth Craft Communities (Earth Craft, 2013), Green Star Communities (GBC Australia, 2013), SBToolPT-UP methodology for Portuguese cities (Castanheira and Bragança, 2014), or a structure of indicators for the Spanish context (Braulio-Gonzalo, Bovea, & Rua, 2015). These tools were designed to give opportunity for projects to demonstrate their environmental, economic, and social benefits to the local community, in all the planning stages of development processes.

5 Conclusions

This research surveys the recent development of the assessment methods of green buildings. The trend in rating systems for buildings appears to be evolving from green to sustainable building ratings. These phenomena can be verified by both the emphasis of new rating systems and the research results as analyzed in dissertations completed in 2014. The major research issues addressed in those dissertations included life cycle cost analysis, methodology for balancing the three pillars, and government vision and public policy.

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