

Title: Framework for Supporting Sustainable Design

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Abstract

In the realm of digitally assisted sustainable building design, computational tools, mostly simulations, are invoked to find loads and predict system performances in terms of energy use. These tools also provide a way of envisioning the effects of choices made during the design process, say, of materials; of heating and cooling systems; and of methods of construction that may detrimentally effect the environment. Although, ensuring energy efficiency is one of many indicators of sustainability, other requirements have to be met in order for a building to be deemed sustainable. Currently, sustainability in the building domain is judged by reference to a standard or rating system by which a building is measured. (Yudelson, 2008) Rating systems, however, “are a moving goal post.” (Walker, 2006) Being able to use the requirements set out by a rating system during design can offer a comprehensive guide towards sustainable design. Taking this into consideration, this paper presents the need to create a flexible framework to encapsulate the requirements of sustainable measures posed by the different rating systems. The development and use of a flexible framework is essential for sustainable building design particularly in the area of organizing requirements and the adoption of a rating system during design. One possible way of creating a flexible framework that can be integrated with a design tool, for supporting sustainable design, is presented.

Keywords: Sustainability, Sustainable building rating systems, LEED, building information modeling.

1 Introduction

Sustainable design encourages the parsimonious use of resources during design, construction and operation of buildings to minimize harmful environmental impacts. This is achieved by making requirements on sustainability central to the design process. Using a combination of knowledge and proactive steps, designers can ensure the desired outcomes through choices for resources, systems, and methods. Unlike natural systems that have endured through millennia without placing the planet at risk, our actions in the post-industrial age have destroyed more of nature than in all prior history. This is not just moral issue; it is of the utmost practical concern for the well-being of the planet and its future.

Sustainable building design and delivery is gradually building momentum and it is manifest in a building's performance and functionality in the overall ecological context. This ongoing revolution of transformation from the traditional to sustainable building design process is no longer a question of whether to build, but rather how. One way is to produce buildings that fulfill criteria of a sustainable building rating system or certain other benchmarks. This process of evaluation is multifaceted and multi-phase, ensuring that measures have been taken for the building to achieve certain performance levels in categories such as energy consumption reduction, conservation of resources, low carbon footprint etc.

As design decisions for building have environmental consequences, the onus of responsibility rests heavily on the designer's shoulders. Along with the more complex building systems and technologies, a designer has to be more facile, capable of orchestrating a wide array of fields of knowledge to design outcomes that suffice as sustainable. At this intersection of design and intended outcomes, computer aided design tools have yet to offer such capabilities in a design environment. Current effort at integrating a building information model (BIM) with rating systems (Biswas et al, 2007) is an attempt at providing such capability.

This paper examines different sustainability rating systems through their categories, which have to be followed to achieve designs that aim to reduce negative impacts on the environment. To embody

the requirements of the various rating systems, a general sustainable information framework (SIF) is proposed. The framework consists of general measures that provide a way to organizing and managing the evolving criteria of sustainable design. When viewed hierarchically, the framework ranks over any given rating system; its objective is ultimately to aid a designer in their intention of designing towards sustainability. The vision to create an integration of sustainable requirements with a BIM is under development and will be used to demonstrate the concept.

2 Motivation

In the United States, buildings account for 65% of electricity consumption, 36% of energy use, 30% of greenhouse gas emissions, 30% of raw materials use, 30% of waste output (136 million tons annually), and 12% of potable water consumption. (Alder, 2006) To meet electricity demands, water has to be withdrawn and consumed. The US Geological Service estimates that 52% of surface water is used for thermoelectric power generation. (US Geological Service, 2000) The built environment may double by the year 2030. (Nelson, 2004) Given the magnitude of effects that the building industry has on environmental quality, impacts become even more significant as the number of buildings increases.

Among all building-related environmental impacts, those concerning building energy use are of highest priority. Recent climbing prices of non-renewable fuels have brought energy related issues to the forefront of public and political discussions. (Alder, 2006) Although it may be argued that energy impacts merit more attention than other building impact categories, energy cannot be accounted for alone. Looking at a building from the perspective of rating systems can not only guide the process of achieving energy efficiency, but also address actions to minimize negative impacts on the environment.

One of the difficulties, however, is in choosing a suitable rating system, as these vary from country to country and are, in themselves, changing. "Sustainability is neither fixed nor static— it changes, iteratively, with evolving knowledge that connects science and design." (Williams, 2007) Likewise, rating systems that gauge sustainability are in a state of flux, that is, in transformation. One of the challenges here is to manage requirements of rating systems and consequently account for them

further downstream when applied in a design environment— for instance, in a design tool such as a building information model.

3 Research Approach

The task of formulating a framework for encapsulating the requirements of sustainable rating systems resembles complexities in that the result of all the criteria is more than a simple sum of the contributing sub-criteria. There is strong synergy between rating system categories, more than often requirements are met by responding to a multiple of strategies spanning across the categories. For instance reduction of energy use depends on type of building envelope, heating, ventilation and air conditioning systems, water heating, lighting and other equipment loads. Reducing water use depends on the use of efficient fixtures along with the use of captured rainwater and recycled wastewater. The method has been, first, to develop a schema to express the requirements of the different categories; second, to identify the contributing categories of the schema to incorporate within a flexible framework.

3.1 Analysis of Rating Systems

The framework is an attempt to capture broad categories and categorize them according to their requirements. **Error! Reference source not found.** shows how categories of common rating systems are distributed; they differ in classification, importance, or methods of calculation and verification. A generalization of categories shows that most sustainable rating systems consider site, water use, energy use, materials and resource use, and indoor air quality as the main categories by which to measure environmental impact. Categories have sub categories, which pertain to rules and acceptable thresholds of, say, site, material and water use; expected energy efficiency and indoor environmental quality in varying degrees without causing discomfort to the users of the space. We can associate with each sub category a number or a collection of numbers that quantitatively reflect their overall environmental impact, which we term as a measurable. The reason for looking at a broad range of rating systems from an overall point of view is to determine how they can be organized for the purpose of ultimately aiding the process of sustainable building design within a design environment, and also for comparing measurables associated with the given categories across rating systems.

Table 1. Rating systems with their main categories

LEED	BREEAM	Green Star	CASBEE
	Management	Management	
Energy and Atmosphere	Energy	Energy	Energy
		Emissions	
Sustainable sites	Land use	Land use	Site
	Transport	Transport	
	Ecology		
Water Efficiency	Water	Water	
Indoor Air Quality	Pollution	IEQ	Indoor Environmental Quality
	Health and Well-being		
Materials and Resources	Materials	Materials	Resource and materials and water conservation
Innovations		Innovations	

Methods used to reach quantification of the measurables vary from one rating system to another. Studies by Fowler and Rauch (2006) evaluated five rating systems from a selected group, based on their consideration for use in the US General Services Administration (GSA) projects. Keysar and Pearce (2007, pp 153-171) show how rating systems compare to one another while designers consider selection of decision support tools. A study by Athena Sustainable Materials Institute (2002) compared LEED to the Canadian version of Green Globes with a view to harmonizing the two standards. (Smith et. al, 2006) It is evident that there are various studies comparing different rating systems for a variety of purposes, some of which include compatibility, ease of use, comprehensiveness, environmental performance and cost of implementation. The American Institute of Architects (AIA) supports the development and use of rating systems and standards, to promote the design and construction of communities and buildings that contribute to a sustainable future (AIA), provided that the rating systems follow certain qualities, of which, one ensures that standards are updated on a regular basis. It is a challenge for experienced designers to keep up with all the change, let alone for novices. To address these unique requirements of rating systems, we envision the framework as an organizer, a placeholder, and ultimately, a bridge, to cater for multiple rating systems when implemented with design software making it amenable to computation.

3.2 Structure of Sustainable Information Framework

The intent of a general sustainable information framework (SIF) of measures is primarily to capture the categories of sustainable rating systems, to cover different phases in the life cycle of a building. In its own right, the framework can be used as a decision-making matrix, as exemplified in existing practice-based methods that have been developed to assist dialogue between design team members and their clients— first, by setting priorities and targets for sustainability, and then, in assisting subsequent reviews and progress reports. (Gething & Bordas, 2006)

For the purpose of this research, the building life cycle is considered generically. Although there are different ways that the phases of a buildings life can be named and separated, the classification adopted here is derived from Gielingh (1988), who proposes a life cycle according to the transition points shown in Figure 1. The periods between transitions are of greater interest, and are referred to as phases. The six phases are: Feasibility, Design, Pre-Construction Planning, Construction, Operation & Management and Decommissioning. Temporal in nature, each phase suggests general components and activities that occur in that period of a building project; they also provide the information required to fulfill ratings evaluation. Table 2 shows the structure of the sustainable information framework.

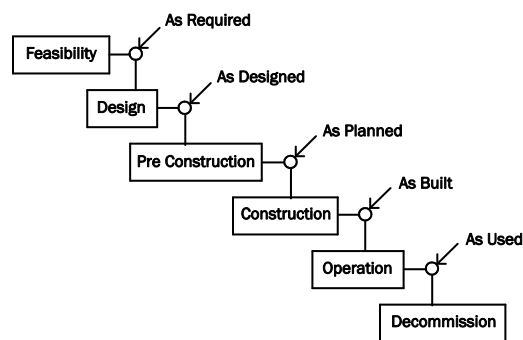


Figure 1 Classification of the building lifecycle addressing phases and transitions according to Gielingh (1988)

Feasibility or Pre Design Phase

A feasibility study is often undertaken prior to embarking upon any building project. Central to the study is a derivation of projects costs, expressed as a total amount or a combination of cash flow, other resources and possibly time from space quantities, mechanical systems, utilities and desired features.

This is clearly a vital phase as the decisions made here affect the overall environmental impact of the project. Teams, which are better informed, can contribute towards achievement of sustainable measures, choice of site and building forms and openings, material and systems selection— all important to the success of a project with ambitions to creating a sustainable design.

Design Phase

This phase covers the inception of a project till execution of the actual building. The stages in this phase require meetings, presentations, reviews and approval of the client, design team and the other stakeholders of the project. Activities include pre design, site analysis, schematic design, design development, construction documents, bidding and negotiations, and construction contract administration. “This list has been amalgamated from several sources including the IAI Code of Practice and the US Army Corps of Engineers submittal requirements.” (Eastman, 1999) Each stage requires both expertise and extensive data support for any kind of design undertaking let alone when the design aims at being sustainable. “It is essential to consider, fairly early on in design, the strategies to ensure some of the key components of sustainable design.” (Bennadji et al, 2000)

The possibility of putting together all the various kinds of technical, performance, economic aesthetic and other issues, come together in this phase. This involves varied representations and many analytic methods, often carried out by specialists on the design team. Although much of the parts-scale drawings, electrical and piping, structural components and building energy performances are being integrated, in most cases the computation is are not straightforward. For instance, analyzing the performance of a building requires expertise and pre preparation of many datasets. “Only occasionally are they used iteratively to evaluate alternative designs and help select the ones with higher levels of performance.” (Eastman, 1999) While the key requirement to any sustainable design is energy efficiency, it is essential to make it a priority, and consider not only the systems efficiency but also building envelope, properties of materials and internal loads as these all have synergies that enable the reaching of the desired performance.

Pre Construction Phase

This phase involves adding further detail to the documents produced during design, so detailed lists of materials and labor costs can be associated. From a sustainable design point of view, it guides the general contractor in carrying out tasks in a certain manner. For instance, procurement of products from local sources may become of higher consideration, as it is specified for achieving the overall goals of sustainability for the project.

Table 2. Structure of General Framework

Whole Project	Phase	Major Category
Project Life Cycle	Feasibility (Pre Design)	Decision Making
	Design	Site
		Building
		Material
		Indoor Environment
		Energy
		
	Construction Management	Pre construction
	Construction	Construction
		Commissioning
	Operation Management	Maintenance and Support
	Decommissioning	Source and Disposal

Construction Phase

The construction phase starts off with the development of construction schedules, which identifies units of construction and sequences of tasks. Construction requires a high degree of coordination, among on-site crews and material deliveries from companies and fabricators. One of the main environmental impacts of construction arises from waste generation and from energy use of equipment and machinery during on-site assembly. These are areas where sustainable design requires certain measures to be met. The quantities of waste material diverted from landfills through sorting, storing and recycling are measured in almost all rating systems. Emissions to soil, water and air from construction activities are taken into account in some rating systems. Following close to construction is the commissioning of building systems, which is increasingly being sought to enable and ensure that buildings are performing to the level intended.

Operation Management Phase

What starts off as a project, for architects and contractors, is, in reality, a facility for the people who use them. In the building operation phase, principle impacts are energy related mostly in form of heating cooling, and lighting. Other impacts are due to usage of potable water, and the use of waste water generation. Facility management related issues include replacement and repair of components to ensure that systems are operating efficiently and as designed.

Decommissioning Phase

Robert Ries (1999, pp. 36) remarks: “Building decommissioning and demolition generates primarily inert materials that have historically been land filled.” Principal components of demolition waste are wood and concrete, which together comprise two-thirds of the demolition waste of an average house. The potential for recycling demolition debris is good. He also states: “The most common materials recycled are concrete and asphalt, wood, asphalt shingles, metals, and drywall.”

Among the different phases, elaboration of the categories of the Design phase have been done by creating a list of general measures, this is shown in Table 3. To identify the elements that are required by each sub category, measures are defined by their intents. Having a structure of the building phases, general views from rating system requirements were cast to formulate the elements of the framework. Research on framework creation show similar approaches. (Weerasinghe, et al., 2007; Keysar and Pearce, 2007; Olbina and Beliveau, 2007) Through providing a general description for each, we are able to match the requirements of different rating system criteria to the sub category measures and ultimately to the objects that they refer to in a BIM.

Table 3. Breakdown of Site Subcategories into elements

Major Category	Sub Category	Elements
Site		
	Biodiversity	AreaVegetatedOpenSpace
		AreaOpenZoningReq
		EcologicalValue
		
	Land utilization	PrimeFarmland
		FloodPlainHeight
		HabitatLand

	Alternative Transportation	BicycleRacks
		Showers
		Lockers

3.3 Mapping of General Measures to Rating System Requirements

As the measures are further broken down into probable objects and attributes, relative methods from each rating systems are simultaneously being mapped. It can be seen through this mapping, we are able to identify objects that are presently available in a building information model, and determine what is needed to fulfill the overall evaluation of a design from a sustainable point of view (Table 4). The credit requirements have mainly three components, the relevant objects and their parameters, methods, and external references that need to be met for evaluation. Most methods are specific to the rating system or refer to external standards such as American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) for efficient heating, cooling and ventilation systems. Similarly for lighting, management practices, materials certification, there are also bodies that are referenced and certain processes that need to be followed to achieve credits. Current design software or building information models do not hold all relevant information, thus the need to store and manage missing information required for sustainable building evaluation, is evident.

Table 4. Elements of measures mapped to rating systems

Element Name	Ref	BIM ref	LEED	BREEAM	Green Star
BicycleRacks		Bicycle stand	SS4.2	Tra 03	Tra-3
Showersand Lockers		shower	SS4.2	Tra 03	Tra-3
DistanceToShower				Tra 03	
AdequateLighting	ref			Tra 03	
StandDistanceToEntrance			SS4.2	Tra 03	
FTE	ref		SS4.2		Tra-3

With respect to the variation of methods and standards referenced, there is an underlying assumption that there are commonalties of requirements. For example, the need for reducing energy consumption from a baseline of energy use is required for most rating systems, requirements for simulations are also needed. Variations occur in the thresholds or benchmarks specified by the different rating systems.

3.4 Sustainable Information Framework

A quality of the framework is that it draws upon an organized list of the requirements for sustainable building benchmarking and allows for the designer to plan achieving them. Foremost, it is envisioned to be a modular and pluggable framework that incorporates rating system requirements from existing systems, with sufficient flexibility to support emerging areas of research and innovation. The modular components are referred to as general measures, which are comprised of major categories that are formulated from the respective building phases. Each sub category contains the comprehensive list of related objects.

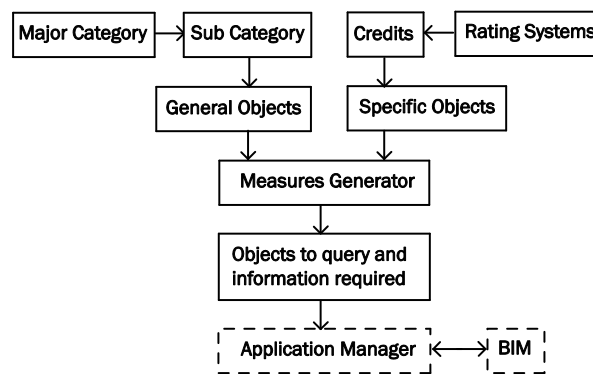


Figure 2 Sustainable Information Framework

A representative list of categories and consequently sub categories have been developed through literature investigation of the different rating systems, mainly for new construction, commercial building types. While the current list of sub categories aims to satisfy the requirements of the different rating systems, it should be noted that gaps emerge as requirements change. When other types of building are considered, the requirements will have variation and perhaps require additional sub categories or categories. For example in LEED for residential building type, it is seen that there are categories/credits that are specific to residential development such as community resources, type of development and non toxic pest control, to mention a few. To address the missing subcategory say, 'type of development,' for some common objects, such as infrastructure, then attributes need to be added and extended to match the credit requirements with an additional sub category of measures. In the case where there are no matches, a new subcategory needs to be created— for instance, for low toxic pest control management. The process of matching specific methods and object requirements to

general measures classified by the sustainable information framework is presently done manually. Ongoing work aims to automate this process through a Measures Generator module (Figure 2), which will create a set of requirements and map query objects necessary for sustainable evaluation with respect to a building information model.

4 Summary and Conclusions

This paper depicts the development of a sustainable information framework (SIF) for management of sustainable rating system requirements and integration of the requirements into a building information model. The intention is to build a common platform that different rating systems can plug into and be used by designers from the early design phases to the completion of the project. The emphasis is on creating the framework to enable the use of information collated from a buildings life cycle in a sustainable manner. We realize that will require further integration of various domains of building information.

The framework lays the groundwork for a process of ultimately analyzing a given building with respect to the requirements given by different rating systems. Aspects of sustainability that designers deal with intuitively will have a structured guideline and gauge as one selects a rating system of choice.

We plan to test and validate the sustainable information framework through case studies of real buildings, which have been certified by a known rating system. Flexibility is considered by evaluating the same building by several rating systems. These exercises will allow us to find gaps in the proposed framework. The framework is still in need of a more robust representation.

5 Future Direction

The sustainable information framework is in its initial stages of development. It is hoped that its modularity and expandability will allow for flexibility of this framework, to accommodate changes in rating system requirements and the subsequent mapping of objects in the building information model. Future modifications of the SIF plan to include a comprehensive list to enable updating of requirements in the construction and management phases.

Designing for sustainability is an undertaking that “begins with the recognition that the whole is more than the sum of its parts that unpredictable properties emerge at different scales.” (Orr, 2006) Teams experienced in sustainable design can achieve desired sustainable outcomes by bringing diverse expertise together. What is second nature to them is unattainable to novice design teams without sufficient guidance. A sustainable information framework is seen as an attempt to address some of the known factors by providing informed choices towards sustainable design.

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