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Soft Tools for Sustainable Design

Sustainability Information Framework

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Abstract. The transformation from the traditional to a sustainable building design process is no longer a question of whether to build green but rather how (Kibert 2005). 'Sustainability' in the building sector is codified by standards, which manifest themselves in the form of a 'sustainable' or 'green' building rating system. These systems offer guidelines and means for comparing and benchmarking the performance of buildings with respect to 'green-ness' (Fowler 2007). However, the nature of rating systems for sustainable buildings is such that the standards themselves are a moving target (Williams 2007). In addition to such rating systems, there are other tools available to the modern designer; these include the software design environment augmented by a suite of simulation packages to analyze and verify aspects of performance. These tools are mainly neither integrated as a whole nor provide the guidance required to achieve sustainable design outcomes. In this respect the research described here specifies a shift in paradigm for computer-aided sustainable design, through the deployment of an information framework in combination with computational tools to provide a range of options for achieving desired qualities of sustainability in design.

Keywords: Sustainability, Sustainable Building Rating System, Building Information Modeling, Parametric Modeling

1 Introduction

Sustainable or green design in general creates solutions that solve economic, social and environmental challenges simultaneously. This can be achieved by making sustainable design a foundation to program requirement. We are interested in a design process where energy, resources, construction and long life are integral to the design solution. Using a combination of knowledge and proactive steps, designers can ensure desired outcomes through choices for resources, systems, and methods. One way is to design buildings that adhere to a sustainable building standard. These standards or benchmarks are encoded through sustainable building rating systems. In the United States, the US Green Building Council (USGBC) led Leadership in Energy and Environmental Design (LEED), provides a benchmarking system to assess levels of sustainability achieved by a building. The process of evaluating a building to meet these standards is multifaceted and multi-phased (Turkaslan-Bulbul 2006). Certification ensures 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.

Environmental impacts caused by design decisions have far reaching effects—the onus of responsibility rests with the designer to create outcomes that are 'green.' A designer needs to be capable of orchestrating a wide array of knowledge from many different disciplines into the design to ensure outcomes that suffice as sustainable. Today's designer almost inevitably works with a computational design tool. Yet, such soft tools do not fully provide, within a single design environment, the capabilities for handling intended sustainable design outcomes. Our current effort directed at integrating building information modeling with sustainable building rating systems (Biswas et. al 2008) is an attempt at addressing this issue.

We begin by examining the categories and requirements of sustainable rating systems that are currently used to certify buildings. Our investigation captures the requirements of these rating systems, and looks at how a designer can work with them during design. These steps serve as the background to this chapter, providing the motivation for bringing them as guidelines to assist designers. We propose a general sustainability information framework (SIF), which embodies requirements of the various rating systems. This information framework consisting of general measures provides an organization for and management of evolving criteria for sustainable design. This vision to integrate sustainability requirements with a building information model, exemplified by a prototype, is used to demonstrate the concept. The work is still in development—this chapter concludes with a discussion of the findings and indicates directions for future work.

2 Background

The current shift towards sustainability is promoted in part by architects and critics who are demanding a broad sweeping reassessment of the way buildings are made and used. In the United States alone, buildings consume 72% of all the electricity; 40% of raw materials, generates 30% of non-industrial solid waste and 38% of carbon dioxide (USGBC 2010). Given the enormity of effects that the building industry has on environmental quality, impacts will only become even more severe as the building industry expands. It is expected that in 2030, about half the buildings will be constructed after 2000 (Nelson 2004)

What started out, as a short-lived portion of the *Green Building* movement, as a reaction to oil shortages in the 1970s (Krygiel 2008), has laid the groundwork for keeping energy and environmental concerns as a major area affecting design activities. Since then august bodies such as the USGBC, and the American Institute of Architects (AIA) committee on the Environment (COTE) have put forward methods in consistent formats for assessing the environmental impact of buildings through their 'Measures of Sustainable Design and Performance Metrics' (AIA/COTE).

Sustainability standards or sustainable building rating systems can guide the process of achieving energy efficiency and address actions that ameliorate negative impacts to the environment in a holistic manner. Some of the difficulties, however, is choosing the appropriate rating system, as these vary from country to county and among regions. Moreover, these rating standards are in a constant state of change as 'sustainability' is neither fixed nor static—it changes, iteratively, with evolving knowledge that connects science and design (Williams 2007). The rapidity with which LEED 2.1 has evolved to LEED 3.0 attests to this constancy of change. The challenge we face is managing the requirements of multiple rating systems, and the consequent accounting of the appropriate system, when applied to a design environment—that is, building information model. Maintaining currency of rating systems working in conjunction with design environments becomes paramount.

3 Review of Sustainable Building Standards and Other Tools

Selection of an applicable sustainable building standard is essential when designing a building to meet the sustainability goals set forth, codified by the rating system. This means that the general framework has to accommodate requirements of the various and distinctively different rating systems. A deeper review is essential to understand the different criteria and calculation methodologies that rating systems employ for evaluation and certification. These are used in developing the parameters for the sustainability information framework.

3.1 Sustainable Building Rating Systems

A green/sustainable building rating system is defined as a tool, which examines the performance or expected performance of a 'whole building' and translates that into an overall assessment that allows for comparison against other buildings (Fowler 2007). In the US, a commercial green building is generally considered to be one which is certified by a sustainable building rating system, for example, LEED, which was developed by the USGBC to establish a common standard of measurement (Yudelson 2008). Claiming to adhere to a standard is, by itself, not the end of the process; achieving a level of certification demonstrates that the project has fulfilled certain requirements set out by that standard.

Different rating systems have categories with similar or synonymous names; however, they can be quite distinctive in their intent, criteria, emphasis and implementation (Glavinich 2008). The ways in which a category is weighted, scaled and quantified in the various systems can differ; consequently, the same building may have different ratings when judged by different systems with "often the focus on regional, global impacts rather than, say site related energy use" (Wedding 2007). Wedding additionally points out that there is variability in environmental impacts, especially from energy use, namely emissions, in the form of carbon dioxide, nitrogen oxides, sulfur dioxide and particulate matter from one version of LEED to another.

3.2 Importance of Rating Systems in the Design Process

A rating system provides summaries of building performance that can be communicated to stakeholders (Cole 2008). The methods by which results are depicted have a direct bearing on how the various performance indicators are used and understood, and by whom. Wider and increasing adoption of rating systems, have motivated innovations—as a result, making environment friendly materials, products and technologies more affordable as they reach economic production scales. Rating systems also provide a vehicle for both, public support and green policy making. According to the architectural firm, Berkebile Nelson Immenschuh McDowell Architect, adoption of "sustainable building rating systems offer a roadmap that lead to sustainability goals and help align requirements" (BNIM 2002).

3.3 Comparison of Rating Systems

Fowler (2006) examined rating systems for the purpose of adoption by the U.S. General Services Administration (GSA). For comparison, he emphasized energy reduction, indoor air quality, and the use of environmentally preferable products. Likewise we have compared various rating systems according to general assessment areas. See Table 1. The left most column are the categories by which we compare the broad categories among the different rating systems.

Table 1. Comparing four rating systems by assessment area

Assessment Area	**USA** **LEED NC 3.0**	**Australia** **Green Star**	**Europe** **BREEAM**	**Asia** **CASBEE**
Management		Management	Management	
Energy and Atmosphere	Energy & Atmosphere	Energy	Energy	Energy
Emissions to the environment		Emissions	Pollution	Off-site Environment
Sustainable Sites	Sustainable sites	Land use	Land use	
Water Efficiency	Water Efficiency	Water	Water	
Indoor Air Quality	Indoor Air Quality	Indoor Environmental Quality	Health & Well-being	Indoor Environment
Quality of Service				Quality of Service
Materials and Resources	Materials and Resources	Materials	Materials	Resources and Materials and Water Conservation
Innovations	Innovations	Innovations		
*Culture and Heritage **				
Ecology			Ecology	
Transport			Transport	Transport

It should be noted that the assessment category 'Culture and Heritage' is not considered by any of the rating systems shown. It is, however, included in the table as it is accounted for by other rating systems. These include Green Globes, Living Building Challenge by Cascadia, and the German Green Building Standard. As shown in the table, categories and assessment areas, in part, conform by name and intent; in part, differ by name or intent; and at times overlap across distinct assessment areas. There have been studies to homogenize rating systems for easier comparison (Athena Sustainable Materials Institute 2002).

The American Institute of Architects supports the development and use of rating systems and standards that promote the design and construction of communities and buildings, which contribute to a sustainable future (AIA 2008). They require that the rating systems follow certain provisos, one of which ensures that standards are updated on a regular basis. To give the designer a deeper understanding, the AIA set sixteen broad categories by rating systems can be evaluated. Three of the four rating systems listed in Table 1 are summarized in Table 2 by four of the sixteen categories. Other studies on comparing rating systems aim at finding the content, priorities and processes for adaptation and implementation (Smith 2006).

Table 2. Comparing three rating systems by four categories from (AIA 2008)

Categories	**LEED NC 3.0**	**Green Star**	**BREEAM**
Renewed on a consensus based process	USGBC members vote on versions prior to releases and updates	Supported by government and industry	All BREEAM products are regularly updated biannually
Require design documentation	It uses web templates for documentation compliance	Documentation based	Documentary evidence is required for evaluation
Requires third party validation	Compliance and certification are validated through a third party review system	3^{rd} party verification done by 2-3 certified assessors	Verification by accredited assessors
Require significant reductions in energy use	Requires all projects exceed ASHRAE 90.1 2004 by at least 14%, which may lead to significant energy reduction	Requires reduction of GHG emissions by efficient operational energy consumption	Requires reduction of CO2 emissions by efficient operational energy consumption

It is a challenge for experienced designers to keep up with all the changes, let alone novices. To address these unique requirements of rating systems, we envision a sustainability information framework as an organizer and bridge, which, ultimately, can cater to multiple rating systems, when implemented with computational design software.

3.4 Tools Supporting Sustainable Design

Tools that are available to help designers make decisions towards sustainable design outcomes are categorized in many ways. The Annex 31 Study (Canada Mortgage and Housing Corporation 2004) describes two broad categories, which define tools as either *interactive software* or *passive*. Table 3 summarizes the main tools.

Table 3. Two categories of decision-making tools (as per the CMHC)

Interactive Tools	**Passive Tools**
Ventilation Modeling	Checklists for Design and Management
Lighting Simulation	Environmental Guidelines
Life Cycle Assessment	Environmental Products and Declarations
Energy Simulation	Rating Systems

Modeling software for energy and ventilation as well as tools for life cycle assessment are categorized as *interactive*. Rating systems, environmental guidelines and checklists for the design and management of buildings, and environmental products and declarations fall into the *passive* category. According to Keysar and Pearce (2007) there are around 275 such tools available. However, what is required to achieve, in particular, LEED certification, is not any one tool, but a combination of tools in the form of software, checklists/matrices, publications, websites and databases.

Adopting a rating system for sustainable design is the focus of considerable research. It is also increasingly becoming part of design practice. According to the USGBC in the United States, LEED standards are mandated by 16 of the 50 states for variety of building types (USGBC 2005). This list does not include some 44 municipalities that have adopted LEED or some other local standard for their buildings. In future it is likely that some form of standard will become mandated by the building codes in all 50 states. Therefore, it is essential that we have a different approach to designing and managing information relevant to sustainability. Figure 1 shows the relation between, current rating systems, performance software, design software and the involvement of policy issues that drive the design process at present. Our focus here is on the tools that support computational design software to enable the design of sustainable buildings and sustainable environments.

Most designers work with some form of computational design tools. Among these, those that work with building information models have the potential to manage building information pertaining to sustainability. “The building information modeling process is by its very nature sustainable” (Jernigan 2007). As it is inherently sustainable, BIM affords advantages over traditional processes. BIM facilitates model change and propagation via parametric object oriented representations; in BIM, we see an ideal place for integrating sustainable building ratings.

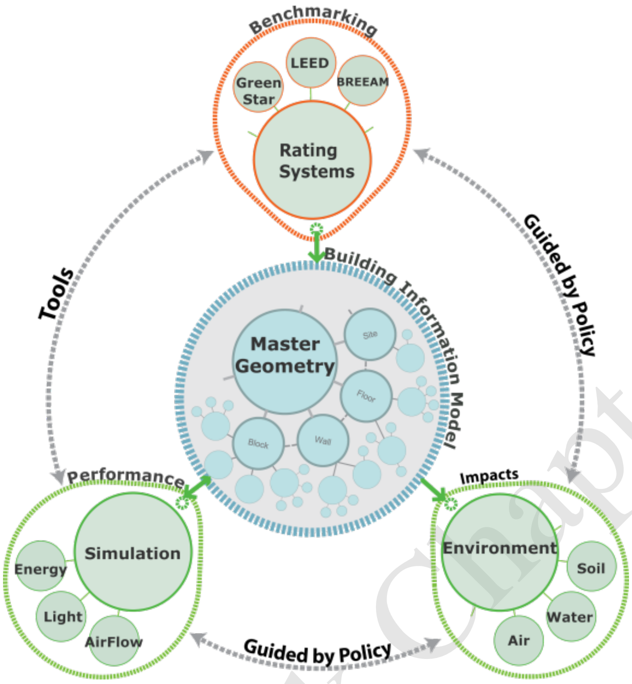


Figure 1. Soft tools which impact sustainable building design

Sustainable building evaluations typically require simulations, mainly of energy use, airflow, lighting and so on. Although there is a range of available simulation tools, interoperability with any specific computational design environment is not always seamless—moreover, such tools can be highly domain specific.

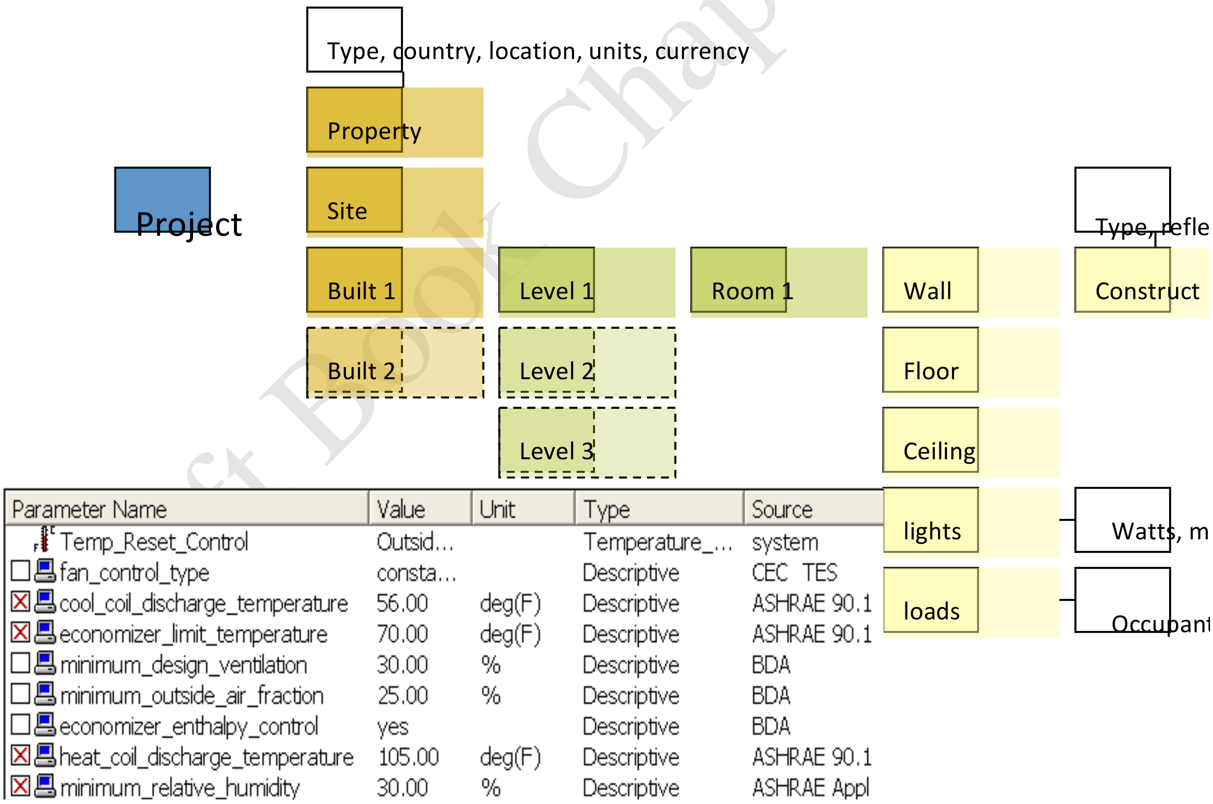
To test our concepts, we work with a specific commercial building information modeler, namely, Revit®. Our findings, on the other hand, in principle, apply equally to other commercial building information modelers.

3.5 BIM Tools and Sustainable Design

We next consider two issues, which are based on the current state of decision support tools for sustainable building solutions. They relate to designing, and ultimately, to satisfying those qualities that deem a building to be sustainable.

- *Sustainable design requires information about sustainability over the whole lifecycle of a project from conception to deconstruction*. Currently, information is fragmented across domains, not readily available in a form either to offer guidance to a designer or be accessible to design software.
- *A rating system is a road map to sustainability that periodically undergoes changes to its requirements*. Currently there is no comprehensive way of managing such changes, nor a way to inform designers of such.

A building information model acts as a data container to hold project and other relevant information. It also serves as a structure with placeholders for data (or information) not yet available to the model. However, building information models, currently, contain less than sufficient data to meet most rating system requirements. Some requirements require data that is external to the building information model; these have to be accommodated in a cohesive manner. Such data might be electronically and geographically distributed; it may need to be salvaged; and it may even need to be certified. According to Krygiel and Nies (2008) “many tools used to measure the impact of sustainable strategies are not directly accessible within a BIM itself; therefore, data needs to be exported to other applications or imported from external sources.” Figure 2 illustrates, for energy analysis, both the kinds of data typically in a BIM as well as the kinds of data that needs to be imported from external sources.



Parameter Name	Value	Unit	Type	Source
Temp_Reset_Control	Outsid...		Temperature_...	system
fan_control_type	consta...		Descriptive	CEC TES
cool_coil_discharge_temperature	56.00	deg(F)	Descriptive	ASHRAE 90.1
economizer_limit_temperature	70.00	deg(F)	Descriptive	ASHRAE 90.1
minimum_design_ventilation	30.00	%	Descriptive	BDA
minimum_outside_air_fraction	25.00	%	Descriptive	BDA
economizer_enthalpy_control	yes		Descriptive	BDA
heat_coil_discharge_temperature	105.00	deg(F)	Descriptive	ASHRAE 90.1
minimum_relative_humidity	30.00	%	Descriptive	ASHRAE Appl

Figure 2. Data for energy analysis, both internal and external to a typical BIM

For the research reported here, we investigated a commercial BIM, to identify the types of information necessary in decision making to achieve certain sustainable qualities of a building. We sought to augment the BIM by supplying the data externally. We integrated the data with the requirements of a rating system and the data repository of the BIM in order to provide feedback to the designer. Our approach comprised three steps:

i) Development of a sustainability information framework

A sustainability information framework (SIF), informally, accommodates rating system changes and designer needs; formally, it provides a general approach to processing the informational needs of a rating system by identifying, categorizing and organizing relevant data requirements.

Explicit formulation of an exhaustive list of data requirements for a rating system enables designers to gauge a building design according to the chosen system. Although the framework can offer guidelines, it does not and should not ensure certification of the design.

ii) Integration of the framework with a building information model

Integration brings together the computational design environment (and thus, a BIM), requirements from the perspective of a sustainable building standard (and thus, a rating system), and the required data for the purpose of evaluating the performance of a design with chosen assessment criteria of the rating system.

In our case, integration is an add-on application to the BIM software, namely, Autodesk® Revit® Architecture 2010.

iii) Validation of results through case studies

We selected a LEED-silver certified building as the test case. A model of the building was created using the BIM software. We compared results from the add-on prototype application with actual results achieved in the project. As the prototype is based on a sustainability information framework, it was also possible to evaluate the test case against other sustainable building rating systems.

4 Methodology

In a broad sense, a framework is a "conceptual structure used to solve or address complex issues" (WIKI 2008). In sustainable design, a framework is seen and used mainly in the form of matrices (Weerasinghe et al. 2007; Hassan 2008; Gething and Bordass 2006). The framework in this project is a relational database that provides a structure for organizing information required by rating chosen systems and identifies information not readily available in a BIM but required for evaluation.

The information required by a rating system in order to evaluate building designs stems from a combination of direct and performance data. *Direct data* refers to data that constitutes building description, while not necessarily a product of user specification. *Performance data* are derived performance metrics of specific domains that characterizes a building. Direct data is inherently integral to a building information model. However, it should be noted that in a multi-layered BIM, what is integral to any single layer may not be the case for another; that is, direct data depends upon the phase of building design or building operation. On the other hand, simulation tools, for example, ATHENA, EnergyPlus or Radiance, typically, generate necessary performance data. Such tools are uniformly data oriented, objective and, mainly, adhere to a formal standard or guidelines such as ISO, ASTM, or ASHRAE (Trusty 2000). Figure 3 illustrates the information flow in a SIF-based system. Implicit in putting together a complete set of data are the following steps:

Step 1. Formulating a comprehensive and general ontology to: i) accommodate and classify all informational requirements of the different rating systems; and ii) lend itself readily to computation.

Step 2. Identifying protocols required to carrying out processes for specific performance evaluations.

Step 3. Mapping rating system requirements to elements in a typical BIM, to determine missing capabilities, which will help identify needed and necessary external data.

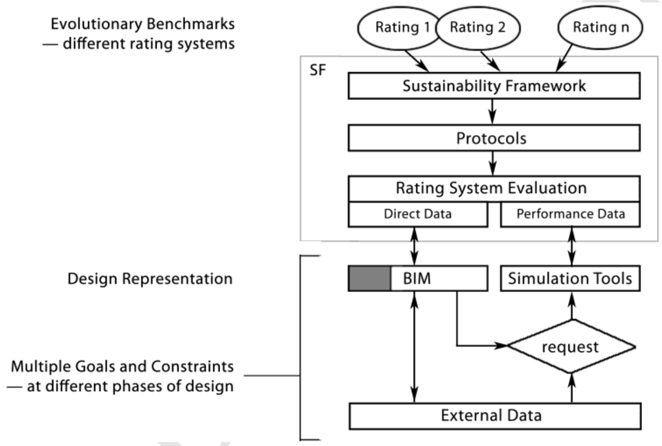


Figure 3. Flow of information in a sustainability information framework based system

At this juncture, it should be noted that in order to integrate rating system evaluations into an actual building information modeling system, automating as much of the process as possible, there has to be access to both direct and performance data. Challenges arise when unwarranted assumptions on data availability are made; as such data related to rating systems are, sometimes, neither accessible nor present in the building model.

In developing the sustainability information framework we aim at creating a structure that can represent information required by any sustainable rating systems. It is created through a list of general measures, which capture rating system requirements. For reasons of flexibility, the framework is developed through schemata representing modular components. A representative list of categories and their subcategories have been developed that cater to the different rating systems. In constructing this framework we concentrated on the requirements in the design phase for new construction of commercial building types. See Figure 4.

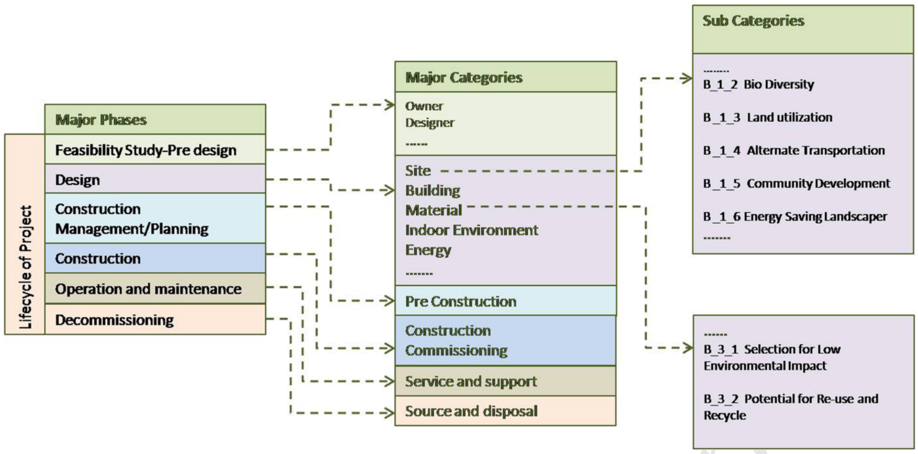


Figure 4. Classification of the building lifecycle addressing phases and transitions

In its own right, the framework can be used as a decision-making matrix, "as seen in existing practice-based method that had been developed to assist a dialogue between design team members and their clients–first setting priorities and targets for sustainability and then assisting later reviews and progress reports" (Gething 2007). The current list of subcategories aims at satisfying the requirements of the different rating systems from a given point in the project's lifecycle. The subcategories are based on the six phases described by Gielingh (1988).

The subcategories comprise elements that are required for assessment by a rating system. The assumption here is that these *'credit elements'* map to *'BIM elements'* in the building information model. As the name implies, credit elements are entities that are required for the evaluation of a rating credit. The term *BIM element* notionally refers to entities (objects or attributes) ordinarily contained in a BIM such as walls, doors, and floors etc., which have attributes such as area, volume and others.

Credit elements may correspond to real BIM objects or their attributes. They may also correspond to quantities derivable by calculation from real BIM objects in which case, we may consider the BIM object to be augmented with additional attributes to specify the BIM element. Credit elements may correspond to entities external to the BIM, but associated with real BIM objects, for example, flow rates of a plumbing fixture element, or the shading diameter of a plant element. Again, we consider the BIM object to be augmented to specify the BIM element. Lastly, the credit element may correspond to an entirely new BIM element or quantity that is not associated with any real BIM entity, for example, occupants with attributes such as occupant number, ground cover with all its attributes such ground cover type e.g., grass, shrub, paved etc.

Thus, in order to integrate requirements of different rating systems with the building information model for automated evaluation the mapping has to establish the required relationship between credit elements and BIM elements. However, not all required BIM elements are found in the building information model. As such there are two possibilities for specifying new BIM elements: adding extensions to existing BIM entities (objects), or defining new elements. This necessitates augmenting the building information model by identifying missing BIM elements with the possibility of accommodating the missing data in external databases. Figure 5 illustrates this mapping between rating system requirement to BIM elements reposited in an external database, which is linked to the add-on application.

The prototype focuses more on how users interact with the evaluation process. As Figure 6 illustrates, there are three required steps before the prototype can actually start evaluating a building project according to the LEED rating system (implicitly, in this case, NC 2.2). The steps are: (i) checking pre-requisite credits; (ii) supplying additional simulation results; and (iii) evaluating credit. The prototype begins to execute the evaluation command only when all pre-requisite credits have been fulfilled, or have been checked by the user. Once this criterion is fulfilled, the prototype can retrieve and store information via a temporary database, and evaluate credits according to the selected standard, which, in the example shown, is LEED. Additional data, if any, such as simulation results, are supplied. Simulation results are calculated by third-party software and saved in a temporary database for retrieval. Results are calculated after the necessary base building information along with all relevant additional information such as simulation results and rating standard have been aggregated. The results are tabulated in the form of a report. See Figure 7.

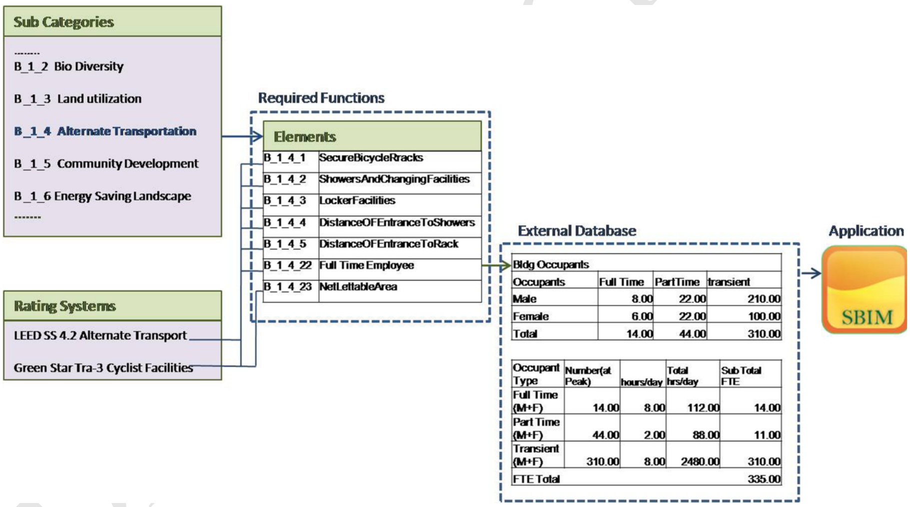


Figure 5. Mapping rating system requirements to elements in a BIM

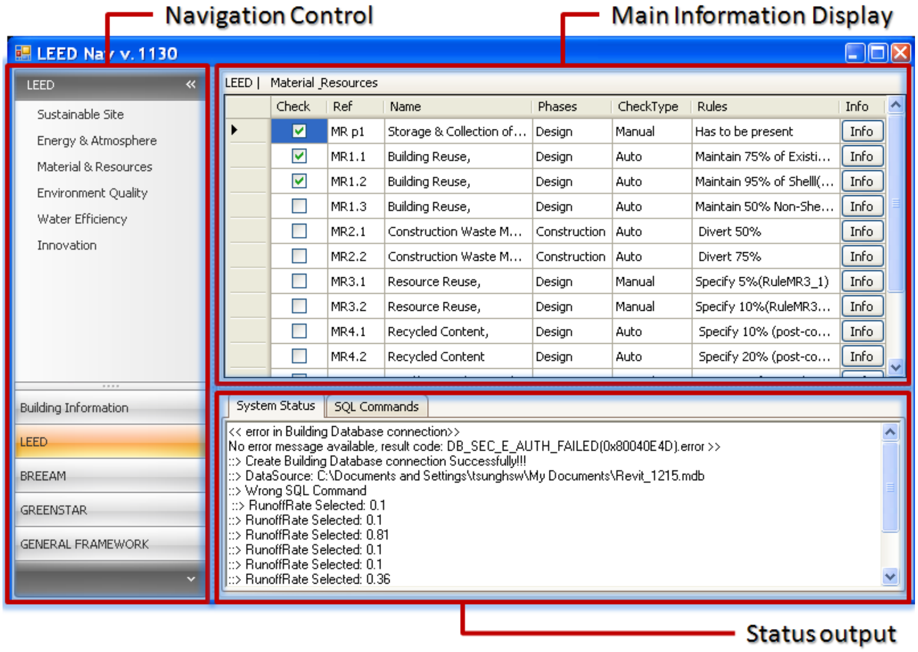


Figure 6. Add-on user interface to the BIM

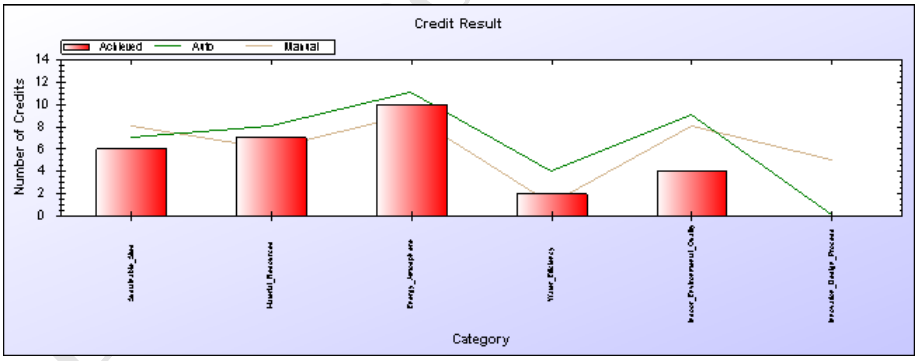


Figure 7. Report shown in graphical format

5 Case Study and Findings

For purposes of validation, we tested the framework on case studies that have been certified by a known rating system. Our first case study is that of a LEED-silver certified two-story office space, 11,000-square-foot structure. It includes a skylight on the second floor for natural lighting and a 25-kilowatt solar cell array on its roof to help power the facility. We compared the actual LEED data from the project with those assisted by the framework and an add-on application on a commercial building information model. We also evaluated the building according to Green Star and Green Globes using information pertinent with the project. This evaluation was done manually, to get an understanding of how the project would measure according to other sustainability rating systems.

The project was modeled from shop drawings using the BIM software. We extracted required objects using the rating system queries to evaluate specific credits or points, in particular, those that were actually achieved by the project, in order to identify elements that are both readily available on query and those not in the model. The case study demonstrates how well the framework holds up when evaluating the building against several rating systems. The framework is stored as a relational database, mapping requirements of the rating system to BIM elements.

Using the current prototype, we begin with BIM elements for which there is readily available information in the BIM—for example, walls, floors, doors, windows, or roofs lend themselves readily to calculation. Evaluations (or credits) pertaining to these BIM elements can provide information on assessing percentage of building and material reuse. Table 4 illustrates some of the results achieved using the prototype for the material and resource category. The two right-most columns represent credits that were actually achieved by the certified project, the first calculated by conventional practice, the second using the prototype. By conventional practice we mean the process currently used by certifying bodies. This process, which may require simulations for evaluations and assessment, is itself neither wholly automated, nor fully integrated with a building information model. Credits that are automatically evaluated by the prototype based solely on the information in the model are shown in green. If we augment the information about the recycled content of materials (this is indicated by the cells colored in yellow), we can compute more credits, which pertain to material qualities not normally considered during the design phase. The prototype is able to automatically compute two additional design credits. In the case, a general model is used; with information on existing non-structural materials such as interior walls, the prototype can calculate more credits.

Table 4: Results achieved using the prototype on both the LEED-certified and General cases (Materials and Resources Category)

Certified Case		**General**	**LEED Category**	**Points**
Practice	Prototype	Prototype	*Material and Resources*	
7	**2**	**4**		**13**
Y		0	Storage & Collection of Recyclables	Required
1	1	1	Building Reuse, Maintain 75% of Existing Shell	1
1	1	1	Building Reuse, Maintain 100% of Shell	1
0	0	1	Building Reuse, Maintain 100% Shell & 50% Non-Shell	1
	0	0	Construction Waste Management, Divert 50%	1

1	0	0	Construction Waste Management, Divert 75%	1
1	0	0	Resource Reuse, Specify 5%	1
…	…	…	…………………………………………	
1	0	1	Certified Wood	1

Achieved

Requires extensions to existing BIM entities

On the other hand, there are certain categories—for instance, the category of sustainable sites—for which it is difficult to extract the BIM elements and their attributes needed for automated calculations as so few are readily available. Even if the object could be easily extracted, the necessary information may not be available. For example, site area is easily obtained; however, for evaluations, we need additional information on site type, vegetation covering the site, etc. Calculations often require user input and external information such as occupant number, surrounding building types and ground cover type, to name a few. Table 5 delineates, according to object availability, credits that are calculable in the design phase in the sustainable sites category of LEED. In addition to the categories of calculable credits shown in Table 4, two more types are highlighted in Table 5: credits that can be calculated were the missing objects available in the model; and credits that rely on results acquired from simulations or by meeting external reference standards such as ASHRAE for HVAC, or IESNA for lighting or local zoning codes.

Table 5. Results achieved using the prototype on both the LEED-certified and General cases (Sustainable Site Category)

Certified Case		**General**	**LEED Category**	**Points**
Practice	Prototype	Prototype	*Sustainable Sites*	
6	**2**	**3**		**14**
Y	–	–	Erosion & Sedimentation Control	Required
1	0	0	Site Selection	1
1	1	1	Development Density	1
0	0	0	Brownfield Redevelopment	1
1	0	0	Alternative Transportation, Public Transportation Access	1
1	1	1	Alternative Transportation, Bicycle Storage & Changing Rooms	1
0	0	0	Alternative Transportation, Alternative Fuel Vehicles	1
1	0	0	Alternative Transportation, Parking Capacity and Carpooling	1
0	0	0	Reduced Site Disturbance, Protect or Restore Open Space	1

0	0	0	Reduced Site Disturbance, Development Footprint	1
0	0	1	Storm water Management, Rate and Quantity	1
0	0	0	Storm water Management, Treatment	1
0	0	0	Landscape & Exterior Design to Reduce Heat Islands, Non-Roof	1
1	0	0	Landscape & Exterior Design to Reduce Heat Islands, Roof	1
0	0	0	Light Pollution Reduction	1

Achieved
Requires extensions to existing BIM entities
New BIM elements
Requires simulation results/reference

Again, the cells are appropriately color-coded for ease of reading. For our certified case study we were able to take the results done for energy simulation, format, collate the values, and provide the user with the energy savings achieved according to LEED standards. The limitations to this approach are that, once there are changes to the building design, these values have to be repopulated and recalculated. Process flows for aggregating performance information, and computing and updating the user are being still being explored.

We were able to compare baseline and designed water usage given that fixtures contain relevant information such as flow rates. The number and type of water fixtures are queried from the model and then mapped to external databases that allow corresponding flow rates to be extracted. Occupant number and harvested rainwater quantities, if available, are also supplemented as external information for providing results on water usage savings. In order to compare quantity of storm water runoff from the site before and after the project is built; the key elements necessary from the model are site area and ground cover for that specific area. At present, these quantities are specified as percentages of the total site; by allocating a ground cover type, the application can supply the remaining information. Barnes and Lacouture (2009) employ a similar approach to integrating BIM with LEED criteria, but their approach is limited to a single rating system (Barnes 2009).

Table 6. Results achieved using the prototype on both the LEED-certified and General cases (Water Efficiency Category)

Certified Case		**General**	**LEED Category**	**Points**
Practice	Prototype	Prototype	*Water Efficiency*	
0	**4**	**4**		**5**
0	0	1	Water Efficient Landscaping, Reduce by 50%	1

0	0	1	Water Efficient Landscaping, No Potable Use or No Irrigation	1
0	0	0	Innovative Wastewater Technologies	1
0	0	1	Water Use Reduction, 20% Reduction	1
0	0	1	Water Use Reduction, 30% Reduction	1

If one looks at the summary of all the credits, one can see that the project achieves a total of 36 credits. The breakdown of the credits potentially achievable by the application is shown in Table 7.

Table 7. Credits achieved using the prototype with multiple rating systems

LEED NC 2.2	Points	Potentially Calculable
Sustainable Sites	14	10
Water Efficiency	5	4
Materials and Resources	13	13
Energy and Atmosphere	17	15
Indoor Environmental Quality	15	6
Innovations	5	1
Percentage	69	(49/69) = 70%

By identifying materials used in the project and mapping them to their embodied carbon content we are able to easily calculate the embodied carbon content of the building. In this analysis, we gave more emphasis on the materials we are able to extract from the project for calculation, conversions being based on research databases for embodied carbon done by Professors Hammond and Jones at the University of Bath (Sustainable Energy Research Team, 2007).

Preliminary tests with the prototype show that we are able to compute for similar credit requirements from two different rating systems; the case study conforms to LEED as the known rating system, and was evaluated by Green Star as a test rating system according to its specifications. Our findings show that as long as there is a mechanism to acquire the different informational needs we can collate information and produce an evaluation based on requirements. As an example, Table 8 summarizes credits from three different rating systems that were computed by the application and achieved by the rating systems.

Table 8. Credits achieved using the prototype with multiple rating systems

LEED 2.2	Green Star	BREEAM
Tra3 Cyclist Facilities	Tra3 Cyclist Facilities	
MR 1.1, MR 1.2 Building Reuse–Structural	Mat2 Building Reuse	Mat3 Reuse of building façade

LEED 2.2	Green Star	BREEAM
MR 1.3 Building Reuse-Interior, non-structural		Mat4 Reuse of structure

The development of the framework is work in progress. Flexibility of the framework is considered by evaluating each building over the different rating systems. These analytical exercises will enable us to find gaps in the framework. We are presently working on a more robust representation for the framework as we push the boundaries of the framework to cater for urban design issues.

Conclusions

The sustainability information framework is in its preliminary stages of development. It is hoped that its modular organization and extensibility will allow for flexibility, to accommodate changes in rating system requirements and the subsequent mapping of BIM elements in the building information model. For future modifications of the sustainability information framework, we plan to include a comprehensive list to enable updating of requirements in the construction and management phases as well.

The research described here is work in progress. The application, which integrates the framework and external databases, is being updated as more databases are constructed. We are also refining the workflows for aggregating, processing or managing relevant sustainability information.

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 outcomes by bringing diverse expertise together. What is second nature to an experienced design team is unattainable to novice designers without sufficient guidance. The sustainability information framework is seen as an attempt to address some of the known factors by providing informed choices towards sustainable design within a software-based design environment.

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