ENABLING SUSTAINABLE DESIGN THROUGH AN INFORMATION FRAMEWORK

Tajin Biswas and Ramesh Krishnamurti

School of Architecture

Carnegie Mellon University
Pittsburgh, PA 15213, USA

ABSTRACT

Services that architects provide are no longer constrained to offering inspiring design solutions to client needs and whims; their services are beginning to spread across domains to ensure that proposed designs are also 'green' and/or 'sustainable'. Indeed, design and delivery of sustainable buildings is gradually gathering momentum, manifest in the way that building performance and functionality are being viewed within an overall ecological context. The ongoing transformation from the traditional to a sustainable building design process is no longer a question of whether to build but rather how (Kibert 2005). Of the many tools available to aid sustainable design, building rating systems offer guidelines and means for comparing and benchmarking buildings performance (Fowler and Rauch 2006). The nature of sustainable building rating systems is such that they are evolving—in this respect this paper describes research that engages this paradigm through the deployment of a sustainable information framework and computational tools.

1 INTRODUCTION

Sustainable or green design in general encourages the parsimonious use of resources—particularly, in the design, construction, and operation of buildings—to minimize harmful environmental impacts. This can be achieved by positing that requirements on sustainability are central to all aspects and processes pertaining to buildings. We are interested in the design aspect. Using a combination of knowledge and proactive steps, designers can ensure desired outcomes through choices for resources, systems, and methods. One way is to produce buildings that fulfill criteria of a sustainable building rating system, for instance, Leadership in Energy and Environmental Design (LEED), or some other similar benchmarking system. This involves a process of evaluation, which is multifaceted and multi-phased, 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.

Design decisions for buildings have environmental consequences; as such, the onus of responsibility of achieving 'green' rests heavily on designer shoulders. Along with an understanding of the more complex building systems and technologies, a designer needs to be facile, capable of orchestrating a wide array of knowledge from many different disciplines into design outcomes that suffice as sustainable. The modern designer almost inevitably works with a computer aided design tool. Yet, such tools do not fully provide, within a single design environment, the capabilities for handling intended sustainable design outcomes. Our current effort directed at integrating a building information model (BIM) with sustainable building rating systems (Biswas et al. 2008) is an attempt at addressing this issue.

We begin by examining the categories of sustainable rating systems, which are currently used to certify buildings. Our investigation captures the requirements of these rating systems, and looks at how changes to them might be handled. These steps serve as the background to this paper, providing the motivation for bringing them as guidelines to assist designers. A general sustainable information framework (SIF) is proposed, which embodies the 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. The vision to integrate sustainable requirements with a BIM, which is still under development, is used to demonstrate the concept. The paper concludes with a discussion of the findings and offers directions towards future work.

2 BACKGROUND

McMinn and Polo (2006) describe shifts in the building process. They quote the technologist Ian McLennan who has declared the shift towards sustainability in all aspects of human activity to be "the fourth wave." This shift follows earlier, equally fundamental, shifts, represented by the agricultural, industrial and information revolutions. 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, 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 2008). Given the magnitude of effects that the building industry has on environmental quality, impacts will only become even more significant as the number of buildings increase. According to Nelson (2004), the built environment may double by the year 2030. The overall impacts that buildings have upon the environment and sustainability thus have become an important and prominent area of for formulating policy goals at different various levels of government.

Although one may argue that energy impacts merit greater attention than other building impact categories, energy alone does not account for all impacts on the environment. What started out, as a short-lived portion of the *Green Building* movement, as a reaction to oil shortages in the 1970s (Krygiel and Nies 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 U.S. Green Building Council (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, mostly through 'Measures of sustainable design and Performance Metrics' (AIA/COTE). As a result of defining standards for measuring and certifying how sustainable a building is, USGBC has developed the Leadership in Energy and Environmental Design (LEED) green building rating system.

Looking at a building from the perspective of a rating system can guide the process of achieving energy efficiency; it can also address actions that ameliorate negative impacts to the environment. One difficulty however, is choosing the appropriate rating system, as these vary from country to county and among regions. Thus, one of the challenges for us is managing the requirements of multiple rating systems, and consequently, accounting for the appropriate system when applied within a design environment— for instance, a design tool such as a building information model (BIM).

Another challenge rests in the fact that 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 also in a state of flux, that is, in transformation; the rapidity with which LEED 2.1 has evolved to LEED 3.0 attests to this. Maintaining currency of rating systems working in conjunction with design environments becomes paramount.

3 A REVIEW OF BUILDING RATING SYSTEMS

Selection of an applicable building rating system is essential when designing a building to meet the sustainability goals set forth by the rating system. For us, this means that the general framework has to accommodate requirements of various and perhaps distinctively different rating systems. A deeper review is essential in understanding the different criteria and calculation methodologies that rating systems require or employ. These have been examined and are used in the development of parameters for the sustainable information framework.

3.1 Sustainable Rating Systems

Fowler (2006) defines a green/sustainable building rating system 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. In the US, a commercial green building is generally considered to be one certified by a sustainable building rating system; for example, Leadership in Energy and Environmental Design (LEED), which was developed by US Green Building Council (USGBC) to establish a common standard of measurement (Yudelson 2008). Claiming to adhere to a standard is not the end of the process; achieving some level of certification demonstrates that the project has fulfilled the requirements set out by the standard.

Although different rating systems have similar categories, these can be quite distinctive in their intent, criteria, emphasis and implementation (Glavinich 2008). The ways in which categories are weighted, scaled and quantified in the various systems 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 and Crawford-Brown 2007). Actual ecological impacts of rating systems have not yet been scrutinized, and nor are they considered in this paper. "However, in spite of their differences and limitations some [rating systems] are being adopted over others due to their relative ease of use and acceptable costs" (Kibert 2005).

3.2 Importance of Rating Systems in the Design Process

According to Berkebile Nelson Immenschuh McDowell Architect, the architectural firm, adoption of "sustainable building rating systems offer a roadmap that lead to sustainability goals and help align requirements" (BNIM 2002).

- Rating systems provide summaries of building performance that can be used to communicate to stakeholders. The methods by which results are depicted have a direct bearing on how the various performance indicators are used and understood, and by whom.
- With increasing adoption, rating systems are seen to motivate innovation; encourage materials and product suppliers to develop new environmentally beneficial products, support services and practice to bring down the costs of these new technologies as they reach economic production scales.
- They provide a vehicle for both public and corporate policy making (Cole et al. 2008).

3.3 Comparison of Rating Systems

Fowler (2006: pp 45-47) examines rating systems with an emphasis on energy reduction, indoor air quality and use of environmentally preferable products, along with other criteria for selecting the rating system to be used by the U.S. General Services Administration (GSA). Table 1 shows some of the general assessment areas by which to categorize the various rating systems.

Table 1: Rating Systems by Assessment Areas
(IEQ: Indoor Environmental Quality)

Assessment Area	**LEED NC 2009**	**Green Star**	**BREEAM**	**SBTool**
1. Management		Management	Management	Economic Aspects
2. Energy and Atmosphere	Energy & Atmosphere	Energy	Energy	Energy & Resource Consumption
3. Emissions to the environment		Emissions	Pollution	Environmental Loadings
4. Sustainable Sites	Sustainable sites	Land use, Transport	Land use, Ecology, Transport	Site Selection
5. Water Efficiency	Water Efficiency	Water	Water	
6. Indoor Air Quality	Indoor Air Quality	IEQ	Health & Well-being	IEQ
7. Quality of Service				Service Quality
8. Materials and Resources	Materials and Resources	Materials	Materials	
9. Innovations	Innovations	Innovations		
10. Culture and Heritage				Cultural & Perceptual Aspects

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 that contribute to a sustainable future (AIA 2008), provided that the rating systems follow certain qualities, one of which ensures that standards are updated on a regular basis. AIA evaluated rating systems according to sixteen broad categories, to give the user a deeper understanding. The rating systems in Table 1 are summarized in Table 2, in terms of four of these AIA categories. Other studies on comparing rating systems (Smith, et al, 2006) aim at finding the content, priorities and processes for adaptation and implementation.

Table 2: Rating Systems by Categories adapted from AIA (2008)
(iiSBE: International Initiative for a Sustainable Built Environment)

Categories	**LEED NC 2009**	**Green Star**	**BREEAM**	**SBTool**
1. 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	Renewed biannually, led by the members of iiSBE

2. Require design documentation	It uses web templates for documentation compliance	Documentation based	Documentary evidence is required for evaluation	Documentation not needed; encourages the completion of an online questionnaire
3. Requires third party validation	Compliance and certification are validated through a third party review system	3rd party verification done by 2-3 certified assessors	Verification by accredited assessors	iiSBE provides a quality audit of a submitted assessment and issues certification.
6. 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	Encourages specific goals for energy reductions by weighting local climate, energy operating costs, and case study models.

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

3.4 Tools for Supporting Sustainable Design

Tools that are available to helping designers make decisions towards sustainable design outcomes are categorized in many ways. The Annex 31 Study (CMHC 2004) describes two broad categories, which define these tools as either *interactive software* or *passive*. Energy and Ventilation Modeling software, and Life Cycle Assessment Tools for Building are categorized as Interactive, whereas Rating Systems, Environmental Guidelines and Checklists for Design and Management of Buildings, Environmental Products and Declarations are in the Passive category. Keysar and Pearce (2007) have identified 275 tools, in 14 categories that are required at some point in the evaluation for sustainable buildings. Furthermore, they show that while there are many tools available, combinations of tools in the form of software, checklists/matrices, publications, websites and databases were used in achieving LEED certifications.

Of the many areas of research into sustainable design, such as cost effectiveness and financial benefits, lifecycle assessment and cost, there has been considerable effort given to green building rating systems (Ahn and Pearce 2007, Kibert 2005). The adaptation of rating systems during design is becoming part of practice. As previously mentioned, BNIM architects have been using a sustainability matrix (BNIM 2002) that incorporates rating systems in the early design phase as a guide towards achieving sustainability goals. In addition to rating systems as guides they also leverage the potential of building information models as a way to start managing information pertaining to sustainability. "The building information modeling process is by its very nature sustainable" (Jernigan 2007). As an inherently sustainable process BIM offers many advantages over traditional processes. BIM facilitates model change and propagation via parametric object oriented representations; in it, we see an ideal place for integrating sustainable building ratings. In this paper, we consider a typical commercial building information model from a software vendor, namely, Revit™. However, our findings apply, in principle, equally to other commercial BIMs from other software vendors.

4 PROBLEM STATEMENT AND APPROACH

Based on the current state of decision support tools for arriving at sustainable building solutions, we have delineated the following problems related to designing and ultimately satisfying qualities for a building to be deemed sustainable:

- Sustainable design requires information about sustainability from conception of design through to the whole lifecycle of the project; currently, information is fragmented across domains, not readily available to offer guidance to a designer or be accessible within a software-based design environment.
- In adopting a rating system as a road map to sustainability, it is important to note that currently there is no comprehensive way of managing changing rating system requirements, nor a way to inform designers.
- A building information model structure acts as a data container to hold project information and also provides placeholders for handling data not yet available in the model. However, current BIMs contain insufficient data to

handle all aspects of a rating system and require additional external data to be accommodated in a cohesive manner. Such external data might be electronically and geographically distributed, may need to be salvaged, and/or certified.

Our approach to this problem comprises three steps: i) development of a sustainable information framework, ii) integration of the framework with a building information model and iii) validation of the results through case studies.

5 METHODOLOGY

The objective of a sustainable information framework (SIF) is, informally, to accommodate rating system changes and designer needs, and formally, to provide 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.

In a broad sense, a framework is a "conceptual structure used to solve or address complex issues" (WIKI 2008). In sustainable design it is seen and used mainly in the form of matrices (Gething and Bordass 2006, Hassan 2008, Weerasinghe et al. 2007). In this paper, characteristics associated with a framework will be used more specifically as a structure to map rating system requirements to their comprising elements; identify processes involved; detect missing information and manage changes in rating systems in a cohesive fashion.

The large volume of 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, tools such as ATHENA, EnergyPlus and Radiance are typically required to generate the necessary performance data. These tools are uniformly data oriented, objective and, mostly, adhere to formal standards and guidelines such as ISO, ASTM, or ASHRAE (Trusty 2000).

Figure 1 gives the system architecture illustrating the information flow in a SIF-based system. Implicit in putting together a complete set of data are the following steps:

1. Formulating a comprehensive and general ontology that can: a) accommodate and classify all informational requirements of the different rating systems; and b) lend itself readily to computation.
2. Identifying protocols required for carrying out specific processes for such evaluation.
3. Mapping rating system requirements to elements in a typical BIM, to find missing capabilities in the BIM, which will help identify the necessary external data that are needed.

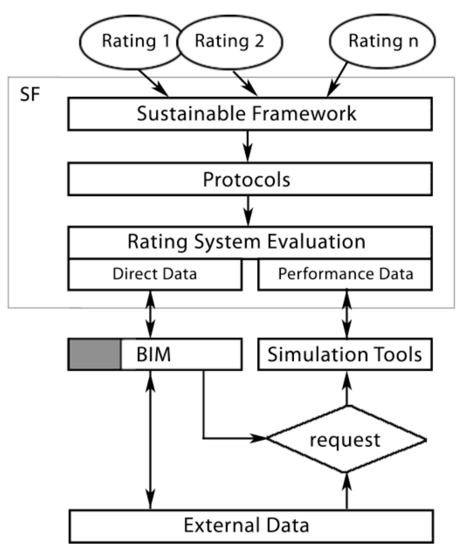

Figure 1: Flow of information in a sustainable information framework based system

At this juncture, it should be noted that in order to integrate rating system evaluations into an actual building information modeling system with possibly automating much of the process, there needs 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.

5.1 Sustainable Information Framework

Development of a sustainable information framework is created through a list of general measures, which captures the categories and subcategories of sustainable rating systems. For reasons of flexibility, the SIF is developed through schemata that represent modular components. A representative list of categories and consequently subcategories have been developed through investigations of the different rating systems, mainly, for new construction, commercial building types focusing on requirements in the design phase. See Figures 2 and 3.

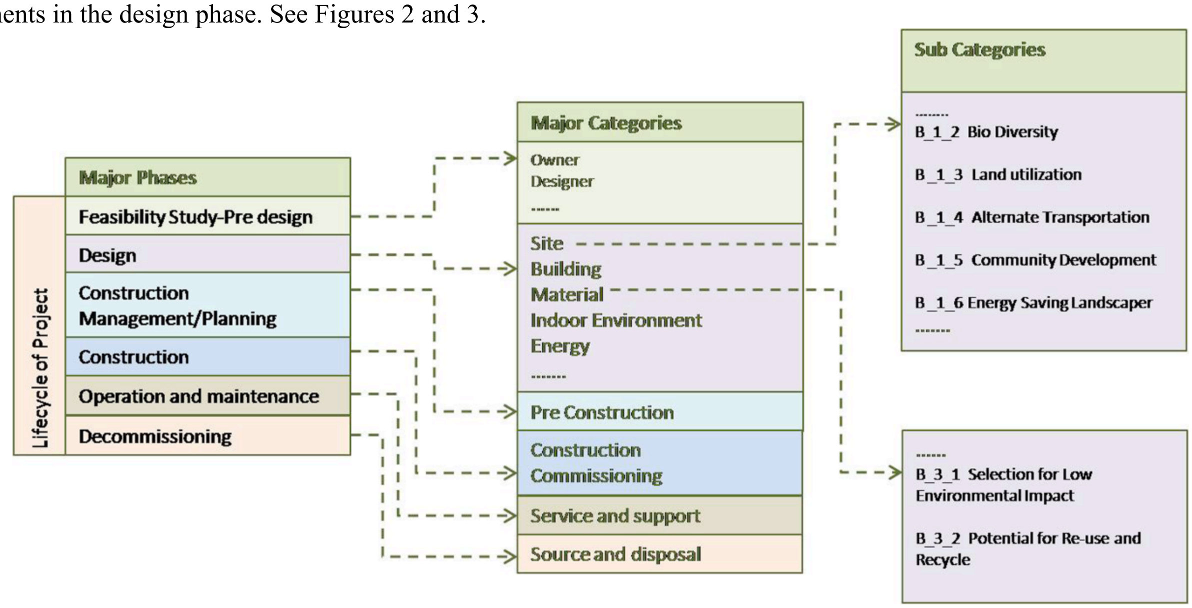

Figure 2: Classification of the building lifecycle addressing phases and transitions

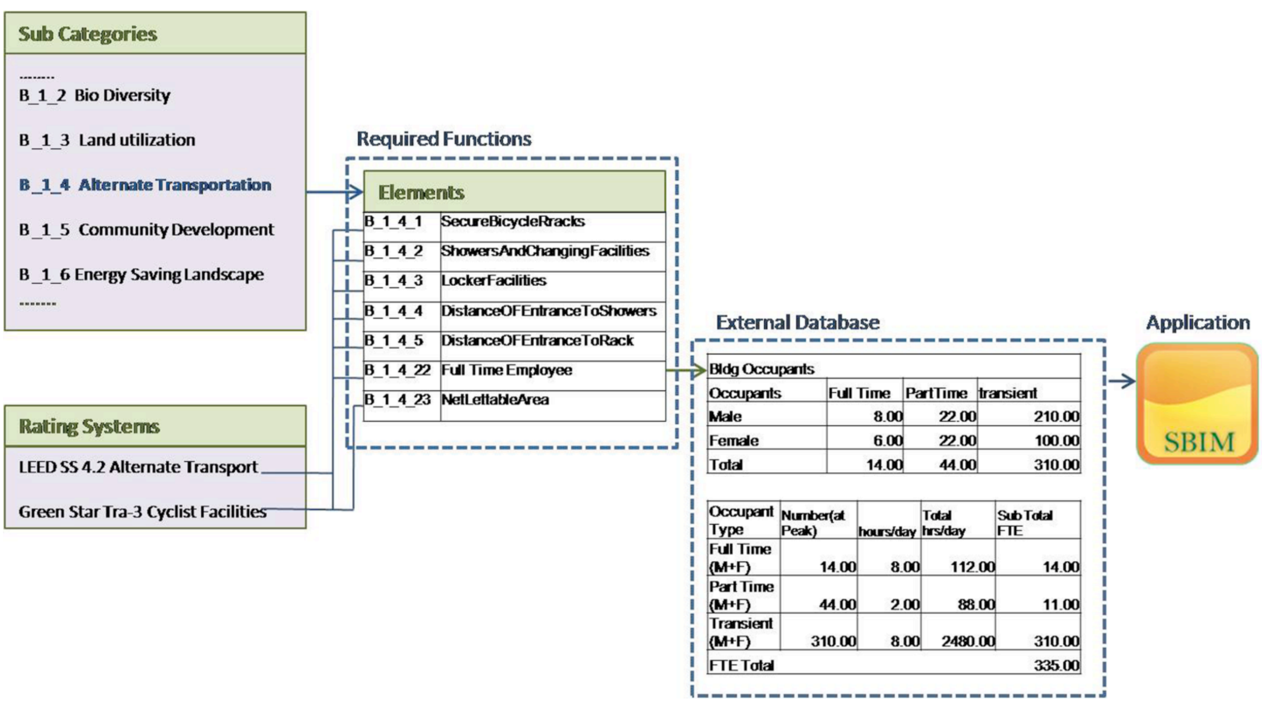

Figure 3: Mapping Rating System requirements to Elements in a BIM

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 the a given point in the project’s lifecycle, adapted from the six main phases described by Gielingh (1988).

The subcategories are comprised of elements that are required for assessment by a rating system. The assumption is that these elements eventually map to objects in a BIM. In order to integrate the requirements of different rating systems and a BIM, mapping is required to establish the required elements/objects for automated evaluation. From past experience, not all required objects are found in the BIM. This necessitates identifying missing BIM objects with the possibility of accommodating data in external databases.

6 CASE STUDY AND FINDINGS

For purposes of validation, we test 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, 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 calculated by the framework. We also evaluated the building according to CASBEE, Green Star and Green Globes.

The project was remodeled in the BIM software from shop drawings. We extracted required objects using the rating system queries to evaluate specific credits or points, particularly those actually achieved by the project, in order to identify elements that are readily available on query and also those not present in the model. The case study begins to demonstrate how well the framework holds up when evaluating the building against several rating systems.

Using the current prototype, we began with those objects for which information was readily available in the BIM. For example, walls, floors, doors, windows and roofs lend themselves readily to computation, thus credits or evaluation pertaining to these objects can provide information in calculating percentage of building and/or material reuse. Table 3 illustrates some of the results achieved using the prototype for the material and resource category. The right-most column represents credits that were actually achieved by the project. Credits that are automatically calculated by the prototype from information solely in the model are shown in green. By augmenting information about the recycled content of materials (indicated by the cells in yellow), we can compute more credits, which pertain to material not normally considered during the design phase. The prototype is able to automatically compute two other design credits. In the case where a general model is used, with information on existing non-structural material such as interior walls, the prototype can calculate further credits.

Table 3: Results achieved using prototype on the LEED certified Case and General Case
(Materials and Resources Category)

Certified Case		**General Case**			
Traditional	Prototype	Prototype			
(Achieved)	Auto	Present			
7	**2**	**4**	**Material**		13 Points
Y		0	Prereq 1	Storage & Collection of Recyclables	Required
1	1	1	Credit 1.1	Building Reuse, Maintain 75% of Existing Shell	1
	0	1	Credit 1.2	Building Reuse, Maintain 100% of Shell	1
	0	1	Credit 1.3	Building Reuse, Maintain 100% Shell & 50% Non-Shell	1
1	0	0	Credit 2.1	Construction Waste Management, Divert 50%	1
1	0	0	Credit 2.2	Construction Waste Management, Divert 75%	1
0		0	Credit 3.1	Resource Reuse, Specify 5%	1
		…	…………	……………………………………………	…
1	1	1	Credit 7	Certified Wood	1

Achieved

Requires extension of objects

In the category on sustainable sites, however, it is more difficult to extract the objects needed for automated calculations, as few are readily available. Even if the object can be easily extracted, necessary information may not be available. For instance, site area can be easily obtained, but this requires information such as site type, vegetation covering the site, and so on. Calculations often require user input and external information such as occupant number, surrounding building types and ground cover type, to name a few. Table 4 delineates, according to object availability, credits that were computable in the design phase. In addition to categories of calculable credits shown in Table 3, Table 4 highlights two more types: credits that could be calculated if missing objects were available in the model, and credits that rely on results acquired from simulations or meeting external reference requirements. 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, 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 explored.

Table 4: Results achieved using prototype on the LEED certified Case and General Case (Site Category)

Certified Case		**General Case**			
Traditional	Prototype	Prototype			
(Achieved)	Auto	Present			
6	**2**	**3**	**Site**		14 Points
Y			Prereq 1	Erosion & Sedimentation Control	Required
1	0	0	Credit 1	Site Selection	1
1	1	1	Credit 2	Development Density	1
0	0	0	Credit 3	Brownfield Redevelopment	1
1	0	0	Credit 4.1	Alternative Transportation, Public Transportation Access	1
1	1	1	Credit 4.2	Alternative Transportation, Bicycle Storage & Changing Rooms	1
0	0	0	Credit 4.3	Alternative Transportation, Alternative Fuel Vehicles	1
1	0	0	Credit 4.4	Alternative Transportation, Parking Capacity and Carpooling	1
0	0	0	Credit 5.1	Reduced Site Disturbance, Protect or Restore Open Space	1
0		0	Credit 5.2	Reduced Site Disturbance, Development Footprint	1
0	0	1	Credit 6.1	Storm water Management, Rate and Quantity	1
0	0	0	Credit 6.2	Storm water Management, Treatment	1
0	0	0	Credit 7.1	Landscape & Exterior Design to Reduce Heat Islands, Non-Roof	1
1	0	0	Credit 7.2	Landscape & Exterior Design to Reduce Heat Islands, Roof	1
0	0	0	Credit 8	Light Pollution Reduction	1

Achieved
Requires extension of objects
Missing object
Requires simulation results/ref

We are 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 this is specified by the user as percentages of the total site, and by allocating a ground cover type, the remaining information is provided by the application.

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 (Hammond and Jones 2008).

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. For example, Table 5 summarizes the credits from three different rating systems that were achieved.

Table 5: Credits achieved using the prototype with multiple rating systems

LEED 2.2	Green Star	BREEAM
SS4.2 Alternate Transportation	Tra3 Cyclist Facilities	Tra3 Cyclist Facilities
MR 1.1, MR 1.2 Building Reuse –Structural	Mat2 Building Reuse	Mat3 Reuse of building façade
MR 1.3 Building Reuse-interior, non structural		Mat4 Reuse of structure
WE1.1	Wat-3	

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.

7 CONCLUSIONS

The sustainable information framework is in its preliminary 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. For future modifications of the SIF, we plan to include a comprehensive list to enable updating of requirements in the construction and management phases as well.

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 a team is unattainable to novice designers 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 within a software-based design environment.

ACKNOWLEDGEMENTS

The authors are part of an endeavour that aims at bringing sustainable design a step closer to designers. Financial support for the research presented in this paper comes from Autodesk®. However, any opinions, findings, conclusions or recommendations presented in this paper are those of the authors and do not necessarily reflect the views of Autodesk®. We are thankful for the support from our colleagues in Building Performance and Diagnostics in the School of Architecture.

REFERENCES

Ahn, Y. H., and A. R. Pearce. 2007. Green Construction: Contractor Experiences, Expectations, and Perceptions. *Journal of Green Building*, 2(3): 106-122.

AIA. 2008. Quantifying Sustainability. <http://www.aia.org/SiteObjects/files/Quantifying%20Sustainability.pdf> [accessed February 19, 2009]

Biswas, T., T.-H.Wang, and R. Krishnamurti. 2008. Integrating sustainable building rating systems with building information models. In *CAADRIA 2008*, ed. W. Nakapan, E. Mahaek, K. Teeraparbwong, and P. Nilkaew. 193-200. Chiang-Mai, Thailand: Pimniyom Press.

BNIM. 2002. Packard Matrix. <http://www.bnim.com/newsite/pdfs/2002-matrix.pdf> [accessed month August 15, 2008]

CMHC. 2004. Type of Tools, Annex31 Energy-Related Environmental Impact of Building. <http://www.greenbuilding.ca/annex31/pdf/D_types_tools.pdf> [accessed May 24, 2009]

Cole R. H., T. Ikaga, and S. Nibel. 2008. Building Environment Assessment Tools: Current and Future Roles. <http://www.sb05.com/academic/4&5_IssuePaper.pdf> [accessed month May 24, 2009]

Fowler K. M., and E. M. Rauch. 2006. Sustainable Building Rating Systems Summary. Technical report no. PNNL-15858, Pacific Northwest National Laboratory/Batelle, Richland, WA. July 2006.

Gething, B., and B. Bordass. 2006. Rapid Assessment Checklist for Sustainable Buildings. <http://www.informaworld.com/smpp/content~db=all~content=a749269529~tab=content> [accessed May 30, 2009]

Glavinich, T. E. 2008. *Contractor's Guide Green Building Construction*. Hoboken, NJ: John Wiley & Sons.

Hammond, G., and C. Jones. 2008. Inventory of Carbon & Energy (ICE) version 1.5 Beta. Department of Mechanical Engineering, University of Bath, UK.

Hassan, M. M. 2008. SDFlex: A framework for the Assessment and Construction of Sustainable Flexible Pavements. *Journal of Green Building*, 3(3): 108-118.

Jernigan, F. 2007. *BIG BIM little bim*. Salisbury, MD: 4SitePress.

Kibert, C. J. 2005. *Sustainable Construction Green Building Design Delivery*. Hoboken, NJ: John Wiley & Sons.

Krygiel, E., and B. Nies. 2008. *Green BIM Successful Sustainable Design with Building Information Modeling*. Indianapolis, IN: Wiley Publishing.

Orr, D. W. 2006. *Design on the Edge, The making os a High-Performance Building*. Cambridge, MA: MIT Press.

Trusty, W. B. 2000. Introducing an assessment tool classification system. <http://www.athenasmi.ca/publications/docs/AssessTypologyTool.pdf> [accessed July 20, 2008]

USGBC. 2008. LEED initiatives in Government and Schools. <http://www.usgbc.org/DisplayPage.aspx?CMSPageID=1852> [accessed May 24, 2009]

Wedding, G. C., and D. Crawford-Brown. 2007. An analysis of variation in the energy related environmental impacts of LEED certified buildings. *Journal of Green Building*, 2:151-170.

Weerasinghe, G. K. S., J. Ruwanpura, and M. Horman. 2007. LEED-PDRI Framework for Pre-Project Planning of Sustainable Building Projects. *Journal of Green Building*, 2:123-143.

Williams, D. E. 2007. *Sustainable Design: Ecology, Architecture and Planning*. Hoboken, NJ: John Wiley & Sons.

Yudelson, J. 2008. *Marketing Green Building Services Strategies for Success*. Oxford, UK: Elsevier.