Data Sharing for Sustainable Building Assessment

Tajin Biswas and Ramesh Krishnamurti

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Abstract

Sustainable design assessment requires information, which is aggregated from different phases of a building design, and evaluated according to criteria specified in a 'sustainable building rating system.' In the architecture engineering and construction (AEC) domain much of the necessary information is available through open source data standards such as Industry Foundation Classes (IFC). However, no single standard that provides support for sustainability assessment completely suffices as a data structure. This paper explores the augmentation of the Construction Operations Building information exchange (COBie) model, as an intermediary data structure, to bridge between requirements of the Leadership in Energy and Environmental Design (LEED) rating system and a building information model. Development of a general framework for data sharing and information management for LEED assessments is illustrated through an implementation of a prototype using functional databases. The prototype checks and augments available data as needed, which is used to populate LEED submission templates.

1. INTRODUCTION

There is increasing interest in green or sustainable architecture; in the building industry sustainable design is addressed by reference to a sustainability rating system, or more generally, a sustainable building assessment standard [1]. There are a number of different sustainability rating systems worldwide, each of which share a common notion, namely, that of a tool which examines the (expected) performance of a 'whole building,' translating this into an assessment scheme for comparison with other buildings [2]. Achieving some sustainable design goal, for example, an energy performance target or some other rating system specific target, requires a change in approach than has been customarily applied [3]. Integration is key to sustainable architecture, and this implies a shift from the modern western pursuit of reductionism to a more holistic view of interrelatedness throughout the design process [4]. Project information needs to be integrated, shared and managed between team members. In this respect, building information modeling offers "rich information in the models that help project team gain insight." [5]

According to Smith and Edgar,

> "A Building Information Model (Model) is a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward." [6]

However, a building information model (BIM) is more than a source of building geometry. A key attribute of a BIM lies in its ability to enable interoperability between applications and databases; however, the semantics inherent in any underlying taxonomy and ontology are not unambiguous [7]. In addition to identifying interoperability issues, it is necessary to identify the appropriate level and type of information for simulations, or other kinds of evaluation that are pertinent to assessing sustainable design [8]. As Krygiel and Bradley posit:

> "One tool cannot be all things—the primary and most obvious need to achieve better sustainable solutions with BIM is better interoperability between software packages. Analysis packages already exist for things like costs, labor, energy, comfort, daylight, and life cycle analysis, with more likely to come. The ability to move the building geometry and necessary ancillary data from the BIM model to an analysis package is critical." [9]

In general, processes employ some kind of information exchange format between model and analysis tool, some of which can assist in software interoperability. This paper addresses issues in data sharing pertaining to sustainability assessment according to requirements of a sustainable building rating system using a lightweight building information model. The paper has four parts. First, sustainable building rating systems and their assessment

methods are introduced in the context of this paper; second, BIM, interoperability and data sharing for sustainable assessment are discussed; third, the development of a prototype using a lightweight BIM and rating requirements for sustainable assessment is demonstrated through a case study of a green building; lastly, the outcomes of the research are summarized.

2. SUSTAINABILITY ASSESSMENT STANDARDS

Green building evaluation is a multi-person multi-phase process [10]. Sharing building design information among the different building domains and professionals is thus essential. Current processes for sustainable building evaluation are highly disparate. Even with the use of modern computer-aided design (CAD) tools, these processes require a substantial amount of human intervention and interpretation—thereby, making assessments of sustainability both costly and time consuming [11].

Moreover, there is a number of different sustainable building assessment systems used worldwide. In their study, Fowler and Rauch [2] combine several of these assessment systems into a list. Their list subsumes rating systems that are derivable from other rating systems. Two main assessments standards, BREEAM and LEED, are briefly discussed.

BREEAM

The Building Research Establishment (BRE) was the first to develop an environmental impact assessment method, BREEAM, Building Research Establishment's Environmental Assessment Method [12]. Subsequently, other countries adopted the BRE approach in developing their own assessment method [13]. BREEAM has become the de facto measure of building environmental performance in Europe [12]. There are versions specific to the United Kingdom; versions that are tailored to other countries or regions address specific environmental issues and weightings, construction methods and materials, or referencing local standards. In assessing a building, points are awarded for each criterion, which are then summed to give a total score. The overall building performance is awarded a 'Pass', 'Good', 'Very Good' or 'Excellent' rating based on the score. BREEAM specifies the following categories of criteria for assessing design and procurement: Management, Health and Wellbeing, Energy, Transport, Water, Materials, Land use, Ecology and Pollution.

LEED

In 2000, the United States Green Building Council (USGBC) established benchmarks for the Leadership in Energy and Environmental Design (LEED) Green Building Rating System [14]. The current version of the rating system is LEED 2009. LEED is a framework for assessing building performance and

meeting sustainability goals. LEED rating systems apply to new construction, existing buildings, commercial interiors, core and shell, schools, retail, homes and health care, and a pilot system for neighborhood developments. In general, each LEED rating system takes an integrated design approach subsuming seven areas of assessing performance: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, Indoor Environmental Air Quality, Innovations in Design and Regional Priority, each addressing specific environmental concerns [15]. There are additional credit categories for LEED for homes and LEED for neighborhood developments. Within each category there are specific design goals that have to be met for a particular LEED certification, namely, in increasing order, certified, silver, gold or platinum. LEED certification requires "greener elements" for higher levels of green building certification. A building is awarded points based on the number of goals it meets. Each goal is worth a point, and final certification is based on the evaluation of goals documented. According to a report on green standards, higher levels of certification include an array of features ranging from storm water retention through landscaping, innovative wastewater technologies, reflective roofs, energy generating sources, personal comfort controls, certified woods, low-emitting materials, and advanced monitoring systems [16]. Although LEED certification is voluntary, it is mandated (or under consideration as a requirement) for certain buildings in many U.S. localities.

In general, every sustainable building rating system including the two discussed above helps to objectively align project goals to sustainability requirements. Whether the goal is meeting minimum criteria for certification, or the pursuit of making a positive contribution to the environment, there have to be standards that can be referenced for comparison. The different rating systems may (or may appear to) relate similar categories of assessment, although they can vary, perhaps even radically, in intent, criteria, emphasis and implementation [17]. The manner and means by which the assessment categories are weighted, scaled and quantified in the various systems differ; as such, a building may have two different ratings when judged according to two different rating systems. It is important to note that the relative ecological impact of rating systems have not been scrutinized, and it is not within the scope of this paper to do so.

2.1. Assessment methods

The various professionals in the rapidly evolving field of building environmental research and practice each have their own agenda and requirements. This inevitably creates different expectations of any assessment tool. By evaluating similarities and differences between sustainable design practices, guidelines and practices for better sustainable design can be developed and universally applied [18]. In addressing a general process of sustainable design and assessments, there are certain

important aspects to note — information for sustainability assessment is gathered and accumulated from pre-design through building occupancy [19.] This is because projects have to register early in the design process to document project performance [8]. Throughout the process, teams of professionals require access to specific kinds of project information for different purposes. For example, site boundary and area information is required by an engineer to assess storm water management; the same information is required by a designer to assess site density and connectivity. The challenges in making specific project information available to interested parties reside in managing information in a suitable format. Additionally, for sustainability assessment, rating systems have criteria, which are evaluated by both quantitative and qualitative measures.

Quantitative measures

Quantitative measures typically reflect numerical values, for instance, annual energy use, water consumption, greenhouse gas emissions, volume of reused material and so on. Although this seems straightforward, in reality, quantitative measures may involve semantic transformations, which entail subjective or human judgment. A simple example is the notion of 'floor area'. In different building information models this quantity might be named 'NetFloorArea', 'NetArea' or 'GSA BIM Area'— and they all refer to the same 'floor area.' Likewise, throughout the AEC domain there are numerous interpretations of the same building element involved in data exchange. Some of the semantic confusion can be avoided if information is stored in a standardized building information model.

Qualitative measures

Qualitative measures employ comparable measurements such as impact on ecological values; such measures may also rely on user testimony, for example, whether certain procedures have been followed, or whether specific documents are available in support of a practice. Qualitative criteria of assessments are generally difficult to encode as they are subject to evaluation from unbiased third parties [6]. It takes time and effort to input data, which varies in interpretation by the different professionals [20]. However, an assessment criterion requiring qualitative measures can be evaluated whenever the relevant information is available in the building information model in an appropriate interpretable format.

3. BIM AND INTEROPERABILITY

Typically, in the AEC domain, where possible, information is made available through open source data standards: for example, IFC (Industry Foundation Classes); ISO standards; XML standards, for instance, IFCXML and gbXML; or BIM templates [21]. An important pragmatic consideration in any

consideration of data exchange format is the prevalence of adoption and implementation by stakeholders in the building industry. For instance, major commercial architectural CAD software vendors such as Autodesk®, Bentley®, Graphisoft®, and Vectorworks® all provide implementations of both IFC and gbXML models. However, no single standard that provides support for sustainability assessment completely suffices as a data structure. According to Huang,

 "There are significant differences between the IFC and gbXML schemas, including comprehensiveness, efficiency, robustness, redundancies, and portability. In terms of comprehensiveness, both formats are not yet able to represent all information across all building performance domains." [22]

Both formats are however extensible and can potentially represent information for sustainability assessment (although gbXML was originally developed to capture information for energy analysis).

There are ongoing efforts in a variety of domains in extending both schemas to represent more information [22]. According to buildingSMART BIM standards will integrate standards used in the AEC industry [23]. 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 placeholders to handle all aspects of a rating system and additionally, require external data to be accommodated in a cohesive manner. Hence, there is a need to support designers by providing a framework for sustainability assessment, which enables a more efficient way to manage and design for sustainability. Figure 1 shows a typical data exchange situation involving only IFC files between the source application, typically, a CAD or BIM software, and the receiving application, typically, a building performance simulation or analysis software such as energy audit, rain water runoff, CFD etc.

▶ Figure 1. Current data exchange from software to another via IFC translation (Adapted from Eastman et al [21]: Figure 3-3)
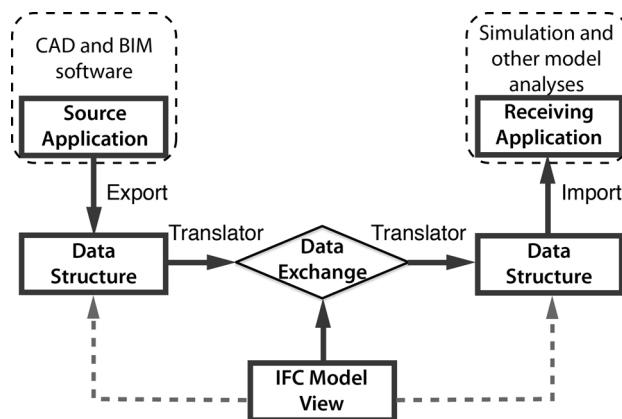
The IFC data model is an extensible framework to describe a large set of consistent building and construction industry data [21]. IFC specifies an EXPRESS [24] based entity relationship model comprising a large number of entities into an object-oriented hierarchy. There are commercial software, which provide BIM solutions, and which employ their own proprietary data structures for representing a building and other design information (containing graphical and non-graphical information).

In practice, IFC has many different implementations; as such, even with good IFC import/export translators, it can prove challenging for BIM tools to exchange useful data. Bimsrver.org provides a set of open source IFC tools [25], and among CAD software vendors, Autodesk® has recently released an open source IFC exporter for Revit® to provide greater flexibility with Revit IFC output [26]. For this reason IFC translations from source applications have to be, perhaps, incrementally enhanced, where such enhancements need to be carefully considered when used by exchanging applications. For example, there are viewers for IFC model geometry and property, which display attributes of selected objects and provide means to view data in different sets of entities [21]. Despite variations in object representation efforts are being made to define IFC uniformly and more precisely. IFC models are non-proprietary; as such they are attractive, and increasingly being adopted by governments and agencies [21]. Figure 2 illustrates the additional information requirements imposed on the BIM model shown in Figure 1 for purposes of facilities management and sustainability assessment. The figure clearly illustrates that an IFC model typically does not contain information sufficient either for sustainability assessment, or to support facility operation and management.
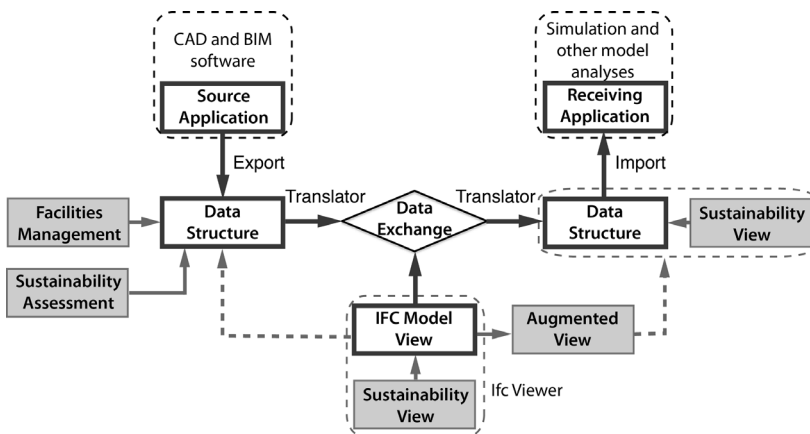
◄ Figure 2. Extended Data Exchange from software to another via IFC translation

To share design information and sustainability related information from a software tool, it is essential to have a data structure that can integrate necessary building information and evaluation requirements. To this end

COBie, the Construction Operations Building Information Exchange [27] is explored as a suitable data structure for lightweight building model information exchange to support sustainability assessment.

3.1. COBie as a data structure

COBie, is primarily intended for the use of managed assets [27]. In the COBie data structure, information is cumulatively supplied during the design, construction, commissioning and handover phases of a building. Information includes lists of rooms and area measurements, material and product schedules, construction submittal requirements, construction submittals, equipment lists, warranty guarantors, and replacement part providers, which are normally included in several different places within current contracts. The objective behind the development of COBie is not to specify an alternative model for information that is required for building management, rather, instead, to provide a standard format for common information that can be derived from a building model, in the process, saving building owners and occupants having to rekey information multiple times.

COBie is based on the Industry Foundation Class (IFC) model. COBie information can be found in one of three formats: IFC STEP Physical File Format (IFC SPFF), ifcXML or SpreadsheetML [27]. COBie adopts a spreadsheet format because this offers a structure that can be easily used, extended and augmented, in particular to work with a functional database prototype. In this paper the data structure is referred to as 'COBie Plus', which is a COBie model that has been modified by augmented information needed for sustainability assessment. Figure 3 illustrates the COBie and COBie+ data models. The left side illustrates how building information is provided in COBie. The right side indicates the augmentation required by sustainability assessment, in particular, the LEED sustainable building rating criteria.

► Figure 3. From COBie to COBie+:
Illustrating the augmentation of COBie for LEED
(Source for the left side: East [27: Figure 5])
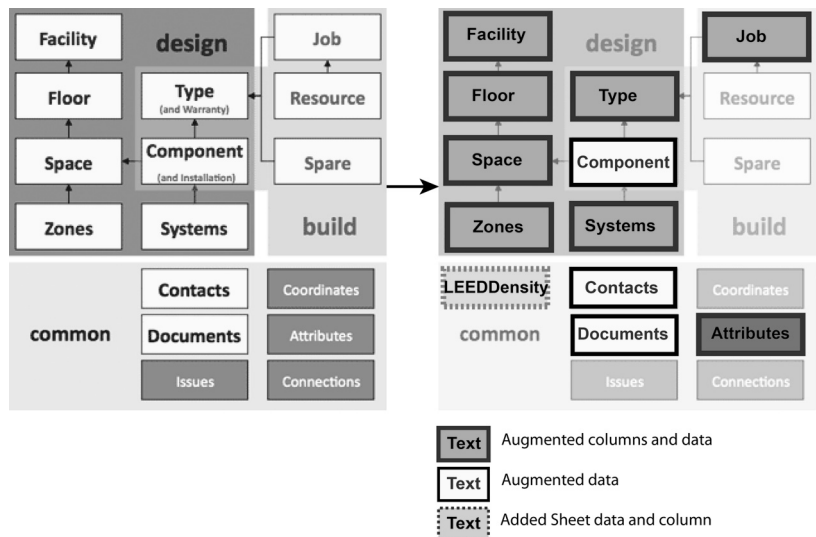
COBie data starts with a listing of *facilities* (i.e. buildings or projects), each of which have *floors*, which within each are *spaces*, typically rooms in the interior and functional spaces in the exterior, such as "parking lot" or "patio seating." Each instance in a *space* also belongs to a *zone*. For spaces to perform as intended specific *systems* are made up of *components*. The *types* of systems include: electrical, heating, ventilating and air conditioning (HVAC), potable water, wastewater, fire protection, intrusion detection and alarms and other systems. Components and types are specified during design, installation or build. *Attribute* contains additional parameters of objects in other sheets *(facility, space, type, component etc)*. All the above-mentioned sheets are generally used from early design to detail design phases. *Document* is used through out the design process. *Spare*, *Resource* and *Job* are for operation and maintenance.

The COBie data model is represented as a spreadsheet with each element considered as a sheet. For COBie+, a new sheet, LEEDDensity, is added to the database. Sheets named Attributes, Facility, Type, Space, Systems, and Job have added columns with new fields and rows of additional data. Sheets Floor, Contacts, Component and Documents retain their original columns but have rows with additional data. For example in the Contacts sheet, LEED assessment needs the name of the 'Architect', 'Civil Engineer', 'Contractor', 'Commissioning Agent' in order to fulfill credit evaluation. In this case it is necessary for the user to be aware that this particular element is queried, and therefore requires it to be filled with appropriate information.

4. FROM BIM TO ASSESSMENT

Recent research using commercial BIM software and LEED requirements have demonstrated the feasibility of semi-automated evaluation [11, 28, 29]. In each study, information for sustainability evaluation was added, either by providing external databases, or by augmenting the model using the capability of the software to store additional information.

Figure 4 shows the process, employed in this paper, of information exchange from an IFC building information model to a COBie+ data structure, which is employed to fill LEED evaluation templates. The source application is ideally a commercial CAD or BIM software that exports a model to IFC, which is then converted to a COBie data structure via data exchange software. According to East,

> "COBie data is created by designers and expanded by contractors using a variety of software solutions." [27]

The COBie data structure is extended to accommodate LEED requirements as per the right hand side of Figure 3. There are three types of data: 'direct data' is COBie data that can be retrieved without manipulation; 'direct w aggregation' indicates data that is to be aggregated from multiple COBie sheets and may need to be processed prior to being used in evaluating the

rules. Augmented data, likewise simulation data, are such that these need to be added to the model; in some cases, users can modify default values. The COBie+ data model is assessed according to the rules, and LEED templates are accordingly filled with available information. At any stage in a project, as project information changes, users can update the COBie + model and generate new or updated LEED submission templates.
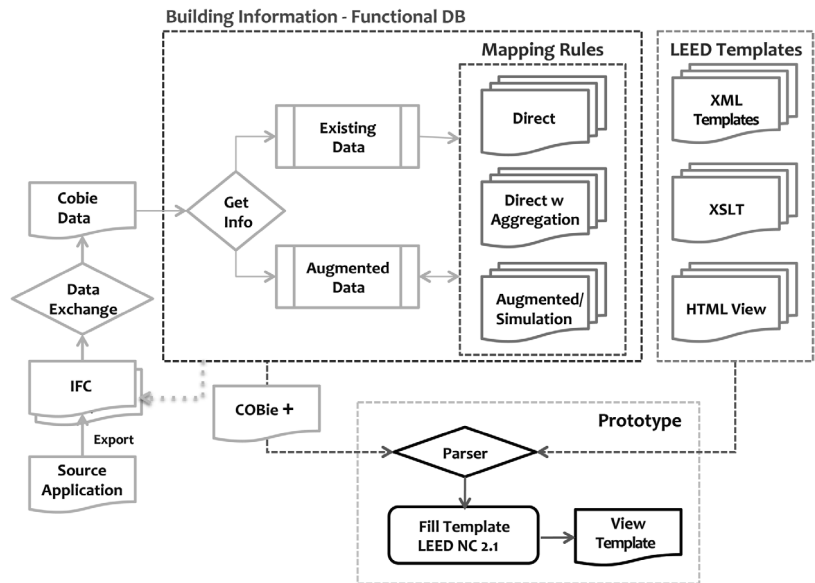
LEED requirements are periodically revised and updated [30]. For this reason, LEED requirements are stored in a database as a set of executable rules, which can be interpreted for real-time assessment. Providing this functionality to an otherwise static database allows the application to potentially and more readily accommodate future rating requirement updates. It enables multi-disciplinary cooperation from sustainable assessment rule mapping to corresponding building data (and vice versa). The output generates LEED submittals in XML format, which contain aggregated results ready for evaluation. This demonstrates a process where design information can be embedded and retrieved by different software and professionals—from design to sustainable assessment. In the sequel, we compare the submission templates for LEED 2.1 and LEED 2009.

4.1. Functional database approach

A LEED NC (new construction) 2.1 silver-certified building was taken as the case study to validate the approach described in this paper, namely, to integrate design information with sustainable assessment requirement. The building model was prepared in a commercial BIM tool, namely, Autodesk® Revit®

Architecture. This was exported as an IFC model, which was translated to a COBie model using BIMServer™ [25]. During translation from IFC to COBie a number of issues were addressed, which were divided into two phases: i) data requirements in the model; and ii) applying LEED requirement rules to query and fill the LEED assessment templates. Figure 5 illustrates the integrative process of the prototype application, which takes a COBie database as input, automates data exchange by executing mapping rules in the functional database, and lastly, populates the XML LEED templates.

COBie + Sample

Name	CreatedBy	CreatedOn	Category	SheetName	RowName	Value	Unit	ExtSystem	ExtObject	ExtIdentifier	Description	LEEDAttribute
Assembly Description	Tajin.@.co	2011-04-15	Requirement	Component	Fixed_Angle:Angular:Angular:210089	Windows	n/a	Autodesk R	IfcProperty	n/a	Assembly Description	
Type Mark	Tajin.@.co	2011-04-15	Requirement	Component	Fixed_Angle:Angular:Angular:210089	28	n/a	Autodesk R	IfcProperty	n/a	Type Mark	
OmniClass Number	Tajin.@.co	2011-04-15	Requirement	Component	Fixed_Angle:Angular:Angular:210089	n/a	n/a	Autodesk R	IfcProperty	n/a	OmniClass Number	
OmniClass Title	Tajin.@.co	2011-04-15	Requirement	Component	Fixed_Angle:Angular:Angular:210089	n/a	n/a	Autodesk R	IfcProperty	n/a	OmniClass Title	
Glass Pane Material	Tajin.@.co	2011-04-15	Requirement	Component	Fixed_Angle:Angular:Angular:210089	Glass	n/a	Autodesk R	IfcProperty	n/a	Glass Pane Mater	n/a
Sash Material	Tajin.@.co	2011-04-15	Requirement	Component	Fixed_Angle:Angular:Angular:210089	Sash	n/a	Autodesk R	IfcProperty	n/a	Sash Material	n/a
Height	Tajin.@.co	2011-04-15	Requirement	Component	Fixed_Angle:Angular:Angular:210089	5	n/a	Autodesk R	IfcProperty	n/a	Height	n/a
Default Sill Height	Tajin.@.co	2011-04-15	Requirement	Component	Fixed_Angle:Angular:Angular:210089	1	n/a	Autodesk R	IfcProperty	n/a	Default Sill Height	n/a
Width	Tajin.@.co	2011-04-15	Requirement	Component	Fixed_Angle:Angular:Angular:210089	2	n/a	Autodesk R	IfcProperty	n/a	Width	n/a
Window Inset	Tajin.@.co	2011-04-15	Requirement	Component	Fixed_Angle:Angular:Angular:210089	6.25E-2	n/a	Autodesk R	IfcProperty	n/a	Window Inset	n/a
Wall Closure	Tajin.@.co	2011-04-15	Requirement	Component	Fixed_Angle:Angular:Angular:210089	0	n/a	Autodesk R	IfcProperty	n/a	Wall Closure	n/a
Soil Stabilization	COBieToLE	2011-01-12	Requirement	Facility	Default	Reference 1	ref	COBieToLE	IfcSite	1G217EQPv3OASE5ZNIFE5v	SoilErosionMeasure	
Sedimentation Control	COBieToLE	2011-01-12	Requirement	Facility	Default	Reference 2	ref	COBieToLE	IfcSite	1G217EQPv3OASE5ZNIFE5v	SoilErosionMeasure	
Permanent Seeding	COBieToLE	2011-01-12	Requirement	Facility	Default	LocalCode	ref	COBieToLE	IfcSite	1G217EQPv3OASE5ZNIFE5v	ListOfMeasure	
IsGreenfield	COBieToLE	2011-01-12	Requirement	Facility	Default	FALSE	n/a	COBieToLE	IfcSite	1G217EQPv3C	IsGreenfield	Design

Rules Sample

LEEDFieldID	XMLPath	TypeForImplementati	COBieImplementationCondition	COBieImplementationValue
LEEDSSp1-0001	SSp1/LEED/Contact1/	DirectwAggregation	(Contact.Category == Civil Engineer)	Contact.GivenName + Contact.FamilyName
LEEDSSp1-0002	SSp1/LEED/SSp1Table1/Soil	Direct	(Attribute.ExtObject == IfcSite) && (Attribute.LEEDAttribute == SoilErosionMeasure)	Attribute.Name
LEEDSSp1-0003	SSp1/LEED/SSp1Table1/Soil	Direct	(Attribute.ExtObject == IfcSite) && (Attribute.LEEDAttribute == SoilErosionMeasure)	Attribute.Value

SSp1 Template

SS Prerequisite 1: Erosion and Sedimentation Control

I, (Civil Engineer or Responsible party), John Doe, declare that I have designed, specific to the site, a sediment and erosion control plan that conforms to the United States Environmental Protection Agency (EPA) Document No. EPA 832/R-92-005 (September 2000) Storm Water Management for Construction Activities, Chapter 3 as follows:

Brief Description of Measures Implemented	EPA 832/R-92-005 Reference
Soil Stabilization	Reference 1
Sedimentation Control	Reference 2

Or,

I, (Civil Engineer or Responsible party), John Doe, declare that I have designed, specific to the site, a sediment and erosion control plan that conforms to the United States Environmental Protection Agency (EPA) Document No. EPA 832/R-92-005 (September 2000) Storm Water Management for Construction Activities, Chapter 3 as follows:

List of Measures	EPA 832/R-92-005 Reference
Permanent Seeding	LocalCode

SS Pr1

Prerequisite Documented

Name	John Doe
Organization	xx
Role in Project	Civil Engineer
Signature	John Doe
Date	11/11/10
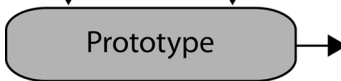
Prototype

◄ Figure 5. Prototype using COBie+ and computable LEED rules to assess and fill temples

In phase one, data requirements are met in the following way. First, potential loss of information during translation is controlled through specific settings to the translation software [25]. Second, the COBie+ structure is created to accommodate additional necessary information. Third, the

COBie file is checked for data. Fourth, default information required for LEED assessment is added. Data added correspond either to attributes of existing elements, for example, IfcSite or IfcSanitaryTerminalType, or to information external to the building model, for example, occupant number, area of surrounding buildings, ground cover type and corresponding runoff values etc. As illustrated in Figure 5, the rules for LEED credit SSp1 (Sustainable Sites pre-requisite1: Erosion and Sedimentation Control) require that a 'Civil Engineer' is present; that data supporting 'soil erosion measure' is necessary in order to fill tables in the template; and that this particular value is treated as an attribute of' IfcSite' which is present in the original project information. In this case study example, 'Soil Stabilization' represents 'soil erosion measure', it is an augmented attribute of IfcSite with a default value of 'Reference1'.

The user can check, change and submit any information added to the model. Figure 6 illustrates user checking and insertion of missing information for the Category 'Civil Engineer,' which is required for assessing the Sustainable Sites SSp1 Erosion and Sedimentation Control credit. It should be noted that the default value of 'Reference1' has been updated to a specific name 'EPA 832/R-92-005 Reference'.

▶ Figure 6. User checking and inserting missing information necessary for filling SSp1 template

In phase two, LEED requirements are subdivided and converted into executable rules. Table 1 illustrates representative sample rules and data output from the case study. The first column is the ID of the value retrieved or processed for use in other calculations. The second column specifies a Type, which indicates how the output value is determined. Some values such as the 'SoilErosionMeasure' attribute associated with an IFcSite are directly retrieved; others like the name of the professional require aggregation—here two distinct string values from the data structure are concatenated. Other data types indicate basic operations such as 'SUM', 'SUB', 'DIV','MUL,' which are used to process values retrieved from the database (illustrated in Table 1 by example rules in the implementation of SSc2 Development Density and Community Connection). The columns, Type, Condition and Value, implement the rules. An initial value is seen in the Output column; these values are propagated to update LEED submission templates, which are prepared in XML format.

▼ **Table 1. Sample LEED rules for SSp1 Construction Activity Pollution Prevention Assessment**

SSp1 Construction Activity Pollution Prevention

ID	Type	Condition	Value	Output
SS-0001	Directw Aggregation	Contact.Category == Architect)	Contact.GivenName + Contact.FamilyName	An Architect
SS-0002	Direct	(Attribute.ExtObject == IfcSite) && (Attribute.LEEDAttribute == SoilErosionMeasure)	Attribute.Name	Soil Stabilization | Sedimentation Control
SS-0003	Direct	(Attribute.ExtObject == IfcSite) && (Attribute.LEEDAttribute == SoilErosionMeasure)	Attribute.Value	Reference1 | Reference2

SS2 Development Density and Community Connectivity

ID	Type	Condition	Value	Output
SS-0027	Direct	(Facility.ExternalFacilityObject == IfcBuilding)	Facility.BuildingFootprint	129.52
SS-0028	Direct	(Facility.ExternalSiteObject == IfcSite)	Facility.SiteArea	647.5
SS-0029	DIV	Null	(SS-0027, SS-0028)	.200
SS-F002	Direct	LEEDDensity.ExternalFacility Object == IfcBuilding	LEEDDensity.Building Footprint	420.32 | 350.62 | 1500.44 | 2300.3 | 3500 | 170 | 130
SS-0035	SUM	Null	(SS-F002)	8371.680

Note that the output may be single- or multiple-valued, or a list of values. For instance, the row with id SS-F002 retrieves a list of the building footprint areas surrounding the project; SS-0035 uses 'SUM' to process information (a single value) for further calculations and to populate fields in the XML template. The extent of automating pre-certification depends on the availability of required information for assessments.

4.2. Assumptions and challenges

Certain assumptions were made in preparing the COBie sheets for evaluation. These are: (i) building data comes from a translated BIM; (ii) data required for LEED evaluation is augmented either by adding new data sets to the original COBie format or by augmenting the structure; and (iii) preprocessed data, typically requiring simulation, such as energy usage, or lighting qualities of a space, e.g., whether 75% of spaces are naturally lit, require the COBie structure to be augmented.

The challenges lay in identifying the kinds of information that would readily translate to COBie, and determining how and where to store the requisite information for LEED evaluation. From a data storage perspective the original data structure requires extension, without altering its basic premise and purpose. From a LEED perspective, both qualitative and quantitative measures need to be assessed through the LEED queries. Qualitative measures in LEED are categorized as those that require user input and are verified by the presence or absence of certain documents as required—these are stored in the 'Documents' spreadsheet. Quantitative measures are processed by queries to mapped entities in COBie. Quantitative values can be numeric, for example, building area or the volume of recycled material used; string, for example, as in the name of plumbing fixtures; or reference, for example, to names of objects. Data is extracted and collected from the given database by invoking the assessment rules codified in the mapping database. The mapping database maintains the underlying interoperation mechanisms for the various data structures.

5. Conclusion

This paper presents an approach to sharing BIM information through a series of interoperation between two standard data structures, IFC and COBie. Data exchange for sustainability assessment is managed by a functional database approach. A prototype application to automate generation of LEED NC 2.1 template within an integrative process is described. The potential contribution of this tool is an effective approach to storing, sharing and managing data between various building professions for the purpose of sustainable building assessment. The prototype uses a flexible approach, which will allow for easy update of assessment rules as rating systems evolve and change. Potentially, the approach can be scaled to assess

multiple buildings [31] and extended to accommodate other sustainable building rating systems, for example, BREEAM and Green Star [32].

During the course of research and development for this project, data required to fill LEED NC 2.1 templates were analyzed. Approximately, on average, 45% of the data is retrieved from the COBie model without augmentation; the remaining 55% is retrieved from data added to COBie. Out of this added data 35% can be identified as attributes of the building elements and includes data that has to be post processed from simulation results. The remaining 20% mainly pertain to queries for support documents that are required for submission.

The approach described the paper is currently being employed to automatically create LEED NC 2009 templates. All templates have been created and the mapping between data requirements and existing database indicates a considerable increase (128 %) in the amount of data required to assess credits. Table 2 shows the data requirements for filling templates of the Sustainable Sites (SS) category. At this point it is seen that the augmented structure used for LEED 2.1 is able to hold the increased data.

Sustainable Sites	Credit Description	LEED 2.1	LEED 2009
SSp1	Construction Activity Pollution Prevention	12	15
SSc1	Site Selection	12	11
SSc2	Development Density and Community Connectivity	20	29
SSc3	Brownfield Redevelopment	12	9
SSc4.1	Alternative Transportation: Public Transportation Access	18	31
SSc4.2	Alternative Transportation: Bicycle Storage and Changing Rooms	15	33
SSc4.3	Alternative Transportation: Low Emitting and Fuel Efficient Vehicles	16	61
SSc4.4	Alternative Transportation: Parking Capacity	18	48
SSc5.1	Site Development: Protect or Restore Habitat	11	31
SSc5.2	Site Development: Maximize Open Space	11	32
SSc6.1	Storm-water Design: Quantity Control	21	23
SSc6.2	Storm-water Design: Quality Control	11	19
SSc7.1	Heat Island Effect: Non-Roof	13	37
SSc7.2	Heat Island Effect: Roof	13	40
SSc8	Light Pollution Reduction	10	50

◄ Table 2. Comparison of LEED 2.1 and LEED 2009 template data for Sustainable Sites category

To determine how much of the data used for LEED 2.1 is reused for LEED 2009 the totals shown in Table 2 are further broken down into qualitative and quantitative values, and analyzed for each credit template in the sustainable sites category. See Table 3. Qualitative measures are represented by 'M' and quantitative values by 'V'. Reused data can include either qualitative measures (document names) or quantitative values (site area, flow fixture rate and names of fixtures etc). A graphical representation of Table 3 is given in Figure 7.

► Table 3. Data Analysis for LEED 2.1 and LEED 2009 in the Sustainable Sites category

Sustainable Sites	LEED 2.1		LEED2009		Reused Data	New Data	Percent Change
	M	V	M	V			
SSp1	11	1	15	0	1	14	86.7
SSc1	11	1	11	0	5	6	9.1
SSc2	10	10	21	8	8	21	44.8
SSc3	9	1	9	0	5	4	-11.1
SSc4.1	14	4	27	4	6	23	54.8
SSc4.2	6	9	22	11	9	24	45.5
SSc4.3	10	6	55	6	6	55	80.3
SSc4.4	12	6	45	3	3	45	87.5
SSc5.1	8	3	27	4	5	26	67.7
SSc5.2	11	0	24	8	4	28	75.0
SSc6.1	15	6	17	6	6	17	47.8
SSc6.2	11	0	13	6	4	15	57.9
SSc7.1	13	0	27	10	0	37	100.0
SSc7.2	15	8	32	8	8	32	60.0
SSc8	10	0	40	10	3	47	88.0
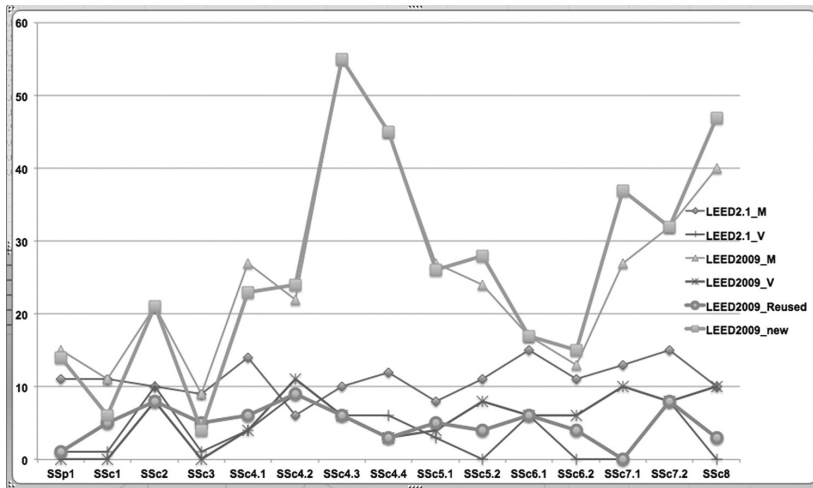
◄ Figure 7. Graphical comparison of LEED 2009 and LEED 2.1 data requirements in the Sustainable Sites Category

There are limitations to the work presented here. These are mainly due to information loss arising from the translation from BIM to COBie, and its unidirectional flow. The augmented COBie data structure and any added data cannot be fed back to the initial BIM due to the internal COBie to IFC mapping structure. Identifying, formalizing and mapping of required LEED data to possible IFC entities or 'psets' is still ongoing work.

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Tajin Biswas and Ramesh Krishnamurti

Carnegie Mellon University
School of Architecture
5000 Forbes Ave, Pittsburgh, PA 15213

{tajin, ramesh}@cmu.edu