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HIGH-LEVEL MODEL ARTICULATION WITH BUILDINGSYNC AND OPENSTUDIO

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ABSTRACT

The use of the BuildingSync schema for describing the contents of buildings is becoming more common with its recent integration into the Audit Template tool as well as ASHRAE's Building Energy Quotient (bEQ) web portal. Although BuildingSync was initially created to store and transfer data related to building energy audits (as defined by ASHRAE Standard 211), it has since been expanded to store the data needed to articulate fully defined physics-based building energy models. BuildingSync combined with abstracted high-level input methods defined in OpenStudio's Standards project and the newly developed BuildingSync gem allows BuildingSync eXtensible Markup Language (XML) (Bray, Paoli, Sperberg-McQueen, Maler, Eve (Sun Microsystems, & Francois, 2008) document to be converted into OpenStudio models. Automatic generation of a building energy model from data collected during an audit 1) eliminates the need to separately generate an energy model, 2) improves consistency between model generation, and 3) simplifies evaluation of various energy efficiency measures.

This manuscript will discuss this open-source project, including: development of the validation infrastructure necessary to provide formalized expectations of informational requirements for BuildingSync documents; development of the BuildingSync gem for translation of BuildingSync documents to OpenStudio models as well as example implementations; and finally, the manuscript will elaborate on the advantages and disadvantages of using high-level models generated from BuildingSync as surrogates to detailed models.

INTRODUCTION

BuildingSync was developed to "address the lack of an industry-standard collection format for energy audit data" (DeGraw, Field-Macumber, Long, & Goel, 2018). In conjunction with the different ASHRAE Standard 211 audit levels, BuildingSync is a useful schema for expediting the energy audit process, and more importantly, for standardizing the reporting of energy audit data to governing bodies. As audits provide a rich source of information about buildings, and many auditing practitioners utilize building energy modeling (BEM) tools as part of the financial analysis required with these audits, desire arose to automate the process of generating energy models from energy audit data.

Furthermore, significant work was recently completed to enable the import and export of BuildingSync files into the Standard Energy Efficiency Data (SEED) Platform (Alschuler, Antonoff, Brown, & Cheifetz, 2014), and to enable export of BuildingSync files from PNNL's Audit Template tool ("Audit Template," 2020). The integration of BuildingSync with these two tools further extends its usefulness, since auditors can generate BuildingSync files using the Audit Template tool (or other auditing applications), and cities can store audit information in a SEED instance.

The feasibility of utilizing BuildingSync documents for streamlining the BEM workflow was demonstrated in the BayREN Integrated Commercial Retrofits (BRICR) project (Hooper et al., 2018). In this project, high level building information and potential retrofit measures were defined by BuildingSync files and used to model 3,800 small and medium commercial buildings (SMB). The BRICR analysis used publicly available data including the building type (Retail, Office, Hotel), floor area, and code vintage (based on the year built) for describing the buildings.

Moreover, cities and other governing bodies are implementing policies requiring mandatory auditing of commercial buildings. The question then becomes: Can the standardization of audit information reporting via BuildingSync streamline the process of evaluating energy efficiency potential at scale? This question is relevant in the following ways:

1. Energy auditing entails the consolidation of relevant building information, providing concise summaries of buildings, their operational practices, and resource uses at annual and monthly levels. Audits are highly useful for gathering asset information in older buildings with limited, unorganized, or outdated information.

2. As the low hanging fruit of energy savings potential disappears, more thorough efficiency analysis is required. Building energy modeling is a primary means of providing this thorough evaluation.
3. Detailed energy modeling of individual buildings at a city, state, or even national scale is economicaly impractical, therefore, improving the workflow of auditing to energy modeling becomes highly relevant for automatic model generation and efficiency analysis opportunities.

These guiding thoughts provided the impetus for development of the BuildingSync gem and related

The rest of the manuscript is organized as follows:

- The background section provides descriptions of how BuildingSync documents are defined for specific use cases. The two main concepts for organizing use cases, modeling level of detail (MLOD) and model view definitions (MVD) are discussed.
- The modeling levels of detail section expands on the previous section to introduce the reader to how MLOD definitions are used and how they align with ASHRAE Standard 211.
- The development section discusses the development of the BuildingSync gem, explaining the primary classes, methods, and external libraries used to generate OpenStudio models from high-level BuildingSync documents.
- The example model articulation section walks through information captured by two different MLODs (Level 000 and Level 100) BuildingSync documents. It also relates these directly back to informational requirements captured by the ASHRAE Standard 211 workflow.
- The final sections discuss results, conclusions, and future work necessary.

BACKGROUND

The ability to capture valuable information about a building in a standardized schema enables software applications to effectively utilize the BuildingSync schema to create value add applications. For example, the BayREN Integrated Commercial Retrofits (BRICR) project made significant use of the BuildingSync schema to automate the generation of multiple OpenStudio Workflow (OSW) files (DeGraw et al., 2018). These building models were then simulated using OpenStudio and EnergyPlus. Through this project, it became apparent that users needed to better understand how exactly BuildingSync files were translated into energy models:

- What data from the BuildingSync file was used to generate the model?
- What assumptions were made in order to go from a high-level building representation (defined by a BuildingSync file) to a fully defined physics-based model?

The need to communicate these translation requirements to users has led to the development of different use cases and tools for use case validation. An introduction to the scope and purposes of these follows.

Use Cases, Model View Definitions, and Modeling Level of Detail Definitions

As BuildingSync has grown in its ability to represent information about buildings, it is able to define aspects of buildings at varying levels of abstraction. Additionally, while originally designed to capture energy audit data, data stored in BuildingSync can be used for other purposes as well. Working with data for different purposes and at varying levels of abstraction in a schema is not something new to BuildingSync. This is a similar problem faced by the building information modeling (BIM) community, where different informational requirements are necessary at different project stages and many different stakeholders are involved in projects. BIM uses the Industry Foundation Classes (IFC) schema for transferring data between applications. The BuildingSync team utilizes two concepts introduced by the BIM world for refining data expectations needed by different users of the schema: Level of Development (LOD) and Model View Definitions (MVD).

The LOD Spec is a comprehensive guide developed by the American Institute of Architects (AIA) and BIMForum to help BIM authors to describe the depth of their models based on phases of design (BIMForum, 2019). MVDs are developed by a variety of users in the BIM community to define a subset of the overall schema necessary for a specific use case or workflow (Lee, Eastman, Solihin, & See, 2016). We utilize these concepts in BuildingSync and define them as follows:

- MVD – A MVD in BuildingSync is intended to provide a narrower focus for which the data stored in a BuildingSync document is intended. It is analogous to an MVD introduced above. The two primary MVDs developed so far are:
  - Audit – To ensure alignment of data contained in the BuildingSync document with portions of the ASHRAE 211 Standard.
  - OpenStudio Simulation – To ensure alignment of data contained in the BuildingSync document with requirements necessary to utilize the

BuildingSync gem for automatically generating and simulating an energy model using OpenStudio.

- MLOD definitions – The MLOD definitions are intended to provide expectations of informational requirements at differing levels of abstraction. For example, in BuildingSync, a *Building*[1] element can be defined to capture high-level information, but narrower levels of abstraction regarding architectural and mechanical space configurations (*Section*, *ThermalZone*, or *Space* elements) can be defined as child elements of the *Building* to provide more specific information. This is analogous to the LOD spec introduced above.
- Use case – A use case is a combination of a MVD and a MLOD. Together, these provide formalized definitions for BuildingSync data expectations.

Six MLODs have been defined in BuildingSync (Level 000 – Level 500), the first four being in alignment with informational requirements defined in ASHRAE Standard 211 (summarized in Table 1).

Table 1 Test Suite alignment with Standard 211

MLOD	MVD	ALIGNMENT TO STD 211	STD 211 SECTION
Level 000	Audit	Preliminary Analysis	Section 5.2.3
Level 100	Audit	Level 1	Section 6.1
Level 200	Audit	Level 2	Section 6.2
Level 300[1]	Audit	Level 3	Section 6.3
Level 400[1]	Audit	Not Applicable	Not Applicable
Level 500[1]	Audit	Not Applicable	Not Applicable

[1]Not yet defined

Generally, informational requirements at a particular MLOD is similar across different MVDs but not the same. A simple example of what this looks is provided by comparing a Level 100 MLOD for both the audit and OpenStudio simulation MVDs:

- Audit MVD:
  - *Sections* – Individual *Section* elements are necessary for capturing details about areas comprising greater than 20% of the gross floor area. Example details include:
    - *PrimaryHVACSystemType*
    - *OccupancyClassification*
  - *Contacts* – Individual *Contact* elements and details must be defined for the auditor and primary point of contact.
- OpenStudio Simulation MVD:
  - *Sections* – Individual *Section* elements are required to have the same informational requirements as above.
  - *Contacts* – OpenStudio does not care about *Contact* elements, and therefore these elements are not necessary for this MVD.

In BuildingSync, we utilize a use case to explicitly define element requirements, which are then formalized into Schematron files for validation (Information technology — Document Schema Definition Languages (DSDL) — Part 3: Rule-based validation, Schematron, 2016).

Providing a formalized and simple to use validation infrastructure for BuildingSync documents is vital to the success of the schema and overall adoption. It provides third-party developers using BuildingSync with a means for testing their implementation, and additionally provides a mechanism for automatically validating document submissions to governing authorities for compliance purposes. Schematron provides the formalized methodology for checking document validity. Additionally, the BuildingSync Test Suite and Selection Tool have been developed to further streamline document validation.

BuildingSync Test Suite

The BuildingSync Test Suite is utilized by the NREL development team for development and testing in multiple areas:

1. Testing of individual BuildingSync specific Schematron functions. These functions are designed to check very narrow informational requirements ("the document defines atleast one *Building*") and are built up into a library of functions. These functions are intended for reuse.
2. Defining and testing BuildingSync use case documents against Schematron files. The Schematron files for a given use case are built up using the library of Schematron functions.
3. Testing of use cases against different BuildingSync schema versions.
4. Testing of OpenStudio Simulation MVD documents for valid generation and simulation of OpenStudio energy models.

[1] Italics are used throughout the manuscript to denote BuildingSync elements

Additionally, the Test Suite provides example files and documentation for how to construct specific concepts using the BuildingSync schema. Current examples include:

- Constructing a Level 200 Packaged Single Zone HVAC system with two stages of cooling and two stages of gas heating
- Constructing a Level 200 Packaged Single Zone Heat Pump

The main outcomes of the Test Suite are a set of Schematron documents which are used for validation of a BuildingSync document against a specific use case. While the source code is available open source and these validations can be performed by anybody, the BuildingSync Selection Tool was developed to facilitate easier validation of BuildingSync documents, discussed in the next section. Examples of use cases currently available via the Selection tool include L000 and L100 OpenStudio Simulation files, L000 Audit files, and a New York City audit requirement document.

BuildingSync Selection Tool

The BuildingSync Selection Tool is a web application with two distinct purposes:

1. Web-based, user friendly browsing of the BuildingSync schema at different versions. Definitions of BuildingSync elements as they are defined in the Building Energy Data Exchange Specification (BEDES) (*Building Energy Data Exchange Specification (BEDES)*, 2019) are also available for users to view.
2. Validation of BuildingSync documents against varying use cases and schema versions. Validation can be accomplished by uploading documents directly to the website or through the API.

It is expected that most users working with BuildingSync documents will use the Selection Tool for validation, specifically taking advantage of the API for integration into applications.

MODELING LEVELS OF DETAIL

Level 000

The Level 000 MLOD provides a high-level overview of a building and aligns with a typical Preliminary Energy Analysis. Information required to define models at this level can typically be found from tax assessor data, publicly available data, annual energy consumption information, and through a brief discussion with the building owner (see Table 2). When this is used in the OpenStudio worfklow, since little information is known about the building, many assumptions are made when performing the translation of a Level 000 BuildingSync model to a physics-based energy model.

Table 2 Sample information for the Level 000 MLOD

DEFINED	ASSUMED
Primary purpose of the building	Type and efficiency of systems
Total building area	Building geometry
Year built, location	Envelope constructions and insulation levels

Level 100

The Level 100 MLOD extends the Level 000 MLOD. The primary additions for the Level 100 model definition are summarized in Table 3. For every space type defined by a Level 1 audit (Level 100 MVD), a corresponding BuildingSync *Section* element is created, with an associated *HVACSystem* element, *LightingSystem* element, and *PlugLoad* element.

Table 3 Sample information for the Level 100 MLOD

DEFINED	ASSUMED
Space types and information for all areas comprising > 20% of gross floor area	Envelope insulation levels and areas
Principal HVAC types	Building geometry
Principal lighting types	Equipment efficiencies
Plug loads	HVAC system capacities

The ASHRAE Standard 211-2018 reporting form (Normative Annex C) requires ‘Prinicipal HVAC Type’ and ‘Principal Lighting Type’ to be defined, but does not provide standardized enumerations for these types. Moreover, defining a ‘Principal HVAC Type’ is lacking in that it does not break out system specific information, such as heating, cooling, ventilation, fan control, or terminal type.

In an effort to standardize the inputs for the ‘Principal HVAC Type’, Table 4 lists the enumerations available for the *PrimaryHVACSystemType*[2] element in BuildingSync.

Table 4 PrimaryHVACSystemType Enumerations

PRIMARYHVACSYSTEMTYPE	
Packaged Terminal Air Conditioner	Four Pipe Fan Coil Unit
Packaged Terminal Heat Pump	Packaged Rooftop Air Conditioner

[2] The authors apologize for the confusing semantics, but the ‘Principal HVAC Type’ as defined in Standard 211 maps to the *PrimaryHVACSystemType* element in BuildingSync

Packaged Rooftop Heat Pump	Packaged Rooftop VAV with Hot Water Reheat
Packaged Rooftop VAV with Electric Reheat	VAV with Hot Water Reheat
VAV with Electric Reheat	Warm Air Furnace
Ventilation Only	Dedicated Outdoor Air System
Water Loop Heat Pump	Ground Source Heat Pump
Other	

While these enumerations provide a good starting point for defining Level 100 HVAC systems, they are not nearly encompassing of all potential HVAC system configurations that may be encountered in the field. Our intention is to expand this list to be in line with the template HVAC System configurations defined by the 'Create Typical Building From Model' measure (*Create Typical Building from Model*, 2020), although that work is outside the scope of this paper.In addition to supporting enumerations for the *PrimaryHVACSystemType,* BuildingSync also provides standard enumerations for *LightingSystem* types via the *PrimaryLightingType* element, with the enumerations defined in Table 5.

Table 5 PrimaryLightingSystemType Enumerations

PRIMARYLIGHTINGSYSTEMTYPE	
Compact Fluorescent	Fluorescent T5
Fluorescent T5 – High Output	Fluorescent T8
Fluorescent T8 – Super T8	Fluorescent T12
Fluorescent T12 – High Output	High Pressure Sodium
Incandescent	Halogen
LED	Mercury Vapor
Metal Halide	Other

The information provided in Table 5 illustrates a difficulty encountered in generating physics-based models (OpenStudio Simulation MVD) at different MLODs. In the case of *HVACSystem* typing, more information is required than typically available from an audit to accurately represent a sufficient number of HVAC systems. *LightingSystem* typing, however, suffers from the opposite problem. Energy models generally only require the lighting power density (LPD), not the specific type of lighting system used, which is not accurately conveyed through an audit since the installation density of the fixtures is typically unknown. The question of how to infer the LPD given a *PrimaryLightingSystemType* is a topic area for further investigation by the authors.

Level 200

The Level 200 MLOD extends the Level 100 MLOD to include detailed system information and overall building geometry, as to mirror the ASHRAE Level 2 informational requirements.

Table 6 Sample information for the Level 200 MLOD

DEFINED	ASSUMED
Counts and definitions of primary HVAC, domestic hot water, and lighting equipment	Detailed building geometry, thermal and lighting zone configurations
General building shape	Equipment locations
Envelope areas, insulation levels, and general constructions	Detailed envelope constructions

While the level of detail provided in the Level 100 MLOD is necessary to provide a general summary of the main system types, it fails to capture system efficiencies and detailed system configurations. Moreover, the general shape of the building is unknown, as well as any information about the envelope elements. The intention of the Level 200 MLOD definition is to utilize the additional data provided from a Level 2 audit to further refine the model articulation. As this is an area of active research, specific examples of this are outside the scope of this manuscript.

DEVELOPMENT

OpenStudio was chosen to help translate from BuildingSync to building energy models based on its ability to infer model parameters using various libraries (referred to as gems in Ruby).

OpenStudio Extension Gem

Part of the effort necessary to develop the BuildingSync gem required the development of an OpenStudio Extension gem. The OpenStudio Extension is a base class used to derive any OpenStudio-related extension, such as the BuildingSync Gem, which encapsulates major functionality such as common OpenStudio measures, shared methods, shared files (such as CSVs and look up tables), and common license files.

BuildingSync Gem

Supporting the articulation of OpenStudio models is the open source BuildingSync Gem, which builds on the previous development effort of the BRICR project (Hooper et al., 2018). While models developed for the BRICR project map relatively well to the Level 000 OpenStudio Simulation use case, the BRICR Gem was purposefully built with BRICR in mind. The BuildingSync gem is a replacement of the BRICR Gem with more generic methods and articulation capabilities for BuildingSync models at differing MLODs. The remainder of this section will focus on the BuildingSync Gem architecture.

Other Gems Utilized

The BuildingSync Gem relies heavily on two other gems:

- OpenStudio Standards Gem (Roth, 2016)
- OpenStudio Model Articulation Gem

The Standards Gem is primarily used to infer specific information about the building based on the vintage, size, and climate zone. It essentially captures ASHRAE 90.1 requirements (insulation levels, system types and efficiencies, etc.) and ASHRAE 62.1 (ventilation rates) into a library for simplified model generation. The Model Articulation gem is used to generate space types, area allocations (blended space types), and geometric configurations. Specific testing as to the generation of ASHRAE 90.1 models being in full compliance of the ASHRAE 90.1 standard is outside the scope of this paper and the BuildingSync gem. The authors rely completely on the correct implementation of ASHRAE 90.1 by the previously defined gems.

BuildingSync Classes

Complex types from the BuildingSync Schema are defined as classes in the BuildingSync Gem, with cascading attributes similar to those defined in the schema. The general class structure for major elements in the BuildingSync gem are displayed in Figure 2. Additionally, Figure 1 demonstrates the major classes and methods used in the workflow of extracting data from BuildingSync files and running OpenStudio models. The following sections provide general descriptions for these classes and important methods.

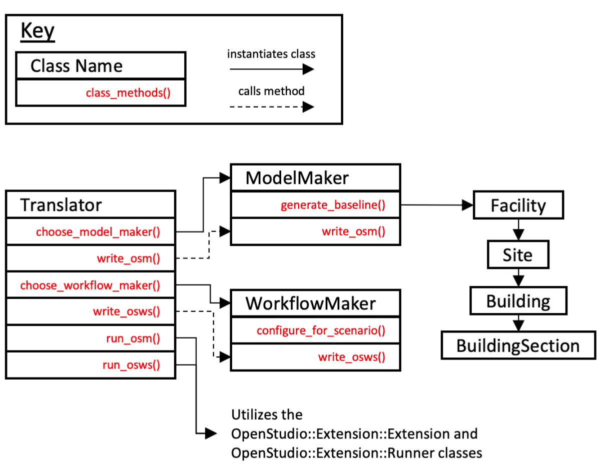

Figure 1 Workflow for Major BuildingSync Classes Used for Generation and Simulation of Models

Translator

The `*Translator*`[3] class is the highest-level class defined by the BuildingSync gem. It is a wrapper class used to streamline method calling to the various model levels defined by the `*ModelMaker*` classes. It has access to the BuildingSync file, the OSM file(s), and the OSW file(s).

Additional capabilities of the `*Translator*` class include:

- Validation of a BuildingSync document (XML) against the BuildingSync schema and the defined use case via the `SelectionTool` class
- Generation of a baseline OpenStudio model (OSM)
- Generation of different scenarios (OSW)
- Adding OpenStudio/EnergyPlus measures to the workflow
- Gathering results from the modeling process
- Saving the modeled results back into the BuildingSync XML file

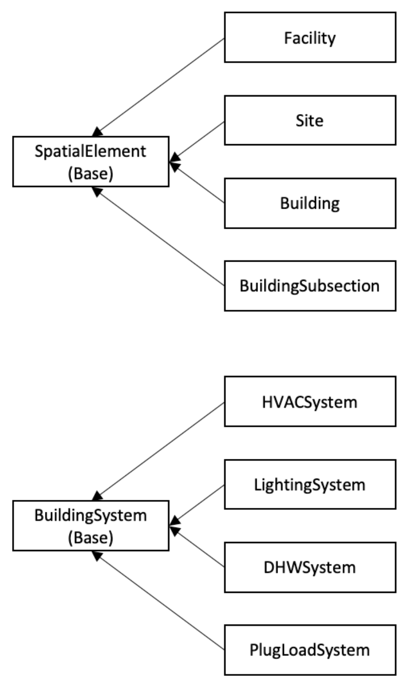

Figure 2 Class Inheritance for SpatialElements and BuildingSystems as Defined in the BuildingSync Gem

ModelMakers and WorkflowMakers

The `*ModelMaker*` and `*WorkflowMaker*` classes are utilized by the `*Translator*` class for defining specific levels for the test suite. They hold the entirety of the

[3] Backticks and italics are utilized when referring to classes and methods

BuildingSync instance (facilities, sites, buildings, systems, etc.) as part of their class attributes. Wrapper methods utilized by the `*Translator*` class, such as `*Translator.get_space_types*`, are implemented by the maker classes.

SpatialElement

The `*Site*`, `*Building*`, and `*BuildingSection*` classes inherit from the `*SpatialElement*` class. `*SpatialElement*`s contain information such as the floor area properties and types (total, conditioned, heated-only, etc.), space types (occupancy classifications), and loads associated with those space types (lighting, plug, process, etc.). The individual `*Site*`, `*Building*`, and `*BuildingSection*` classes contain attributes and methods specific to their purpose and in line with the BuildingSync schema. For example:

- A `*Site*` defines the `*climate_zone*` attribute
- A `*Building*` defines the `*built_year*` attribute
- A `*BuildingSection*` defines the `*occupancy_type*` attribute

EXAMPLE MODEL ARTICULATION

Demonstrations will be created in accordance with both the Level 000 and Level 100 OpenStudio Simulation use cases defined by the Test Suite. Both example files are avaible on the Test Suite repository and are summarized in Table 7.

Table 7 Level 000 and Level 100 Data Sources

LEVEL	DATA SOURCE
Level 000	The Building Data Genome Project (BDGP) (Miller & Meggers, 2017).
Level 100	Custom. The building is structured around the 90.1-2013 Retail Standalone prototype building ("Commercial Prototype Building Models," 2018), with a second-floor office (and accompanying characteristics) added. High level details of the model are provided in Table 10.

Level 000 Model Definition

The BDGP is a collection of whole building electrical interval data and metadata for 507 commercial buildings from around the world (Miller & Meggers, 2017). The dataset is similar to the dataset used for the BRICR project; however, it contains interval whole building electrical meter data, enabling comparison of results from the modeled building to the actual building.

A typical building was desired from the BDGP dataset. The Buildings Performance Database (BPD) was used as a benchmarking mechanism, and the Office Carolina building was selected from the BDGP since its electrical EUI was within the 50th percentile of New York Office[4] buildings, as summarized in Table 8.

After determining a representative building to model, metadata from the BDGP meta_open.csv file was extracted and translated into an equivalent representation via a BuildingSync XML file. The relevant metadata characteristics extracted from the Office Carolina building are summarized in Table 9.

Table 8 Summary Statistics for New York Office Buildings Electrical EUI (kBtu/sf)

MEAN	MIN	25%	50%	75%	MAX
55	0	34	49	64	931

Table 9 Office Carolina Metadata

METADATA PARAMETER	VALUE
UID	Office Carolina
Industry	Education
Primary Space Usage	Office
Area (ft^2)	31,053
Sub Industry	College/University
Time Zone	America/New_York
Year Built	1915
Electrical EUI (kBTU/ft^2)	46

Level 000 Translation and Simulation

After capturing the relevant metadata in a BuildingSync document, the BuildingSync gem can be used to translate the document into an OpenStudio model and simulated using the following steps:

1. Instantiation of the `*Translator*` class
2. Generation of the baseline model and scenarios based on that baseline
3. Running the simulation(s)
4. Cleaning up results and saving back into a BuildingSync file

4 Filtering criteria used in the BPD was limited to Building Classification = 'Office' and State = 'New York', which returned 899 buildings.

Translator Instantiation

Five parameters must be passed to the `` `Translator` `` class upon instantiation:

1. *`xml_file_path`*: Path to the BuildingSync file. Required.
2. *`output_dir`*: Output path to save the model and results to. Required.
3. *`epw_file_path`*: Path to a valid EnergyPlus Weather (.epw) file. Optional. The BuildingSync gem will select an appropriate weather file based on either the *`ClimateZone`* or the *`City`* and *`State`* elements.
4. *`standard_to_be_used`*: One of: ['ASHRAE90.1', 'CaliforniaTitle24']. Default is 'ASHRAE90.1'.
5. *`validate_xml_file_against_schema`*: True or False. Default is True.

Upon initialization of the *`Translator`*, *`Facility`*, *`Site`*, *`Building`*, and *`BuildingSection`* classes will also be instantiated (Figure 1), with many of the accompanying attributes being populated along the way.

Writing Files

After instantiation of the *`Translator`* and before running of the models, two things must be done:

1. *`Translator.write_osm`*: Generates the baseline OpenStudio model file (in.osm) to the *`output_dir`* specified during instantiation.
2. *`Translator.write_osws`*: writes the OpenStudio workflow (in.osw) for the different scenarios specified.

Simulation

The simulation can now be run. The *`Translator`* class provides wrapper methods to the *`Runner`* class from the OpenStudio Extension Gem in order to perform the simulations via OpenStudio workflows. Running a simulation using the *`Translator`* class is simple:

1. *`Translator.run_osws(runner_options)`*. The *`runner_options`* parameter allows users to specify how many simulations to run in parallel, the verbosity of the output to be received, and whether to run the simulations or simply configure the in.osw file.

Cleaning Up

Since the simulations use many measures from the OpenStudio standards project, the output directory can become large and difficult to manage. Additionally, as BuildingSync was designed to store results from multiple scenarios, a new BuildingSync file could be written containing the results from the simulations.

1. *`Translator.gather_results_and_save_xml(out_dir)`*: This method cleans up the *`out_dir`* of large files and many measure directories. It additionally gathers the results from all of the *Scenarios* defined in BuildingSync and saves it. For the Office Carolina example, as only a Baseline *Scenario* was defined, no additional information is added to the XML document.

Level 100 Definition

Information used to generate the Level 100 example model was obtained by performing a 'virtual' Level 1 audit on a modified version of the RetailStandalone prototype building (located in Chicago, IL). Data captured from this Level 1 audit is represented in Table 10. As the workflow used for generating a Level 100 model is the same as for the Level 000, those details will not be expanded upon in this section.

Table 10 Characteristics of the Two Space Types Present in the Level 100 Model Example

SPACE NUMBER	A	B
Function type	Retail Store	Office
Original intended use	Retail Store	Office
Gross Floor Area	24,695	24,695
Conditioned Area	100%	100%
Number of Occupants	370	123
Plug Loads (W/sf)	0.50	0.75
Use (hours/week)	91	86
Use (weeks/year)	52	52
Principal HVAC Type	Packaged Rooftop Air Conditioner	Packaged Rooftop VAV with Electric Reheat
Principal Lighting Type	Compact Fluorescent	LED

INSPECTING MODEL CHARACTERISTICS

Level 000 Model Characteristics

Since the BuildingSync Gem workflow builds on the main OpenStudio workflow, the OpenStudio model can be examined using the OpenStudio Application. For example, the following can be observed from the in.osm file defined during the workflow:

- General: The model used weather data from Ithaca, NY based on ASHRAE Climate Zone 6A with a total floor area of 31,054 ft^2,

- HVAC System: A single, nine-zone packaged variable air volume (PVAV) HVAC system is used. This system type is inferred since the Office Carolina building falls into the category of a MediumOffice building, which has the above default system type. It has a two-speed DX coil with an EER of 8.92. Heating is supplied to the PVAV via a hot water loop, fed by a natural gas boiler with a 74% thermal efficiency.
- Envelope and Constructions: Constructions are based on standards from the 'DOE Ref Pre-1980 – Office – ASHRAE 169-2013-6A' construction set. This includes, for example, an R-6.9 exterior mass wall construction and an R-16.67 IEAD roof.
- Spaces and Loads: A single space type of 'Office WholeBuilding – Md Office – DOE Ref Pre-1980' is used, which defines a people density of 200 ft^2/person, an equipment power density of 1 W/ft^2 and a lighting power density of 1.57 W/ft^2

Although the primary purpose of this manuscript is to demonstrate how the BuildingSync gem works, preliminary results of model performance are discussed below. The only basis of comparison for energy consumption of the Office Carolina building is the annual electrical EUI. As shown in Table 11, the modeled consumption matches quite well to the actual consumption and is also within the 50^{th} percentile of results from the BPD, showing the potential of the workflow.

Table 11 Electrical EUI (kBtu/ft^2) for Office Carolina

MODELED	ACTUAL
43	46

CONCLUSION

The ability to create energy models using high-level building information is a valuable tool for the building simulation community, particularly as this high-level metadata is being collected via mandatory energy auditing legislation. An important consideration in this workflow, especially considering the vast range of information that can be captured in a BuildingSync file, is that data validation infrastructure is in place and is use case centric.

This article introduced the two main concepts employed by the BuildingSync team to define use cases, namely, modeling levels of detail and model view definitions, as well as the validation infrastructure in place (the Test Suite and Selection Tool) to help developers and other users integrate data validation into their own workflows.

These use cases were discussed in terms of compliance with ASHRAE Standard 211 requirements, as well as the informational requirements for generating energy models via the BuildingSync gem and OpenStudio. The inner workings of the BuildingSync gem were demonstrated using two example buildings, describing the main classes involved in translating a BuildingSync document into an OpenStudio model, simulating it, and analyzing the energy model characteristics inferred.

FUTURE WORK

While the capabilities of the BuildingSync gem have been preliminarily demonstrated and tested, a large scale study utilizing information generated from energy audits should be conducted. It is also desired to modify the workflow in the following way to increase the effectiveness of generating energy models from audits:

1. Utilize the monthly timeseries data required for ASHRAE Standard 211 audits to perform automatic energy model calibration. This would provide a more optimal baseline model for performing energy efficiency analysis.
2. Perform the efficiency analysis (similar to BRICR) and select recommended measures.
3. Determine the measure effectiveness via post-retrofit analysis conducted in accordance with the CalTRACK methods (Ngo, 2019)

What is most desired is to automate as much of the above workflow as possible. An additional task that would help expedite the above workflow would be to align the applicable schema concepts from BuildingSync with equivalent concepts in Project Haystack ("Project Haystack," n.d.) and Brick (Balaji et al., 2016), as these are the primary open source metadata schemas used for operational data collection.

Other necessary tasks include providing formalized definitions to more use cases, including Level 300, 400, and 500 MLOD definitions. These MLODs will provide increasing specificity and should evolve with best practices in energy auditing. In cities such as New York or Washington, DC, where legislation mandating increased performance of existing buildings is in effect, the low hanging fruit to achieve decreases in energy consumption will soon be gone. Auditors will need better tools to capture information where energy savings opportunities are present, but which currently goes undocumented such as sequences of operation. Figuring out additional methods for capturing and representing information about the most promising energy savings opportunities present in buildings should be the focus of development for energy auditing practitioners, and in turn, the BuildingSync schema.

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