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Transforming BIM to BEM: Generation of Building Geometry for the NASA Ames Sustainability Base BIM

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This project would not have been possible without the considerable modeling contribution of Nataša Mrazović.

This project and report would not have been achievable without the multi-year development of SBT-1, originated by Tobias Maile and expanded by Cody Rose.

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Executive Summary

Typical processes of whole Building Energy simulation Model (BEM) generation are subjective, labor intensive, time intensive and error prone. Essentially, these typical processes reproduce already existing data, i.e. building models already created by the architect. Accordingly, Lawrence Berkeley National Laboratory (LBNL) developed a semi-automated process that enables reproducible conversions of Building Information Model (BIM) representations of building geometry into a format required by building energy modeling (BEM) tools. This is a generic process that may be applied to all building energy modeling tools but to date has only been used for EnergyPlus.

This report describes and demonstrates each stage in the semi-automated process for building geometry using the recently constructed NASA Ames Sustainability Base throughout. This example uses ArchiCAD (Graphisoft, 2012) as the originating CAD tool and EnergyPlus as the concluding whole building energy simulation tool. It is important to note that the process is also applicable for professionals that use other CAD tools such as Revit ("Revit Architecture," 2012) and DProfiler (Beck Technology, 2012) and can be extended to provide geometry definitions for BEM tools other than EnergyPlus. Geometry Simplification Tool (GST) was used during the NASA Ames project and was the enabling software that facilitated semi-automated data transformations. GST has now been superseded by Space Boundary Tool (SBT-1) and will be referred to as SBT-1 throughout this report.

The benefits of this semi-automated process are fourfold: 1) reduce the amount of time and cost required to develop a whole building energy simulation model, 2) enable rapid generation of design alternatives, 3) improve the accuracy of BEMs and 4) result in significantly better performing buildings with significantly lower energy consumption than those created using the traditional design process, especially if the simulation model was used as a predictive benchmark during operation.

Developing BIM based criteria to support the semi-automated process should result in significant reliable improvements and time savings in the development of BEMs. In order to define successful BIMS, CAD export of IFC based BIMs for BEM must adhere to a standard Model View Definition (MVD) for simulation as provided by the concept design BIM MVD (buildingSMART, 2011). In order to ensure wide scale adoption, companies would also need to develop their own material libraries to support automated activities and undertake a pilot project to improve understanding of modeling conventions and design tool features and limitations.

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1 Background and definitions

A BIM is an instance of a populated data model of buildings that contains multi-disciplinary data specific to a particular building, which it describes unambiguously. It contains all data that define the building and are pertinent from the point of view of more than one discipline. A BIM includes all relationships and inheritances (predefined hierarchies) for each of the building components it describes; in that sense it is "intelligent" (Bazjanac, 2004).

From a general industry point of view, a BIM is a shared digital representation of a building and its physical and functional characteristics, based on open standards for software interoperability. It contains information supplied by all participants in building design, procurement and operation, and forms a reliable basis for decisions throughout its lifecycle. It facilitates effective collaboration by different stakeholders at all phases of that lifecycle (Bazjanac, 2007).

The basis for the definition and population of any BIM is a data model of buildings that all BIM authors and users agree to apply in the case of a particular building. While there are many proprietary data models of buildings, usually limited to data definitions that represent only a part of the building cycle, the IFC (Industry Foundation Classes) model, developed by buildingSMART who promote open BIM throughout the building life cycle (buildingSMART, 2012), is the only open specification that covers the entire lifecycle. It is recognized by the International Standards Organization as ISO 16739.

With these definitions at hand, this report now highlights the benefits of semi-automated BIM to BEM data exchange in Section 2, and details the most up to date technical processes that support this data exchange (Section 3).

2 The benefits of semi-automated BIM to BEM data exchange

An increase of awareness about the critical role of buildings in the overall consumption of energy in all industrialized economies is resulting in increased use of building energy performance (BEP) simulation to quantitatively justify building design and operations decisions. Yet, it is becoming increasingly common that the results of such simulation are often questionable, and may lead to wrong decisions. Poor simulation model definitions and the use of inappropriately acquired and transformed data are two of the most common causes of this (Bazjanac et al., 2011). Bazjanac (2001) identified time savings of 75% for the creation of building geometry in small to medium buildings through the appropriate application of automated processes.

A formal representation of this process, called the "IFC BIM-based methodology for semi-automated building energy performance simulation" (Bazjanac, 2008), semi-automates BEP simulation data acquisition, transformation and input for building energy modeling, and thus, where possible, removes error associated with human decision making from the simulation data definition process. There are three major software components necessary to deploy this methodology (Figure 1): 1) import building

geometry; 2) define mechanical systems and 3) define schedules of use and operation. The first component, called the Space Boundary Tool (SBT-1) (LBNL, 2012a), is already in use (Bazjanac, 2009). The work on the second component, an interoperable HVAC graphic user interface (GUI) called Simergy for EnergyPlus, is currently available as a Beta release (LBNL, 2012b; See et al., 2011). Given the necessary funding, the third component, an Internal Loads generation Tool (ILT) that would automatically assign schedules and loads by space type, will be developed in the near future by LBNL or added to existing CAD tools.

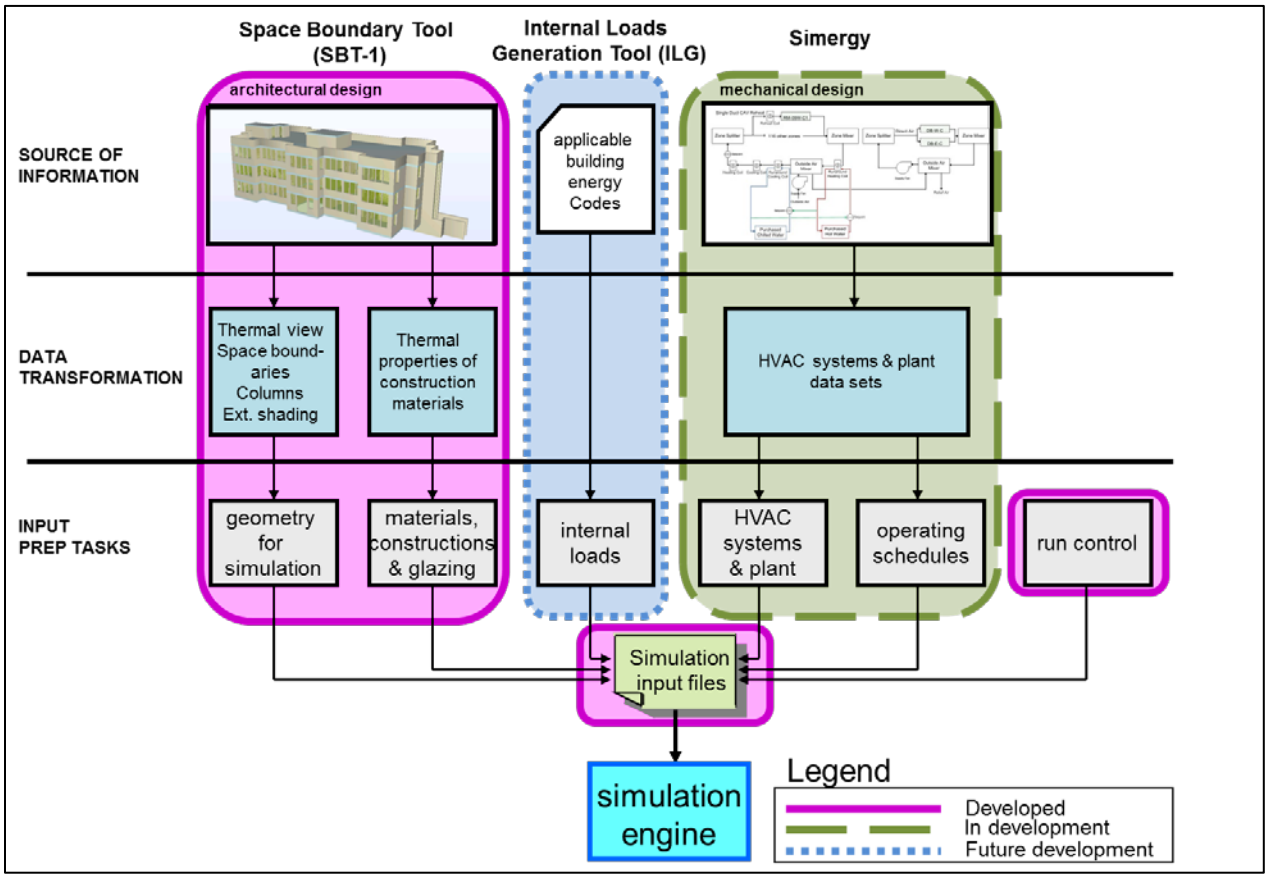

Figure 1: Implementation of the methodology for semi-automated building energy performance simulation

The methodology for semi-automated BEM simulation data input was originally, and still is, based on the use of data defined in IFC format according to the rules and protocols standardized by the IFC data model of buildings (buildingSMART, 2012). If appropriately defined, other BIM data formats could also be used.

3 Semi-automated process: BIM to BEM geometry transformation

This section describes the overall technical process required for semi-automated data exchange of building geometry for the purposes of whole building energy simulation. Generally speaking, BEM requires simplistic geometry definitions that define walls in planes, as opposed to 3D space, where all heat transfer between elements is orthogonal to zone boundaries. As a consequence of current heat transfer limitations, BEM geometry definitions are unable to model curved surfaces. The overall process requires an Architect to create a properly defined BIM for energy simulation as opposed to BIM with the substantial information for building construction. The difference is in more simplified representation of walls and slabs, but also in more detailed information about thermal performance of building elements. The BIM is exported from a CAD environment into an interoperable IFC based BIM and rigorously validated using a model checking tool. Precision and correct modeling conventions are of the utmost importance for process. At this point the information needed for BEM is not present in IFC and the BIM to BEM transformation software called Space Boundary Tool (SBT-1) adds space boundaries to the IFC file in order to identify different types of heat transfer surfaces for BEM. This enriched IFC file is further processed by SBT-1 and transformed into a format required by whole building energy simulation tools like IDF for EnergyPlus. It is important to note that IFC based export of building geometry does not include explicit material and element cross section definitions that are consistent with BEM needs and consequently, workarounds are required.

Each of the following subsections corresponds to a process step defined in Figure 2:

- Create/Edit BIM in a CAD tool (Section 3.1)
- Validate BIM in Model Checking Tool (Section 3.2)
- Process Geometry in Space Boundary Tool (SBT-1) (Section 3.3)
- Validate Geometry for Simulation in CAD tool (Section 3.4).

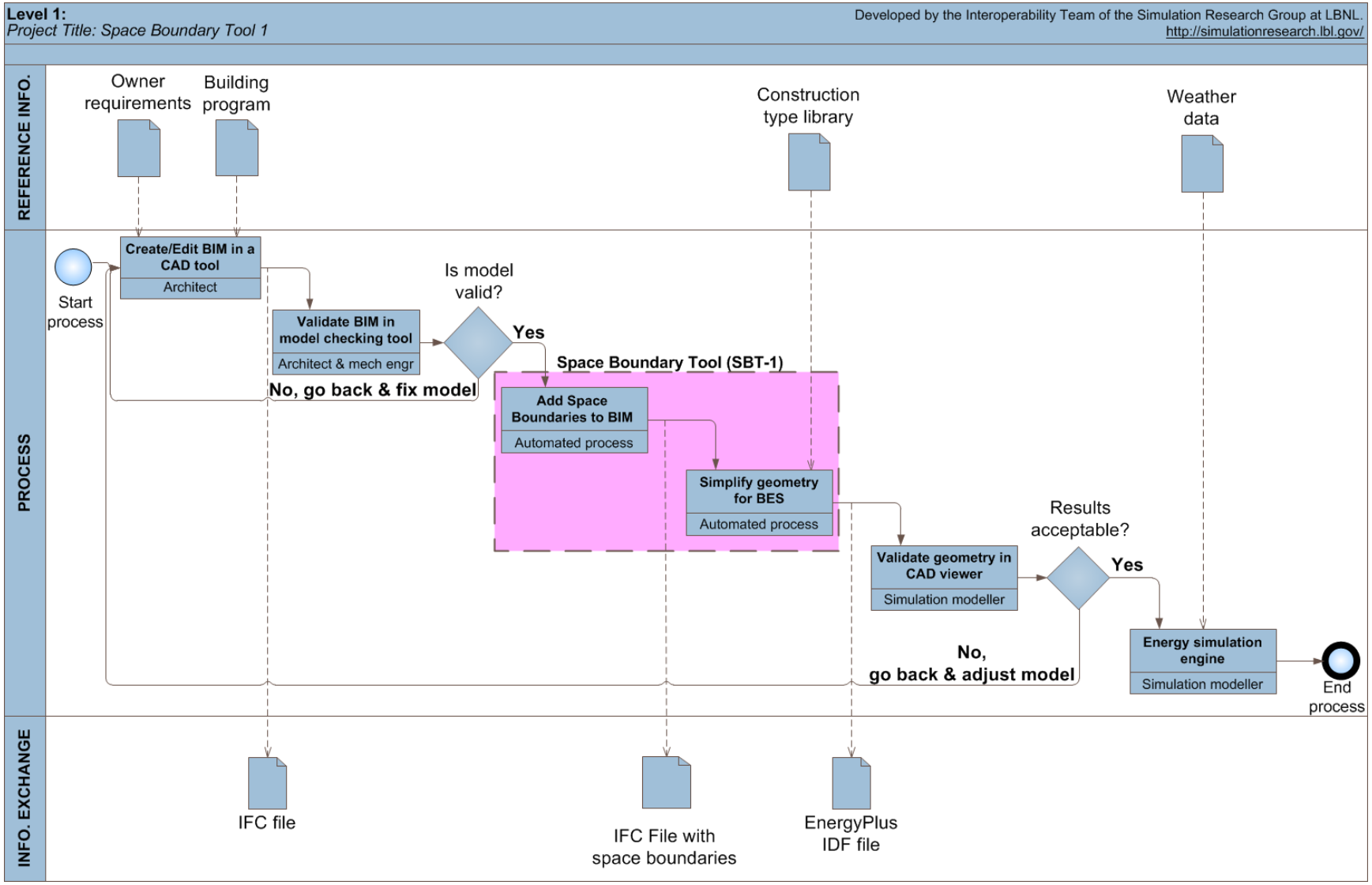

Figure 2: High-level diagram of software architecture data flow in semi-automated process, which is built around SBT-1

3.1 Create/edit BIM in a CAD tool

Each of the following subsections defines the conventions required for modeling the parts of a building that are important for whole building energy simulation. Where possible the order of the following sub-sections is consistent with the process of defining a building in a CAD tool.

3.1.1 General process outline

The authors recommend that the users of this process appropriately leverage CAD 'layers', a grouping mechanism that allows a defined subset of entities to be displayed or hidden on the screen. For example exterior walls should be on one layer and slabs on another. By doing so it is much easier to make global changes in the BIM.

3.1.2 Building location

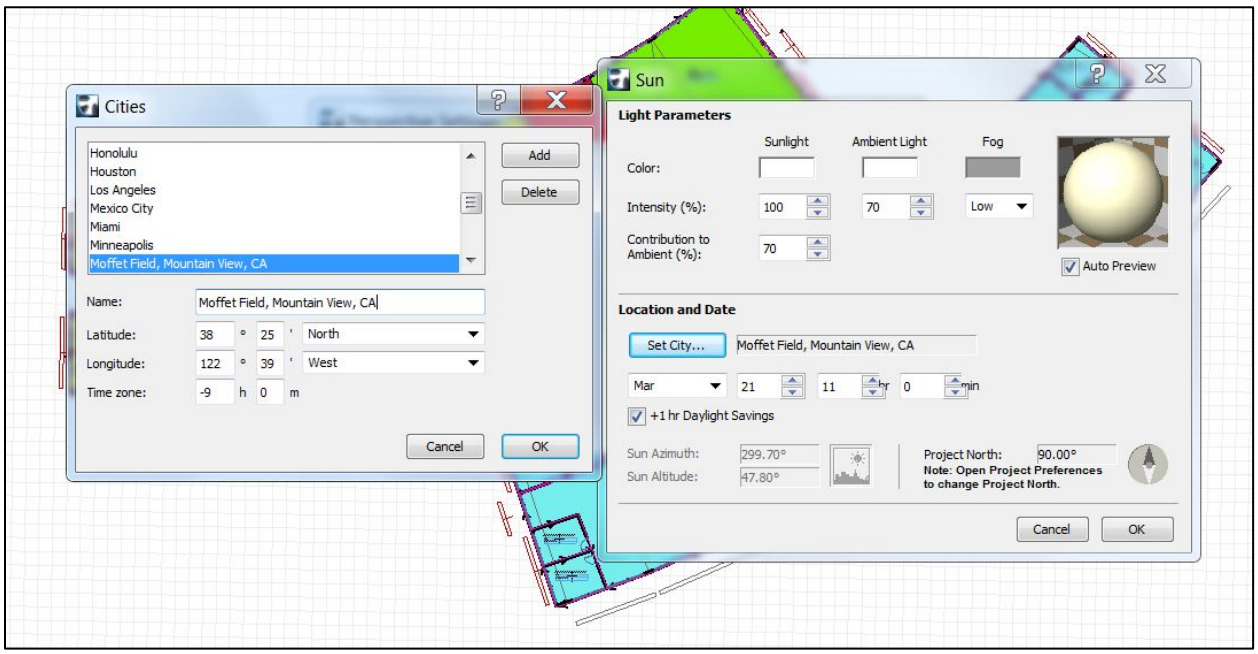

Figure 3: User selected location for NASA Ames and user entered value for building orientation.

Most of the data useful to define the geographical location of the building in EnergyPlus comes directly from the CAD tool. For example, in ArchiCAD and under 'View' -> '3D View mode' -> '3D Projection Settings', click on 'More Sun'. Here, the user can specify the city and the project's north orientation to true north (Figure 3).

User entered city latitude and longitude coordinates for the project correspond to similar properties in the 'Site:Location' object in EnergyPlus. Additionally users need to enter the site elevation as a property on the Site in the IFC Tree View window within ArchiCAD (Figure 3).

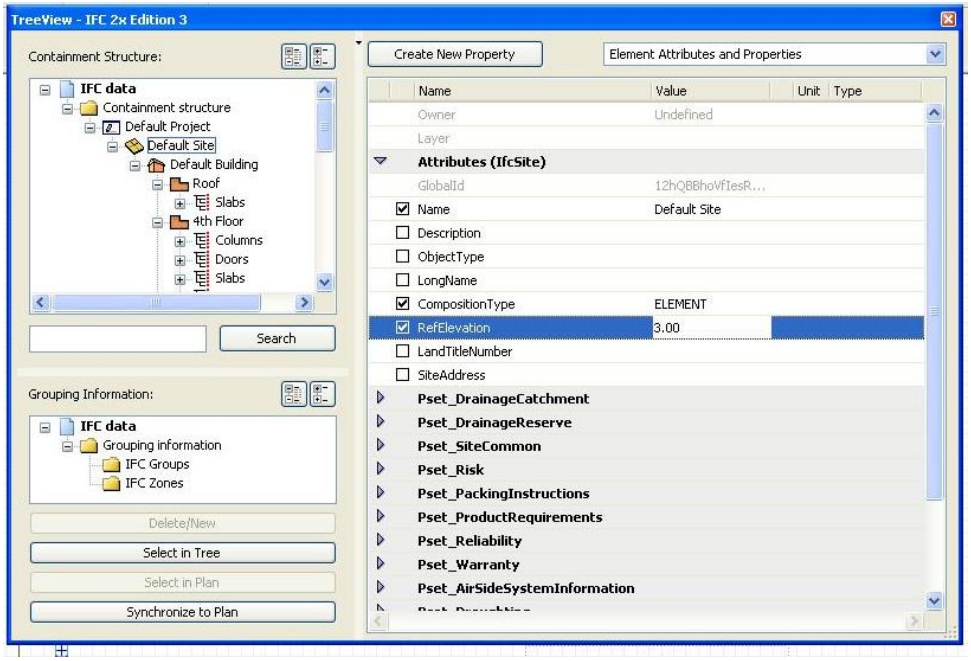

Figure 4: Input mechanism for user entered site elevantion for Nasa Ames, note the entry is in the ArchiCAD IFC window utility.

Note that the name of the city, for example Mountain View, is not saved in the IFC file and therefore does not pass through SBT-1. As a result it is important to manually enter the city name and time zone in SBT-1.

The north axis will also become a property of the 'Building' object ('North Axis' field) in EnergyPlus. It is important to note that EnergyPlus and ArchiCAD have different conventions for North Axis The EnergyPlus 'building azimuth' corresponds to' ArchiCAD 'project north' + 90°.

3.1.3 Building elements: materials and constructions

Thermal performance of construction materials is important for energy simulation. Each CAD tool has its own system of materials' definition. As ArchiCAD is taken here as the initial BIM authoring tool, the material definition in this tool will be defined in more detail. For the purposes of energy simulation, users should define one ArchiCAD 'fill type' for each material layer used in walls, slabs and roofs. Each 'fill type' will appear as a 'Material' in the IDF file which is necessary format for EnergyPlus input and an EnergyPlus material definition includes thickness. In parallel, users must create material library in IDF format that contains all of the relevant thermal properties and thicknesses for the materials. These thermal properties are currently not added to IFC BIM by CAD tools but this feature is planned to be added in the future to all CAD tools while exporting IFC format, as specified by the Concept Design BIM (buildingSMART, 2011). In order for the correct mapping to take place in SBT-1, the IDF material library must contain identical names to the 'fill type' definitions in ArchiCAD (Section 3.3). Users may also add

materials to the IDF material library or reference a different IDF file that contains the materials for a specific project[1].

A material layer or 'composite' in ArchiCAD is a list of material layers in a defined order. This ArchiCAD composite corresponds to an EnergyPlus 'construction' which also adopts the previously mentioned interior to exterior convention. EnergyPlus requires a 'construction' definition for each heat transfer direction that is perpendicular to a zone boundary. Special attention is needed for constructions of internal walls or internal slabs that are asymmetrical in cross section. SBT-1 presently skips asymmetrical constructions but places a warning in the IDF file for the user to manually correct. Users must therefore define a unique ArchiCAD 'composite' for each of corresponding 'construction' in EnergyPlus, for example, a unique definition for each type of wall, floor or slab cross section.

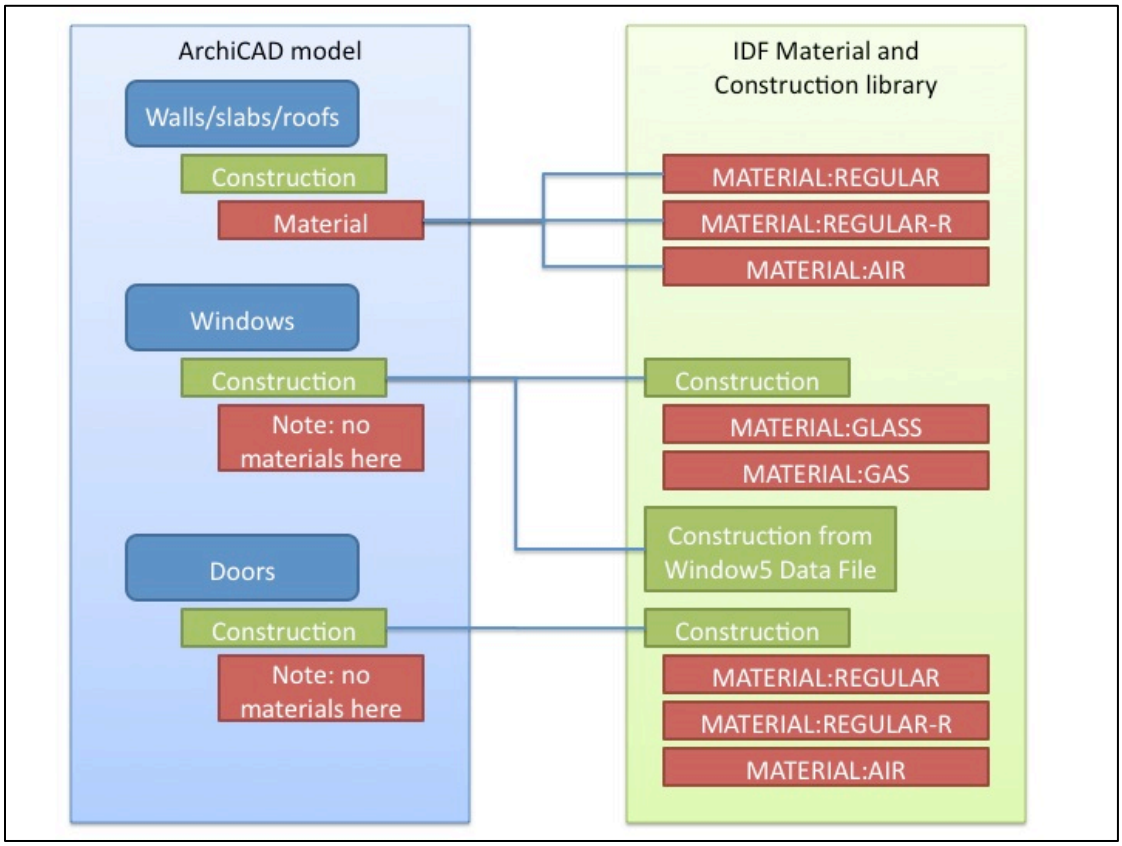

Figure 5: Material and Construction mappings for walls, slabs, roofs, doors and windows from ArchiCAD to EnergyPlus

In summary, SBT-1 uses two mapping processes between IFC files generated by ArchiCAD and EnergyPlus. Currently the materials and construction objects are supported as illustrated in Figure 5 depending on the object type classification:

[1] This process will change over time, especially if IFC files are required to contain material property definitions required for whole building energy simulation, these properties are currently optional in the Concept Design View Model View Definition 2010 (buildingSMART, 2011).

1. For standard opaque building elements, walls, slabs and roofs, mapping is performed at the material level (Figure 5). Each material definition is mapped to complete a construction.
2. For windows and doors mapping occurs at the construction level (Figure 5) and material definitions are not included in the mapping but are accounted for through the referenced materials file.

In order to enable IFC settings for Windows and Doors in ArchiCAD, the user must select entries from the IFC library of windows and doors rather than standard window and door entries, which are not properly exported to IFC. With this library in place users must select: 'Options' -> **'**Work Environment' -> **'**Tool Setting Dialog Boxes'

- Select the 'Window Tool' and enable Energy IFC 2x3
- Select the **'**Door Tool' and enable Energy IFC 2x3
- Click 'Ok'

The assignment of construction names for windows and doors requires a different process. Users must insert the appropriate 'construction' name in the PSet_WindowCommon. Reference or PSet_DoorCommon.Reference property that becomes available in the object settings for windows and doors once the settings have been enabled (Figure 5).

Special cases exist for windows in doors. For example, in the case where the door is completely comprised of glass (with only a small frame), SBT-1 will convert this arrangement to an EnergyPlus object: 'GlassDoor'. Alternatively one could define the window and door as separate sub-surfaces of a wall as EnergyPlus does not allow a window to exist as a subsurface of a door. The area of the wall and door will be off by the window area.

BIM consists of different definitions for different building elements. When drawing windows and doors it is important to use developed geometric conventions:

- For windows, draw the window and frame area, which is normally worked out from the schedules, and let SBT-1 assign a default perimeter of 1cm around for the window or define a customized frame in Window 6.3 (LBNL, 2012c).

- For doors: draw the door area which is normally provided by the schedules.

A special case of material definition also exists for when two adjacent zones are not separated by a wall or a floor/ceiling slab. In such cases a user must define a so-called "AirWall" which are automatically converted a 'Material:InfraredTransparent' in EnergyPlus, a definition with low thermal resistance and high absorptance of both long and short wavelengths.

EnergyPlus is unable to model curved objects and in order to account for these curved objects they must be approximated with flat surface segments. Furthermore, columns and curtain walls are not explicitly modeled in EnergyPlus and must be accounted for accordingly in the CAD tool. Only columns that are rectangular in plan are processed:

- SBT-1 converts rectangular columns embedded in walls into walls with the appropriate construction.
- SBT-1 converts rectangular freestanding columns into walls in zones with the appropriate construction.
- Explicit curtain walls are not supported in EnergyPlus so should be modeled as a combination of wall and window objects in ArchiCAD.

Application of CAD to BIM at NASA Ames Sustainability Base

The original BIM provided by Swinerton Inc. was appropriate for construction and cost evaluation but not applicable for BEM. Originally, Swinerton Inc. provided an ArchiCAD model and afterwards the original Revit based model. Issues arose with respect to many aspects of both BIMs and the model needed to be completely redrawn in ArchiCAD. The fact that the building's design also approximates a segmented curve compounded modeling difficulties and resulted in a case where very few walls intersect perpendicularly. Consequently, many small areas and angles persist throughout the IFC model. It is the authors' opinion that adequate training in the design of BIM for the purposes of BEM could resolve the majority of the issues encountered and a remodeling would not be necessary.

Issues encountered in the original ArchiCAD model include the fact that model was incomplete. The model did not contain accurate zone and space definitions. Exterior shadings, interior doors and windows were not drawn. Curtain walls were drawn as curtain wall objects as opposed to standard wall objects with arrays of windows. Opaque glazing surfaces, particularly spandrel glass elements, were not properly defined and thus created an incorrect intersection between walls and spaces. Based on a detailed construction site and 2D drawing analysis, the model was a few feet too short and had an incorrect orientation. Furthermore, the model had some construction elements, for example in detail drawn foundation that is unnecessary for BEM model.

Conversely, the original Revit model was drawn in too detailed a manner, for example it included all furniture and interior glazing that are not required for BEM, while on the other side it contained hundreds of small errors and inconsistencies. Firstly, detailed shading elements and curtain walls would not export correctly to IFC and required simplifications. The definition of many void spaces in the building was inaccurate, primarily because of the modeling inaccuracy where, for example, many interior walls intersected the exterior façade at a window. The floor slab was drawn as a single element, a feature that SBT-1 does not process because of the curved-like building form. Instead, the slab had to be drawn as a composition of many smaller slabs. Zones were inaccurately drawn resulting in numerous cases where space containment would have been an issue. Furthermore, plena were drawn as a void space without a zone definition (see Section 3.1.4 for a guide on zoning). The light wells, above the second floor, as illustrated in Figure 6, were too detailed for EnergyPlus to model due to the combination of localized increase in zone height and daylighting provided by their complex geometries. Consequently, the final BIM model developed for BEM simulation does not contain these skylights.

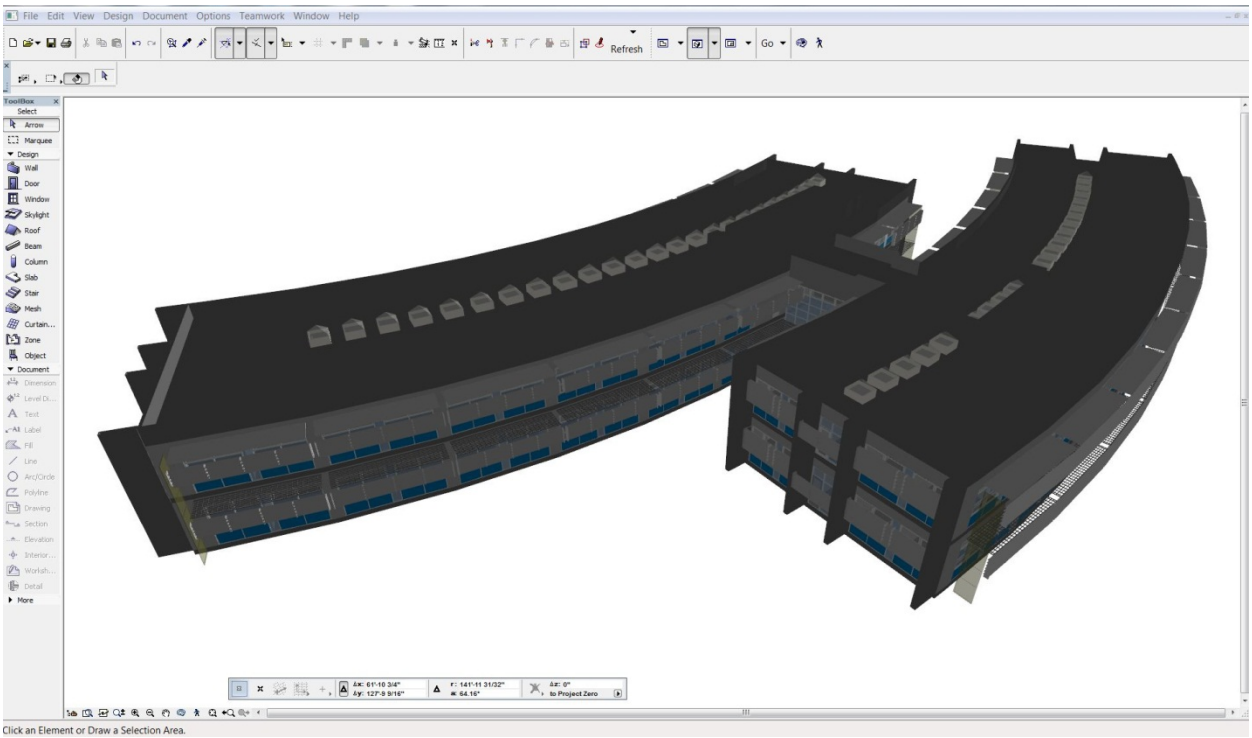

Figure 6: Original detailed BIM for NASA Ames Sustainability Base in ArchiCAD (courtesy of Nataša Mrazović)

In the context of the BIM to BEM process, the richer Revit based BIM provided much of the material and construction information required for development of the material database used by SBT-1. Any missing data came from the construction site specifications and a site survey.

3.1.4 Zoning

'ArchiCAD Zones' correspond to architectural spaces and IFCSpace entities. For the purposes of BEM, architectural spaces may be combined into thermal zones or IFCZone entities. It is important to define 'ArchiCAD Zones' for all spaces that are relevant to the energy model. A key modeling technique is to use the auto-fill function or 'magic wand' to automatically define spaces. The 'magic wand' also works as a checking mechanism as it will not generate a space if the space is not completely bounded, which is a critical requirement of EnergyPlus.

Within the IFC tree view in ArchiCAD it's possible to define IFC zones and combine or agglomerate spaces (defined as ArchiCAD zones) into an IFCZone. If two contiguous spaces are assembled as a unique zone, the resultant EnergyPlus definition comprises of the outer boundary surfaces of the new zone and the interior walls or slabs are converted to internal mass. A key point here is the definition of the plena by users on a separate building story, either above or below the standard zones. Figure 7 and Figure 8 show the use of color coding of ArchiCAD spaces to represent a simplified thermal zoning strategy in EnergyPlus where each thermal zone has a different color.

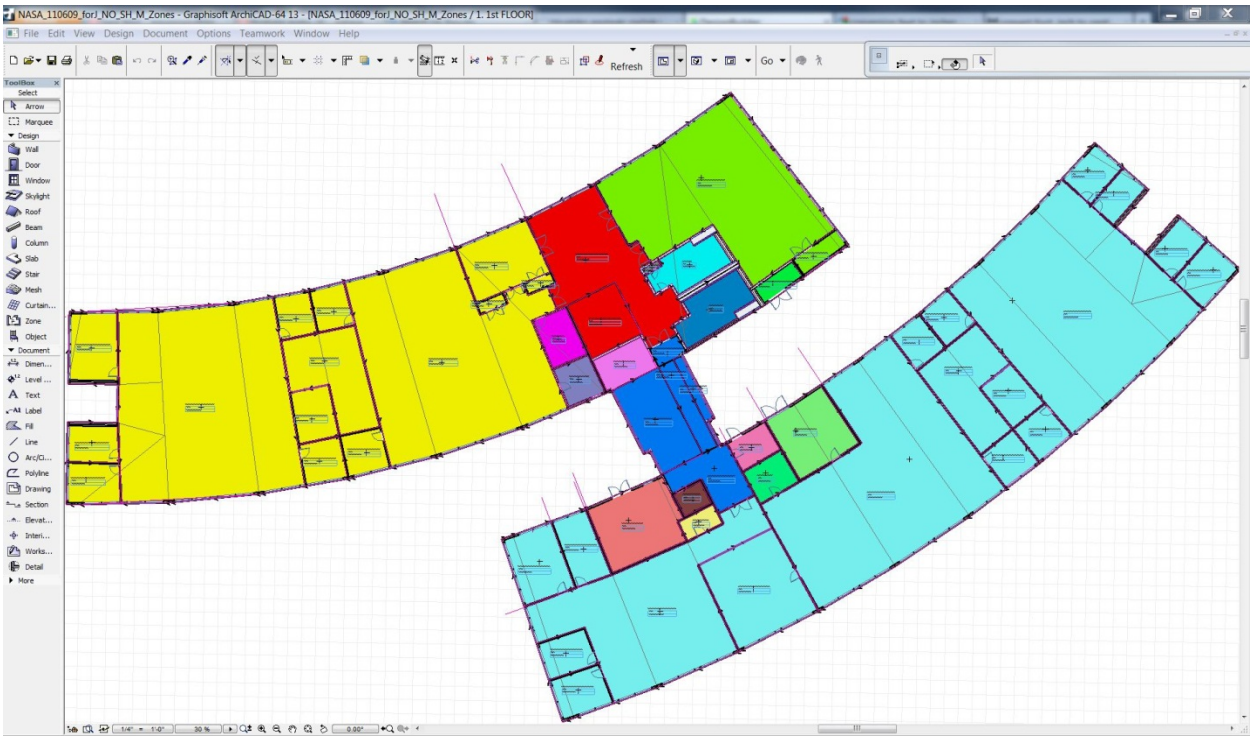

Figure 7: First floor simplified zoning layout for the Sustainability Base at NASA Ames (courtesy of Nataša Mrazović)

SBT-1 checks for unique space and zone names and uses Global Unique IDentifiers (GUIDs) in cases where non unique names appear.

As GUIDs are 16 randomly assigned character codes, not easily interpretable by humans, SBT-1 includes the following translation options for easier identification of zones in EnergyPlus:

- User assigned Zone names
- User assigned Zone Ids
- User assigned Zone names + Zone Ids

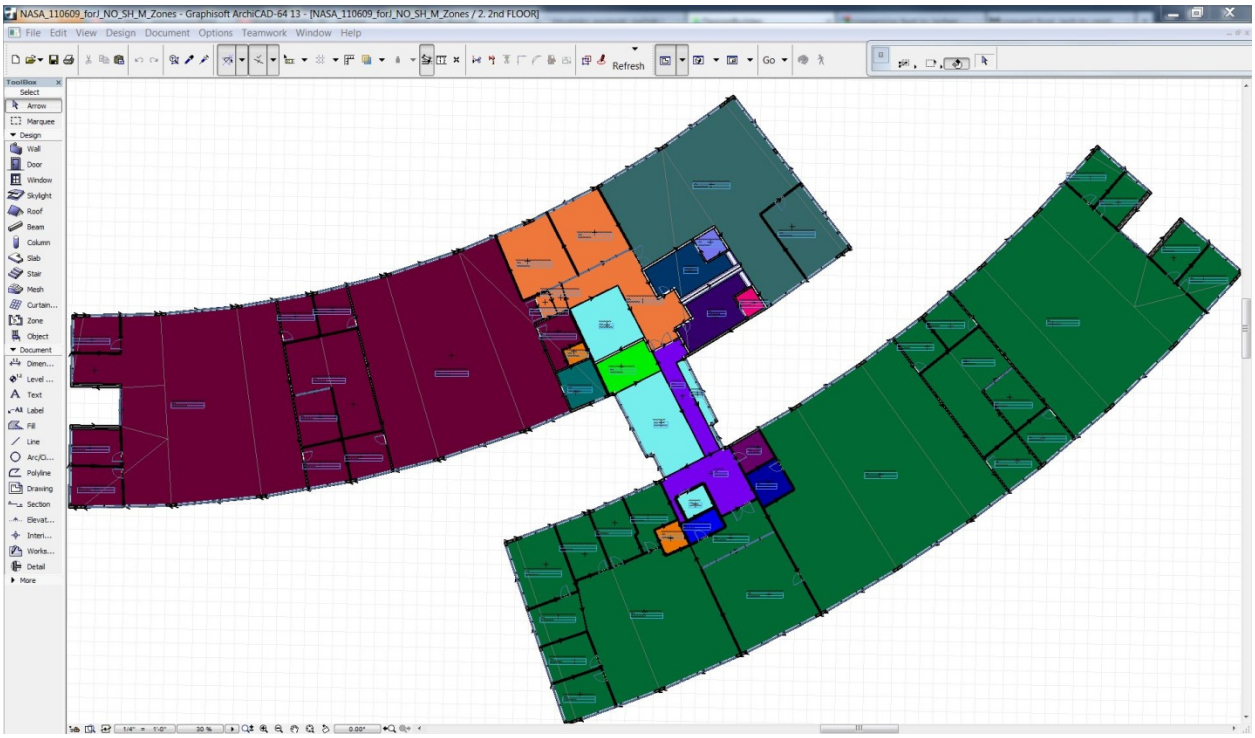

Figure 8: Second floor simplified zoning layout for the Sustainability Base at NASA Ames (courtesy of Nataša Mrazović)

Application of Zoning at NASA Ames Sustainability Base

The architects that designed the NASA Ames Sustainability base building adopted a simplified zoning strategy by assuming uniform conditions over large areas of the building. The presence of curtain walls technology that incorporated operable windows reduces solar gain while enabling natural ventilation, light shelves that allow daylighting to penetrate deep into the space and a system of radiant panels, all contributed to the simplified zoning strategy that agglomerated similar space types into large thermal zones. From the energy simulation point of view, a reduced number of thermal zones also significantly reduce simulation runtime.

3.1.5 Shading surfaces

Within the CAD tool, a wall or slab object should be used to represent shadings such as overhangs and fins. The walls or slab are saved in the exported IFC file as an extrusion profile with an extrusion direction as illustrated in the figure below:

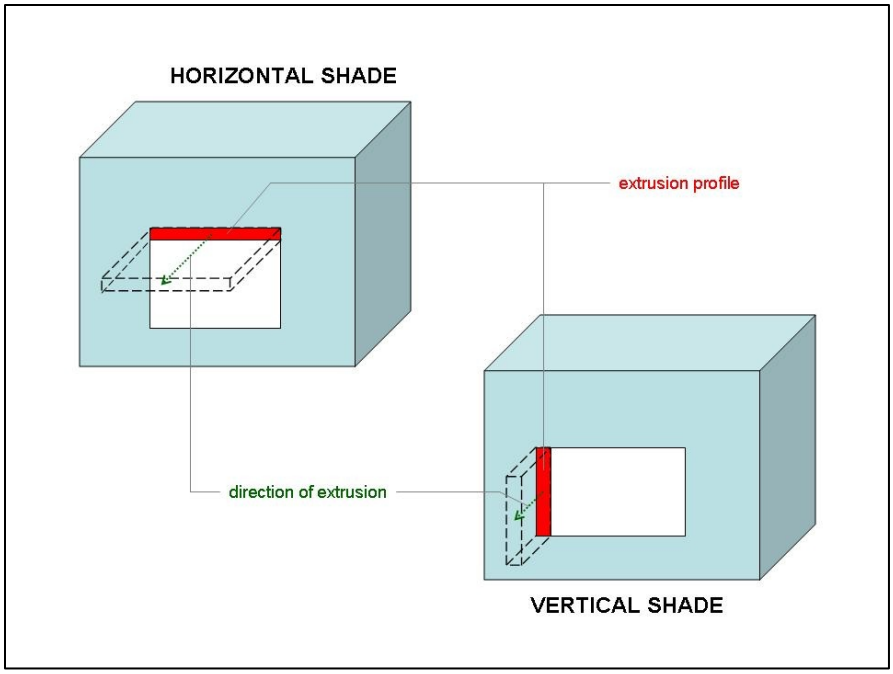

Figure 9: Technical conventions for horizontal and vertical shading

Shading elements as illustrated in Figure 9 are cuboid definitions attached to an exterior surface. Shading elements are not horizontal slab extrusions or vertical wall extrusions. For specific shading definitions, SBT-1 converts each cuboid into five shading planes in EnergyPlus. In each case the sixth cuboid surface or red surfaces in Figure 9 is omitted. Shading elements attach to exterior walls that are defined as planes with a thickness property in simulation. In each case the plane is in fact the space boundary and the exterior surface of the wall is offset from the space boundary by the thickness of the wall. SBT-1 automatically accounts for this offset and moves the shading surfaces to represent correct facade shading accordingly.

Application of Shading at NASA Ames Sustainability Base

With correct location and proper definition of shading in the CAD tool, the CAD model is ready for export to IFC BIM. See Figure 10 for a complete visualization of the BIM that was exported from ArchiCAD. The positioning of the horizontal and vertical shading elements correctly reflects the deployed shading structure.

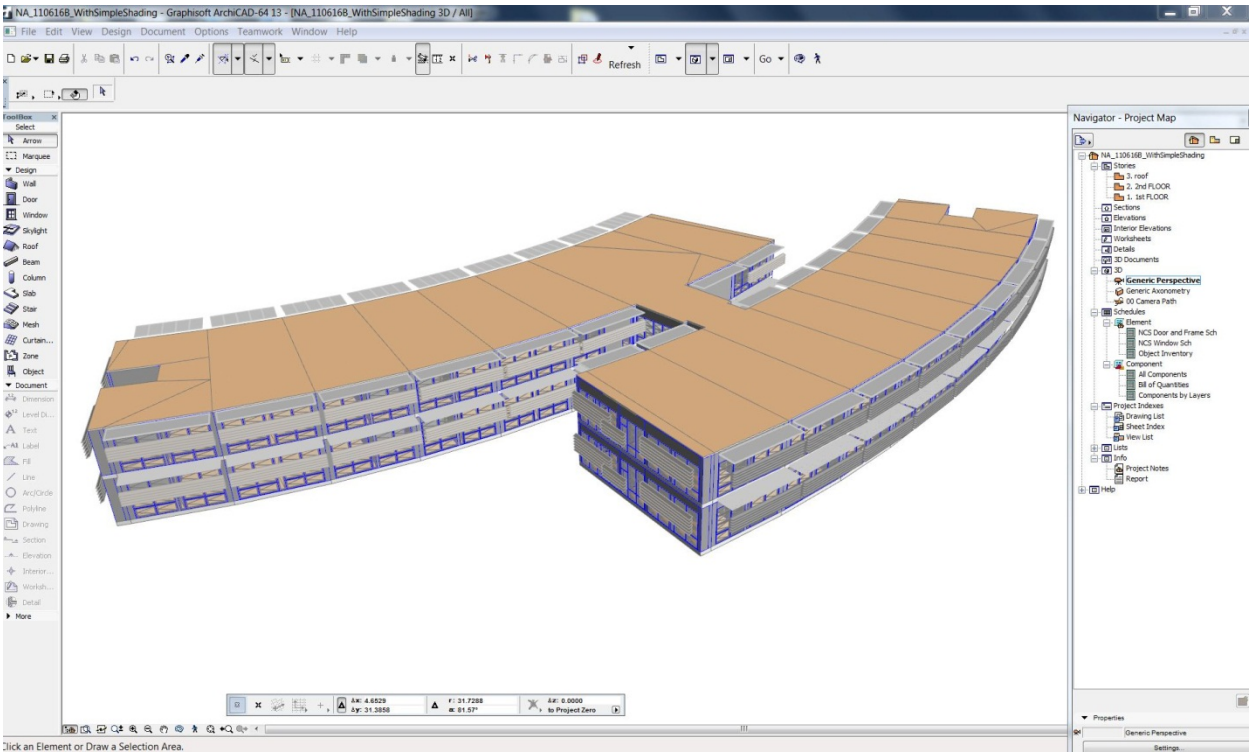

Figure 10: Complete BIM representation of NASA Ames Sustainability Base for the purposes of whole building energy simulation (courtesy of Nataša Mrazović)

3.1.6 Export as IFC file

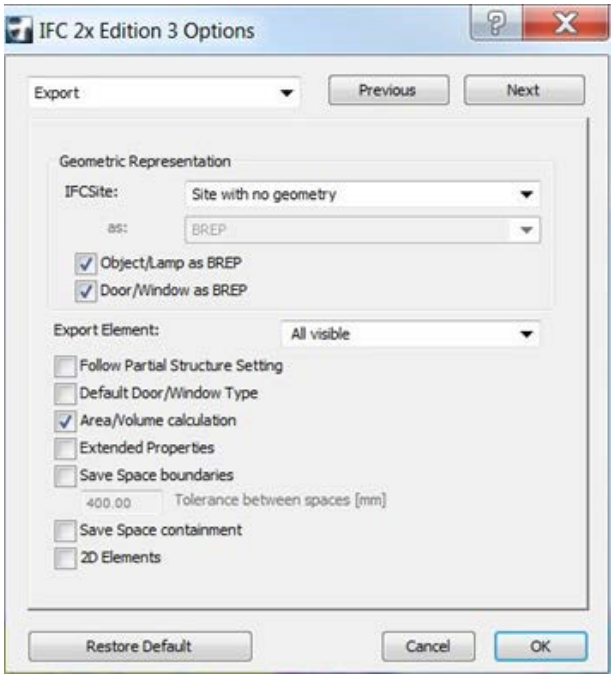

Figure 11: Required export settings for IFC export from ArchiCAD. Note that space boundaries are not selected.

Certain settings are important for export of geometry to the IFC file. It is crucial to select the 'Area/Volume' calculation from the export settings menu (Figure 11). The area and volume for each IFCSpace is calculated and saved in the IFC file and mapped into IDF format by SBT-1. EnergyPlus performs its own calculation and checks for significant differences between the results. In the cases that identify a difference in volume or height, the input parameter overrides the equivalent calculated value in EnergyPlus. A final item to remember is that the height in EnergyPlus is referred to as ceiling height (floor to ceiling height), which is not the same as floor to floor height.

Another detail to consider is users must enable the "Door/Window as BREP" (Boundary REPresentation) option as without it ArchiCAD does not save windows. That is IfcWindow objects are absent in the IFC file.

3.2 Validate BIM in model checking tool

This section describes how to check the appropriateness of the IFC file for use in SBT-1 using a customized model checking tool such as Solibri Model Checker (SMC) (Solibri, 2012). Open the IFC file which has been exported from ArchiCAD in SMC and check the file for errors using the latest ruleset (a predefined set of checks for a defined purpose such as building code compliance, BEM, etc.) for SBT-1, in Solibri. For details on the history of these rule sets and to download them online, the user should visit RuleSetHistory section of (Maile, 2012), as of writing this report "GST_IDFGeneratorRuleSetV8.2.cset" is the latest version.

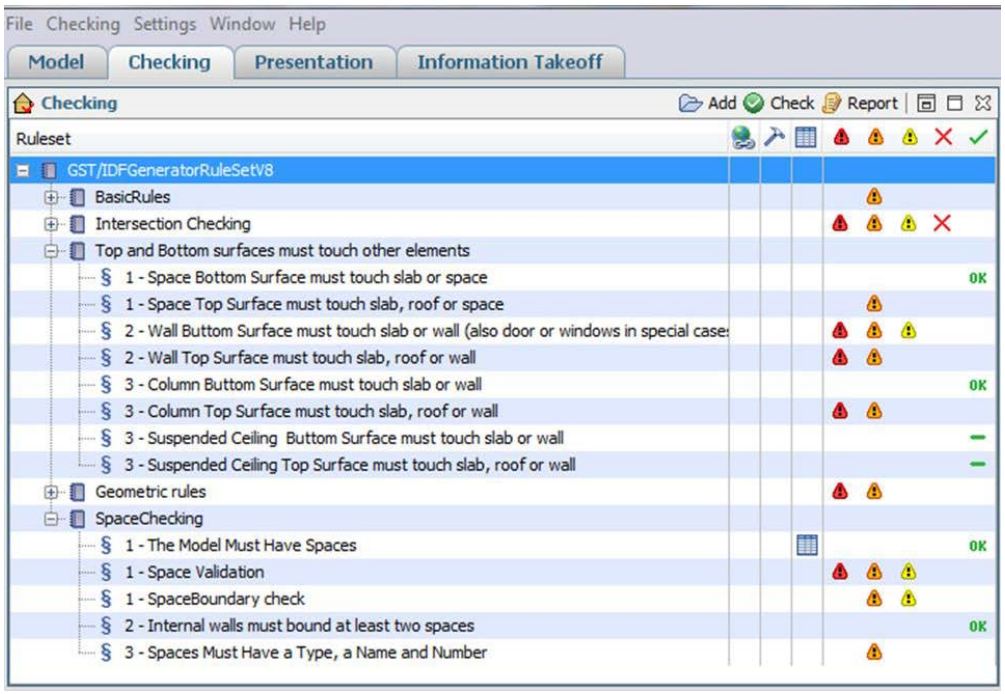

Figure 12: Example of a summary of results from model checking with SMC

The basic premise is for the user to identify the errors in SMC, locate and correct the errors in ArchiCAD and export the updated file as an IFC file and repeat the Solibri checking process once more to confirm that all errors have been corrected properly. This may take multiple iterations until all errors have been corrected.

3.2.1 Customized SBT-1-SMC rule set for BEP simulation

The authors developed a customized rule set to support the checking of model correctness in the BIM to BEM process. The rule set includes the following rules:

1. **Basic rules:**
   A number of very basic rules are present that should all be passed such as all required components are present in the model, a check for doors or windows that are not embedded in a wall and that all elements have a GUID.
2. **Intersection checking**:
   There should not be any intersections between building objects, for example parts of a wall and slab should not occupy the same 3D space.
3. **Top and bottom surface must touch other surfaces**
   This is the most important part of the rule set as space boundaries are generated at the connection between space and building object, therefore spaces and building objects must align in a way that there are no gaps. If for example a user creates a floor or a ceiling slab with a void, then the user must also define an air slab to account for this missing volume. Currently, we can only check if this is the case for top and bottom surfaces. In certain cases, some walls or other objects may indicate no object on the top surface which may be a false positive if for an adjoining wall a window is close to 100% of total wall area.
4. **Geometric rules:**
   - **Allowed profiles for columns:**
     Highlights all columns that are not rectangular and a width or length greater than 5'
   - **Wall validation:**
     Checks if walls are extrusions.
   - **Verify material layer thickness:**
     This rule checks if the geometrical thickness is equal to the thickness of the related material layers.
5. **Space Checking (All checks applied to instances of IFCSpace)**
   - **The model must have spaces**
   - **Space properties:**
     Checks some properties of spaces. These are not necessarily required, but help to identify spaces that have non-unique combination of names, ids and numbers.
   - **Space Validation**:
     Since space boundaries are calculated based on the space volume it is crucial to test if the volume of the space intersects with other elements, i.e. the element and the space occupy the same volume.
   - **Space dimensions must be within sensible bounds:**
     Makes sure that the spaces have a somewhat reasonable size.
6. **Property Sets:**
   - **Window/Door property set check:**
     Checks if the reference property of the PSet_WindowCommon (or PSet_DoorCommon) is filled to define the window/door construction.
   - **Shading device PSet:**
     Checks if the shading device's property set is present (can be ignored if no shading devices are defined).
7. **Verification rules**
   - **Construction check**:
     Checks the constructions or 'material layer sets' against a set of user defined constructions.

Can be useful to check the correct construction assignment as this check can also list the construction assignments on an element by element basis.

- **Visualization of spaces by height:**
  Just visualizes the spaces by height, can be useful to find problems with space heights.

8. **Windows and Doors:**
   - **Doors and Windows must be connected to spaces:**
     Checks if internal windows/doors are connected to two spaces and external windows/doors are connected to one space (works only if external walls are defined) .

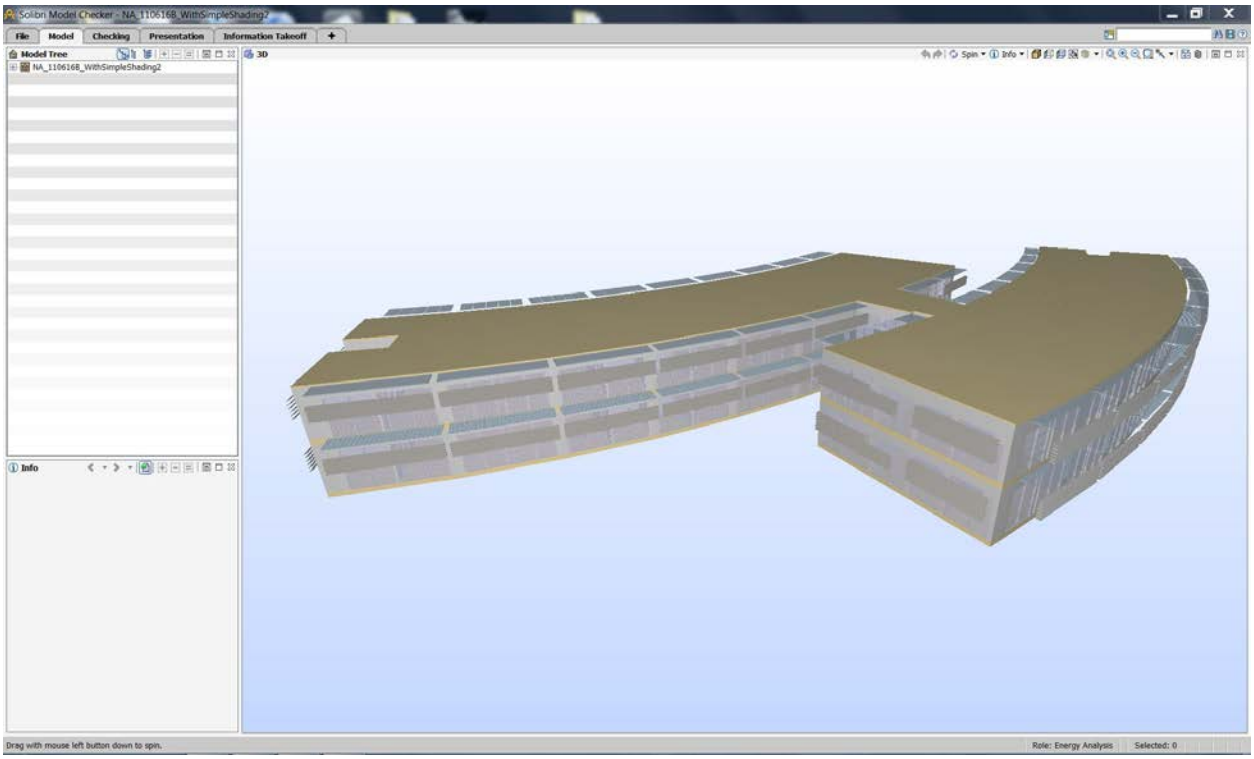

Figure 13: SMC representation of the IFC file for NASA Ames Sustainability Base (courtesy of Nataša Mrazović)

Application of Solibri Model Checking Tool at NASA Ames Sustainability Base

The IFC files exported from the original CAD files that contained the BIM information not developed with BEM in mind (Section 0), showed hundreds of SMC errors while checking the files. The fundamental lessons learned were that modeling precision is of the utmost importance and if the BIM designer had a set of guidelines, most of the errors and lost time associated with fixing the errors could have been removed. The custom built BIM required numerous iterations due to the issues that arose from the absence of perpendicular walls, curtain wall definitions and shading element definitions. Once all tests were passed the model was ready for processing through SBT-1.

3.3 Process geometry for BEM (SBT-1)

SBT-1 is a standalone tool that processes IFC files for the purposes of BEM. The tool contains a rudimentary interface that enables selection of IFC files, a number of runtime options and the specification of an output file, Figure 14 illustrates some the selections and runtime options from two of the 5 tabs. This tool contains two sub processes, the first of which adds space boundaries, as defined in

(Bazjanac, 2010), to the clean IFC file. Without space boundaries it is virtually impossible to determine the heat transfer and non-heat transfer surfaces required by whole building energy simulation tools.

The second sub process transforms the space boundary definitions now contained in the amended IFC file into the geometry representation appropriate for BEM. This second process also references a user defined external materials file in order to align geometric and thermal properties for BEM. The output of this process is the simulation input file that is ready for simulation, in this case IDF format for EnergyPlus.

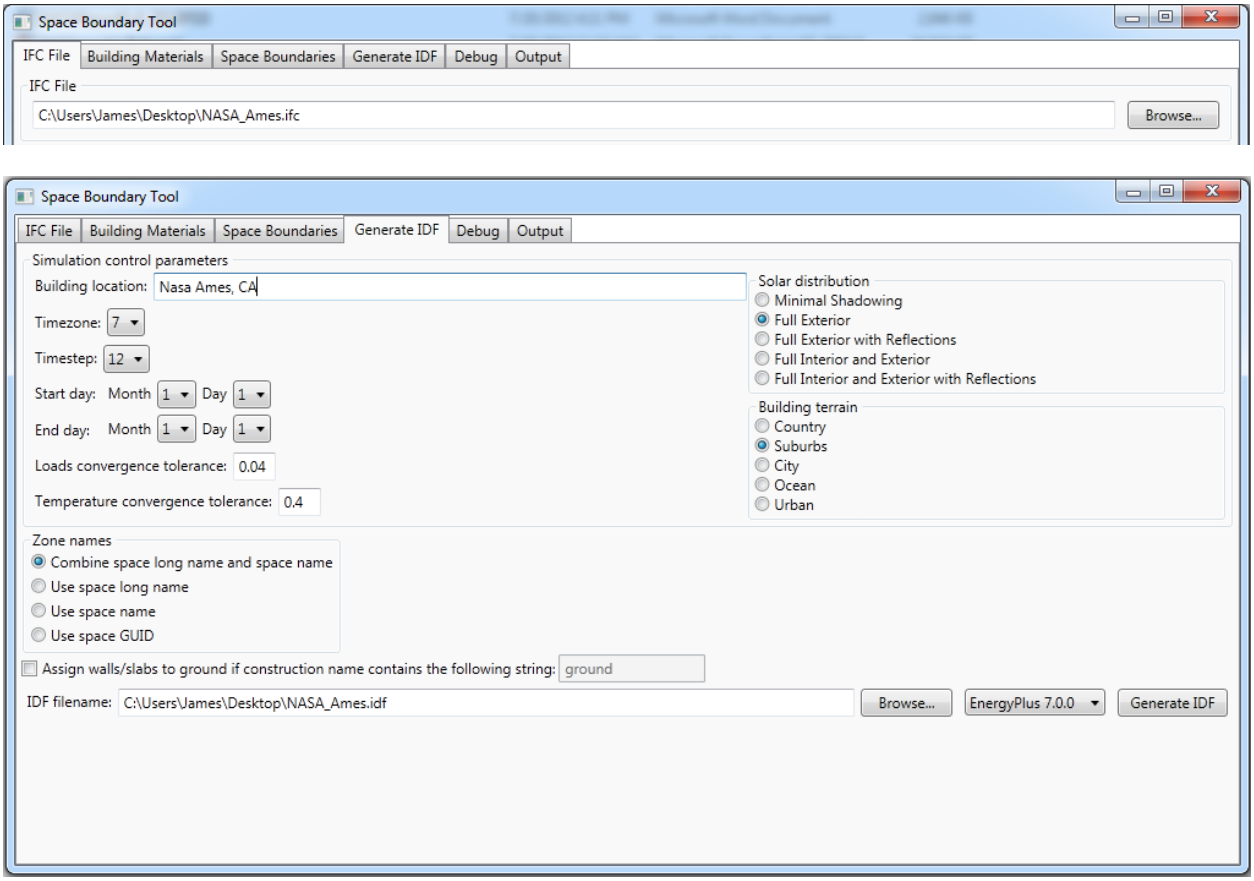

Figure 14: Two of the SBT screens showing IFC file input selection and corresponding IDF file name

Application of SBT-1 at NASA Ames Sustainability Base

Figure 15 illustrates a space boundary representation of NASA Ames Sustainability Base which is only available after the first part of the SBT-1 process has executed.

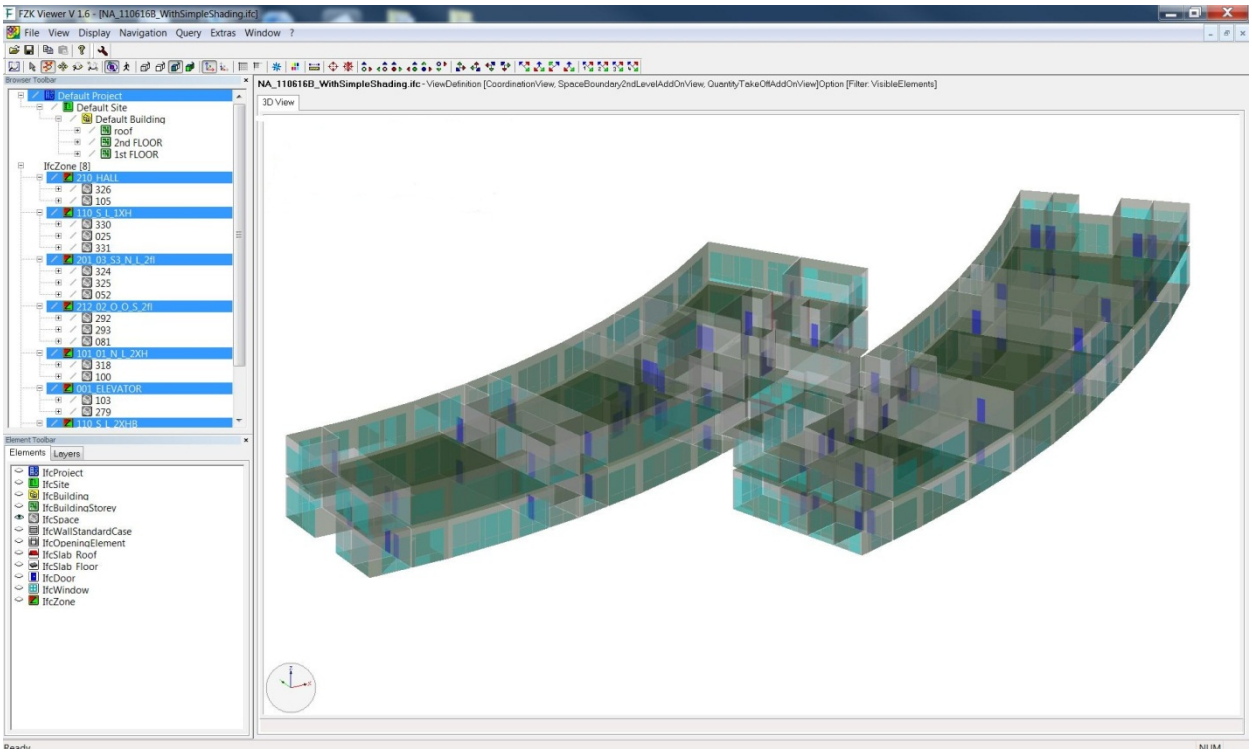

Figure 15: Space Boundary representation of NASA Ames Sustainability Base as displayed in FZK viewing tool (courtesy of Nataša Mrazović)

Figure 16 illustrates the output from part 2 of the SBT-1 process, an IDF file ready for simulation in EnergyPlus. The Sketchup image clearly displays all surfaces in their correct locations (Ellis et al., 2008). A graphical check of output offers users a preliminary investigation into the fidelity of the transformation process from BIM to BEM allowing easy identification of missing or erroneous surfaces.

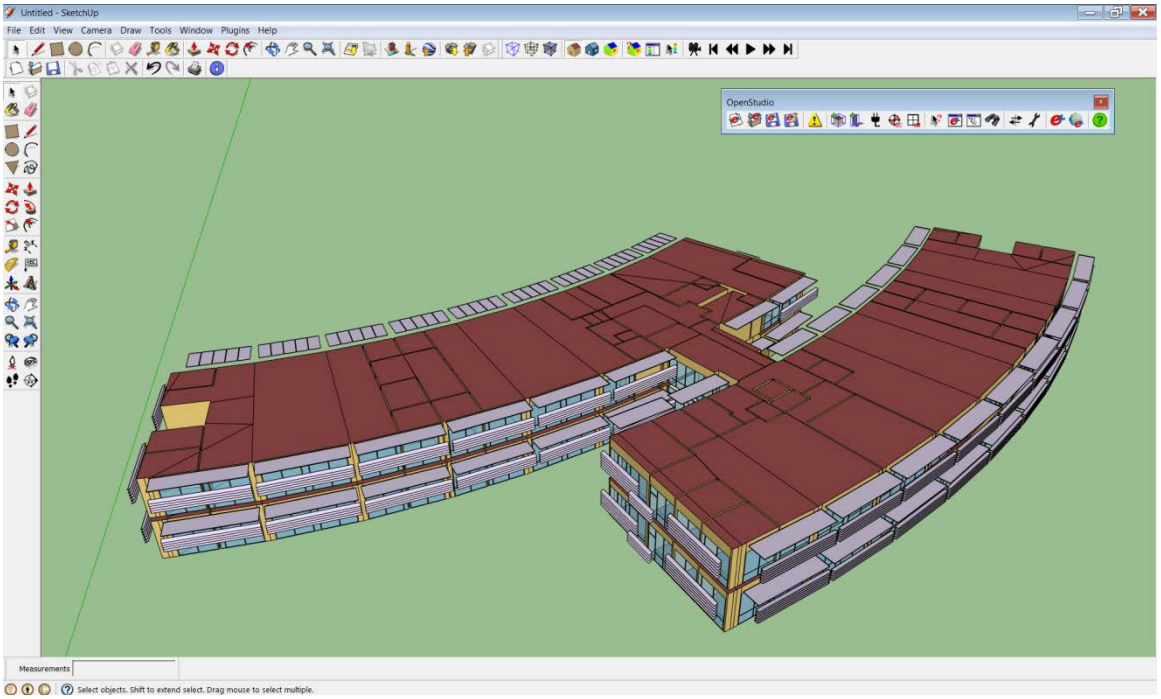

Figure 16: EnergyPlus IDF representation of NASA Ames Sustainability Base geometry prior to simulation run (courtesy of Nataša Mrazović)

Due to the complex nature of the building geometry, NASA Ames Sustainability Base required some manual manipulation of IDF geometry in order to deliver the final image displayed in Figure 16, examples of which include some corrections to windows in curtain walls, some missing floors and ceilings and manual triangulation of some surfaces. In spite of this manual intervention, the semi-automated process delivered significant time savings when compared with other geometry input methods such as a text or spreadsheet editor or some of the available graphical user interfaces.

3.4 Validate geometry for simulation

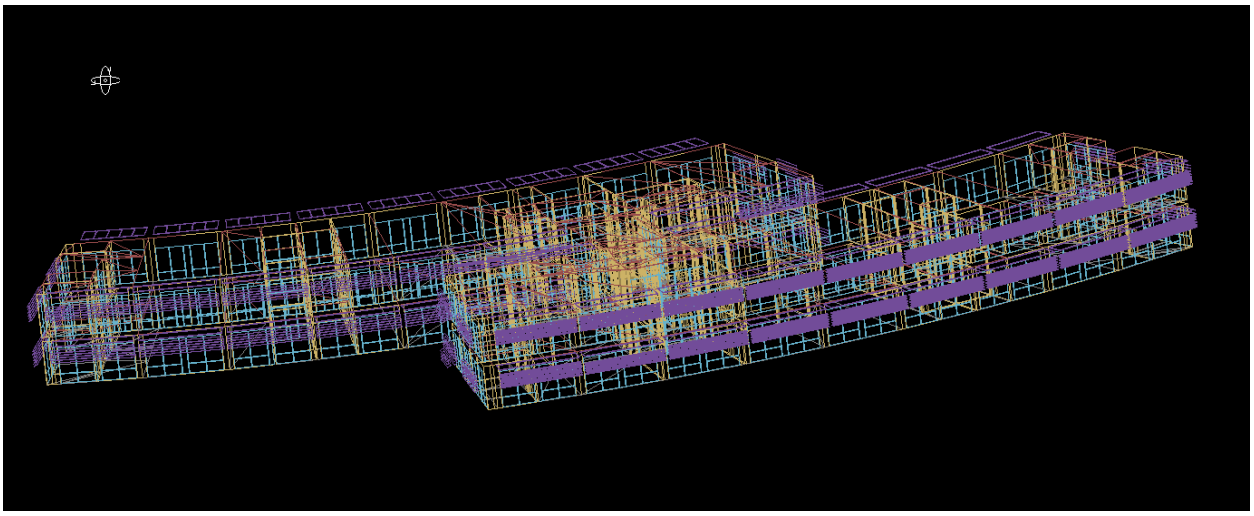

Figure 17.EnergyPlus IDF representation of Building geometry, that is converted to DXF format for viewing purposes, prior to simulation run (courtesy of Nataša Mrazović)

The final check is to ensure that the model runs successfully through EnergyPlus without any geometry related errors or warnings. Figure 17 illustrates a DXF representation of NASA Ames Sustainability Base as understood by EnergyPlus which generates the DXF file as the program executes. It offers a further wireframe validation of interior surfaces as well as façade representations.

4 Ensuring success

Developing BIM based criteria to support the semi-automated process should result in significant reliably improvements and time savings in the development of whole building energy simulation models. In order to define successful BIMS, CAD export of IFC based BIMs for BEM must adhere to a standard Model View Definition (MVD) for simulation as provided by the concept design BIM MVD (buildingSMART, 2011).

Some initial overhead must be expected as companies would need to develop their own material libraries to support automated activities and undertake a pilot project to improve understanding of modeling conventions and design tool features and limitations. To ensure a successful process developing BIM criteria to support the semi-automated process:

- Start discussions before design starts
- Engage all relevant stakeholders
- Expect some educating will be needed
- Develop BIM models with BEM in mind – a precise process based on rules and conventions as opposed to the imprecise and ad-hoc representations of contemporary BIM.
- Document the process and the results
- Keep the BIM criteria as a living document throughout the project in order for future projects to benefit from lessons learned.

- An investment in defining the BIM criteria to support the semi-automated process should enable a fair analysis of all design alternatives and provide long term value as part of an easily updated BEM for use as a performance benchmark during operations.

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The interoperability team at Lawrence Berkeley National Laboratory, Berkeley, CA, USA focuses on delivering life cycle interoperable solutions to the challenges faced by our current and future building stock (LBNL-SRG, 2012).

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