BIM to BEM Processes in the Centre Block Rehabilitation

Adrian Soble[1], Selena McRae[1], Daniel Knapp[1], Martin Sing[1]
[1] WSP Canada / CENTRUS, Ottawa, Canada

Abstract

This paper presents two methodologies being investigated to support building performance simulation in the Centre Block Rehabilitation project. The translation of building information models (BIM) to building energy models (BEM) aims to leverage existing architectural data to produce energy models more effectively. A significant amount of time is spent by simulation practitioners developing model geometry, hindering the response time between when an analysis is requested, and when results can be shared with a stakeholder. The vision of BIM to BEM research is to one day have tools available that can take a complex BIM file and produce a workable energy model with minimal time spent manually correcting the data to meet the specific needs of an energy model. The proposed processes discussed are augmented, meaning that scripts are used to expedite the process, but still require manual work to create simplified geometry models. The first process presented uses Revit's gbXML export feature to produce a file that can be imported into IES. The second process presented uses a Grasshopper component called Grizzly Bear to generate a gbXML file. In both workflows, architectural information still must be simplified prior to export. The intention of presenting these methodologies is to share the work that has been conducted at CENTRUS to meet the need for a functional BIM to BEM workflow.

Introduction

The Centre Block is Canada's main parliamentary facility, hosting both the House of Commons and Senate chambers. The building, which first opened in 1920, will be completely rehabilitated to meet modern standards and the future needs of Canada's democracy. As part of the project delivery a robust amount of modelling has been conducted. CENTRUS is the design joint venture between WSP and HOK leading the Centre Block Rehabilitation. Building information modelling is being leveraged throughout the delivery of the rehabilitation.

Building information models (BIM) are developed collaboratively by architects, engineers, and other designers in order to integrate all of a building's systems together prior to the construction phase. The intention of employing a BIM model is to develop a detailed drawing package that can be easily revised and reviewed, minimising conflict between building elements (Sacks, Eastman, & Teicholz, 2018). With the increasing use of BIM within the building industry, building performance practitioners are working towards leveraging existing BIM models to more efficiently produce building energy models (BEM). BIM models contain geometric information about the proposed building, data about materials used in the building, and other metadata related to space use and occupancy; all of which are critical to producing a BEM file (O'Donnell, et al., 2013). Although this useful information may be presented clearly in the BIM tool, the clean conversion of this information to a workable format in an energy modelling tool has been proven to be labour intensive and often exceeds the level of effort required to create a new energy model from scratch (Fernald, Hong, Bucking, & O'Brien, 2018).

The collective industry vision for BIM to BEM is to develop a tool that can convert a BIM file into a workable BEM file with as few steps and as little manual work as possible (GbXML Inc, 2022). In tools such as Revit, there are gbXML export features which attempt to offer this capability, but are hindered by the fragility of energy modelling software which requires, among other things, precisely defined bounded volumes (Yang, Pan, Zeng, Lin, & Li, 2022). The promise of a fully automated conversion process has yet to be realized for industry practitioners.

As a stopgap for when more of these tools are made available and made more resilient to complex geometry, an augmented translation approach has been investigated. This approach uses scripting to translate the BIM into a workable format that can be successfully translated into a BEM in IESVE. IESVE is a preferred energy simulation tool because of its capacity for complex and easy to manage HVAC system modelling. The purpose of this approach is to create a repeatable, stable, and deployable methodology–using Revit, Rhino Inside, and Grasshopper–that leverages existing BIM information to create an energy model that can successfully run. The essence of this process is to strip the BIM of unnecessary information and simplify the geometry to a level where completeness of space enclosures is more likely to be maintained during the gbXML export and import process. Within the workflow a new simplified BIM is generated which is tuned to match the priorities of an energy modeler and is expected to pass through a gbXML export with reduced corruption. Details like window geometry and wall construction groupings are also translated.

An Augmented Revit Workflow

The geometry in the BIMs developed for Centre Block is influenced by site measurements such as detailed point cloud data (Chow, Graham, Gallant, Rafeiro, & Fai, 2019). This means that the walls in the Revit file accurately represent natural deformations and irregularities that one could expect from a heritage building. The workflow presented in Figure 1 is most applicable when the building geometry is large, complex and possesses irregularities. For smaller scale models or cases where model zoning does not need to be as granular, this process may require more time and effort than drawing the energy model from scratch.

Metadata like thermal construction properties are not directly transferred from Revit to IESVE using gbXML in this workflow. Rather, the groupings of wall constructions, i.e. wall types, are preserved. Detailed constructions and thermal performance are then assigned manually to each wall type in IESVE.

Each floor of the model is processed individually and each of the gbXML files that are produced represents a single floor. The levels are stacked within IESVE following import. Spaces that span multiple levels are represented as multiple zones and holes between levels are manually added in IESVE.

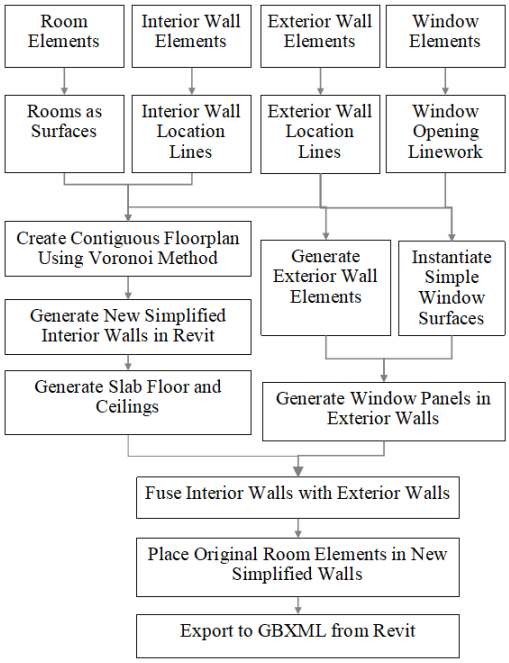

Figure 1: BIM to BEM methodology using Revit.

Revit Model Elements

The process takes four main element categories of a BIM file and converts this information into simplified linework geometry for further processing. The elements are targeted individually as there are scenarios where the building elements in large Revit projects are stored in different files and linked together in a work session. In smaller Revit projects one could expect to see all relevant elements hosted in the same file.

Rooms as 2D Surfaces

The room elements are conceptual volumes that are placed within the bounding walls, ceilings, and floors within the Revit model. The volume of the room element is generated as a closed polysurface in Rhino Inside and an XY cross-section of the volume is taken to collect planar room boundary lines. A midheight crossection is used to prevent complex wall geometry (such as baseboards) near the base of the walls from unnecessarily complicating the footprint of the Room. Room elements have properties related to room name, number and other logistical information used for planning. These properties are applied as Rhino attributes to the corresponding simplified surface. The 2D surfaces are translated down to match the elevation of bottom boundary of the room and are baked into a Rhino file. When using Rhino and Grasshopper, baking is the command that saves new geometry into the Rhino document based on the current state of the Grasshopper script. As seen in Figure 2, looking at the floorplate from above, a space between room surfaces can be seen; these gaps represent the thickness of the room-bounding walls within the Revit Model.

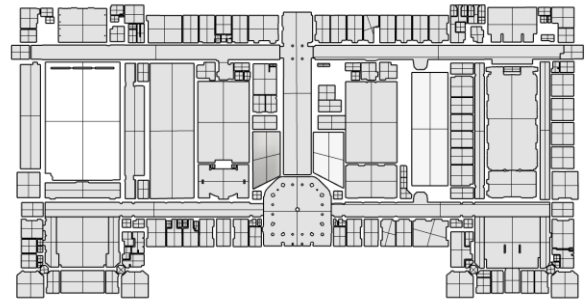

Figure 2: Room elements as 2D surfaces

Interior Wall Location Lines

The interior wall elements are selected, and the centre location lines are identified and baked into a Rhino file. Construction information like the wall family type is stored into Rhino as an object attribute. The line locations are re-adjusted to ensure they match the lower boundary elevation of the level being worked on.

Exterior Wall Location Lines

Similarly to the interior wall elements, the exterior wall elements are selected, and the centre location lines are identified and baked into a Rhino file. The exterior wall locations then must be simplified to prevent complications further down in the workflow. A slight angle mismatch in the linework can cause volume enclosure issues once the

gbXML is imported into IESVE. In order to increase the rectilinearity of the exterior walls, the lines are projected onto a finely scaled grid of points. The exterior lines are shattered into individual line segments. The start and endpoint of each line segment is adjusted to align with the grid. The spacing of the grid points is adjusted until the exterior line segments overlap, and can be re-joined as a closed polycurve. This process was observed to not guarantee perfectly rectilinear exterior linework but has been observed to reduce the number of irregularities.

Each level will require its own exterior linework, and must be manually reviewed to ensure that exterior walls that extend through multiple levels are correctly aligned. The exterior lines for each level should be generated simultaneously to ensure that the new geometry remains stackable and flush along each façade.

Create Contiguous Floorplan Using Voronoi Method

The objective of this step is to produce linework that will be used to draw new walls in the simplified Revit model. These lines will ensure there are no gaps between rooms and that the walls are rectilinear. Smaller spaces that do not receive their own room element in the original Revit model will be absorbed into the area of those surrounding spaces that are large enough to receive a room element.

Within an energy model, each adjacent thermal zone must touch in order for the software to properly recognize heat transfer between adjacent zones. Shafts, closets, plenums and other unoccupied spaces must be represented as distinct thermal zones or as part of larger neighbouring zones depending on the level of zoning detail required for the analysis (Lloyd, et al., 2018).

The gap between simplified room surfaces must be filled so that the walls are interpreted by the energy modelling tool as adjacent. In order to fill the gap between rooms, a new wall must be generated that is shared by two neighbouring zones. This wall should ideally be equidistant between both spaces and rectilinear. Voronoi mathematics are effective at calculating the even distribution of area between points (Hou, Yuan, & Schwertfeger, 2019). For the purposes of BIM to BIM, Voronoi mathematics are used to generate partition lines between rooms that approximate wall separations while guaranteeing that there are no gaps between spaces (Rhinoceros Forums, 2022).

The simplified 2D linework of the rooms is used to host Voronoi site points at a regular interval along the room edge as seen in Figure 3. The Voronoi component in Grasshopper then generates a network of lines, where all lines are equidistant between all points, as seen in Figure 4. The Voronoi network lines that do not intersect with the room boundary lines are isolated. As seen in Figure 5, the isolated lines that remain are meridian between

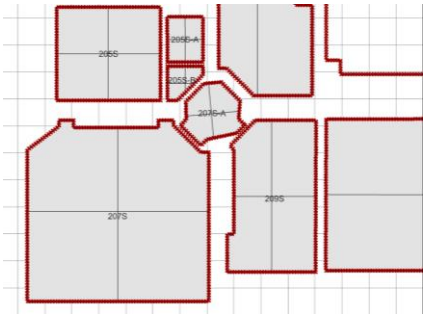

Figure 3: Room surfaces with Voronoi site points along perimeter.

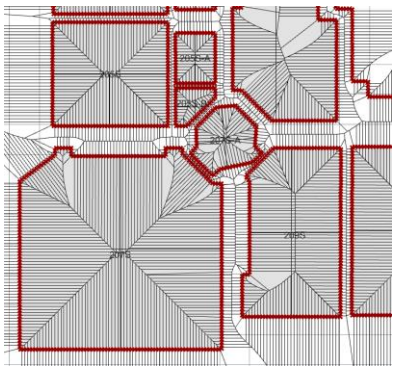

Figure 4: Voronoi network generated from Voronoi site points.

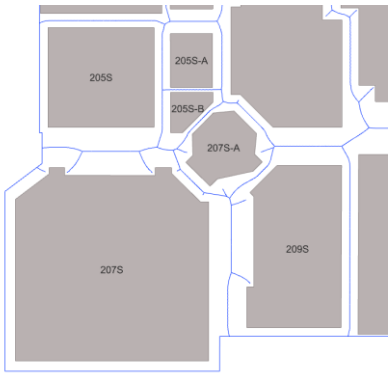

Figure 5: Meridian axis lines, isolated from the Voronoi network.

The building footprint defined by the exterior wall location lines is used to generate a surface that is partitioned by the meridian lines. The meridian lines are rectified onto a grid and are used to partition out the surface area into closed regions that are contiguous. The resulting geometry has an appearance as shown in Figure 6. If the initial rooms surfaces are too close together and a full meridian axis cannot be drawn to close the space, they will be merged together to represent a single zone as seen with rooms 205S-A and 205S-B.

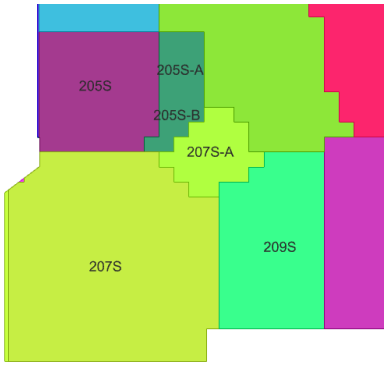

Figure 6: Contiguous rooms with rectilinear boundaries.

Within its current state, the methodology removes internal diagonal zone partitions and replaces those lines with a step pattern. This is to ensure the model imports as simplistically as possible, with only straight lines for room partitions. This translation is at the cost of geometric accuracy, but is more likely to export a workable gbXML. It is understood that the addition of the stepped wall geometry adds additional surface area between zones. The area of the rooms are also altered from the original geometry in order to evenly close the gap. These changes in wall area and floor area may impact energy modelling inputs such as lighting or equipment power density which are typically entered in units of power demand per unit area (W/m^2) and will be further investigated in future work to examine their impact.

Generate New Simplified Walls in Revit

Once the location lines have been created for all interior and exterior walls, they are used to draw new walls within Revit using Rhino Inside. The simplified wall linework in Figure 6, is used to define where the new walls should be drawn. The upper and lower boundaries at the top and bottom of the wall are carried over to ensure that the walls are generated at the same elevation as in the original model.

There are challenges in the export of the wall's thermal properties from Revit to IESVE using gbXML export. Even if the walls are drawn in Revit at a high level of detail with accurate thermal properties, the thermal properties and construction details have not been observed to transfer over to IESVE consistently. A more effective approach is to preserve the grouping of walls with similar constructions, i.e. wall types. When using the Revit gbXML export feature, walls with the same wall type are grouped together in IESVE. This means that the construction and thermal properties of each wall type in IESVE will need to be manually adjusted by the practitioner, but the assignment of wall types to each wall is maintained.

The wall types from the original model are stored in the simplified Rhino linework under a Rhino attribute. When the new simplified walls are drawn in Revit, the Grasshopper script generates a simple wall construction that possesses the same wall type name as the original, potentially more complex, walls. Each of the new simplified walls created in Revit have the same simple construction, but are named differently to match the original wall type names. The construction used to represent the wall, must have a non-zero R-value, otherwise it will be overwritten in the export to gbXML phase by a default construction. This is to ensure that when the gbXML is imported into IESVE, all walls of the same construction are grouped together under the same name.

Generate Slab Floor and Ceilings

Within Rhino Inside, the closed polycurves that are generated by the Voronoi method are used to generate generic celling and floor slabs that fully enclose the spaces.

Window Opening Linework

The objective in this step is to collect the geometry of the exterior window openings and approximate the openings as simple surfaces. Rather than drawing every window with its own simplified surface, windows with similar geometries are grouped together and simplified, and then the simplified surface geometry is copied to each relevant location. This way, all windows of the same type can be edited as a group.

Geometry like the windows seen in Figure 7 are manually examined and surveyed for diversity in geometry. The number of window geometry types is determined and catalogued. One window of each geometry type is isolated, and the opening shape is traced to create a simple surface geometry with a minimum number of line segments defining the edges as seen in Figure 8. The window shapes are simplified to increase the likelihood that the window can be generated as a curtain panel as discussed below.

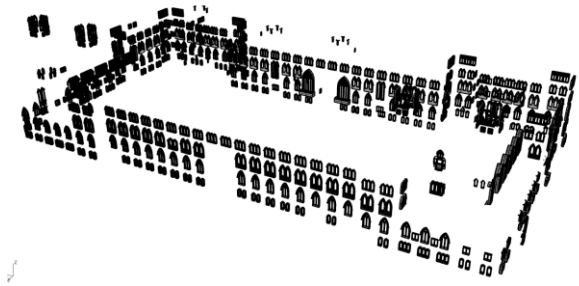

Figure 7: Isolated complex window geometry for exterior walls.

Figure 8: Simplified window geometry for each window architype observed.

Instantiate Simple Window Surfaces

The simplified window surfaces that represent each of the window types must then be copied and placed at the correct coordinate. All of the complex window geometries are selected, and a Grasshopper script is used to determine which window archetype most closely represents each window by examining, depth, width, and height. Figure 9 displays how each surface type is instantiated to the correct location. Each of the simple surfaces is then copied, moved and rotated to the location that has been identified to possess that kind of window. A manual inspection is required to ensure this process is successful.

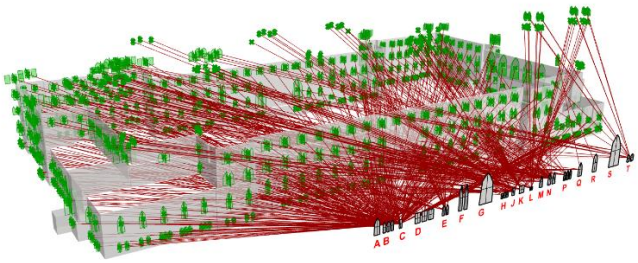

Figure 9: Simple surface instantiation with Grasshopper.

Generate Window Panels in Exterior Walls

Using a Rhino Inside script, the window surfaces are used to generate glazing curtain panels that are embedded in the exterior wall geometry as seen in Figure 10. Curtain panels are used rather than window elements as various gbXML export tests showed that the shape of the opening is more likely to be preserved in the gbXML export.

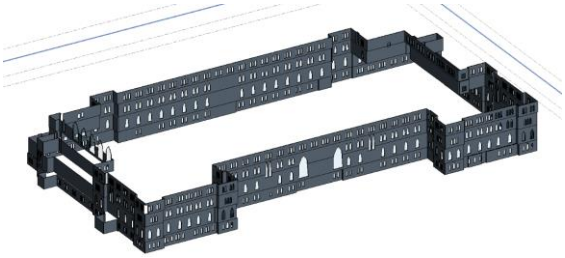

Figure 10: Exterior walls with simple glazing panels in Revit.

Merge Interior Walls with Exterior Walls

The newly drawn interior and exterior walls are merged to fully enclose the building. Any walls drawn using the interior simplified linework that coincide with the exterior walls are removed. This process requires manual inspection to ensure that interior and exterior walls are successfully joined.

Place Original Room Elements

The original room elements are copied from the source model over into the new simplified model. The room elements should naturally fill the new space within its bounding walls, ceiling and floor. The upper boundaries may need to be adjusted to ensure the room element touches the ceiling slab, otherwise the gbXML export will not recognise the ceiling as a thermal boundary.

Export to gbXML

Using the native Revit gbXML export feature, the model is exported using the room/space elements setting in Revit (Autodesk, 2022).

Import into IESVE

When beginning the process of importing the gbXML files, it is important to remember to create a new blank file with the Detailed (ApacheHVAC) HVAC Methodology setting selected. This ensures that more complex HVAC modelling is possible once the geometry is fully assembled and ready to be analysed. Figure 11 displays what a single level of the Centre Block looks like following import into IESVE.

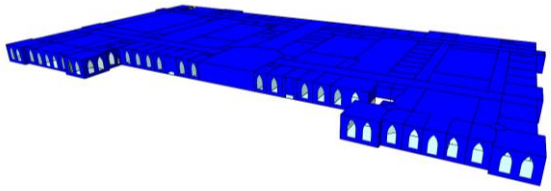

Figure 11: A level of Centre Block imported into IESVE from gbXML.

Each gbXML file is imported, and minor abnormalities caused by the import can be removed using the IESVE healing feature. This IESVE tool, has the ability to close small gaps in the geometry and has been generally observed to remove minor issues, but can also generate zone enclosure issues as well. The model reporting tool provides an overview of issues within the file such as if a space has zero volume, if surfaces are non-planar, if zones are intersecting, if there are external holes in a zone, if there are unmatched edges and any other type of enclosure issue. Spaces that wrap around another space often cause problems, and do not heal well with the tools available, in this scenario it is best to break up the wrapping zones. In cases where any zone issues present themselves after healing the entire building, using the built-in room level gbXML healing functions such as Cap Volumes, Surface Merge, Surface Fill, and Surface Trim can prove useful. Finally if these attempts are unsuccessful it has been proven most effective if the zone is deleted and redrawn using the IESVE ModelIT tool.

Highly detailed zoning of the model is necessary for calculating room-by-room mechanical loads and because the model contains many spaces with specific uses and schedules. There is also a need to account for the thermal mass of the internal masonry walls. In more common projects, zoning of a building can be grouped by space type and orientation.

The Grizzly Bear Method for gbXML

As an alternative to using Revit to generate the gbXML, the Honeybee-legacy component Grizzly Bear, can be used within Grasshopper (Thornton Tomasetti, 2022). However, this process requires the geometry drawn in Rhino be converted into a functioning OpenStudio model prior to being exported for use in IES. The purpose of this workflow is to circumvent drawing model geometry directly in IESVE which can be taxing, especially for newer IESVE users. This leverages the flexibility and ease of use of Rhino, which is a tool specifically dedicated to geometry. This also makes it possible for other BIM experts to contribute to an energy analysis workflow without having access to or familiarity with IES. This process also produces Rhino geometry that can be used for parallel performance analysis studies in Grasshopper.

The process as outlined in Figure 12, displays the steps involved in generating a gbXML file using Grizzly Bear. This process is most effective in scenarios where each floor of a building has no more than around 150 rooms.

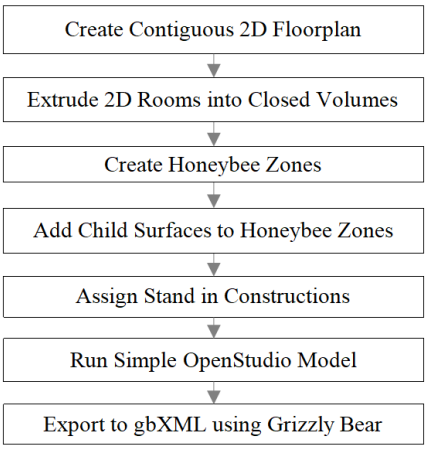

Figure 12: Methodology to use Grizzly Bear to generate gbXML.

If the building being examined has a Revit model with room elements, then the contiguous floorplan can be generated using the Voronoi methodology presented in the previous sections. If there is no Revit data to leverage, a drawing package can be imported into Rhino and used as a guide to manually draw a contiguous floorplan in Rhino. The lines drawn to represent each room must be perfectly coincidental, and ideally exist within the midline of separating walls. IESVE does offer a suite of drawing tools for developing building geometry but does not offer the same diversity of drawing tools as Rhino.

As the contiguous floorplan is drawn, the desired names of the zones are stored in a Rhino attribute. The Parliamentary Welcome Centre was drawn manually in Rhino as seen in Figure 13. Once the floorplan is complete, the surfaces that represent each room are extruded to create a closed volume. A Grasshopper script converts the closed volumes into Honeybee Zones and names each zone with the corresponding Rhino attribute.

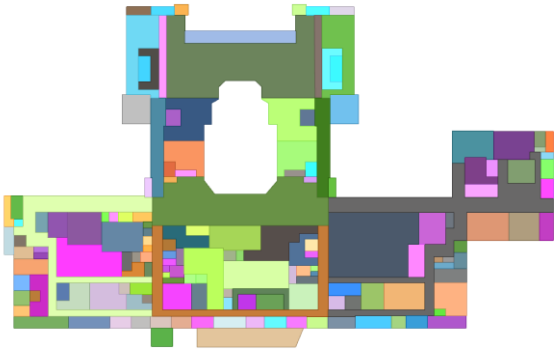

Figure 13: A level of the Parliamentary Welcome Centre contiguous floor plan, drawn manually in Rhino.

The zones have simple window surfaces assigned where applicable. Windows with more complex geometry have been observed to import less consistently using this method. Wall constructions have also been observed to not import consistently, and further research is required to determine if a grouping strategy similar to the one used in the Revit workflow could be employed with Grizzly Bear. This means that all wall thermal properties are manually edited to match the analysis requirements in IESVE following import.

Once the geometry has been assigned stand-in constructions, and windows have been assigned as child surfaces to the simple geometry, it can be run in the OpenStudio engine. It is important to ensure the Rhino file units are set to meters with a tolerance of 0.01 for this step, otherwise errors interpreting the intersection of zones could occur. The OpenStudio simulation settings are set as simplistically as possible, and for a short analysis period. This is to cut down on simulation time, as no results from OpenStudio will be used.

Once the OpenStudio model has been successfully run, the model files can be exported into gbXML using the Grizzly Bear component.

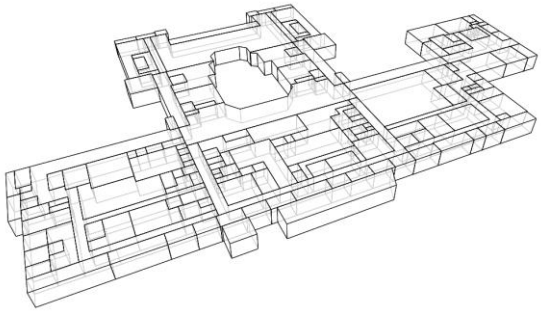

Figure 14: A level of the Parliamentary Welcome Centre, imported into IESVE from gbXML.

Conclusion

The processes discussed are still under development and are expected to change as they continue to be applied to analysis work for the Centre Block Rehabilitation project. The purpose of these workflows is to leverage existing BIM in a way that is feasibly usable within IESVE.

The Revit workflow is intended to support the development of whole building energy models for the Centre Block by leveraging the existing Revit model geometries being developed by the architecture and BIM team. Several floors of the Centre Block have been successfully processed using this methodology however further work is required to represent the proposed changes to the building's geometry. As the architecture and BIM team continue to develop new Revit files to represent the proposed design, more work will be done to leverage this information to iteratively generate up-to-date IESVE models. This research aims to reduce the turnaround time between changes to the geometry, and the communication of analysis results.

The Grizzly Bear methodology is an alternative to using Revit to generate a gbXML and circumvents the need to draw geometry directly in IESVE. It is better suited to scenarios where there are less Revit data available. This methodology has been used to develop an energy model of the Parliamentary Welcome Centre in IESVE using PDF and CAD drawings for reference. This research aims to increase the flexibility in the way simulation practitioners generate building geometry for analysis.

Acknowledgement

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