Analytical Model (SAM 2.0): A New Frontier in Open-Source Building Energy Simulation

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Abstract

The Sustainable Analytical Model (SAM), developed by Michał Dengusiak and Jakub Ziolkowski, is an innovative open-source software that broadens the selection of building energy modelling tools written in .NET C#. SAM focuses on enhancing the accuracy and efficiency of energy analysis for architects, engineers, and energy consultants, engaged in the development of energy-efficient buildings. Its open-source nature ensures a wide accessibility, making it an effective tool for bridging the gap between theoretical modelling and practical application. Furthermore, as building design continues to evolve towards more sustainable practices, SAM stands ready to meet these new requirements, providing a customisable, dependable and futuristic platform for energy modelling.

1. Introduction

Open-source tools are gaining greater prevalence within the Architectural, Engineering and Construction (AEC) industry. One example of an open-source toolkit is Sustainable Analytical Model (SAM) which enables specialists to optimise their workflows by tailoring the software tools to their specific needs. SAM can import or create geometry and related data from various sources like Rhino, Revit, etc. to build watertight models. In the creation process, building elements with the material information and spaces with internal conditions, such as thermostats, heat gains and schedules, are attributed to the building. This allows the generation of an analytical model, which is defined as a complete object that can be stored in the JSON format.

2. Background

2.1 Abstract

SAM aims to achieve the goal of the digital twin, where any buildings, with all their associated data, can be replicated, including their HVAC system, or any other custom data decided by the user. The complete development of SAM is defined by the following five key milestones:

SAM 1.0 – geometry creation
SAM 2.0 – loads and dynamic simulation (using the generated geometry from SAM 1.0 and attributing it with constructions that consist of materials, and assigning to the spaces the internal condition with their profiles)
SAM 3.0 – HVAC system generation (creating a detailed HVAC system on the attributed model from SAM 2.0 to perform a dynamic simulation)
SAM 4.0 – adding HVAC system controls
SAM 5.0 – digital twin

In this publication, the focus will primarily be on SAM 1.0 and SAM 2.0. At these stages, SAM facilitates the generation of a building's geometry through the Grasshopper interface and enables the simulation of energy systems; embracing aspects like heating, cooling, and ventilation.
These simulations are performed using external software, such as Ladybug Tools that utilises EnergyPlus and Tas EDSL with its own engine. The latter provides a much more direct and closer integration primarily due to its compatibility with the .NET framework. Furthermore, it also links with a pleth

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ora of tools and toolkits such as Revit, Topologic, gbXML, Excel, IFC, GEM, and BHoM.
Although SAM is mainly accessed through Grasshopper in Rhino, the SAM_UI interface was created to enhance the productivity for tasks that are less efficient in this environment. This includes tasks like space renaming, adjusting specific panel constructions, or generating Revit-style 2D floor plans, color-coded with the specific data. Such features significantly reduce the time and effort required for complex analytical tasks, streamlining the workflow for professionals.

3. Main

SAM 1.0 – focused on geometry - supports multi-method geometry generation. This can then be used to create an Adjacency Cluster. This includes creating detailed 2D outlines of walls at specific level heights, modelling from closed polysurfaces, and generating models from planar panels. It also includes an innovative Revit-style approach in building generation. This is a method for attaining watertight models by extracting the walls per level, performing snapping by aligning elements within a model to precise positions based on a set of predefined rules to a high tolerance and lastly, closing the space by attaching a floor and roof. Unlike other tools that store geometry as 3D elements, SAM represents most of the geometry as 2-dimensional objects with a plane, although still allowing to query its 3D version. This increases the efficiency of the various operations undertaken due to the simpler data management, efficient storage, and optimized computations.

SAM 2.0 is dedicated to dynamic energy simulation and load sizing. The workflow aims to automate the attribution process. Firstly, an Adjacency Cluster is created out of the geometries, for instance, by boundary representation (BREP), as defined in SAM 1.0. Subsequently, SAM offers a broad range of methods to create and assign internal conditions based on predefined strategies. In the last step, an analytical model needs to be created with a material and profile library. Throughout the process, default values are provided to reduce the input required from the user. This approach enables users to initially run simulations on the default settings to validate the model's functionality. Once confirmed, users can then invest time in adding detailed data, saving time and effort.

Objects in SAM can be categorised as either analytical or geometric and are defined in SI units.

3.1 Analytical

For analytical objects, the SAM hierarchy is as follows (Fig. 16), where the majority of objects permit the addition of custom data, making the workflow very customisable and flexible:

Analytical model: comprehensive representation of a building that encapsulates all of the necessary attributes. In SAM this consists of the Adjacency Cluster, Location, Materials and Profiles, along with additional model properties.

Adjacency Cluster: abstract container for storing the relations between objects including Panels, Spaces, Zones. This is the only object where these connections can be queried, e.g. what panels belong to a given space, or which spaces belong to a zone.

Zone: collection of similar properties that spaces share. This allows for an efficient data manipulation, by allowing modifications at zone-level. It is defined by type and name.

Space: each space may contain a location (stored as a Point3D) and an Internal Condition. Point3D representing the interior volume within a building, defined by boundary Panels. To query the spatial geometry of the space, e.g., the volume, the panels need to be queried from Adjacency Cluster.

Internal Condition: variables affecting the indoor environment such as gains, thermostat settings, or any other custom data related to specialists e.g., acoustic, fire, etc.

Panel: instance of a building element. It is defined by the geometry, Construction, Apertures and properties such as PanelType, for example: internal wall, floor, roof, external wall.

Aperture: windows, doors or skylights. It consists of the geometry, ApertureType, ApertureConstruction – which includes the Pane and Frame Construction layers.

3.2 Geometry

SAM analytical objects such as Panels or Apertures are defined by SAM geometry (Fig. 17)

Face3D: currently implemented as a three-dimensional closed planar shape, limited by polygonal external and internal edges. It is represented as 2D polygonal edges positioned on a given plane (Fig. 4).

External Edge 3D and **Internal Edges 3D:** ordered points in 2D space, placed on a given plane. When 3D representation queried, the edges are recalculated from their stored values (Fig 3).

Polygon2D: two-dimensional curve with closed, straight segments. It is stored as ordered points in 2D space. (Fig. 1)

Face2D: two-dimensional closed shape limited by edges (such as Polygon2D). The External Edges describe the limit of the face, whereas the Internal Edges outline the holes. Face2D that have a single external edge and may have multiple internal edges. This is saved as a collection of Polygon2D (Fig. 2)

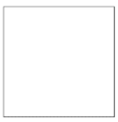

Fig. 1 – Polygon2D

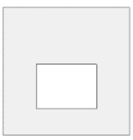

Fig. 2 – Face2D

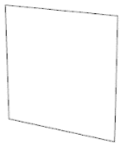

Fig. 3 – Polygon3D

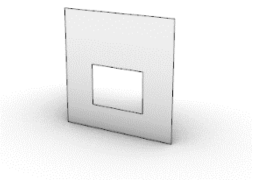

Fig. 4 – Face3D

3.3 Adjacency Cluster

The Adjacency Cluster (Fig. 5) is a fundamental, yet abstract component that provides the essential functionality and efficiency for organizing and analyzing spatial data within the SAM structure. It stores spaces, zones, panels etc. as well as the relations of these objects within the context of given analytical model (Fig. 6).

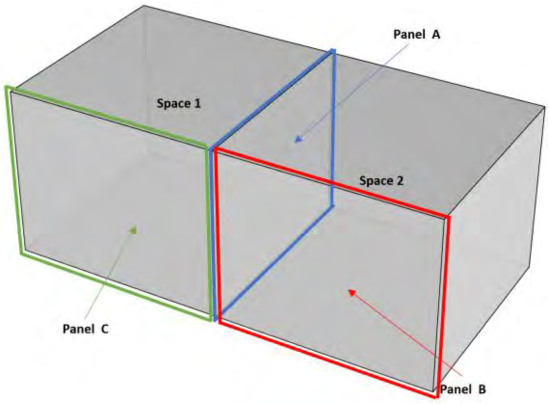

Fig. 5 – Adjacency Cluster

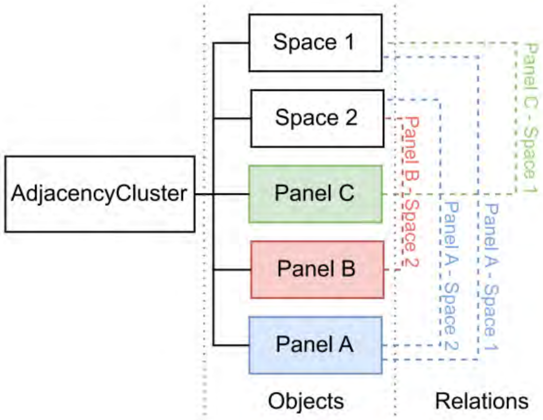

Fig. 6 – Adjacency Cluster Relations

The Adjacency Cluster (Fig. 5) will be accessed, in simplified terms, in the SAM structure as a set of two dictionaries. One will include all of the different analytical objects e.g., spaces, panels, etc. The second dictionary consists of the relations between these objects via their GUIDs. This approach allows for an efficient query and modification method.

Currently there are numerous methods to create a watertight Adjacency Cluster, ranging from 2D outlines to Revit models, that continuously satisfy the tolerance requirement. The following examples will focus on one of the possible methods, namely: CreateAdjacencyClusterByBrep, and incorporate the input of three distinct BREP boxes, with highlighted internal panels. Each test case undergoes a different transformation of the geometry to demonstrate the capabilities of SAM 1.0.

Initially, the boxes are aligned edge to edge (Fig. 7). Therefore, to refine the geometry, all overlapping surfaces will be merged. Afterwards, the correct PanelTypes are assigned, creating an Adjacency Cluster with three spaces.

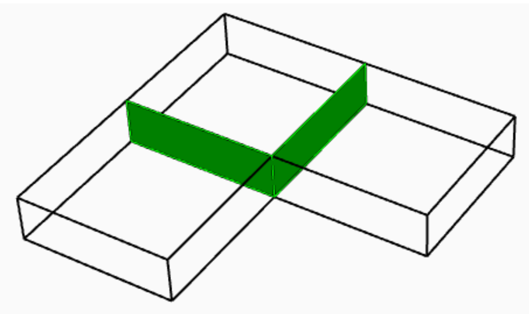

Fig. 7 – Three BREP boxes

In the second scenario, the right box was moved along the y-axis (Fig. 8). The overlapping surfaces between the BREPs are split and merged, so that the correct PanelTypes can be recognized by the appropriate location and adjacency.

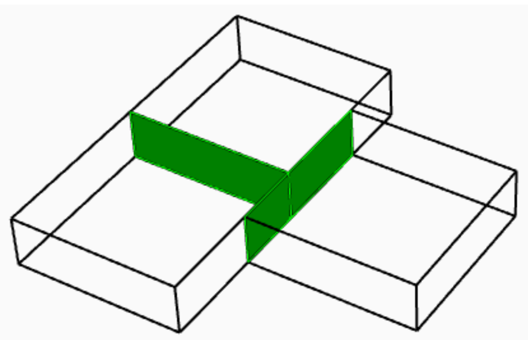

Fig. 8 – Overlap in Y-axis

This approach is not limited to perfect edge matching and accepts geometries on different levels (Fig. 9).

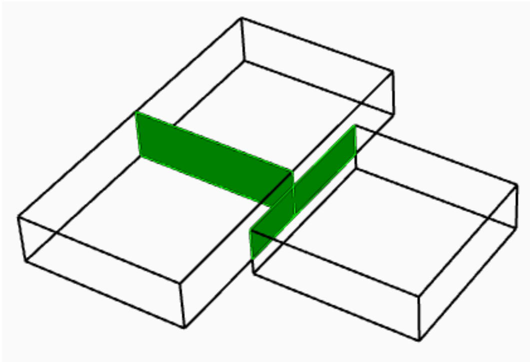

Fig. 9 – Lower 1m by Z-axis

The method is not limited to adjacent BREPs but also functions on intersecting volumes (Fig. 10). However, in this example, besides the split operation being performed, two additional spaces will be created. Therefore, the resulting AdjacencyCuster will consist of five spaces.

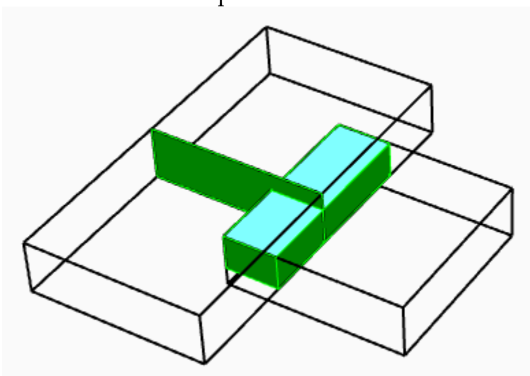

Fig. 10 – Translate -3m by X-axis.

Furthermore, the following modification based on the rotation of the right box along the Z-axis (Fig. 11), shows the versatility of SAM in accepting various geometric inputs.

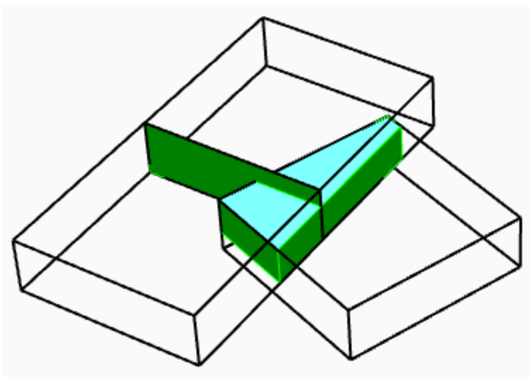

Fig. 11 – Turn Z-axis

In the final transformation, the right box is moved along the X-axis to completely intersect the two remaining geometries (Fig. 12). This operation creates an Adjacency Cluster with five spaces and correctly recognized PanelTypes, illustrating SAM's adaptability to complex geometry.

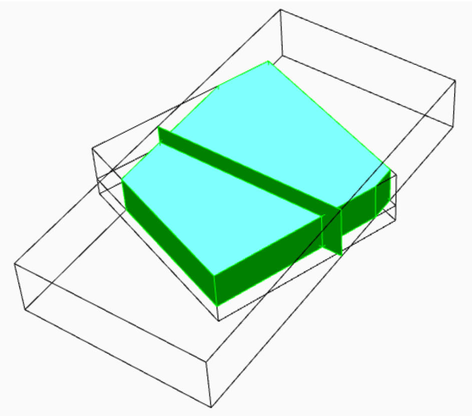

Fig. 12 – Transform -7m by X-axis

The provided examples reveal how SAM streamlines the process of geometric model creation, optimizing the efficiency and accelerating the design iteration process. By reducing the required workload from the user in preparing the input geometry, SAM enables engineers to focus on design innovation rather than geometric technicalities. This not only validates SAM as a powerful tool for engineers, but also highlights its potential in optimising the model creation process in AEC applications.

3.4 Analytical Model

An Analytical Model consists of the following:

- **AdjacencyCluster**
- Materials stored in the **MaterialLibrary** (a centralized repository with essential information about the e.g., physical and thermal properties of different materials)
- Profiles stored in the **ProfileLibrary** (a centralized repository for storing assumptions, e.g., in Internal Conditions, where often on an hourly basis the gains, and thermostat settings are saved)
- **Location** (in latitude/longitude) and address of the model

It is not necessary to provide Materials and Profiles, as SAM has default values, so that only with an Adjacency Cluster, an Analytical Model can be generated. This provides the user with fast feedback on whether the model can be simulated before valuable time is invested into inputting detailed data. Finally, the validated model can be exported in various formats such as IFC, gbMXL and Revit, or directly imported into tools like Honeybee Model or Tas EDSL depending on the needs of the user (Fig. 13 and 14). A model is converted into the different formats below:

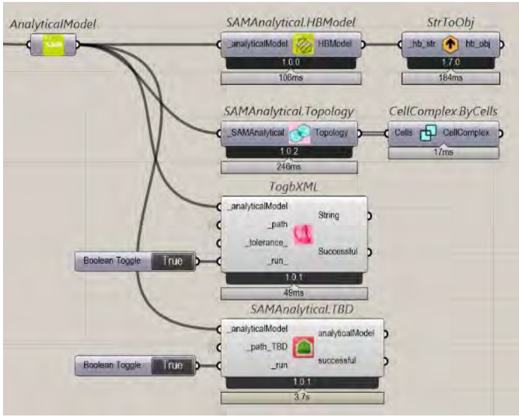

Fig. 13 – SAM Analytical Model conversion into different formats (Honeybee, Topologic, gbXML, TasTBD)

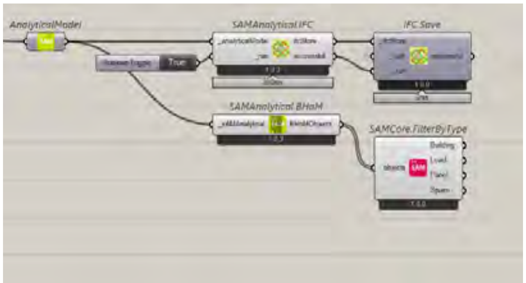

Fig. 14 – SAM Analytical Model conversion into different formats (IFC, BHoM)

For instance, the Figure 12 was used to generate the simulation model in Tas EDSL (Fig. 15).

Fig. 15 – Tas Model in Building designer

4. Conclusion

In conclusion, SAM has demonstrated significant potential as an innovative resource for architects, engineers, and energy consultants, especially in designing energy-efficient buildings. By automating geometry creation, SAM reduces user workload, thereby fostering innovation and creativity. Additionally, the default attribution facilitates efficient model testing with preset data, making it an invaluable tool for diverse applications. As an open-source plugin, SAM's transparency and flexibility in storing objects in JSON format promote widespread data access, sharing, and reuse across models.

Looking ahead, the continued development of SAM 3.0 promises to enhance existing workflows, potentially increasing the adoption of HVAC system simulation. SAM 4.0 will enable the exploration of control strategies for HVAC systems, allowing for the evaluation of different approaches. This will help in selecting optimized solutions for HVAC systems, thereby contributing to better building designs and more accurate emissions evaluations, which are crucial for achieving net-zero targets. SAM's capabilities not only streamline the design process but also support sustainable development by providing tools that aid in the creation of energy-efficient and environmentally responsible buildings.

This enhanced functionality and focus on sustainability directly address the need for innovative solutions in the built environment, thereby facilitating the creation of better buildings and supporting the net-zero strategy.

Acknowledgement

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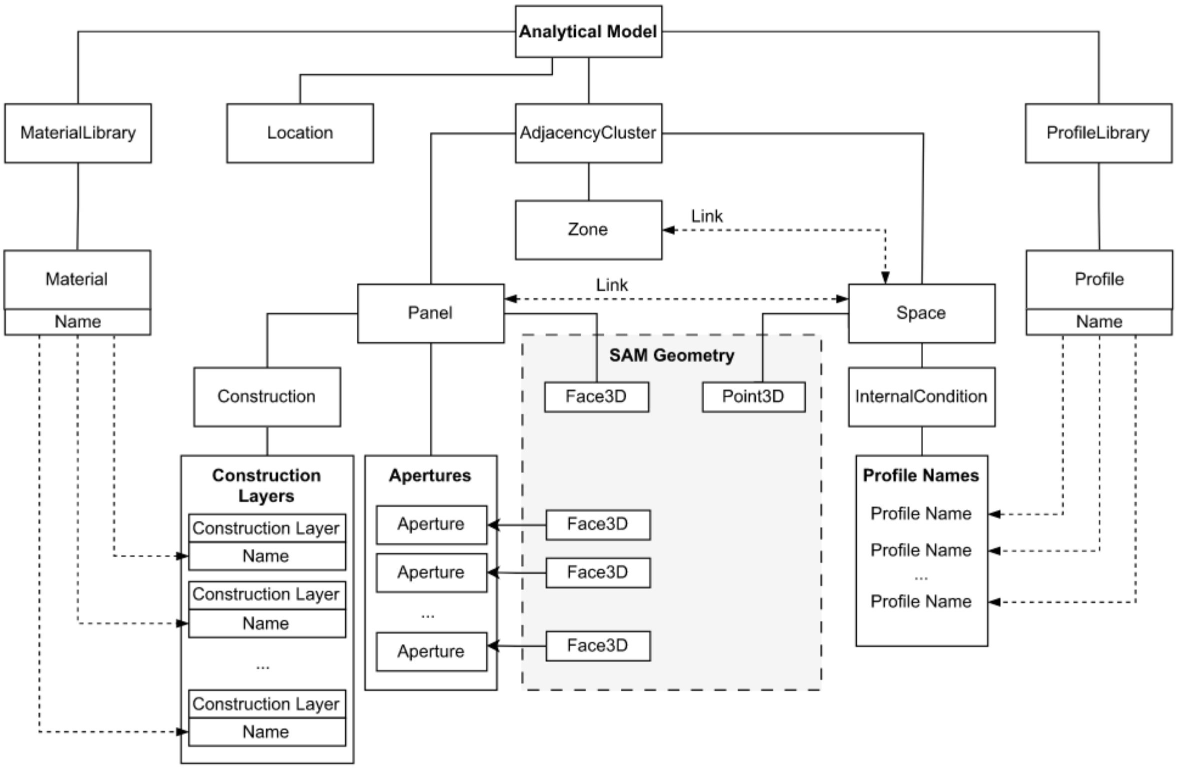

Fig. 16 – SAM Analytical Model simplified structure

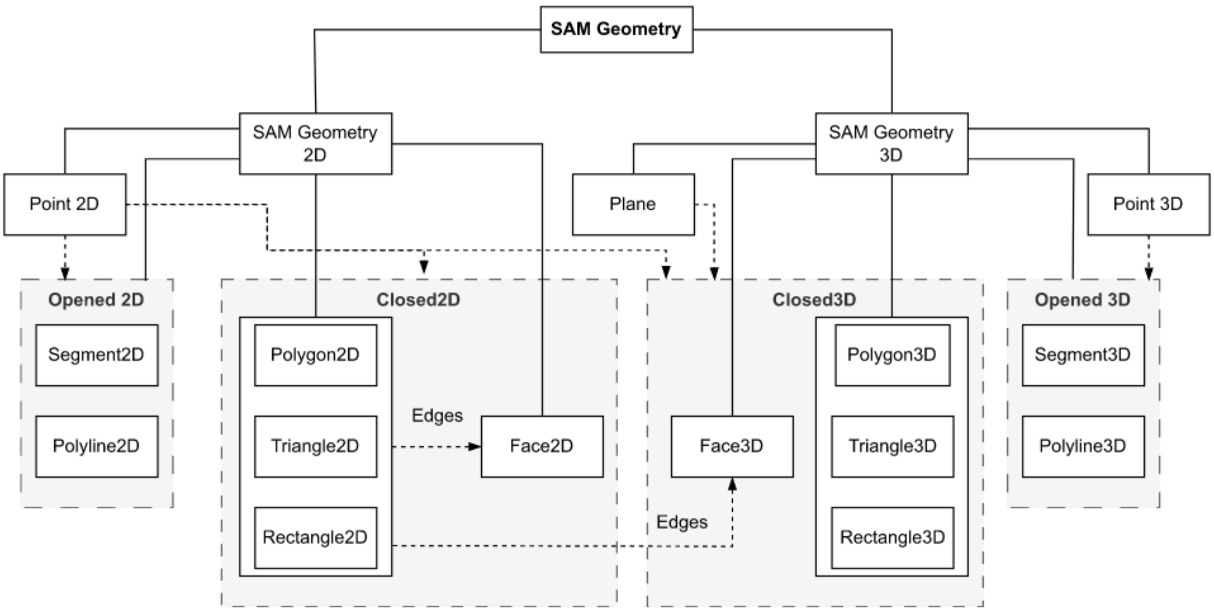

Fig. 17 – SAM Geometry simplified structure