IFC TO CONTAM TRANSLATOR

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ABSTRACT

Building security issues are of serious concern in the industry today. This paper will describe the design, development and testing of a software tool that can be effectively used to translate three dimensional building data sets of geometry, materials and HVAC components into an input file for the airflow and contaminant concentration simulation program CONTAM. The objective of the exercise is to allow for shorter turnaround time in evaluating IAQ strategies and building security related issues.

The software tool, 'fsIFCCTM', has been successfully tested to translate 3-D building elements like spaces, walls, doors, windows, and HVAC components like ducts, duct junctions, terminals, fans, filters etc. With additional work, the software can be further extended to translate elements like sensors and controls. It uses the Industry Foundation Classes (IFC) data model for achieving the translation.

INTRODUCTION

The ability to predict how contaminants generated by a potential chemical attack disperse, assumes elevated significance in the present scenario. This requires a renewed and innovative focus on strategies that combine building and HVAC (heating, ventilation & air conditioning) systems to mitigate the influence of incoming chemicals and pollutants. Simulating the movement of contaminants, caused due to pressure differentials, using zonal models for the building and the movement due to the HVAC system acting as the pathway along with the building's components like walls, doors, windows, stairways etc. is the most attractive solution to the problem. This can also be effectively harnessed to cater to maintain and enhance the IAQ (Indoor Air Quality) requirements in buildings today. As is widely accepted and has been well documented in the past though, modeling building geometry, its HVAC systems, controls and facilities and the interaction amongst all these different entities for simulation purposes is a very tedious and specialized task. But advances in simulation techniques has allowed engineers and architects a cost effective mechanism of evaluating different parameters that need optimization and can help in the design of an energy efficient, safe building while maintaining a high level of occupant comfort.

However, current IAQ and Energy Analysis software simulation tools are not well integrated with Architectural Design and Drafting tools like Architectural Desktop or ArchiCAD. Geometric, material and HVAC system component data sets contained in three-dimensional architectural CAD are not readily transferable to the IAQ or Energy Analysis tools. Thus, the building geometry and HVAC system information has to be regenerated to run simulations in different software, necessitating skilled modelers to manually define and characterize the building and the HVAC system. Industry experts believe that modeling and input preparation can actually be 80% of the effort in running a successful building simulation for building performance studies (Bazjanac V., 2001).

The objective of this work is to develop a software tool that would allow for import of 3-D CAD data in the form of an input file to building simulation software. The input file will be used by the multi-zone airflow and contaminant transport simulation and analysis program CONTAMW. CONTAMW is a software program developed and distributed by the National Institute of Standards and Technology (NIST). CONTAM (denoted as CONTAMW for Windows and the simulation engine CONTAMX) and its supporting documentation can be downloaded free from the NIST website (NIST, 2006). Automatically importing the 3D CAD data will save precious man hours in developing the building model, and reduced human interaction in the process can further help in increasing accuracy and maintaining the integrity of the data from the design to simulation phases.

This interoperability was achieved using the Industry Foundation Classes (IFC) data model developed for the building and construction

industry, by the International Association for Interoperability (IAI). IFC is based on the STEP (Standards for the Exchange of Product model data) standards, a comprehensive ISO standard (ISO 10303 - PART 21) for representation and exchange of digital product data. The IFC data model is still under development and the current version of the translator (fsIFCCTM 2.0) is based on the IFC model schema 2x2 addendum 1 (IAI, 2006).

An early indication of interoperability and its benefits in the building simulation arena was the IFCtoIDF utility that is available with the current version of the building energy simulation software EnergyPlus (Bazjanac, Maile, 2004). Software tools like the BS-Pro COM server for IFC files from Olof Granlund Oy (Karola et. al., 2001) were used as middleware to facilitate interoperability of an IFC compliant CAD tool with EnergyPlus. A variation of this concept, the 'fsIFCCTM' creates an input file for CONTAMW, but it uses a middleware solution called the Express Data Manager^{TM} (EDM) developed by EPM Technologies (EPM, 2006) to facilitate this translation. The 'fsIFCCTM' tool has been developed using the Microsoft Visual Basic platform and Microsoft Access databases provide for the data repository needs. The current version of the 'fsIFCCTM' creates a CONTAMW input file for version 2.3a of CONTAMW.

OVERVIEW

CONTAM is software that accepts only two dimensional building input data, and the building 3-D CAD data must be converted into a file format called the ".PRJ" file, which CONTAMW accepts as input. This ".PRJ" file is displayed by CONTAMW on a sketchpad using lines and icons to represent the various building boundaries and elements. The IFC file of the 3D CAD must be available to use the translator. Many popular architectural CAD design and drafting tools are now IFC compliant, for example ArchiCAD from Graphisoft Inc. and Architectural Desktop from AutoDesk Inc. An IFC data model in the form of a STEP PART 21 (with extension '.ifc') can be obtained from such software. At this point it must be noted that the IFC file only contains the building geometry and material data sets as most of the commercial CAD tools currently do not support HVAC modeling. HVAC modeling for the purpose of this project was done using the DDS HVAC Partner^{TM} tool which is also IFC complaint. The

IFC file from the CAD software was imported in IFC format into the HVAC modeling tool. Once the HVAC modeling was completed, it was exported as an IFC flat file with the building and HVAC model integrated. This is the file to be used as input to the fsIFCCTM translator program.

The general methodology for using the 'fsIFCCTM' Translator is as follows:

- Using the 'Import IFC file' option from the IFC Translator menu options, specify the file name and path of the IFC file for the building under consideration.
- The translator will create an EDM^{TM} database on the fly using an IFC 2x2 (Addendum 1) Schema. This is done by parsing the IFC file of the building model by importing it into an EDM database.
- Extract the layout of the building and its HVAC elements using the Geometry Conversion routines. These can be viewed by the 'Layout' option from the 'View' option of the Translator menu.
- Select zones that have been reported as problem zones by the Translator, to be skipped (based on a numeric problem level parameter). An iterative process in this step might be required to get a working Translation of the IFC file.
- Use the auto generate feature to obtain the smallest possible resolution for the CONTAM sketchpad.
- Create the '.PRJ' file as input to CONTAM 2.3a by using the 'Save as CONTAM PRJ file" option in the menu.

The CONTAM '.PRJ' file consists of the following sub-sections:

Section 1: Project, Weather, Simulation, & Output Controls	Section 12b: Control Nodes
Section 2: Species and Contaminants	Section 13: Simple Air Handling System (AHS)
Section 3: Level and Icon Data	Section 14: Zones
Section 4: Day Schedules	Section 15: Initial Zone Concentrations
Section 5: Week Schedules	Section 16: Airflow Paths
Section 6: Wind Pressure Profiles	Section 17: Duct Junctions
Section 7: Kinetic	Section 18: Initial

Reactions	Junction Concentrations
Section8a:.Filter Elements	Section 19: Duct Segments
Section 8b: Filters	Section 20: Source/Sinks
Section 9: Source/Sink Elements	Section 21: Occupancy Schedules
Section 10: Airflow Elements	Section 22: Exposures
Section 11: Duct Elements	Section 23: Annotations
Section 12a: Control Super Elements	

Table 1 CONTAM .PRJ file sub-sections

Of the above sections, the fsIFCCTM can currently translate Level and Icon Data, Filters, Airflow Elements, Duct Elements, Zones, Airflow Paths, Duct Junctions, and Duct Segments. The Project, Weather Simulation and Output Control, contains information about the simulation scheme to use and other user defined project description and miscellaneous values to set display size etc. is defaulted. The sections for Species and Contaminants, Day and Week schedules, Wind Pressure Profiles, Kinetic Reactions and sections such as Control Nodes, Exposures, Occupancy schedules etc. are also currently being defaulted. Defaulting these sections, for which no data is usually available in the IFC files, means that they need to be written into the .PRJ file as CONTAM requires placeholders for every section to be present to determine the file complete and readable. The mapping of the IFC classes to the CONTAM elements was as below:

Corresponding IFC Element	CONTAM Element
IfcSpace	Zone
IfcBuildingStorey	Level
IfcDoor	Door (Airflow Element)
IfcVirtualElement	Opening
IfcWindow	Window (Airflow Element)
IfcWallStandardCase	Wall
IfcFlowSegment	Duct Segment
IfcFlowFitting	Duct Junction
IfcFlowTerminal	Duct Terminal
IfcFlowMovingDevice	Fan
IfcFlowController	Damper
IfcFlowTreatmentDevice	Filter
IfcDistributionControlEl-ement	Sensor

Table 2 CONTAM element to IFC element mapping

Connections in the HVAC system, for example the connection between a duct and duct junction or between a duct segment and a fan, are tracked through the IfcRelConnectsToPorts enumeration and relationships in IFC.

Menu and Interface Options

Figure 1 shows a screen shot of the Visual Basic Interface for the fsIFCCTM. There are three pull down menu items, and a few check boxes and text input boxes that allow the user to choose the resolution and select the tolerances to be used during the building geometry translation. The tolerances are necessary because the CONTAMW sketchpad will display a wall adjoining two zones as a single line whereas the CAD file actually has a thickness associated with walls as is reality. Thus, when translating the zone layout of the building to be shown on the CONTAMW sketchpad, the zones have to be shown as closed polygons with the airflow elements for the doors, windows etc connecting them as two parallel lines in a tunnel-like fashion. Inter-zone leaks can also be translated should the information show up in the IFC file in the form of an IfcOpeningElement. The CONTAMW sketchpad is limited in the form of memory requirements wherein large resolutions (above 3000x3000 pixels) require large memory resources, so the actual dimensions of the building have to be scaled in order to fit on the sketchpad. Scaling the geometry is possible as long as the polygons for the spaces do not intersect with each other and tolerances are provided to ensure the same. There is an option to let the program automatically calculate these tolerances so that the zones do not end up intersecting each other when the scaling down takes places. A feature has been provided to automatically optimize the size of the sketchpad resolution, so that the zones do not intersect each other.
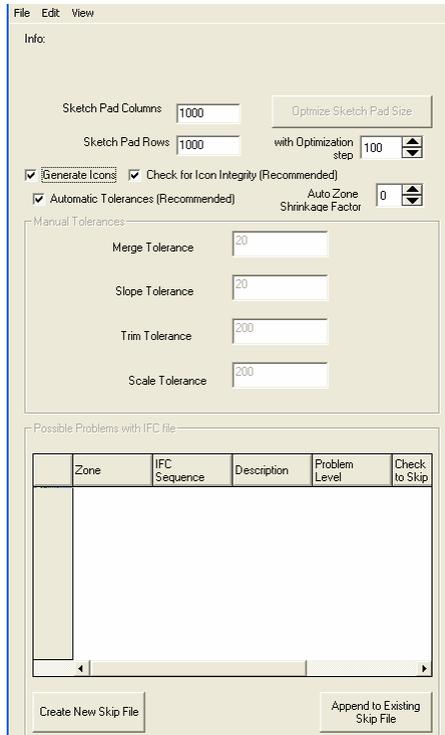
Figure 1 User Interface - fsIFCCTM

Scaling the zones and showing them as closed polygons with tunnel-like connections for opening elements is acceptable as CONTAM treats every zone as well mixed, in that every zone represents only a single node during simulation and hence only the relationship of the openings between zones and the zone volume is important and not the exact shape. The following tolerances and options can be used for display optimization on the sketchpad:

- **Merge Tolerance:** This is the tolerance to merge the points that are in close proximity when the zone layout is extracted from the IFC file.
- **Slope Tolerance:** Sloped lines (in the plan view of the zone layout) with a value equal to or less than this tolerance, for their inclination from the perpendicular are made horizontal or vertical. This step is required as the CONTAMW sketchpad does not accept non orthogonal wall shapes.
- **Trim Tolerance:** Trims projections by the indicated distance in the zone layout.
- **Scale Tolerance:** This tolerance specifies the scaling distance for the zones when they are shrunk to remove overlapping of spaces.

The translator is designed to run a final integrity check of all zones in the IFC file which are translated. Not selecting the option will result in this integrity check being skipped. This particular feature is especially useful if the ".PRJ" file is being produced to run only with CONTAMX simulation engine and not be displayed in the CONTAMW sketchpad. Deselecting this option will greatly speed up the translation process however there is no guarantee of proper icon generation and CONTAMW might fail when loading the translated '.PRJ' file. Another unique feature is a table on the user interface that displays problematic zones when translating. A "problem level" associated with the zone will show the severity of the bad data for that zone. The user has the option of adding or appending the checked zones to a text file called a "ZonSkip" file. Every time a user chooses the IFC file to be translated, a pop up dialog will allow the user to either use or ignore the zone skip file. Bad zone data can at times result from faulty modeling in the 3-D CAD file or an improper export of the CAD file as an IFC file.

The 'File' menu, shown in Figure 2 below, has an 'Import IFC File' option and another option to 'Re Import from EDM database'. The second option is useful when trying to use the optimize feature or the zone report and skip feature of the Translator. Importing the model directly from the EDM database saves time required in re-creating the EDM database on the fly. There is also an option to 'Save As CONTAM .PRJ File', allowing the user to save the imported IFC file as a CONTAM .PRJ file.
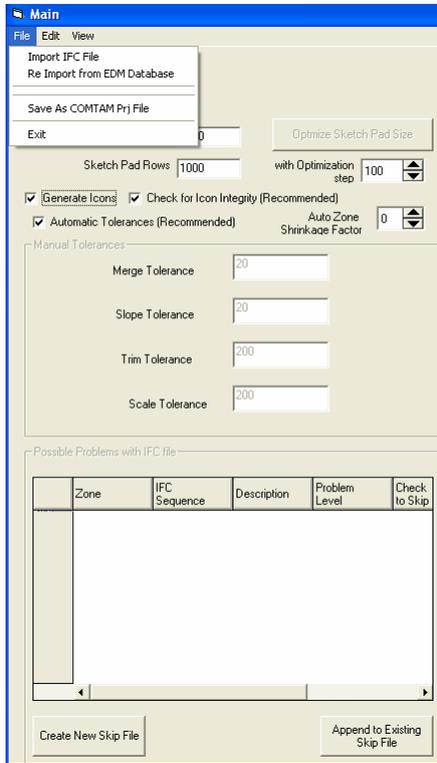
Figure 2 Menu Option

Figure 3 Edit Air Flow Elements

The menu item 'Edit' with sub-option "Edit Airflow Elements" and the related interface is shown in Figure 3. In CONTAM, wall leaks, door, windows and inter-zone leaks are all mathematically modeled as airflow elements and this model governs the flow characteristics of the air and contaminants through that particular opening. The Translator uses default elements from the library for modeling doors and windows. Staircases and elevator openings are modeled as a default leak element, but the user can either choose from a default library or add their own airflow elements to model openings using this menu option. The "Edit Airflow Elements" option also allows the user to modify parameters like laminar flow coefficient and so on for existing airflow models.

The menu 'View' has two options, called 'Layout' and 'Log File'. This can be used to view the zones, walls, their center-lines, the opening elements like doors, windows and ceiling openings and the HVAC layout of the building from the translated IFC file. The log can be used to view a log of the translation with all the associated errors and warnings.
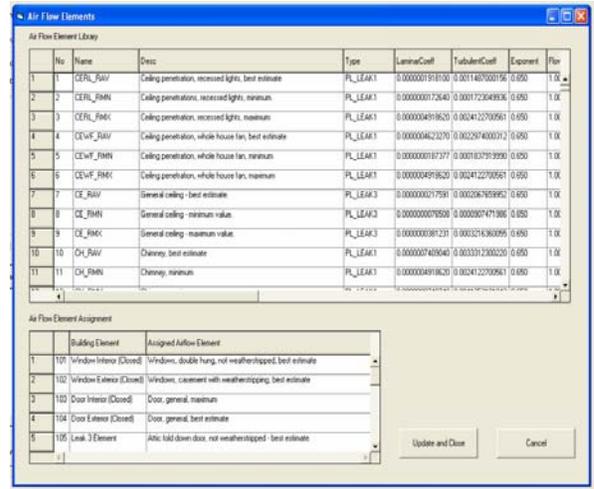
SOFTWARE ARCHITECTURE

The Translator program has the following main components:

- Access Database - contains tables for all CONTAM elements.
- CONTAM Server containing VB classes for all CONTAM elements.
- Interface – to allow the user to select the IFC file for translation, check the log and use a viewer to see the results of the translation.

A class and collection module is written for each of the above mentioned sub sections of the .PRJ file. The program structure is such that the class module consists of the all the variables that need to be written for each sub section of the .PRJ file. The collection modules consist of the code that allows for multiple instances of the each class object to be written to the .PRJ file. When the data is initially read in through the IFC file, the Translator will create instances of the class object for the collection and then all the set of collections are written to the .PRJ file. Figure 4 shows a graphical view of the class and collection hierarchy of the Translator.
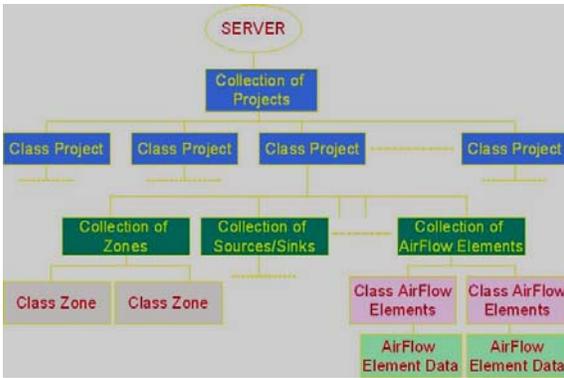
Figure 4 Class Hierarchy

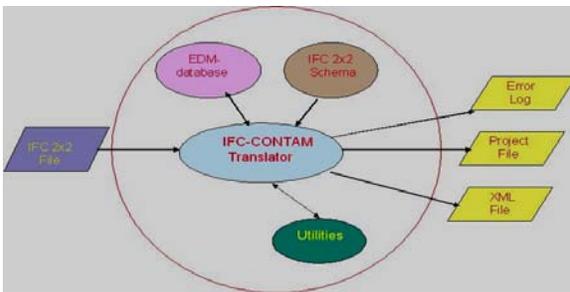Figure 5 shows the component diagram of the fsIFCCTM.

Figure 5 Component Diagram

The core of the Translator consists of the CONTAM server. It reads input in the form of the EDM database which is automatically created from a user specified IFC file. The server will also use the IFC schema file that has been specified in the Data directory and with the help of some geometric utilities as mentioned above, the translator will output a PRJ file along with an error log of the inconsistencies that were reported during translation.

Every collection of a class that represents a subsection of the .PRJ file has a function that will access and extract the data from the IFC file and use this data to build the object from the class. The load data subs access the EDM database that is created from the IFC file.

The user interface for the fsIFCCTM consists of two main forms; the basic interface for the Translator and the display serves as a visual interpreter of translated results.

The Express Data Manager™ (EDM) has been used as an IFC parser by the fsIFCCTM. The IFC parser allows the Translator to read an IFC file into a database, the structure of which is decided by the IFC schema file that is specified to the Translator. Creating an EDM database allows the Translator to access the required data of the IFC in a hierarchical fashion and will speed up the data access process. An important feature of the EDM parser is that it allows for late binding of the data and it allows the user to access the database using user defined VB functions. EDM integration has been done in the server and the user does not have to access or use this middleware directly.

An Extensible Markup Language (XML) file can also be generated as an output from the fsIFCCTM translator. In the absence of a standard schema for CONTAM elements, the FSEC schema closely follows the structure of the server relationships and each class, usually a subsection in the .PRJ file, is a component in the schema. Every component has certain attributes, some an internal part of the code and some required to be written in the .PRJ file. For every attribute, the schema will list the minimum, maximum and the default values as well as the type of data that the attribute will take. The minimum and maximum values can then be used to check the actual values that are being translated by the Translator. Should a value fall outside this range, an error or warning can be flagged. Should a value be missing in the IFC file, a default value for that particular attribute can be specified from the schema. Along with an option for easy electronic data transfer, validation is also an intended utility of the FSEC schema. A detailed error checking mechanism has been incorporated in the Translator which will, based on error codes, alert the user of possible errors in the translation.

RESULTS

Once completed, the Translator was used to test a small sample of IFC files made available to the authors. These included buildings with and without HVAC systems, files with staircases between floors, number of floors ranging from one to six and number of zones from three to a few hundred.

Following are the screenshots of a building being translated with the fsIFCCTM software. The original building was a two story commercial building with HVAC elements. It is seen in the DDS IFC file viewer™ (DDS, 2006) in an isometric form in Figure 6.
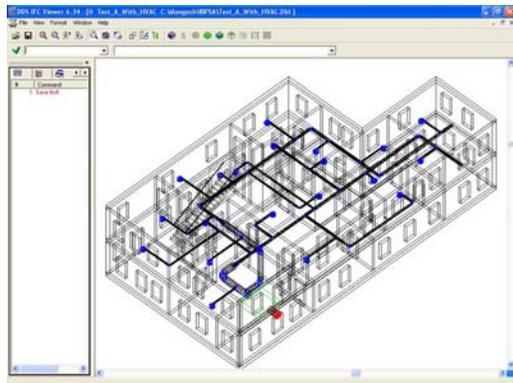
Figure 6 Building 1 3-D IFC model with HVAC

Figure 8 Building 2 3-D IFC model with HVAC

The above building was translated with the fsIFCCTM and the Figure 7 shows the translated file in the viewer of the Translator.
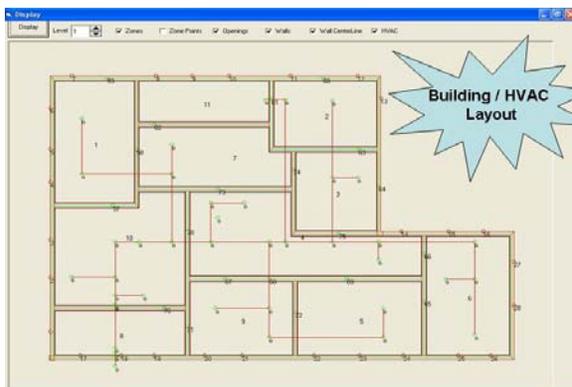
Figure 9 below, shows the translated .PRJ file being opened in CONTAMW.

Figure 7 View translation results – Building 1

Figure 9 Building 2 in CONTAMW sketchpad

The above building can be opened in the CONTAMW sketchpad but the optimized resolution is not enough to show a significant part of the building in one single screen of the CONTAMW sketchpad.

Figure 8 shows another building in the DDS IFC viewer[TM]. This was a 5 story building whose length to width ratio was better suited for reduction of scale and is more completely seen in the CONTAMW sketchpad screenshot. The zones are laid out as polygons and (tunnel-like) connections representing the doors, windows, leaks etc. are created between them. Since this is only the visual part of the data and is necessary to simply view the translated building and final simulation results on the screen, it should be noted that the simulation results are not affected or changed in anyway due to modification of representation of zones and their connections.
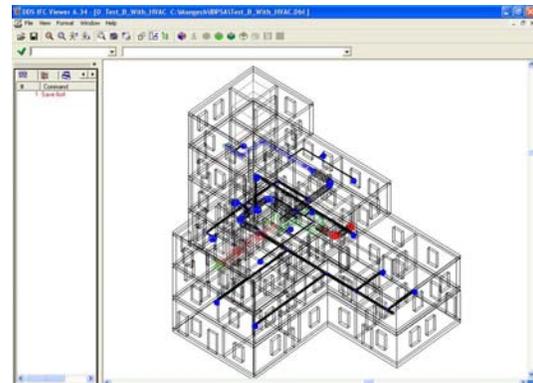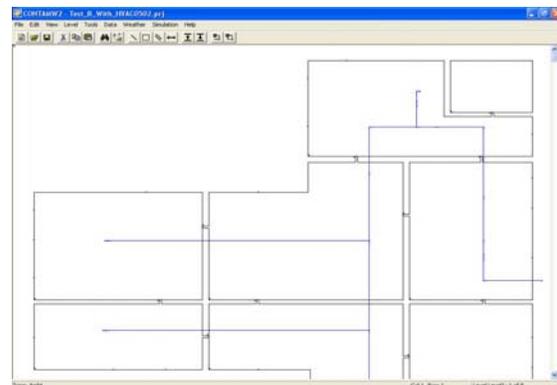
A number of issues have come up during the translation process from IFC to an input file for CONTAM. The biggest limitation has been the fact that IFC delivers three dimensional data, whereas the CONTAMW sketchpad can only display two dimensional orthogonal geometry inputs. The translated data could be used very easily with the CONTAMX simulation engine, but the bulk of the effort was required in manipulation this real world data to be displayed in the CONTAMW sketchpad. A number of algorithms were written to smoothen the zones, remove spikes, make them as regular a polygon as possible, scale them, remove close and collinear points, step inclined walls and so on. Following is a quick look at some of these issues in isolation and a few general guidelines that should be kept in mind when modeling the building and the associated HVAC in CAD.

General Caveats

- The Translator will work on a windows based system only.

- The translated '.PRJ' file will conform to CONTAM version 2.3a.
- There is a limitation on the overall resolution of the building that can be translated. A resolution higher than 3000 x 3000 will not be very effective when using the CONTAMW sketchpad.
- The Translator will translate IFC files based on the IFC 2x2 (Addendum 1) schema released by the IAI.
- Express Data Manager Version 4.7.21 is used as the IFC parser. The Translator will install the required EDM DLL's in the client machine.

Listed below is a set of component wise limitation, caveats and guidelines for the use of the Translator. Most of these are significant from the IFC modeling of the building and its HVAC component viewpoint.

Levels & Envelope

- The fsIFCCTM translator will not handle mezzanine floors. The translator assumes that each space spans only a single level.
- Circular walls will not be translated by the fsIFCCTM. Inclined walls will be translated and the program will try to step the inclined walls. The user is advised not to use more than 1 inclined wall per space.
- Staircases and elevator shafts should be modeled as openings in the slabs in the IFC file.
- Care should be taken by the modeler in IFC or CAD to use walls having at least some significant thickness. Spaces having common sides created due to overlapping walls will have to be skipped in the Translator using the zone report feature.

Zones (Spaces)

- Circular zones are not translated. They will be flagged and a warning can be found in the log file. These zones are then skipped in the translation.
- Zones with consecutive inclined sides will not be translated.
- Zones with self intersecting sides will be flagged and skipped.
- Overlapping zones will be flagged. The user has an option of skipping the ones with the most problems. This can be determined from the problem level parameter reported by the translator.

- Very small spaces should ideally be avoided when modeling the building in IFC.
- Jagged lines should not be allowed in the space boundaries when defining them in the IFC building model tool.
- Very small and thin needle like projections in the shape of the spaces should be avoided as far as possible.

Airflow Paths

- Airflow paths that have no neighboring spaces (zone 'n' and 'm' assignment for CONTAM, flow is from zone 'n' to 'm' or vice versa) will be flagged and skipped.
- Airflow paths that are located on the zones that might be skipped due to data problems will not be translated in the '.PRJ' file.
- It is advisable to avoid putting doors and windows on the corners in the building envelope as this might cause problems during icon generation.
- The translator will load a default library of airflow elements which can be edited by the user from the interface.

Duct Segments & Elements

- Each of the duct segments should have a minimum of two port connections. If a segment is shown to have a single port, it is assumed that there is an "end cap" at the other end of the segment.
- Each duct segment will have an associated duct element that is created based on the duct segment type entity associated with that segment.
- Inclined segments will be converted into stepped ones as the CONTAM sketchpad will not handle inclined segments. The user is advised to minimize the use of inclined segments.
- Every duct segment is expected to have one source and one sink port.
- Based on its ports connections, a segment will be assigned its 'm' and 'n' junction or terminal number. Should the translator not find this 'm' or 'n' junction or terminal, an error will be written to the log file.

Duct Junctions and Terminals

- Every duct junction in the IFC file is also expected to have two port connections. An error will be logged if two ports are not found.

- Should a junction be reported to have only one connection, it will be converted to a terminal.

Other elements in the HVAC system like fans, dampers and filters will appear as duct segments in the HVAC layout as this is how it is modeled in CONTAM. The segment is then specified as a filter or fan and an element of that kind associated with it to model the performance.

CONCLUSION

Converting existing building and HVAC geometry to industry foundation classes (IFC 2x) model architecture and then to zonal model formats for contaminant and thermal analyses is critical for occupant health and safety, especially in the present scenario. The fsIFCCTM translator is a step in that direction and a successful proof of concept has been provided. The translator has been tested to translate buildings ranging from a single storey to six storeys as some of the results show, and buildings from three zones to well over a hundred zones. Some of these .PRJ files from the translation have opened directly without manual intervention in CONTAMW and simulations could be run with a few additional inputs.

However, the results so far do not mean that the simulation outputs are immediately useable. A systematic and probably industry wide standard is required for 'intelligent' building modeling in CAD so that essential data sets, for example inter-zonal leaks, small opening elements, schedules, virtual space boundaries and so on, are not missed when the IFC file is created. Either this data must be input during modeling or credible defaults need to be provided. Future work on the translator can also focus on establishing a reverse connection i.e. from flow and energy analysis software to CAD wherein valid recommendations for changes from the analysis can be implemented in the CAD model. Another interesting possibility is the use of CONTAMX as the simulation engine and the display of the translated building data and the simulation results in a third party user interface other than CONTAMW which could reduce a lot of complexity in visual data representation.

The proof of concept though, implies that current technologies can provide a platform to address interoperability, scalability, reusability and extensibility that are crucial to well-designed robust and component-based applications and translate building data available in electronic format to IFC and then to zonal model formats. These capabilities when implemented can save considerable time, effort, duplication and loss of accuracy and help accelerate towards the goal of safe, healthy and energy efficient buildings.

ACKNOWLEDGEMENT

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