A NICE THING ABOUT STANDARDS

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Abstract The paper documents the implementation of automated data exchange process as an alternative to the manual workflow an architect needs to go through if he wants to comply with the EPR and acoustic regulations imposed by recent Flemish standards. This application is able to import specific IFC files and interpret its information. It automatically acquires the information needed and performs the calculations. The results of the calculation are then displayed through a user-friendly interface, to enable a designer evaluate his design and immediately make improvements to his model. This application was tested in a case-study using an exemplary BIM model. The overall functionality of the communication process from BIM to the application is analysed and the resulting concerns are outlined.

Keywords Building Information Modelling, Building Simulation, Industry Foundation Classes

1 INTRODUCTION

The research topic elaborated in this paper is summarized as follows: how can we automatically exchange the data required between digital building models and thermal, acoustic evaluation tools, rendering the architectural design process more efficient? The thermal calculation method is based upon the "*Calculation method of the primary energy consumption level of residential buildings"* as imposed by the Flemish Government[1]. For the acoustic evaluation we rely on the European Standard EN12354-3, "*Building Acoustics – Estimation of acoustic performance of buildings from the performance of elements"*[4].

But first we need to define the concept of 'a digital building model'. Recently the application of the Building Information Modelling (BIM) paradigm seems to gain importance in design offices all over the world. This new paradigm stands for a huge shift in the way designers construct digital building models, and the most important difference in comparison to conventional modelling techniques is the semantic richness embedded in BIM models.In contrast to merely describing geometrical objects (lines, arcs, boxes, ...) as in conventional modelling practices, the BIM paradigm introduces the concept of object-oriented modelling, meaning that the building model is composed by objects resembling real world things (door, roof, wall,...). Geometrical descriptions can only exist as a representation of a certain object or building component. Moreover, one has the ability to add all kinds of attributes to the components, e.g. the materials a wall is constituted by. Secondly the idea of parametrically defining component geometry was introduced. As stated before a component is defined by several attributes, which might have a geometrical nature. These kind of parameters describe the component's shape, possibly in relation to another component, e.g. the position of a door within a wall.

Another feature of present BIM applications is the availability of more abstract objects as rooms, zones or spaces. It should be mentioned that, although the range of applications for those concepts is huge, the present implementations are still young and still have many problems to be resolved. However, the space-object is of outmost importance for our purpose, since thermal and acoustic evaluations both use this concept as the primal starting point for the respective calculations: acoustic performance is measured between rooms or between a room and the environment, as is the case in this research project, since we want to evaluate the acoustical insulation of a building facade. Likewise the energetic or thermal performances also relate to rooms, spaces or zones. In addition, space-objects can be defined in relation with its bounding constructions, meaning that the space-objects have references to components (walls, floors, roofs, windows) delimiting the space or room. These references also provide the geometrical representation for the boundaries.

Considering the facts abovementioned, the BIM paradigm should be able to, theoretically at least, provide digital building models which contain a lot of reusable data for our purpose. Now, what are the possibilities to extract this kind of data from a digital model? For this purpose two strategies exist: one could use a the application programmers interface (API) of the host modeller, which is a proprietary set of objects and methods or one could use the ISO standard for exchanging building information, namely Industry

Foundation Classes (IFC) developed and maintained by the BuildingSmart Alliance [3]. Surely the former is most likely to be more efficient since the internal data structure of the model is exposed. On the other hand, this strategy is exclusively applicable for a particular application and demands for as many exchange modules to be developed as the number of proprietary models one wants to use or serve. This consideration leads us to the conclusion of developing one single module to extract the data required based on a IFC model, the building data is then fed into thermal and acoustic evaluation modules.

2 GEOMETRIC DATA REQUIRED VERSUS PROVIDED

2.1 Geometric data required by calculation methods

Before describing the research objectives more detailed, the data required for energetic and acoustical evaluations is listed. We will focus on the geometrical part of the data transfer, since the geometrical difficulties and respective solutions make up the difference in respect with existing procedures. As summarized in Table1, the required geometrical data consists of the internal and external volume V (m^3) per space i.e. as seen from the in- and outside, the internal and external area A (m^2) for each bounding construction as well as its surface normal N (providing the orientation and inclination angle i.e. Θ and Φ).

		V,zone (m^3)	A,construction (m^2)	d,construction (m)	Θ,construction (°)	Φ,construction (°)
Energy	Qt,zone,m (MJ)		■	■		
Energy	Qv,zone,m (MJ)	■	■			
Energy	Qi,zone,m (MJ)	■				
Energy	Qs,zone,m (MJ)		■		■	■
Energy	ηutil,zone,m (-)	■	■	■	■	■
Acoustic	Ratr (dB)	■	■			
Acoustic	La (dB)				■	■

Table1, Geometric data required for the energy and acoustic standard [3,4]

2.2 Geometric data provided by the IFC2x3 model scheme

Next, we evaluate the data structure of the IFC2x3 model scheme [5] with respect to the required data previously described. In fact, from a geometric point of view, the IFC model scheme defines the building in two ways. The most straightforward description is the one which individually defines each component accompanied by its own geometrical representation. This representation consists of a two dimensional plan representation as well as a three dimensional solid representation e.g. in most cases a wall is defined by an extrusion of a two-dimensional profile, residing on a certain storey level. Note that spaces also have a three-dimensional representation, albeit not always as accurate as one might expect (in Revit Architecture for example more complex spaces are defined by a bounding box). Thus, the three-dimensional representation for the building as a whole is formed by the collection of the individual building components, with very little, if any, topological relations. In practice, this way of describing a building's geometry is most likely to be well supported by commercial BIM applications.

In contrast, the second strategy has found until today less attention but is much more interesting from a topological point of view. This strategy starts from the idea of describing a building based on the spaces enclosed by its structure. In addition, each space description holds pointers to the construction components by which it is bounded and, more interesting, to a geometric object representing the shape for that specific boundary. By generating the geometric representations for each individual boundary and collecting them for all boundaries one is able to reconstitute the inner dimensions of a space instance. The geometric descriptions for the individual boundaries will most likely be a planar curve. Triangulating these curves enables us to calculate the space inner volume and inner area quantities for the bounding constructions. A next step consists of generating the space external volume and external construction areas, based on the information previously processed in combination with data describing the thickness for each bounding construction. A very important step at this point is the processing of a directed, triangulated closed mesh as the geometric representation for the space inner dimensions. Note that in the previous step we already triangulated the curves representing the inner boundaries, however, this step did not necessarily result in a directed, closed mesh representing the spaces. Indeed, some triangles constituting the mesh might not have their neighbourhood defined correctly. Therefore an intersection test for all triangles has to be performed, after which a straightforward offset algorithm for each mesh vertex is executed, resulting in the external dimensions of the space. Summarizing the abovementioned leads to the following objectives:

For each space:

° collect all spaceboundaries and generate the corresponding geometrical representations as described by the model;

° for each spaceboundary: triangulate the original curve provided by the geometrical representation and reference each triangle to the construction component;

° search for intersections between all triangles and retriangulate if necessary, add all triangles to the mesh data structure and check all triangles for neighbourhood, this results in a mesh representing the inner dimensions of the space;

° for each triangle in the mesh data structure: direct the surface normal outwards and generate a solid object based on the construction component thickness, providing the outside dimensions for the boundary, thus for the space mesh as a whole;

° at this point all geometrical data is generated and the required information for the energetic and acoustical evaluation can be delivered in.

3 IMPLEMENTATION METHODS

In collaboration with the Department of Electronics and Information Systems a IFC-Parser application was developed, enabling the mapping of an IFC file on Java and .Net class instances. Combining the IFC2x3 model scheme and the functional requirements needed for the evaluation methods, the set of *IfcRelSpaceBoundary* instances for each *IfcSpace* delivers the best entry point. Each of these *IfcRelSpaceBoundary* instances incorporates the four following properties (fig 01):

° *RelatingSpace* : references to one space that is delimited by this boundary;

° *RelatedBuildingElement* : describes the construction element used as a boundary for the space (assuming that such a physical boundary exists);

° *ConnectionGeometry* : establishes the geometrical relationship between an IfcSpace entity and the related bounding construction;

° *InternalOrExternalBoundary* : states whether the bounding construction neighbours the exterior or the interior;

° *PhysicalOrVirtualBoundary* : states whether the space is bounded by a physical boundary or by a virtual (open) boundary.

The argument for using the *IfcRelSpaceBoundary* instances as a starting point has a geometrical and relational nature. The IFC2x3 model scheme provides for several ways to geometrically represent an *IfcSpace*, varying from roughly described bounding box definitions to accurately defined B-Rep solid definitions. Evidently, since we want for the evaluations to be as precise as possible, an exactly defined shape for the *IfcSpace* instances is required. Moreover, each geometrical part of an *IfcSpace* geometrical representation has to be related to an *IfcBuildingElement*, since the physical properties of the construction used for this particular *IfcBuildingElement* are required for the evaluations.

Previous considerations, i.e. the need for an exact geometrical representation of spaces related to the constituting construction components, renders the availability of the shape by the individual *IfcSpace* geometrical representation useless since there are no relations provided with the *IfcBuildingElements* which bound it. The only way to process the exact shape with relating components is by using the set of

IfcRelSpaceBoundary instances which each hold a pointer to the *IfcElement* bounding the space. *IfcRelSpaceBoundary* instances have an optional property called *IfcConnectionGeometry* which provides for a geometrical description of the surface connecting a construction component to a space. It is by assembling these connecting surfaces that we are able to develop an interrelated mesh for a given *IfcSpace* instance.

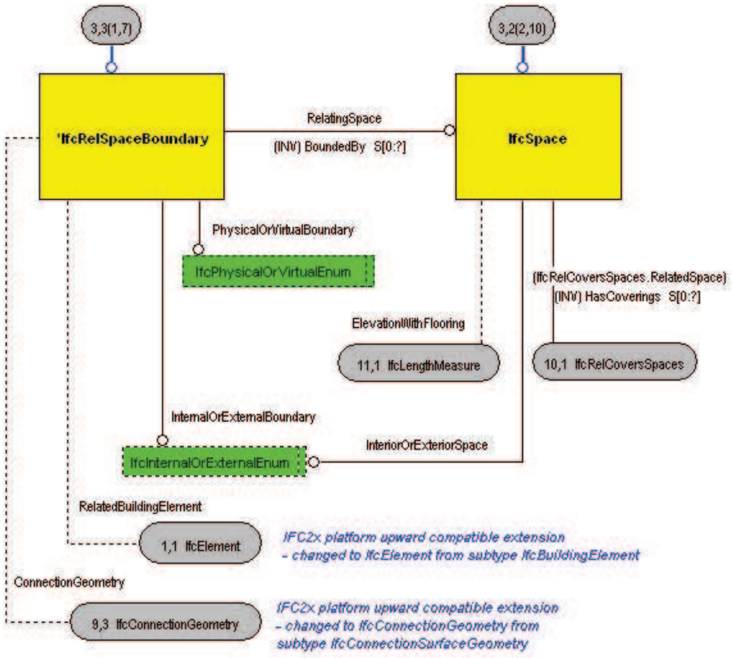

Figure 1 The EXPRESS definition of the IfcSpace in relation to the IfcRelSpaceBoundary entity

Several possibilities are provided by IFC2x3 model scheme to define the connection geometry and different definitions are encountered when observing IFC models generated in practice. The *IfcConnectionGeometry* for horizontal slabs, for example, is often defined as an *IfcCurveBoundedPlane* instance, which provides a closed and planar curve, as a boundary facet. However, in compliance with the model scheme, the wall connection geometry might be defined by means of an *IfcSurfaceOfLineairExtrusion* instance. In that case, the generation of the curve defining a wall connection geometry is far more complicated. Merely a prismatic surface is provided, determined by a two dimensional profile, an extrusion direction and height (fig 02). Surely, the profile to be extruded matches the line segment where the wall connects to the flooring, but problems arise when trying to define the line segment connecting the wall to the space ceiling. Note that the extrusion height is derived from the *IfcSpace* individual representation, which is in some cases the space bounding box and therefore does not necessarily coincide with the exact shape. A strategy is presented to generate the exact shape and represent it by a closed, directed mesh.

3.1 Triangulating connection geometry representations.

A first step consists of triangulating the curve or surface which represents the connection geometry between a bounding component and the space. Several algorithms exist to perform a triangulation, but the one preferred is the algorithm by Domiter et al. [6]. This recent algorithm provides a constrained Delaunay triangulation for a planar point set by using a sweep-line paradigm combined with Lawson's legalisation [7]. The algorithm simultaneously triangulates points and constrained edges resulting in a very fast and reliable procedure. The algorithm delivers a constrained Delaunay triangulation and thus the convex hull for the input points. Since the original curve might be concave, we need to perform a last step, namely removing all triangles which violate the original boundary by applying a winding number test for each triangle. Finally, the triangle set is stored in a data structure which holds a list of triangles, each referring to the constituting vertices and connecting edges with a pointer to the neighbouring triangle, resulting in a triangulated, directed mesh for each bounding component.

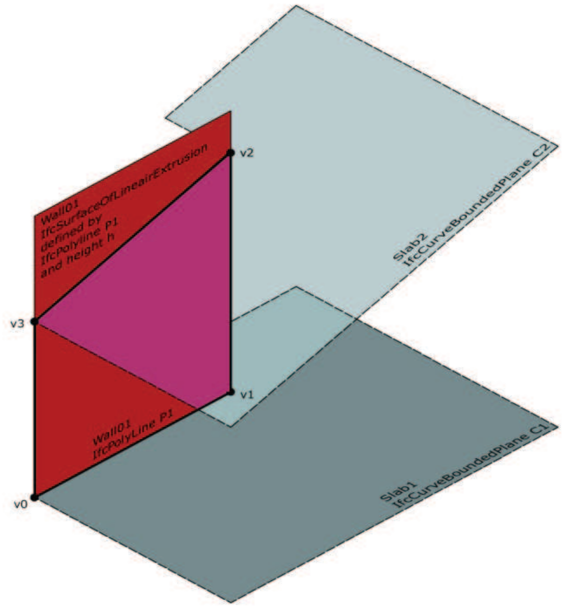

Figure 2 The intersection of the extruded surface of the wall with the slab curve defines the wall curve.

3.2 Testing for mesh intersections.

The triangulated curves or surfaces are combined representing the *IfcSpace* shape. However, several triangles do not coincide with the exact shell. By using for instance the *IfcSurfaceOfLineairExtrusion* entity to represent a wall, the upper boundary is completely incorrect with respect to the ceiling when the latter is not horizontal. To overcome this kind of deviations an intersection test is performed between all triangle sets originating from the different bounding components. The algorithm used for the intersection test is based on the work of S.H. Lo and W.X. Wang [8] which we use to determine the intersection line segments between two sets of triangles.

The previous steps deliver subsets of the original triangle sets which are hit by one or more intersection segments. Those triangles need to be subdivided according to the new segments, which can be seen as newly developed constrained edges for a Delaunay triangulation of the point set originating from the parent triangle vertices combined with the intersection points calculated. At this stage the algorithm explained in 3.1 is called again and the original triangles are replaced with the resulting triangle sets, leading to a subdivided mesh according to the intersection curves.

A last step in defining the exact geometry for the *IfcSpace* consists in eliminating all redundant triangles for the subdivided mesh. This is done in a very straightforward way, by excluding each triangle which has an empty value for the neighbourhood property for one of its edges. A closed and directed mesh, exactly representing the *IfcSpace* internal geometry, is delivered (fig 03).

3.3 Generating the external shape.

The resulting mesh does not yet provide the data needed for the evaluations, i.e. the external volume of an *IfcSpace* or the external area for a component. Gaps appear between neighbouring spaces and the building's outside geometry is completely absent, due to the lack of geometry for all bounding constructions like walls, floors and roofs. Therefore we elaborated an algorithm which inflates the *IfcSpace* internal geometry, to match its outer boundaries, by generating the boundary volume, based on the thickness of the corresponding construction component. This algorithm results in a new mesh representing the external dimensions for the *IfcSpace* which enables the calculation of its external volume and external area's for the construction components (fig 04 & 05).

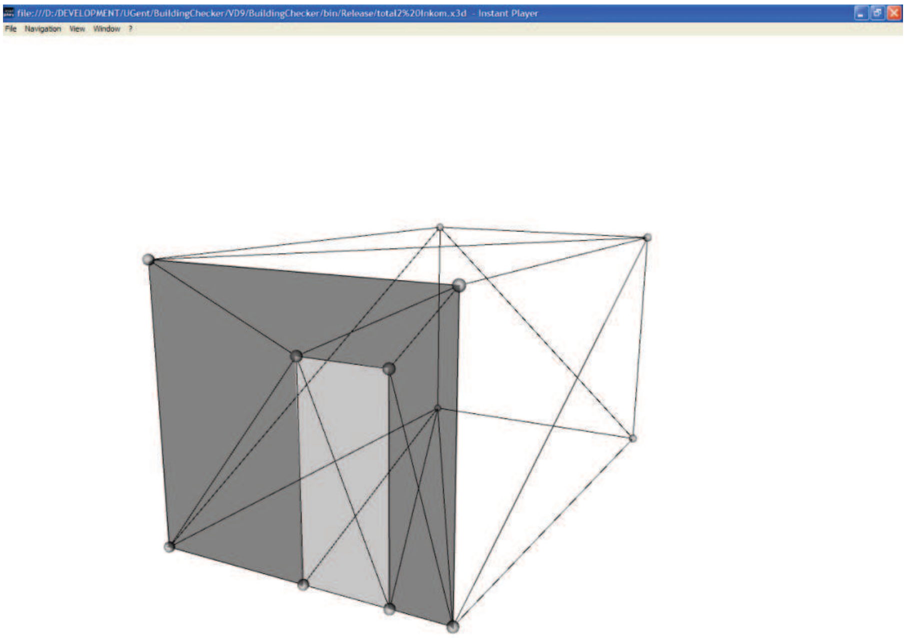

Figure 3 The closed and directed triangulated mesh, representing the internal geometry.

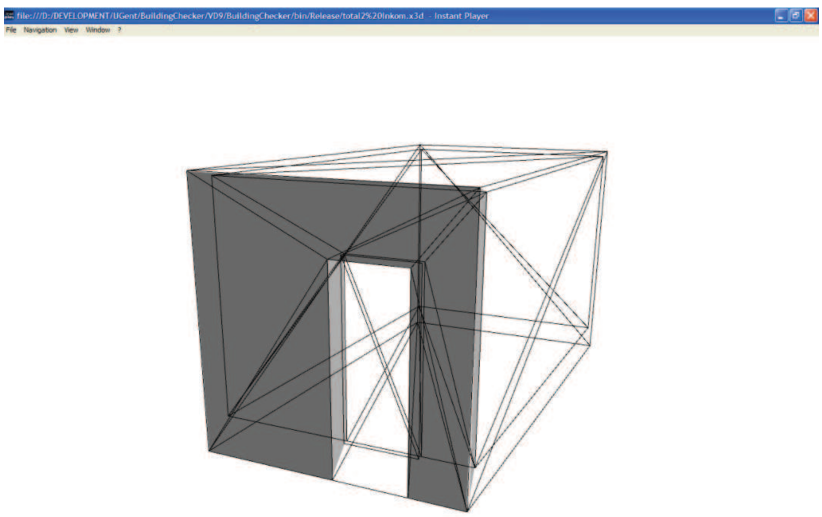

Figure 4 The inflated mesh, representing the external geometry for a IfcSpace instance.

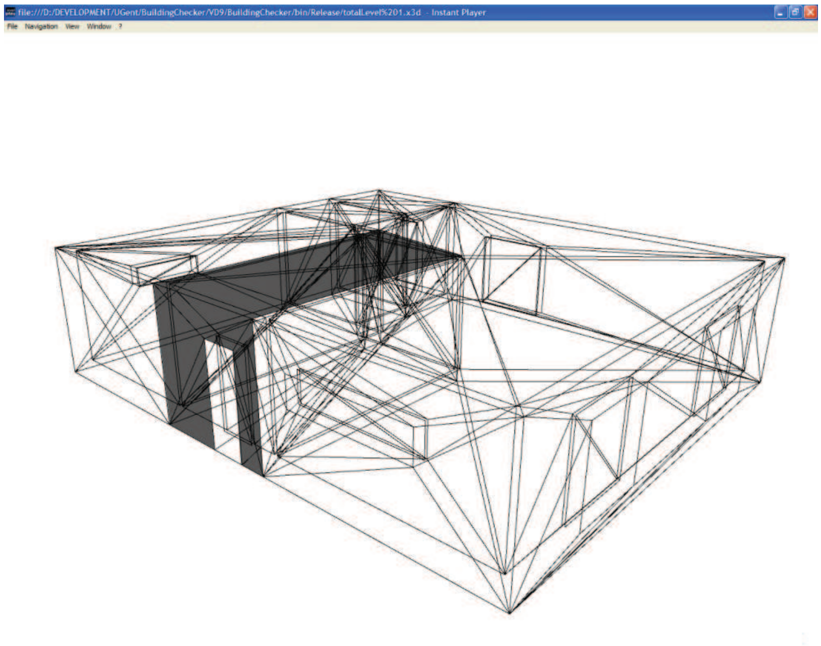

Figure 5 Collection of closed, directed, interrelated and inflated IfcSpace meshes.

4 THE PROTOTYPE APPLICATION.

Following the investigation of the evaluation methods and the building-specific information found in the IFC model scheme, we implemented a prototype application: the Tiatab BuildingChecker. This application enables the import of a complete BIM model in the IFC file format, starting from which an automated calculation of the evaluation methods can be carried out, resulting in a relatively detailed overview of the energetic and acoustical performance of the different building elements and of the complete building itself. The main concerns thus far in the implementation of the Tiatab BuildingChecker covered the incorporation of the IFC model scheme and its possible successive versions, the extraction of the required data out of specific IFC files, the execution of the evaluation methods, and the development of a user interface with an acceptable level of clarity. The test case used is a building design modelled in Archicad12, consisting of four storey's containing several spaces with orthogonal as well as curved walls (fig 06).

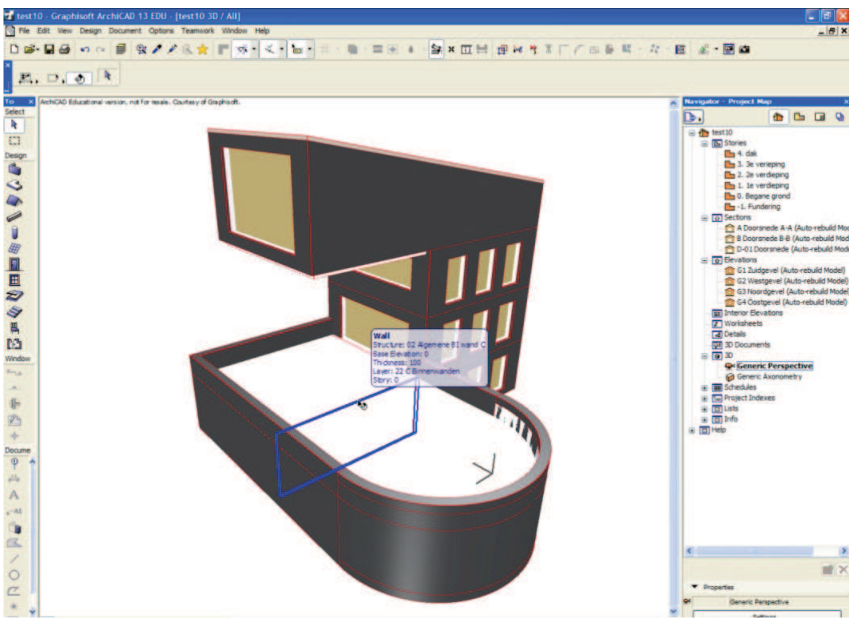

Figure 6 Test case: building design in Archicad12

Because the evaluation methods procedure itself starts from a Xml-based input files, Xml schemes have been developed comprising all required data. This intermediate step was introduced to enable the import of both model files based on the IFC standard as model files based on other formats (e.g. GbXml). For each import, all IFC objects in memory are thus iterated in order to collect the required data, which is stored into several Xml-files, containing a description of the geometry and the material layers for all construction components, completely in a space-based structure.

The user interface needs to be as intuitive and structured as possible to allow the desired level of understanding for designers and architects, especially those who are not familiar with similar calculation tools. Therefore we decided to split the user interface in a tree view containing the structure of the underlying building model (left in fig 07) and a content view consisting of a 3D view. When an object is selected in the tree view on the left, the corresponding object will also appear visibly selected in the content view on the right and specific properties of the object are shown in a window at the bottom of the left pane. The result of the sample IFC import can be seen in (fig 07).

Although the IFC model scheme enables the description of a material by its physical properties or by an external reference, only visualisation properties can be found in practice. Since this information is needed in the evaluation procedure, a material database is introduced to overcome this problem. This database supplies the required properties, such as thermal conductivity and acoustic profiles per material. Once a material or material layer exists in the database it will automatically be attributed to its corresponding construction component, meaning that the assignment is a non-recurrent user intervention. A screenshot of the material library is shown in (fig 08).

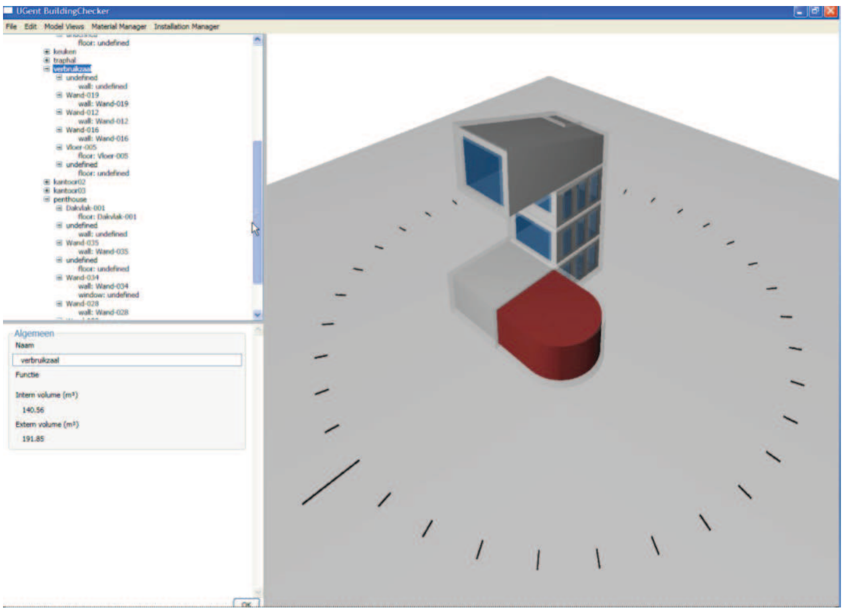

Figure 7 The Tiatab BuildingChecker application, model import.

The material library is a user specific collection of building materials. The BBRI implemented a public database providing building product information: the Tiatab Database. Import functionality is provided by the TiaTab BuildingChecker application to consult the Tiatab Database and import the product information, enabling a quick setup and maintenance of the user specific library. Once each space boundary instance is referenced to the corresponding materials in the library, note that this referencing operation is a nonrecurring step, the geometrical transformation algorithms can be executed, i.e. triangulating the boundary curves, constituting the closed, directed and inflated space meshes.

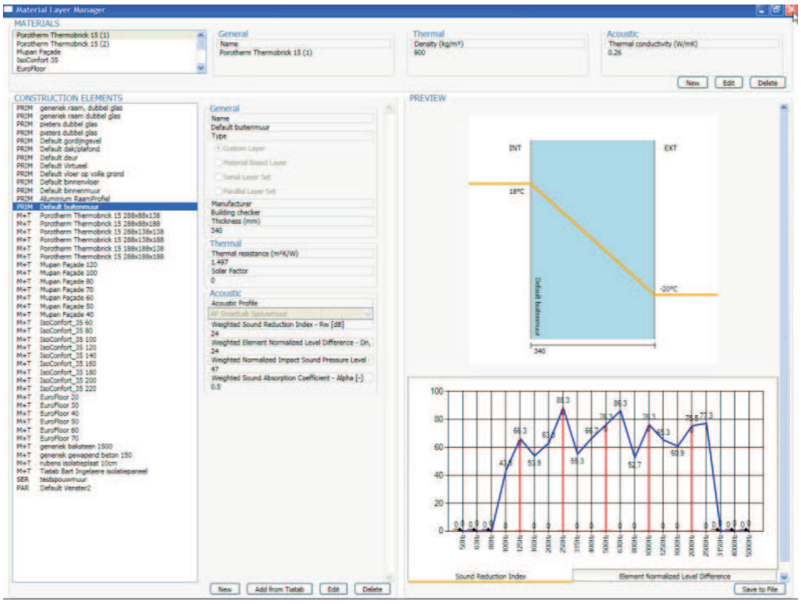

Figure 8 Tiatab BuildingChecker application, material library.

5 CONCLUSIONS

Emerging BIM applications combined with the interoperability of the Industry Foundation Classes trigger unique possibilities and advantages for architectural design and construction. The development of downstream applications for calculation and simulation purposes based on BIM technology allows a highly improved evaluation of preliminary and detailed architectural design projects. At this point, this methodology or work process is mainly being used by national and international (research) initiatives and large-scale companies. In order to bring BIM usage on a larger scale level, further improvements need to be determined and developed for the communication of information between different partners in the design process and the application they use.

This research is addressing this issue by investigating the IFC compliance with delivering the information needed to perform an energy and acoustic performance calculation. As a basis for performing such a calculation, we started from the Energy Performance Regulation, which is mandatory in Flanders for newly constructed and renovated buildings as well as the new European acoustic standard. These regulations imposes the qualification of the starting from explicit building characteristics. The regulations were analysed for the information that could be obtained from a BIM model. All required building-specific information was extracted from the formulas in which this information is used. This required information was then summarised to enable comparison with accessible information sources and their corresponding possibilities to communicate this information.

A brief and schematic overview is then given of the ways in which building-specific information is stored in a regular BIM model and the ways in which this information is accessible from external calculation software. Since maintaining a maximal level of interoperability forms the highest priority in our research, we selected what came out as the most interoperable communication method, namely the Industry Foundation Classes.

Research has then focused on the applicability of IFC to store and deliver the building-specific information needed to perform the calculation. This has resulted in advantageous workflows, but also in certain limitations. In order to comply with IFC and the calculation methods, certain workarounds needed to be developed in the form of extra algorithms. These workarounds are documented in the report.

Surely there is no doubt about the usability and necessity of vendor neutral data formats in the era of building information management. The present design and construction process undeniably demonstrates the potential for information standards, as is illustrated by this research project. However, when investigating the present import and export implementations in today's architectural modelers, one must conclude that a common agreed upon interpretation and implementation of the model scheme is still lacking. The nice thing about standards nowadays is that there are so many to choose from, at least this holds for the implementations analysed in this paper.

6 ACKNOWLEDGEMENTS

The authors would like to acknowledge the support of the Belgian Building Research Institute.

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