THE ROLE OF MVD IN DEFINING CURTAIN WALL SYSTEM FOR ENERGY ANALYSIS

Justin Wong[1]
[1]University of New South Wales, Sydney, Australia

ABSTRACT

Model based exchange has the potential to improve the process of information exchange between different disciplines (Eastman, 2006), such as architect and engineer. However, there has not been a lot of success in automating the process of acquiring building geometry for energy analysis. This paper is part of a PhD research that investigates ways to improve the efficiency of exchanging building geometry for energy analysis. To achieve this efficiency, it is best to adopt a formal system with an open data structure to define the scope of information to be exchanged and graphically represent where to get it. This will ensure the quality required for automating the information exchange between heterogeneous applications. For processes where significant semantics are required to enable successful exchange, such as that of acquiring building geometry for energy analysis, a highly structured approach is needed to ensure that data exchange is explicitly defined. This paper will discuss the use of the Model View Definition (MVD) as developed by buildingSMART International (2007), examining the information exchange requirements to undertake an energy analysis of a glazed curtain wall system with a view to identifying and resolving the issues associated with effective information exchange.

INTRODUCTION

The process of preparing the input data for energy analysis has been very time-consuming and error prone. As reported by Bazjanac (2001), more than 70% of the allocated time for building simulation is typically spent preparing data input for the analysis. This can be attributed to the fact that preparing such input data requires both experience and a solid understanding of the underlying physical phenomena (Hong et al, 2000). Very often, the environmental interactions experienced by fenestration systems are extremely complex as depicted in Figure 1(ASHRAE, 2009).

Glazed curtain walls, particularly those found in commercial buildings, are subjected to significantly more interaction with the environment than any other building elements. Generally, a significant percentage of cooling loads is attributable to glazing, especially in Australia. Advanced simulation tools are used to undertake analysis that establishes the energy impact of glazing in commercial building.

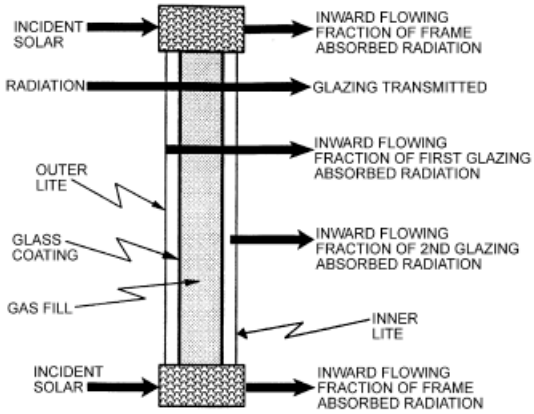

Figure 1Environment interaction experienced by fenestration system (ASHRAE, 2009)

Advancements in product model technologies has led to efforts to address inefficiency related to the process of input preparation for energy analysis by engaging in model based exchange, using a building information model (BIM). These models are very complex as they can include very detailed information about a building, but they are also typically constructed for a very specific purpose (such as design documentation or component fabrication) that may not align with the needs of energy analysis. Curtain wall elements are a good case in point: they are typically modelled as a single entity made up of panel and frame components and generally span across several storeys in the building. For the purposes of energy analysis, the thermal engineer is really only interested in that part of a curtain wall that bounds a space within the building that is the object of the thermal calculation.

Another factor that affects the adoption of model-based exchange is model quality. Gallenger et al (2004) point out that the cost of inadequate interoperability in the construction industry maybe high, but the cost of cleaning up poorly defined building information models can be equally significant for downstream processes. This is because proprietary data structures used by different software tools have complicated the data exchange process (Spooner and Hardwick, 1997).

DATA EXCHANGE AND MODEL VIEW

Figure 2 shows the data exchange process between two applications using a neutral format. On the conceptual level, both system A and B exchange information between their internal data structure with the neutral format through a mapping operation. On the physical level, both systems perform reading and writing functions through the software interface based on its conceptual mapping. The core issue discussed in this paper addresses the interaction of the receiving application (system B) with the neutral format at both levels.

In current practice, Building Information Model (BIM) is exchanged in their entirety between IFC-compliant applications without considering process. In this way, automatic translation between different BIM applications inherently removes the ability for the energy analyst to decide and control what goes into an energy model. As a result, downstream actors are forced to clean up models to suit their analysis. If context sensitive control can be exercised on the conceptual level, the significant cost associated with cleaning up model for downstream analysis (Bruning, 2011) can be avoided.

This can be partially attributed to the fact that different information is required for different downstream analyses. For instance, it is sufficient to exchange the shape of window as a boundary representation for clash detection. However, boundary representation is not adequate to be exchanged for energy analysis. This is because it lacks the semantics to meet the user requirement of computationally differentiating the glazed area from the frame area of a window in an energy model. This reflects the current practice that, while time-consuming and error prone, paper –based exchange is still the preferred way of exchanging information for energy analysis. This is because it allows the energy analyst to decide what to put into the energy model, which (very often) is a reflection of experience and professional judgment. Paper based exchange handles the issue of trust very well because it allows energy analyst to be sure of the inputs to the energy model. Hence, the energy analyst feels confident about the result generated from energy analysis using simulation tool because he has control over the input.

In essence, the energy analyst would like to decide and control which aspect of the IFC model goes into which part of an energy model. This can be conceptually interpreted as the ability to define a configurable subset of a neutral format such as the IFC model, which is formally defined as a view. Formally defined view can be perceived as a configurable subset of a model. We propose that such a formal view definition is capable of incorporating the ability to decide and control the model based exchange for energy analysis. In the context of energy analysis, the exchange scenario dictates that swept solid representation should be used to define the shape of a window. This demonstrates the need to formally communicate the required representation for process for each specific exchange scenario.

As depicted on the physical level in Figure 2, one of the requirements for the receiving application (system B) is to be able to read the appropriate information from the neutral format, transform and write that data into its own internal data structure. There is a risk of failure if the neutral format does not contain the information required for that purpose. Hence, this raises the need to identify the scope to extract the appropriate information from a neutral format for reliable exchange. Formal articulation and integration of view within the development cycle of the receiving application will better meet user requirement. Hence, 'view' can be seen as a mechanism that enables better success with model based exchange. In addition, it will allow users expectation to be met more effectively by existing and/or new applications.

This relates to the difficulties in formally representing semantically complex ideas. One very good example of this is the ability to isolate vision panel from a curtain wall. Its formal representation requires extensive use of relationships of different type, even in neutral format like IFC. Therefore, proper integration of view into software/middleware development will bridge the information gap in meeting user expectations more effectively and it is very important for model based exchange. Hence, a gap exists in allowing downstream actors to control what subset of BIM is being input into energy model for further analysis. The information exchange framework (IDM+MVD) used in this work was developed by buildingSMART (2011). It consists of components for defining the underlying process undertaken by actors in the construction industry and its associated exchange requirements as well as the view of the IFC model from which these exchanges are supported. The prior is defined by Information Delivery Manual (IDM) where the latter is defined by Model View Definitions (MVD).The Model View Definition is used to define a subset of the IFC model that corresponds well with curtain wall system definition in energy model. The IDM part of this work has been published elsewhere (Wong et al, 2008). The MVD, together with a testing framework, will serve as a technical translation of domain knowledge required to ensure that the scientific basis of the analysis is not invalidated.

Once a view has been formally defined for an exchange scenario using MVD, it can be a better enabler to address the problem on low rate of adopting IFC reported by Rezgui et al (2011). Furthermore, the formally defined view for energy analysis can address the issue of efficient information exchange with minimal downstream cleaning of the model.

We assume that if data model mapping is defined correctly conceptually, then the read/write processes will happen correctly at the physical level. The successful articulation of the model view will also serve as an open platform for more robust way of certifying applications that support the process of energy analysis.

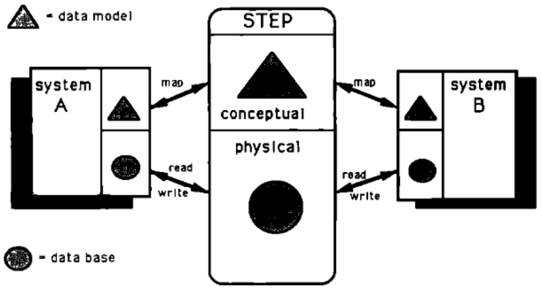

Figure 2 Data exchange between two systems (Augenbroe, 1992)

METHOD

ERM

The ERM diagram is a graphical representation of the technical implementation of exchange requirement. Figure 4 shows the information requirement to properly defined curtain wall in an energy model; described in a language that domain expert can understand. A key component of a glazed curtain wall is the vision panel. It will be used as an example to illustrate the process of developing an ERM diagram for the curtain wall. Essentially, the ERM diagram serve as a way of visualising the different aspects of vision panel in a structured manner. It should be noted that the purpose of the ERM diagram is to provide a technical implementation of the exchange requirement and has nothing to do with the IFC model yet. Generic concept is used to describe vision panel in an ERM diagram. Variable and Static concepts are the two types of concepts that are allowed in an ERM diagram. Static concept will have a corresponding IFC specific concept and variable concept is free to have any number of static concepts to define the exchange scenario. The underlying philosophy of having the ability to define as many static concepts as you can for the exchange requirement. This allows different aspect of the same element to be defined for different purposes. Figure 3 shows the graphical representation of the implemented ERM for vision panel. In this context, we are only showing the fact that we are defining the3D geometry of vision panels amongst many other aspects such as the aggregation relationship to the curtain wall or its optical properties.

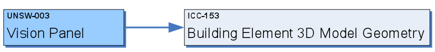

Figure 3 ERM for Vision Panel

MVD

The MVD diagram is created after the ERM diagram. A one to one binding has been imposed and provided between each static concept in ERM and MVD. This is so that each variable concept in ERM can be defined independently. As mention before, certain type of shape representation is more appropriate for information exchange to support energy analysis. Figure 5 is a MVD diagram that shows a graphical view of the possible ways of representing vision panels in an exchange. It should be noted that some of the boxes have been "greyed out" in Figure 4. This shows that the static concepts that make up shape representation can be dynamically configured for a reduced scope. The idea behind this is to show the scope of supported concepts for this exchange. For example, Mapped Item Representation is the only representation type supported in this model view definition. Therefore, if the shape representation of vision panel is represented using a different type of representation, it will not be supported by applications that implement this model view.

For example, ICC-481 shown in Figure 5 is a concept used to describe the type of shape representation permitted on this model view.

Instantiation Diagram

Instantiation diagram are graphical representation of the partial IFC model corresponding to a static concepts in the MVD diagram. The modelling expert needs to use two of the other diagramming templates to create an instantiation diagram. The "IFC 2X3 Entities" template contains all the entities defined in the IFC 2X3 model. The "IFC instance diagram" template provides the necessary linkage between attributes of different entities that represents a single concept. The purpose of the instantiation diagram is to graphically display a view of the data structure or partial model that represents the IFC specific concept to illustrate the partial IFC model.

Figure 6 shows an instantiation diagram that corresponds to an IfcPlate having a mapped item representation type. The rationale behind mapped item representation is to reduce the number of instances of shape representation for vision panel. For a fully glazed office building, it may have hundreds of vision panels. In order to reduce the number of instances as well as size for the IFC model, the mapped item representation shown in Figure 6 allows every instance of vision panel (IfcPlate) that is of the same dimension, to refer to a single extruded area solid shape representation. This will reduce the number of shape representations in the model significantly.

In addition, Figure 6 also provided the graphical representation on how to traverse the IFC tree structure so that the read function on the physical level of Figure 2 can be implemented correctly so that the write function to the internal data structure can be implemented correctly with a clearly articulated way of getting the information.

This graphical definition serves a number of different purposes. It can be a standalone implementer agreement. i.e. this dictates the way an IfcPlate with a mapped representation should be implemented by the host/upstream software (refer to System A in Figure 2). This is the most critical information for solution providers because they rely on this definition to traverse the "tree" or IFC model to obtain the necessary information from the IFC file. Solution providers can then process the obtained information to fill in information for the internal data structure. Through consultation with domain expert, the modelling expert decides on which of these attributes are suited for which part of the downstream application. For instance, when cross-referencing with Figure 7, the modelling team may decide that it is most appropriate to use the depth attribute of IfcExtrudedAreaSolid that is being referenced by the second instance of IfcShapeRepresentation 9see Figure 6). Hence, this provides a clear way of mapping attributes from the IFC model with the internal data structure of the host software.

RESULTS

An application, replicating the ability to read and write functions on the physical level, has been developed using the MVD process discussed above with special reference of discomposing the curtain wall into vision glazing and opaque wall. The result shown in Figure 9 is the automatic generation of input for energy model. This is created using an application developed using the MVD for energy analysis of curtain wall. It has demonstrated clearly that positive outcome can be achieved through application development using the MVD process.

When comparing Figure 8 and Figure 9, the reader will notice that input for energy analysis provided by the application is very similar same as the one depicted in the IFC viewer shown in Figure 8. This is the result from an application developed based on formally define view of IFC. In addition, rules driven by both expert opinion and domain knowledge can then be incorporated into the development through the use of configuration and definition in MVD. The defined view in MVD provides a fair platform that allows formal discussion between domain expert and solution provider.

The implementer agreement also enables discussion at a more granular manner. For instance, domain expert can inspect the final mapping outcome from MVD, such as vision panel details shown in Figure 4. It has clearly shown that the aggregation relationship between IfcCurtainWall and IfcPlate has been incorporated into the application and such incorporation is in line with energy analyst's thinking through association of parent wall and window name respectively. Such visual evidence will give domain expert the confidence about the expected quality when adopting model based approach for energy analysis. This has evidently meet user expectation of how vision panel of curtain wall should be defined.

Another benefit of developing application using the MVD process is that it allows application to be more flexible on a more granular level. For instance, once the overarching data structure for the shape representation of IfcPlate (vision panel) has been defined, control logic can be incorporated into the application based on the defined value for the depth and extruded direction attribute. Therefore, new generations of application can be more "tolerant" to incomplete implementation from host application (system A in Figure 2). A better platform for communicating exchange issue is formed as a result of using the MVD process because solution providers now have a clearer understanding of the required effort to respond to user needs.

DISCUSSION

It has been successfully demonstrated that MVD is perhaps one of the better candidates in developing application that meet user requirements. It should also be noted that when comparing the original IFC file(Liebich, 2007) (Figure 8) with the energy model (Figure 9), some instances of IfcPlate(s) which represent vision panel of curtain wall has been trimmed and some of these IfcPlate(s) are not in the energy model. Such operation has been driven by domain knowledge in that we know from Figure 8 that there are 32 panels associated with the curtain wall. However, in order to ensure that correct solar radiation coming into space 02 (the space show in Figure 8 bounded by curtain wall) is considered in the analysis, only the bottom row panels have been exchanged unaltered whereas some modification is done to the row of panel above it. Panels from the third and fourth row are completely ignored by the application for space 02.

This highlights one of the challenges faced in this work, i.e. the ability to integrate domain knowledge in the form of business rules into the application so that some form of intelligence can be elicited and built into existing and/or new applications. It is noted that rules that integrate domain knowledge is distinctively different from rules that addresses the localisation issue. Since the author is both domain expert and solution provider, the communication pathway required to integrate domain knowledge into the way information obtained from the IFC model are manipulated has not been considered thoroughly. This is the typical case for the construction industry where domain expert also develops solution for analysis.

However, there exists a scope for properly defined constraints such as those discussions in the previous paragraph. In essence, these constraints can be expressed as rules. There are two types of rules, one is more relevant to how energy analyst think and the other is how different simulation tools interpret the same information. The former is more generic toward model based exchange on a disciplinary level while the latter is more concerned with effective change at the application level. For example, the rule that 'filters" the top two row of panels are generic to all energy simulation tool but where to map the depth attribute of the IfcPlate's representation is highly dependent on the internal data structure of the energy simulation tool of choice. While there has been some discussion about how to implement constraint in the form of formal rules in MVD, the current version can only make certain assertion on the enumeration through implementer agreements, a textual document on how the IFC model should be implemented. Therefore, it is extremely important to note that constraints driven by domain knowledge are very likely to come from exchange requirements. This paper suggest that more work are required to understand how constraints can be incorporated into MVD so that these rules can be communicated to solution provider more effectively.

This also raises the question on whether there is a need to define proper mechanism for mapping between IFC specific concepts and proprietary data structure from the receiving application. Typically, this will not be a problem since solution providers will normally be involved in MVD definition and hence, the need to articulate the mapping between IFC specific concept and proprietary data structure will not be necessary. However, this will lead to the discussion in the future that when different simulation tools are used within the context of energy analysis. The question then is whether MVD should support exchange at application level or discipline level. More works is required to address these issues to further advanced model based exchange.

CONCLUSION

This paper demonstrates the process of formalising user requirements into implementable view through the diagramming method of MVD. When the implementable view is graphically represented together with its documentation, it can serve as an excellent platform for communicating user needs to solution providers. In addition, implementable views also enable solution providers to visualise and understand the expected effort to fully support user's view.

The advantage of using graphical tools to communicate ideas between different actors was also observed in earlier product modelling efforts (Augenbroe, 1992). In addition, process using graphical means also provided some level of assurance to end users/domain expert of the supported scope using the MVD approach. We hope that this is a step towards removing barriers so that design professionals can start using IFC as a way of communicating design intent. In this way, more efforts can be spent on design iterations that will generate an energy efficient outcome rather than cleaning models or re-creating what has already been defined.

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Type of Information	Information Needed	MAN	OPT	Actor Supplying	Functional Part
Building Elements					
Curtain wall	As energy analyst is concerned with accurate definition of its vision portion. Curtain wall for energy analysis can have two representation: It can be represented using aggregated entity of IfcCurtainWall. ***RULES:*** *The value assigned to IfcRelAggregates.RelatedObjects shall be IfcPlate and IfcMember.* *The enumeration for vision and spandrel should be CURTAIN_PANEL and SHEET respectively.* Alternatively, curtain wall can be represented as a standard wall with windows in it. In this case, dimensional information and placement of vision panel, to be used in energy analysis software, will be derived from window entity from BIM	√		Building Design	fp_model_plate fp_model_window

Figure 4 Information requirement for defining curtain wall (Wong et al, 2008)

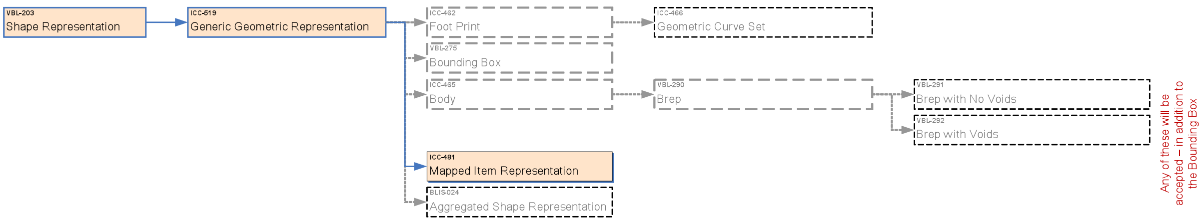

Figure 5 MVD diagram of shape representation for building element

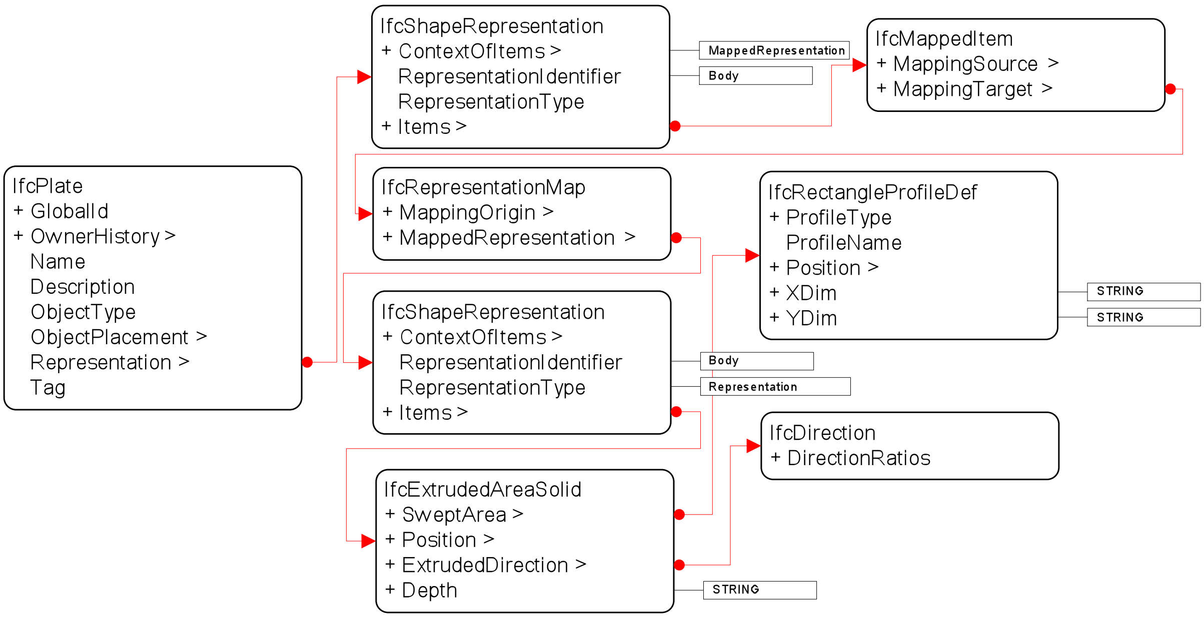

Figure 6 Implementation details for mapped representation in IFC

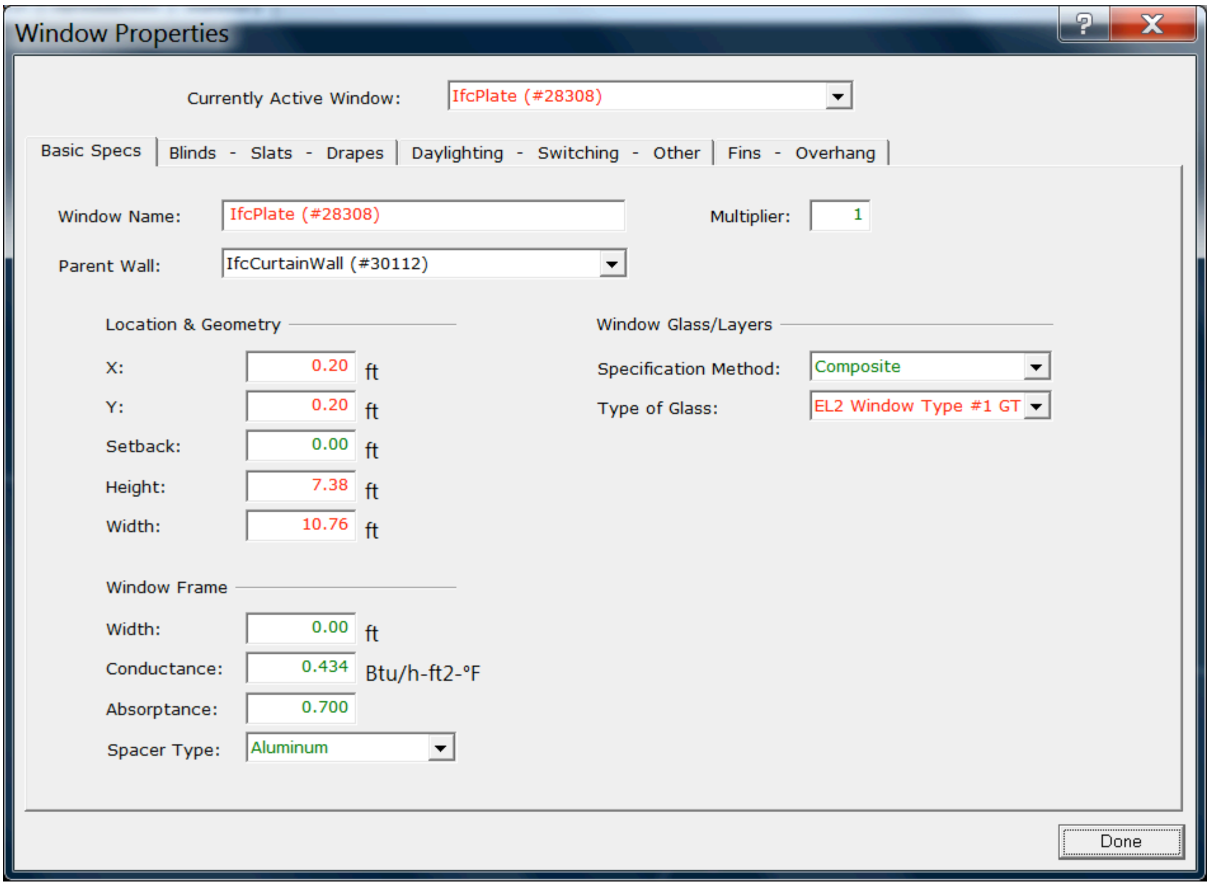

Figure 7 Window properties in destination software

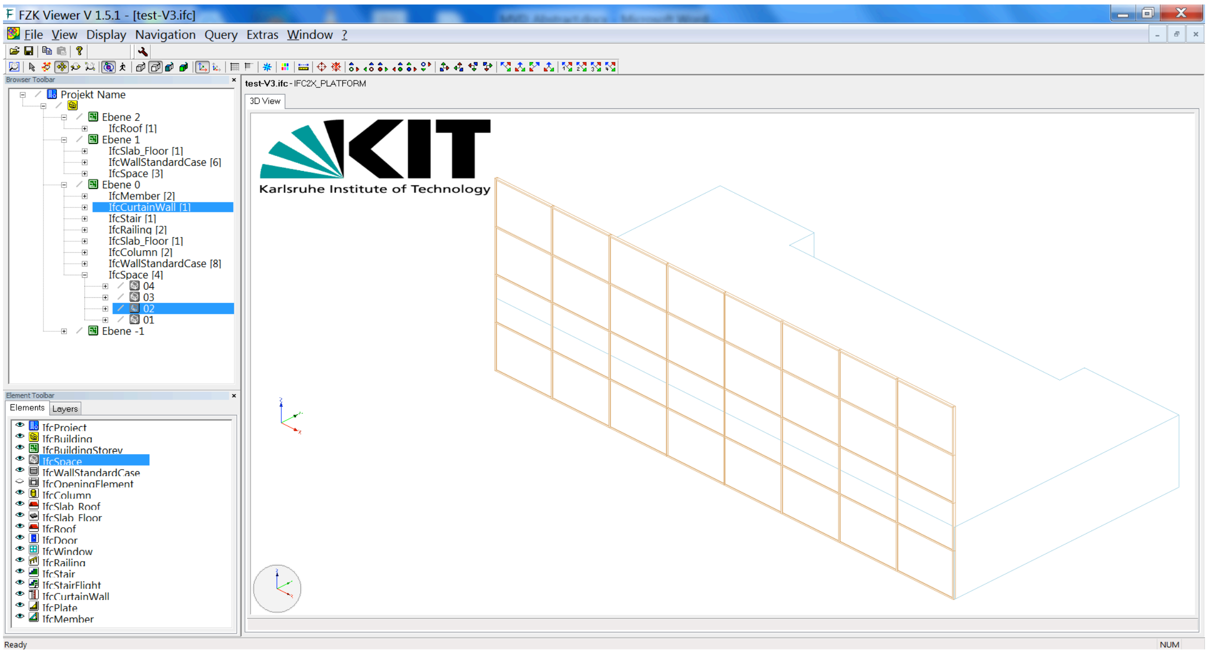

Figure 8 IFC model displayed in a viewer

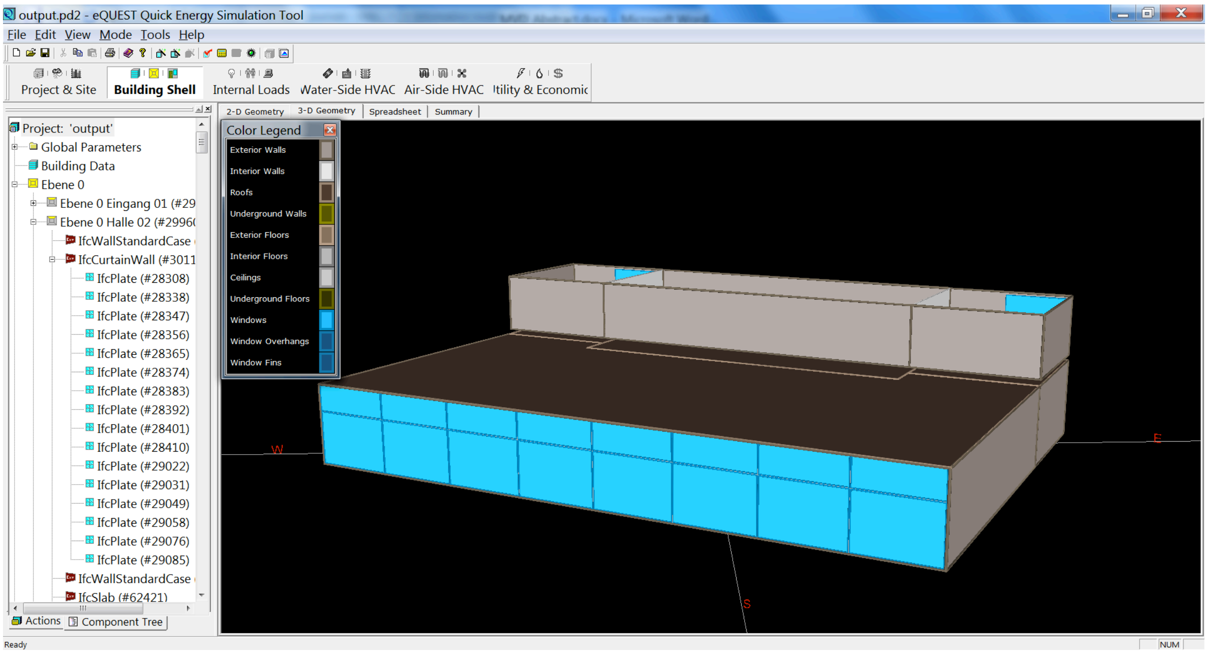

Figure 9 Input for energy analysis