SPECIFICATION OF AN IFC BASED SOFTWARE APPLICATION TO SUPPORT CFD SIMULATION

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ABSTRACT

It is proposed that existing validated Computational Fluid Dynamics (CFD) models could be used to support the asset and performance requirement of a building as prescribed in EU Directive 2002/91/EC. The most significant barriers to the potential role of these models are their complexity, the lack of CFD expertise in the industry and the lack of user-friendly effective software interfaces that recognise and mirror the users (building designers) physical and conceptual working environment.

This paper describes an integrated software environment that supports the development of black box CFD simulation models based on the Industry Foundation Classes (IFC) data schema.

KEY WORDS

Interoperability, information technology, IFC, CFD simulation, computing.

INTRODUCTION

EU Directive 2002/91/EC, requires building owners to quantify the energy usage and comfort rating of their proposed or existing buildings through a prescribed certification process by the year 2006. This certification will most likely involve an asset rating and an operational rating. The purpose of the asset rating is to determine a benchmark value for the energy consumption and environmental performance of buildings that comply with existing and proposed national and European building regulations (European Union 2003).

Current energy auditing methods may meet the requirements of the EU Directive for existing buildings. However, to predict accurately how a 'yet to be constructed' building will perform requires a modelling approach. This will have an added economic benefit as accurate simulations and analysis at design can significantly reduce operation and maintenance costs of a building. Figure 1 shows the tendency to underestimate the effect that design decisions have on Building Lifecycle (BLC) expenditure. From design to construction alone the initial design process accounts for 80% of a project's expenditure commitments while the actual expenditure at this point is minimal showing the lack of importance being placed on the design process (Kinney 2004).

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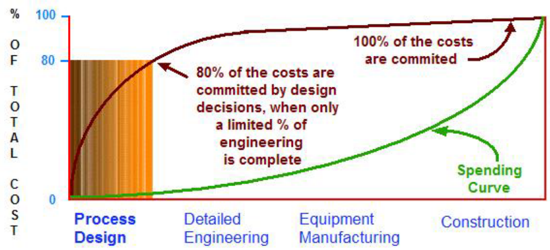

Figure 1 Project Expenditure Commitment Vs Project Spending (Kinney et al. 2004)

Complete design stage building simulation requires both macro (e.g. dynamic thermal, multi-zone airflow, etc) and microscopic (e.g. Computational Fluid Dynamics (CFD)) simulation tools (Malkawi 2004). Macroscopic tools are generally used for whole building and whole system analysis and are gaining popularity in the industry for their energy analysis capabilities. Microscopic tools provide within-room detailed results but are under utilised due to their inherent complexity.

Microscopic tools can use information from macroscopic tools results such as flow rates, etc. to provide detailed results of specified building zones. Therefore a natural coupling between these two tools can be seen. The current coupling between macro and micro tools means that the majority of the inputs require the manual transfer of data as most packages have independent file formats. A more interoperable approach is required (Augenbroe 2002) (Bazjanac 2004). A data centric approach would eliminate much of the time wasted in transferring data between tools during design. Figure 2 shows how a central data model could achieve a more interoperable design solution.

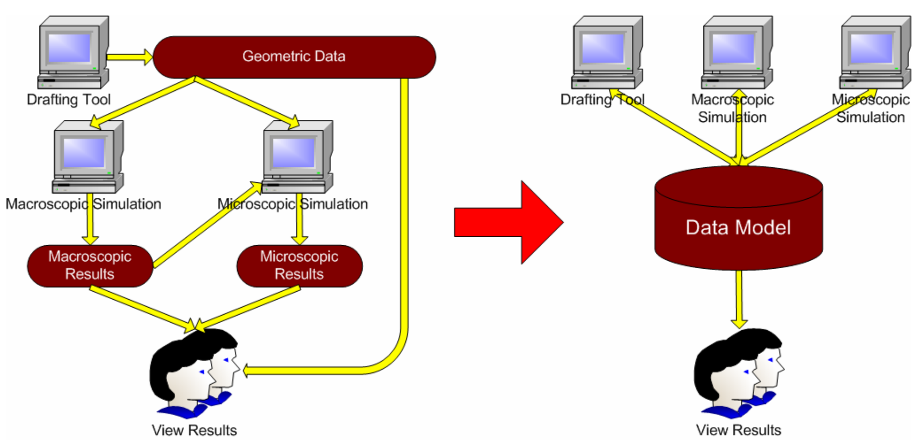

Figure 2 Changing current mapping into a data centric system.

This data model can then be extended into a Building Life Cycle Model that could facilitate interoperability between all stages of the building project (BLIS 2004) (O'Sullivan et al. 2004) as shown in Figure 3.

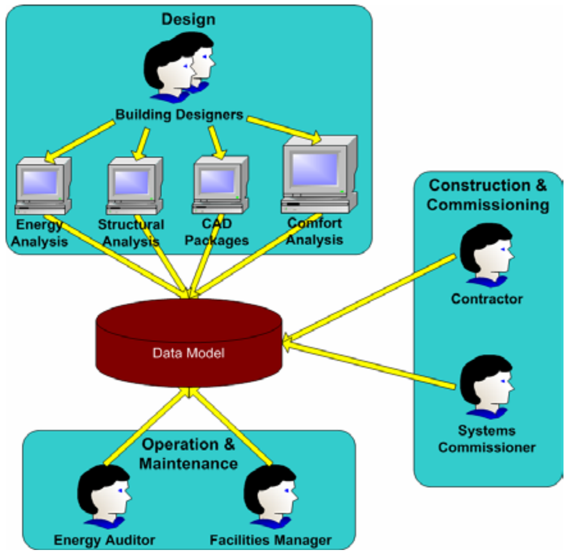

Figure 3 Use of Data Model throughout the BLC

An integrated data model improves the input of data into CFD tools but the complexity using CFD software must also be addressed. To do this, a context sensitive software environment that simplifies the interaction between the user and the CFD tools is needed. The environment needs to have an interface familiar, both in content and interaction, to the end user i.e. the Building Designer (BD). It needs to be able to supplement for the possible lack of CFD knowledge of the BD in order to make effective CFD analysis available to non-experts (experienced BD's with little CFD knowledge).

CFD AND INTEGRATED DATA MODELS

COMPUTATIONAL FLUID DYNAMICS

CFD is the application of numerical methods to the solution of discrete models of the constitute equations of fluid mechanics (Hirsch 2001). CFD can be applied in the many areas in building design including, energy savings, pollutant containment and temperature and humidity. The EU Directive requires that building owners minimise their energy consumption or incur economic penalties. However the directive also requires the safeguarding of comfortable environmental conditions, switching off the heating/air conditioning altogether is not an option. Therefore every cubic metre of treated air supplied to a space needs to be used to its full potential. CFD is a highly accurate tool which could and should supply the BD with very detailed information at the simple click of a button. However, since CFD can be used in numerous disciplines, the CFD software environments tend to be inherently complex having to support a variety of applications from the flow of air across an airplane wing to the flow of blood around the body. There is no specific environment aimed solely at the BD making CFD time consuming and unattractive to the building industry. By creating a Building Designer Intelligent Interface (BDI^2) for CFD it is hoped to overcome this obstacle. The first stage in developing BDI^2 is to determine the most appropriate Data Model.

BIM DESIGN

To improve the input of data into the BDI^2 a central data model is required. This Building Information Model (BIM) (Figure 3) provides a virtual building on which calculations, simulations, etc. can be carried out during the design stage. All design decisions made are stored into the model making it an up to date description of the building for the construction phase to follow. It would therefore contain all the specifications required by the building contractor for the construction of the building and the targets to be met during the commissioning process. During the operation stage of the lifecycle the BIM is used to store performance metrics of all the various components of the building for quantifying energy consumption (Morrissey et al. 2004), calibrating simulation models, etc. and still contains all the information required to perform new simulations to determine the viability of prospective changes.

Making information used in the design stage of the BLC available in the operation stage could seriously reduce the time required to analyse future changes to the operating systems employed in the building. For example the Facilities Manager could use the now calibrated energy model of the building, used in the design, to predict the performance of a proposed heating system and/or occupant schedules. Tracking and storing all the changes made to the building throughout its lifespan allows for the assessment of design decisions helping to improve design in the future.

INDUSTRY FOUNDATION CLASSES

To ensure efficient interoperability with the BIM an appropriate data format needed to be chosen. The Industry Foundation Classes (IFC) (latest version is IFC2x3) is chosen as it is a comprehensive, multidisciplinary and intelligent data model of buildings that defines data throughout a BLC. The International Alliance for Interoperability (IAI) (IAI 2003) was set up in 1995 by members of the Architecture, Engineering and Construction/Facilities Management community, as a non-profit making organisation, to create this standardised object-orientated data model. IFC is also the only open and ISO standard model. It therefore allows for unparalleled interoperability, allowing any member of the building project with any IFC compliant software to access the same building information or add new data to the model. The IFC schema is written in the ISO-STEP language Express and its graphical notation Express G (STEP, 2005).

BDI^2 DESIGN

The fundamental goal of this software is to make highly informative CFD analysis more available to the Building Designer. The current feeling in the industry is that CFD is essentially a luxury and is only used by highly resourced consultants for special building areas such as clean rooms as it is both a time and financially hungry resource. BD's readily accept that CFD is a very useful resource and could greatly improve the design of all buildings but do not use it due to the time required to train personnel in the use of the highly technical software, the time required to set up the model for analysis and the lack of a context sensitive interface.

Therefore to make CFD more appealing to the end user i.e. the BD, these problems needed to be addressed (Figure 4). The following sections detail the list of objectives of BDI^2.

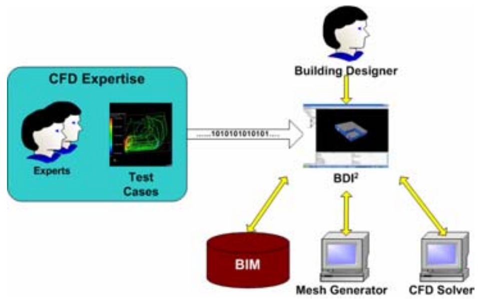

Figure 4 BDI^2 Design.

OBJECTIVE 1: TO MAKE CFD MORE ACCESSIBLE

To achieve this, a CFD intelligent software environment is needed i.e. CFD expertise must be coded into the software. CFD parameterization can be categorised into two distinct parameter sets, physical and computational. Physical parameters consist of entities already very familiar to the BD, such as geometry, temperatures and flow rates. The complexity of CFD for BD's lies in the computational parameter set. This set contains variables such as computational mesh topology, error thresholds, flow regimes, etc. and are required for accurate simulation (Broderick et al. 2001). For analysis of rooms in most buildings however many of these variables remain constant from project to project. Therefore with the detailed study of calibrated test cases standard values for many of these variables, which would provide sufficiently accurate results, can be found. These values can then be used as intelligent defaults in the software to provide realistic CFD results allowing a user who has little CFD knowledge to obtain accurate CFD results. Essentially by reducing the complexities of the computational parameter set from the BD's system of work, the CFD complexity can be made more manageable.

OBJECTIVE 2: RAPID MODEL GENERATION

The time required to set up the model for analysis is immensely reduced by the automatic import of geometric data and macroscopic simulation results from the BIM. Since the data model is in IFC format, all the information in it is available to other tools that access it and all these tools can similarly store data created by them back into the model. Therefore geometric data from a 3D modeller and air flow and temperature data from a dynamic thermal simulator can all be quickly imported from the data model eliminating the time required to manually construct the model. This also means that if changes are made to this imported data it can be quickly accessed, the model automatically reconstructed again and a new analysis performed. This would eliminate the current practice in the building industry of hoping that the changes made will not have a significant impact on the CFD results because it would take too long to manually reconstruct the model.

OBJECTIVE 3: BUILDING DESIGNER INTERFACE/ENVIRONMENT

This is possibly the most important feature of the software environment and yet the simplest to achieve. Since the overall aim (something which is often lost sight of during a project) is to make CFD simulation more available to the building industry, it is vitally important that a software environment is created that mimics the end users current environment. An example of the graphical user interface is shown in Figure 5 developed using Java (Sun 2005). The main window provides the user with a 3D image of the building, a realistic view with which any BD is familiar, more informative than 2D CAD applications. On the left a data tree depicts the component break down of the building with each floor broken down into rooms and each room into constituent building elements such as walls, doors, etc. The bottom table provides the user with relevant data on the element selected, e.g. coordinates, material, etc.

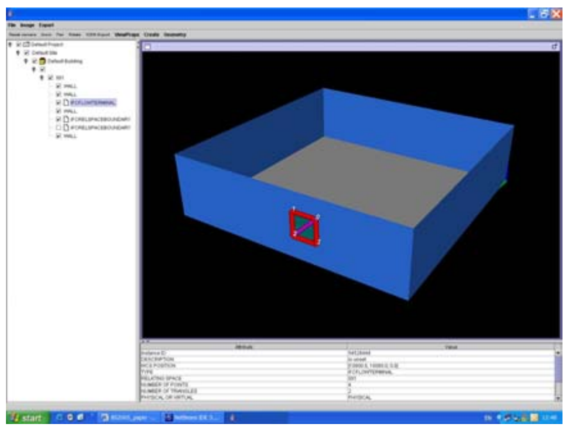

Figure 5 Graphical User Interface

An important aspect of BDI^2 is its ability to isolate building zones from within entire building geometry. Since whole building CFD analysis is not practical and in most cases only a few areas in the building require detailed analysis it is important to be able to isolate specific zones from the entire building geometry.

Another aspect of this software is to allow the user to specify boundary conditions (e.g. HVAC components) to improve the accuracy of the CFD analysis. For the purposes of this paper industrial standard air terminal elements will be used. It is important to specify models of industrial standard inlets (4-way diffuser, plain grille, etc.) because in spite of the effort employed in the simulation model not using these inlet models will lead to dramatically inaccurate results (Chow et al. 2003). However it is possible to use simplified models of these industrial diffusers to produce accurate CFD simulations (Djunaedy et al 2002).

OBJECTIVE 4: STANDARDS DEPENDENCY

In keeping with the interoperability philosophy it was decided that all file/data mappings be in international standard formats as much as possible. The mappings between the mesh generator and the CFD solver are to use ISO standard file formats such as IGES (IGES 1998) for 3D geometry and CGNS (CGNS 2003) for mesh data. This is to ensure that any mesh generator or CFD solver can be used with the software ensuring its adaptability and versatility and avoiding the danger of becoming dependent on a particular software package as is often the case with many new software developments. Essentially the goal is to create an application independent and standards dependent software environment.

OPERATION

BIM OPERATION

The BIM can be instantiated in an IFC compliant database (e.g. EDM^{TM} (EPM 2002)).

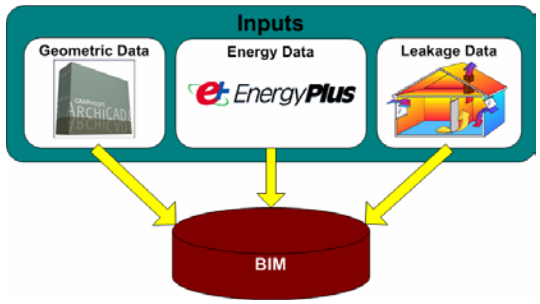

Figure 6 Population of BIM with data relevant to CFD simulation

Initially the geometric data is created using an IFC compliant 3Dmodeler (e.g. ArchiCAD^{TM} (Graphisoft 2005)) (Figure 6). Once this is done the various BD's can access it and perform the relevant analysis ranging from structural analysis to energy performance. For the purpose of this development the energy aspect of the design will be dealt with. The BD can access the geometric data from the BIM and load it into an energy analysis package (e.g. EnergyPlus (US DOE 2005)) to obtain the total energy performance of the structure, or into a multi-zone airflow modeller (e.g. COMIS (COMIS 2003)) to obtain leakage data. The results can all be stored back into the BIM making it available to all parties of the project. Certain sections of this data are relevant to CFD simulation and can be used in the analysis.

BDI^2 OPERATION

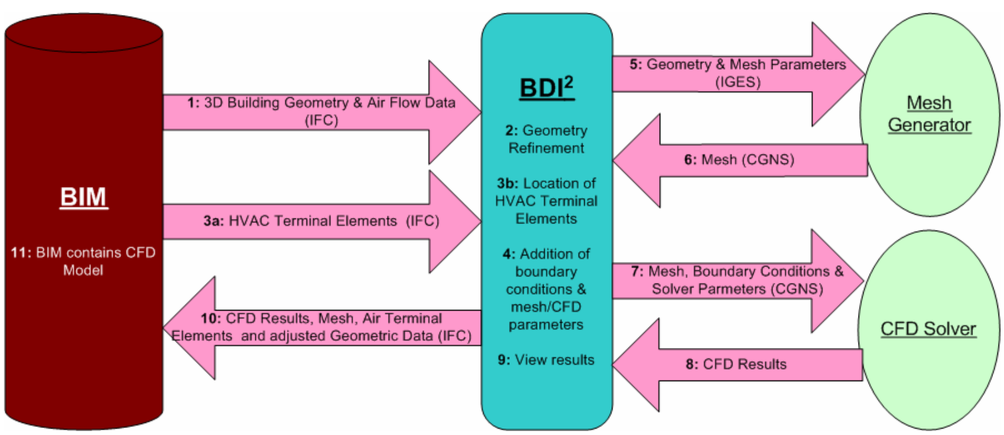

Figure 7 BDI^2 operating procedure

BDI^2 provides an interface between the BIM and the CFD analysis software. It not only aids the flow of data from the model to the analysis package but it also allows the user to refine this data by removing excess data and adding in extra information that may be required. Since BDI^2 is a data driven application its operation begins once the BIM has been populated. The CFD relevant data contained in the BIM is geometric data (from a 3D modeller), flow and temperature data (dynamic thermal simulator), leakage data (multi-zone airflow tool) and any other relevant information. Figure 7 show the operating procedure of BDI^2 once the BIM has been populated.

Step 1: Importing 3D Building Geometry

At the start up the user specifies the building to be analysed. All the relevant data that is in the BIM is imported into the BDI^2 environment. All the data is stored and a 3D image of the geometric data is presented to the user. The data tree allowing the user to specify the elements of the building to be viewed is also displayed

Step 2: Geometry Refinement

Using the data tree the user can isolate the zones he/she requires for analysis, stripping away all excess geometry (Lydon et al. 2001).

Step 3: Import and Location of HVAC Terminal Elements

From drop down menus the user can specify HVAC Terminal Elements (diffusers) to be used in the building zone. These industrial standard diffusers are to be stored in the BIM in IFC format where they can be accessed easily (3a). The user then specifies the geometric location and size of the diffusers in the zone (3b).

Step 4: Addition of Boundary Conditions and mesh/CFD parameters

The associated properties such as air flow rate and temperature can be added. These properties can be either manually inputted or, if energy simulation has been carried out and the results are available in the BIM, can be automatically imported and used for the CFD analysis. Since BDI^2 is aimed at an end user who may or may not have much CFD experience, various combinations of mesh default values are provided to allow the user to obtain different quality meshes and therefore different quality CFD results. Rough meshes would be used for systems comparisons while fine meshes used for more detailed analysis. As with the mesh parameters realistic default values, obtained from the study of validated CFD test cases, for the solver parameters are also provided. These default parameters are provided to the user for straightforward analysis but the specification of user defined parameters is also supported.

Step 5&6: Mesh Generation

The first step in the analysis is the mesh generation. BDI^2 passes geometric data and mesh parameters in a standard file format (e.g. IGES) to a mesh generator chosen by the user (e.g. ICEM (ANSYS 2004)) and the generator returns the mesh to BDI^2 in a standard mesh format such as CGNS. At this stage the mesh could be analysed for accuracy but this will be discussed in the conclusion.

Step 7&8: CFD Solver

This mesh file along with boundary conditions such as flow rates and CFD solver parameters such as the flow regime are mapped, in an application independent format (CGNS), to the CFD solver, which is again chosen by the user (e.g. CFX (ANSYS 2004)). The solver produces a results file which is returned to BDI^2. All this is done behind the BDI^2 interface eliminating the need for the user to work with numerous applications and file formats.

Step 9&10: Results

The results can be viewed by the user in the BDI^2 interface where it can be decided to re-analyse the zone. The user can make adjustments to the diffusers physical parameters or the computational parameters and perform a new analysis if the results are not satisfactory. When the analysis is satisfactorily completed the CFD results, the mesh and the adjusted geometric data are stored back into the BIM.

Step 11: Storage of CFD Model

All the data generated during this analysis is to be stored back in IFC compliant format in the BIM. However, the IFC schema is not currently fully supportive of the BDI^2 data model. Geometric and HVAC entities are supported in IFC but mesh and CFD entities do not currently exist and will need to be developed as IFC entities. However the IFC schema provides a method of creating properties for non-existing entities allowing the user to expand the scope of the schema to incorporate new information such as CFD data.

CONCLUSIONS

The basis for this research has been described. Currently much progress has been made with regard to geometric import, representation and export. Further development is required in the area of the mesh intelligence, CFD intelligence and the BDI^2 interface. Also the option for more CFD experienced BD's to check the accuracy (skewness, etc.) of the mesh in the post mesh generation phase should be investigated. A detailed analysis of academic and industrial calibrated CFD test cases to obtain realistic default values is required and the application must be developed in conjunction with the industry to ensure efficient software environment design.

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