

Simulation framework for design sustainability of buildings

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Abstract: The development of integrated building simulation environment is now firmly rooted in the current available computer technology. Over the past decade developments in the field of building simulation have given rise to the prospect of a new generation of design tools that has the potential to allow rigorous hypothesis testing at design stages. The move towards providing simulation support to the building industry has also been driven by the on going revision and introduction of new building regulations. This paper describes the DASS approach in bringing the simulation technology to the design profession. In delivering this service DASS has developed a business model of Participation, Integration, Open source resource Knowledge sharing (PIOK) together with a simulation framework, whereby all simulation tasks are operating upon a common data model, as technical support. The major elements of the simulation framework is described and the use of which is demonstrated by design examples.

Keywords: sustainability, simulation, CFD, fire

1. Introduction

Building designs require an integration of specialist knowledge from different engineering disciplines. While each performs design tasks specific to its domain based on its underlying design criterion, the integration of these individual designs could give rise to conflicts in design solution which may eventually cause failures to the final design solutions. Research indicates that about 50 % of the building failures originate from initial design, while 40 % of failures are due to construction. [Parand, 1995] The construction industry is moving towards 'intelligent' buildings and sustainable designs. Newly available technologies, material and design concept, e.g. Transparent Insulation Materials (TIM); Photovoltaic; Passive and Active solar devices; energy recovery systems; movable insulation and the increasing use of natural ventilation and daylight in buildings, are constantly evolving and being introduced in more and more designs.

Using traditional design methods, such as those from CIBSE or ASHRAE, in combination with hand or spreadsheet calculations, the designers are finding difficulties to ascertain the design objectives and environmental credentials to which their clients aspire. Sustainability design requires a balance between comfort, occupant satisfaction, visual delight, economic, low environment impact to ensure designs that meet these criteria. The provision of accurate assessment tools to building design would be the only choice to

ensure the improvement of design quality and reduction of construction and maintenance cost prior to the building being built. This makes necessary that the design teams to incorporate tools and methodologies in a fashion only previously seen in academic research of low energy design cases.

The demand for simulation support to the building industry has also been driven by the on going revision and introduction of new building regulations. In responding to the EU Directive of the European Climate Change Programme, the 'Climate Change – the UK Programme' detailed the UK's commitment to reduce greenhouse gases. The introduction of the Climate Change Levy and the revision of the Building Regulation Part L2 in April 2002 had led to a rethink on the design approach adopted on new buildings. One of the main changes is the introduction of a requirement to prove that the proposed building meets a certain carbon emission rating when compared to a notional building. These requirements are promoting designers to look for a more environmentally progressive design approach and consider the use of environmentally conscious sustainable designs.

2. Simulation support to the industry

The development of computer simulation tools for building performance assessment can be traced back from the late 60s and a succession of simulation software, e.g. DOE2, TRNSYS from the US and ESP-r, CLIM2000 from Europe, emerged since then.

Commercial building energy simulation software were also came into market from then on. Over the years significant resources from government all over the world have invested in the research and development of building simulation software. To date, the capabilities of a large number of such software systems have evolved to be able to offer calculating of annual solar regime, appropriate hvac sizing, daylighting and luminaries performance, detailed mass flow, building energy management controls and computational fluid dynamics (cfd).

Arguments remain that whether the use of such simulation software are appropriate to the engineers or better leave them to the modelling experts. Typically such discussions have been seen in the recent articles of the Building Services Journal. [Paul Kingston, 2002] [Danny Coyle, Karen Fletcher, 2003]

In responding to the new challenge of the building industry, a new service business model, PIOC, has been developed, i.e. Participation, Integration, Open-source software resources and Knowledge sharing.

2.1 Participation

By participation, we participate the design by firstly meet with the clients, to understand their objectives, methodology and the perceived building design issues. Working with the project team, we identify simulation scenarios required to test the design concepts and allow informed decision making. These can range from lighting simulation on a room, walk through & exterior appearance, predicting peak heating and cooling load using realistic climate conditions of the location, to a full cfd simulation of the building. Thereafter a fully budgeted proposal for the simulation scenarios is prepared for approval.

2.2 Integration

By integration, our simulation support services are committed to be an integral part of the design process, a practical understanding of the problems gained from first hand experience working in the construction industry, combined with technical expertise in the application of advanced building simulation technology. We understand that simulation support is not just provide simulation results, which can very often be overwhelming and misleading if not interpreted appropriately. We work closely with the client throughout the stages of the designs whereby problems

are identified and design optimised by simulations, until that the design is produced and progressively refined to reach the desired outcome - a model with natural realism & client satisfaction. In practice we have been working as part of the concept design team for a number of UK design corporations.

2.3 Open-source software resources

Very often it is misleading that commercial software would be superior to software available in the public domain or open source. Arguably a typical example would have to be Microsoft Windows versus Linux. In the field of building simulation software the comparison are much more obvious. A wealth of building simulation software are available free or at low cost over the internet, e.g. the Building Energy Tools Directory, among which, EnergyPlus, ESP-r, DOE-2 for building and hvac system, COMIS, CONTAMW for multizone airflow and indoor air quality, LISA, BEES for life cycle analysis, and Radiance, Pov-Ray, Rayshade, Polyray for ray-tracing lighting simulations, etc. are some of the best known.

Within the framework ESP-r and Radiance have been used as primary simulation tools for dynamic thermal and light simulations. ESP-r is a comprehensive modelling tool for the simulation of the thermal performance of buildings developed at Strathclyde University. The Commission for the European Communities has nominated ESP-r the European Reference Simulation Model. Radiance is an advanced lighting simulation and render software developed by Lawrence Berkeley National Laboratory.

Both software systems were originally developed for Unix platform. Although PC Windows version are now available, none of them has been able to provide the full capability and features that have been available on Unix platform. Our Software development has focused on the provision of toolkits to improve the productivity of the open source software via a simulation framework that allows all the simulator modules sharing the same data model and interact with each simultaneously at runtime.

2.4 Knowledge-sharing

At present time in the use of simulation technology within building design, many companies may not have the resource to build a team of suitably trained engineers and simulation experts to carry out all the

required tasks. The services provided under the business model PIOC are packaged towards sustainable designs, enabling the design professionals to make their own decision whether an in-house simulation capability is required or only the solutions. Sharing of knowledge is provided through the Open Source community whereby updates, bug-fix, are posted and the development are re-contributed back to the community. By the use of Open Source software, it is not only cost effective, the cost saving will also be passed onto the clients.

3. The simulation framework

3.1 The integrated data model

Recent development at the DASS has been focusing on the provision of a simulation framework that enables the interaction of all simulation modules and using the same data model. Central to the simulation framework lays the Integrated Data Model (IDM), that acts as the internal standard for data exchanges among various software modules. Since ESP-r was part of the European research project COMBINE [Augenbroe, 1993] for developing an operational computer-based Integrated Building Design System (IBDS) based on STEP data type exchange, the data model of ESP-r was adopted as the prototype of the IDM. Within the simulation framework all software modules operate upon this single IDM and thereby facilitating transfer of data, saving time and minimising error. Once data and other information are entered and held in the Data Model, it is available to all processes during the life-time of the design project.

The resulting IDM is a multi-layered, multi-thread open database structure that contains standardised primitive building descriptive data and data derived from the primitives. It is used repetitively and upgraded continuously by all the simulator modules throughout its life-cycle. The IDM has been provided maintenance tools to support CAD's DXF and ISO STEP data exchanges with other CAD environments. Data structure of the IDM can be sub-divided into four categories:

Primitive data	geometrical information represented in 3D vertices.
Material data	thermal physical properties of homogeneous building materials.
Functional data	data types such as climate, site information, activities profiles, etc.

Composite data data aggregates derived from primitive, material and functional data types or other composite data types, e.g. composite walls, surface attributes, etc. Where a composite data is created, it contains references to the data sets from where it was created.

The four data types are stored in different layers within the IDM thereby to minimise the interference between data types and optimise the access by various application modules. Once a data type is entered, it will be stored in its particular layer permanently and made available to all application modules.

The simulation framework provides a CAD modeller for the creating and maintaining the IDM. The CAD modeller is a suite of toolkits for the creation and maintenance of the IDM's 3D geometry and physical properties. Initially, CAD toolkits are used to set up a database containing all the model information pertaining to the design. All design calculation and application software will subsequently access the IDM for necessary information and update the database. However the IDM does not contain specific application information, e.g. light fitting distribution. In such cases where there is insufficient data for a particular application, the user will be offered intelligent defaults or the opportunity to augment the model with whatever information is required.

Within the simulation framework, IDM is constantly being accessed and updated by all the simulator modules throughout its life-cycle to provide the user with comprehensive information into how the building will actually perform, e.g. energy consumption; occupant comfort; air movement; lighting; and cost-in-use.

3.2 The simulation framework

The simulation framework consists of a range of simulators and toolkits for the simulation of the thermal, visual and acoustic performance of buildings and the assessment of the energy use and gaseous emissions associated with the environmental control systems and constructional materials. In undertaking its assessments, the system is equipped to model heat, air, moisture and electrical power flows at user determined resolution and incorporating the virtual reality facilities for simulation result presentation.

Fig. 1 shows the conceptual diagram of the DASS simulation framework. The modules of the simulation framework include:

1) Geo3 - The CAD modeller for creating the 3D geometry of buildings, site and the maintenance of the IDM of the framework. Geo3 provides a set of 3D primitive objects from which any physical object may be created. Different layers can be defined for different objects e.g. furniture, terrain, trees and

other site obstructions. Geo3 supports data exchange with AutoCAD and other CAD packages and thereby models created with commercial CAD packages can be used directly. 3D CAD geometry models created by Geo3 are used by all simulator modules within the framework.

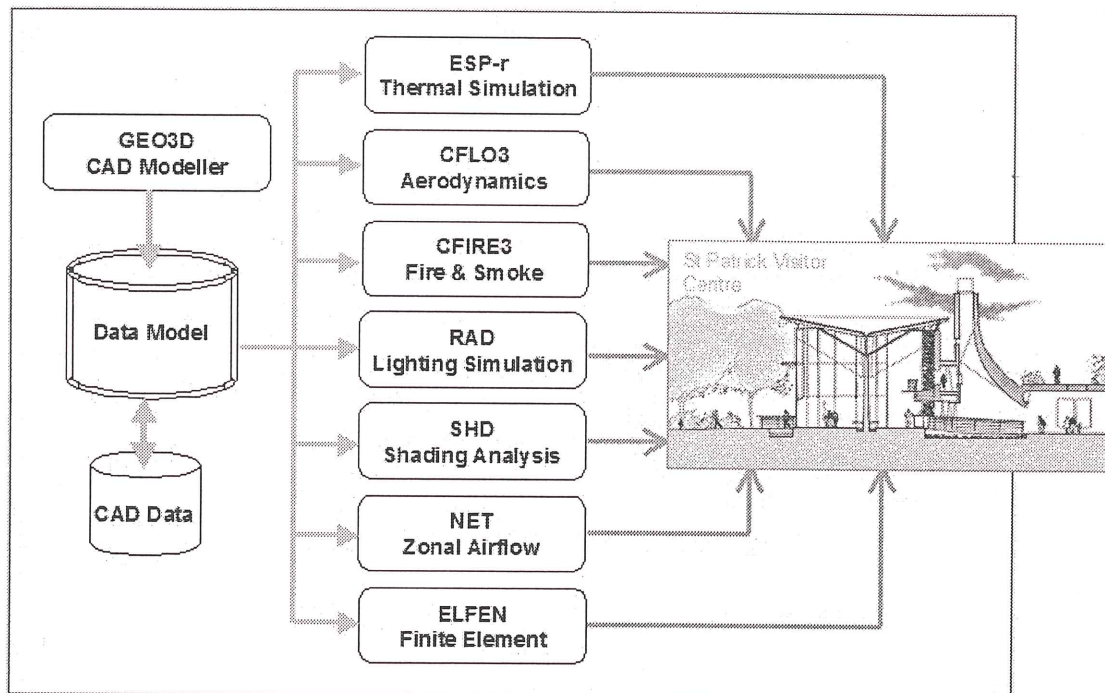


Fig.1 The simulation framework for building designs

2) ESP-r – simulation module for building energy simulation system based on first principle theories of many branches of physical science. ESP-r permits the user to conduct first principle modelling of the energy processes in a building simultaneously through time.

Similar to most academic research software, although advanced in the core, they usually suffered the kind of user interface that commercial software provide to enable the users to fully exploit their potential. DASS has been working in tandem with ESP-r development team for the development user front-end using modern graphical tools. A number of toolkits have been developed to improve the productivities of ESP-r, which include CAD modeller, database management and results presentation. At present only the bld and mfs modules of ESP-r have been incorporated in the simulation framework.

3) Cflo3 – Cflo3 is a new generation of CFD software developed using the currently available software technology. Different from the many traditional CFD code derived from the Pheonics family, the concept

of coding of Cflo3 has been focused on memory efficiency to enable it to run on mid or low-end PCs. For instance, it is able to solve a 2 million cells model with full set of eight variables, i.e. U , V , W , K , ϵ , P , T and C , on a PC with 256 MB memory. In comparison to Pheonics Cflo3 uses 125 times less machine memory and runs 3 times faster for the same problem. Together with the meshing and post processing modules of the package it allows rapid prototyping and testing a variety of design options to find the best solution.

4) Cfire3 – The fire simulation extension of Cflo3 that links with NIST Fire Dynamics Simulator. It incorporates state-of-the-art numerical and physical methods, e.g. LES turbulence model, MFC combustion model, RTM grey gas radiation model, conduction model, etc. and can model fire and smoke risks and fire fighting.

5) Rad – The light simulator based on Radiance of the LBL. At DASS the full version of the Radiance on Unix platform is used and toolkits developed to improve productivity.

6) Shd – The solar shading analysis module is able to

perform annual solar shading studies for buildings and site. The visualisation facility is able to display sun position shade view as well as viewing the building external and internal shade from any view point. Shd was developed from the original ESP-r module and the information generated are used by ESP-r for accurate prediction of thermal performance of building.

- 7) Net – The zonal mass simulator for the prediction of inter-zone airflow within a building subject to real climate and internal thermal conditions. Net was developed from the original ESP-r module, mfs, which is able to run standalone as well as simulating in parallel with ESP-r.
- 8) Elfen – A commercial finite element software package that is used at DASS for the modelling of structural problems, fracture, elasto-plastic, structure-thermal and structure-fluid coupling.

It should be emphasised that all the above simulator modules are not working in isolation, they are instead interacting with each other dynamically through the IDM. For instance, the shading information generated from Shd is used by ESP-r for accurate thermal simulation; the light illuminance information generated by Rad is used by ESP-r for the control lighting in buildings operation; the thermal condition of the building generated by ESP-r is used by Cflo3 as boundary conditions of cfd simulations; while the airflow information by cfd simulation can be reused by ESP-r to update the convective heat transfer coefficients.

4. The applications

The DASS simulation framework is an enabling technology that can be used to answer the type of 'what if' questions clients, design teams and users that have always wanted answered. It is able to provide integrated information on the performance of the design to enable the design team to actually 'see' and 'feel' the building before it being built.

Currently, the DASS simulation framework has been used on a large number of commercial projects in conjunction with architects and engineering organizations to provide insight to sustainable the designs throughout the all the stages of the design process. The resulting design is more energy conscious with better comfort levels attained throughout.

The design of Devonshire hi-tech building was one of such examples where staff of DASS were participated as members of the concept design team and the simulation framework was successfully applied to achieve the design objectives.

4.1 The concept of sustainability in design

The building located at Newcastle, England was designed to be used as laboratories and office spaces. It was conceived as a flagship environmental friendly hi-tech building adopting the highest standards of sustainable design, aiming to demonstrate the highest possible sustainable design targets. The building will be a high internal quality, low energy building, exceeding the current UK national best practice targets by circa 30%. The building was expected to be designed to capitalise on the local climate and will be predominately day lit and naturally ventilated. Massing will be optimised to aid natural ventilation and wind tunnel studies will be employed to determine the best configuration.

Within the building, there will be a number of different spaces, ranging from the closely controlled laboratories to a very loosely controlled central atrium that will follow outside conditions. The atrium will act as a climatic buffer that whilst benefiting from passive solar heating, serves to reduce heat loss and heat gain to the adjacent spaces.

Climate responsive façade systems will optimise the levels of daylight and solar penetration, according to time of day and season. Efficient active services solutions will be employed, such as displacement ventilation, geothermal cooling to meet the cooling loads associated with some of the laboratories.

Renewable energy will be harvested on site, and the use of very small scale CHP, to meet baseline electrical and thermal cooling/heating loads will be investigated. In addition, the use of geothermal heating and cooling will be considered. Current designs envisage the use of a PV covered atrium that provides the main circulation spaces for the building.

Building massing responds to the local microclimate and prevailing wind systems. The massing aims to achieve a positive impact in terms of microclimate, improving the wind environment locally, and will not reduce solar access and passive solar heating to the existing buildings.

4.2 The application of simulation framework

DASS was invited to assist in the design by providing simulation assessment support throughout various stages of the design to address the various design issues, including:

1) Integrated dynamic thermal simulation to assess:

- The comfort condition within the building in summer and winter conditions
- Heat and cooling load demands and potential targets for energy savings achieved
- Energy savings based on the use of renewable energy, new energy conservation techniques and equipments, which results in tax cut and government grants with respect to the new regulation underlying the 'Climate Change Levy'.
- Critical sizing of the plant system.
- Operational strategy for maximise the use of natural ventilations, with the impact on the microscopic climate to the central buffer zone, and the rest of the building.

2) Light simulation to assess:

- The use of daylight and alternatives.
- Prediction of illumination level, daylight factors, glare and visual comfort for critical regions of the building.
- Comparative studies for artificial and natural lighting, risk of glare and avoidance.

3) CFD simulation to assess:

- pressure loading on the climate responsive façade and the high level PV solar panels.
- Wind speed at street level which may cause pedestrian discomfort.
- The impact of infiltration driven by wind pressure through window openings that may cause discomfort to the occupants.
- Internal airflow and comfort condition within the building and the central atrium.
- Thermal comfort conditions within the occupied spaces where displacement ventilation were used.

4) CFD fire & smoke risk assessment:

- Fire and smoke risk in the open-plan office to investigate the dynamics of fire and smoke growth, to ensure that the time required for occupants to evacuate.
- Fire and smoke movement and spread in the office compartments.
- Performance of fire fighting using sprinklers.

5. Conclusion

Computer hard and software technology has developed to the point that complex building physical modelling can be achieved in relatively short time and less expenses. The move towards providing simulation support to the building industry has also been driven by the on going revision and introduction of new building regulations. In answering such demands from the building industry DASS emerged as a design and simulation support services provider that aims to bring the simulation technology to the design profession. In delivering such simulation support services DASS has developed a business model of Participation, Integration, Open source resource Knowledge sharing (PIOK), together with a simulation framework, whereby all simulation tasks are operating upon a common data model, as technical support. The business model, PIOK and major elements of the simulation framework are described and the application of which is demonstrated by design examples.

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