Simulation Support For Sustainable Design Of Buildings

Dechao Tang[1], Jaemin Kim[2]

[1] Director ESRU Consultancy, University of Strathclyde
[2]Research Fellow, ESRU, University of Strathclyde

Abstract

This paper describes the integrated simulation environment developed at ESRU. Using the simulation environment, architects and engineers are able to address the design issues of energy performance, air quality, lighting, natural ventilation, comfort, fire and safety concurrently within an integrated simulation environment, operating on a common data model. Application is then elaborated using design cases.

Keywords: sustainability, integrated simulation, energy, environment

Introduction

Over the last twenty years clients' criteria for good building design have changed significantly. Architects and engineers are increasingly aware that, as well as designing a building that does not fall down and looks attractive they must meet many other requirements. In particular, a building must be able to provide a healthy working environment with good air circulation, heating and lighting. Buildings also need to be flexible to accommodate changing functions and technology and the building life cycle cost. [Haves, 2001]

The demand for simulation support to building design has also been driven by the on going revision of building regulations and introduction of new legislations (e.g. the UK's Energy White Paper and the European Commission's Directive on Energy Perfoemance of Buildings). These requirements are promoting the designers to take more environmentally progressive approaches in order to achieve the design targets towards sustainability of the environment. This will place considerable burdens on the software tools that are presently available to undertake the design support tasks.

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 be seen in the recent articles of the *Building Services Journal*. [Paul Kingston, 2002] [Danny Coyle, Karen Fletcher, 2003]

This paper describes the integrated simulation environment that have been developed at ESRU that is able to address concurrently the design issues of energy performance, air quality, lighting, natural ventilation, comfort, HVAC systems and electrical power flow, fire and safety etc. Future development for the next generation simulation tools are then elaborated as the answer to the emerging IT technology focusing on the use of distributed computing, broadband communications.

Contact Author: Dechao Tang, PhD CEng FCIBSE FEI, Director ESRU Consultancy, University of Strathclyde, 75 Montrose Street, Glasgow G1 1XJ, UK
Tel: +44 141 5485765 Fax: +44 141 5525105
e-mail: dtang@mecheng.strath.ac.uk

The Integrated Simulation Environment

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.

Figure 1 shows the concept of the simulation environment.

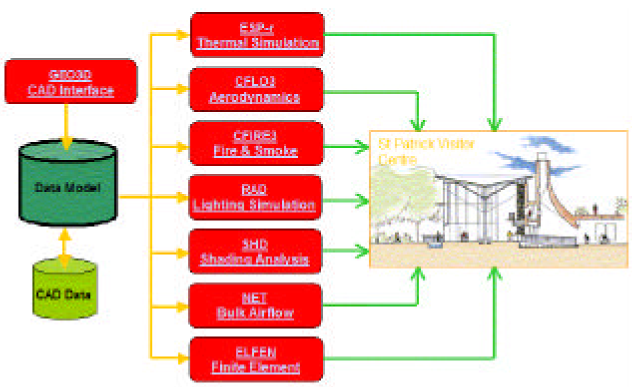

Figure 1. The integrated simulation environment

The integrated data model

Central to the simulation environment is the integrated data model (IDM). All the simulation modules within the environment are acting upon the common data and thereby facilitating concurrent transfer of data, saving time and minimising error.

Once primary data and their attributes are entered, they are held in the Data Model and available to all simulators during the lift-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 building materials.
Composite	aggregate data type derived from primitive, material and functional data types or other composite data types.

Within the simulation environment, the IDM is constantly being accessed and updated by all the simulators 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.

The Integrated Data Model is created and maintained by the CAD toolkit, geo3d. Geo3d is able to create the IDM either from importing existing CAD data or allow users to create models using the facilities provided by it. Once created, the simulation modules of the Simulation Framework (SF) will be operating concurrently upon the single data model. Figure 2 shows the CAD toolkit Geo3d.

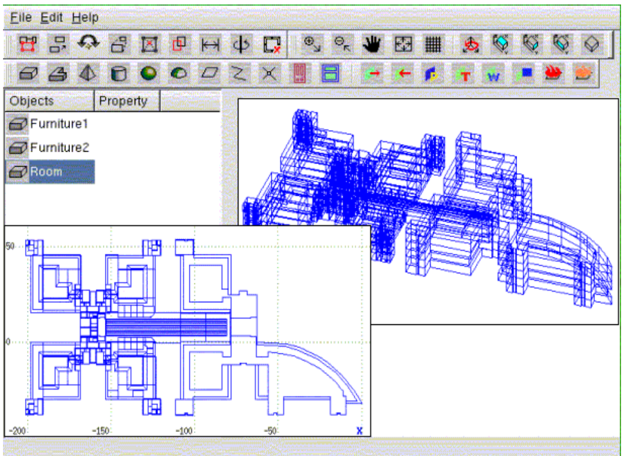

Figure 2. The CAD toolkit

ESP-r: Dynamic Thermal Modelling

ESP-r is an advanced building energy simulation system based on first principle theories of many branches of physical science. ESP-r permits the users to conduct first principle modelling of the energy processes in a building simultaneously through time. ESP-r was awarded the European reference model for building thermal modelling.

SHD: Solar Shading and Shadow Mapping

SHD is the solar shading analysis module that is able to predict visually as well as numerically solar shadings and shadow mappings over time for interior and exterior of the buildings and the site. The information is then used by ESP-r the dynamic energy simulations. Figure 3 shows the shadow mapping of a railway station.

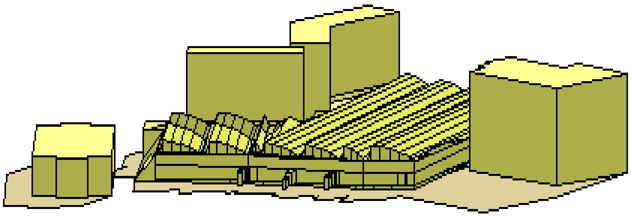

Figure 3. Shadow mapping using SHD

NET: Building Zonal Airflow

NET is a zonal mass flow simulator for the prediction of inter-zone airflow within a building subject to wind pressure and buoyancy effect. NET is equipped with extensive GUI facilities to aid the data input and result analysis and presentation. Figure 4 shows the airflow within the building is modelled and the resulting instance of airflow presented graphically.

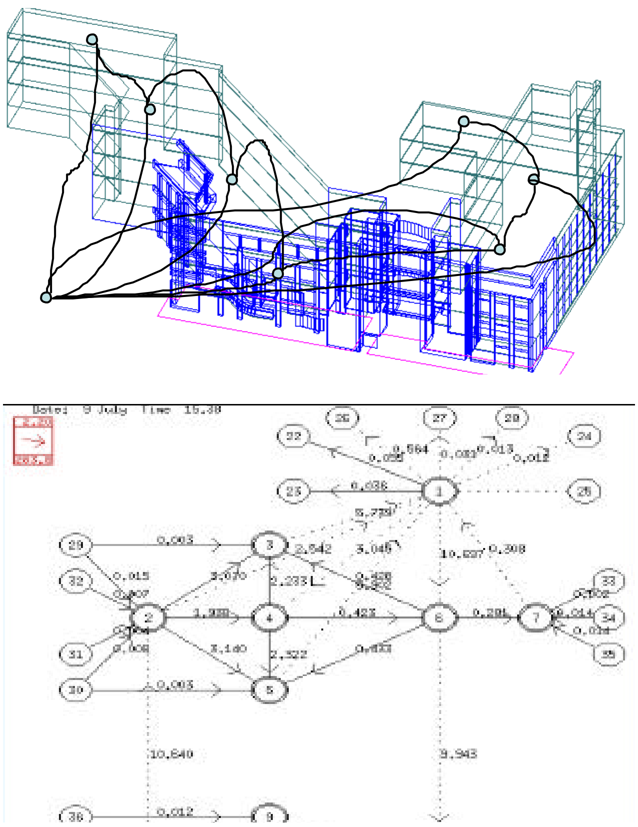

Figure 4. Building zonal airflow and presentation

CFLO3: Computational Fluid Dynamics

CFLO3 is the CFD simulation toolkits of the simulation environment. The unique features of Cflo3 enable it to be used efficiently for rapid prototyping while yielding accurate results for building design problems and provide vital information to support sustainable designs. Cflo3 supports fully conflated simulation with the thermal simulator, ESP-r; memory efficient and hence suitable for low-end PCs; together with the powerful pre and post processing facilities made it the best choice as a building design support toolkit. Figure 4 shows the animated airflow for an IAQ study of Radio France.

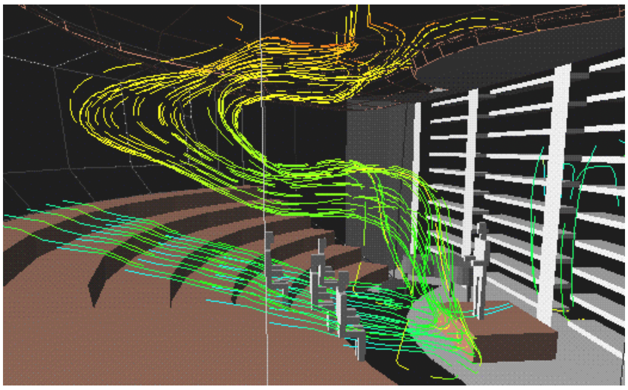

Figure 4. airflow streamline presentation

CFIRE3: Computational Fire Dynamics

CFIRE3 is the fire simulation extension of CFLO3 based on the NIST Fire Dynamics Simulator (FDS). FDS offers state-of-the-art numerical and physical methods in fire modelling including LES turbulence model, MFC combustion model, RTM grey gas radiation model, conduction model, etc. At ESRU Consultancy, extensive GUI has developed the GUI to enable 3D geometry creation, automatic meshing and simulation control and the fire and smoke modelling is

Figure 5 Modelling of fire risk in an visitor centre

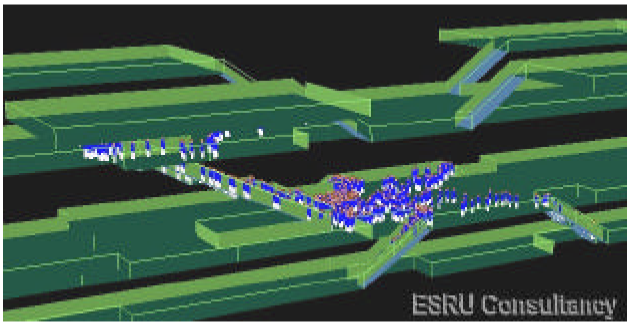

Figure 6. 3D Occupants evacuation in a metro station

linked with the 3D occupant evacuation module. This makes the software module significantly user friendly towards building designers. Figure 5 and 6 shows the modelling of fire risk and occupant evacuation in an metro station.

RAD: Computational Light Modelling

RAD is the GUI toolkit developed to work with the light simulator Radiance of LBL. RAD GUI toolkit is targeted for advanced users for natural and artificial light simulations. Most importantly, the simulator is fully conflated with the modules of the simulation environment by which the light information is used for the control of artificial lights in the building. Figure 7 shows a typical example of the daylight glare image from RAD.

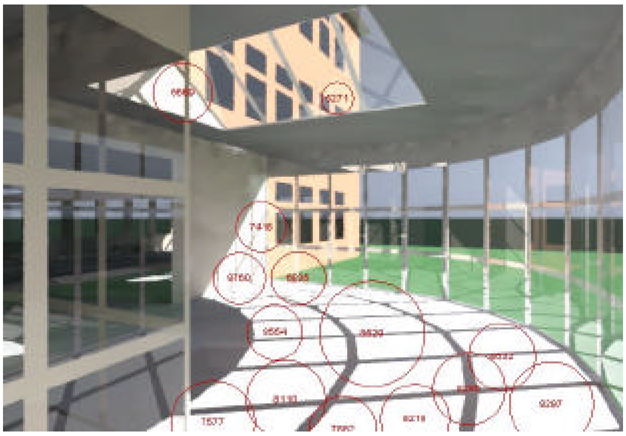

Figure 7. Glare index modelling

ELFEN: Finite Element Structure Modelling

Elfen is a third party finite element software package developed by the Rockfield Software Ltd. Elfen offers advanced structural analysis for fracture, elaso-plastic, structure-thermal and structure-fluid coupling. This module is included into the simulation environment for completeness and hence the Simulation Framework (SF) is able to offer completeness to offer conjugate thermal-aero-structural analysis capability.

The Applications

The simulation environment is an enabling technology that can be used to answer the type of 'what if' questions that 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 simulation environment has been used extensively in a large number of high profile construction projects in conjunction with architects and engineering organisations to provide insight to sustainable the designs throughout all stages of the design process. The resulting design is more energy conscious with better CO2 emission levels attained throughout.

The concept of sustainability in design

The design of Devonshire hi-tech building was one of such examples where the simulation environment was successfully applied to achieve the design objectives at concept design stage.

The building located in 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. Figure 8 shows the concept design of the building.

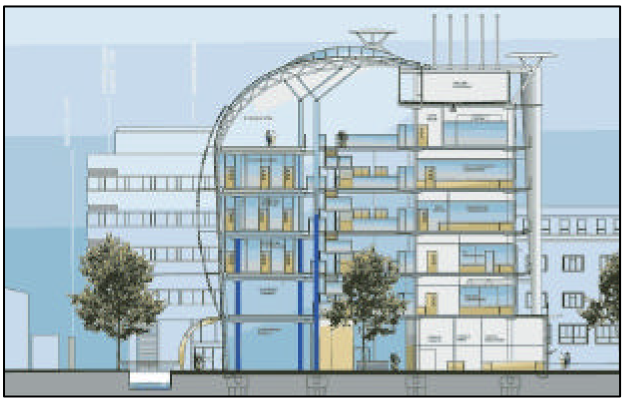

Figure 8. The concept design of the Devonshire building

Application of simulation framework

The simulation environment was applied in the concept design stage to evaluate issues arising from the various stages of the design, including:

Energy issues:

- 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.

Lighting issues:

- 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.

Issues of airflow and natural ventilation:

- Wind 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.

Fire and Smoke risk and fire fighting:

- 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.

The project proved a successful example of applying simulation technology in design. The client acknowledged that without the technology, they would not have been able to challenge all aspect of the scheme and deliver the most environmentally friendly building possible. The use of the simulation environment allowed innovative strategy and control of heating and ventilation to be tested and minimised possibility of energy wastage through overheating and an energy saving target of 0.5 million was achieved.

The Next Generation

The current generation of computer simulation tools have been evolving, over the last two decades, from text based simple design calculation tools in the early 80's to the current fully window based with event driven GUI complex simulation tools that are capable of modelling integrated performance of buildings.

Entering the 21st century has seen the exploitation of technologies around the Internet. The demand for next generation simulation software has been driven by the rapid development in computer hardware, IT infrastructure and software technologies, e.g. the Internet, the availability of broadband and the communication technologies that are based upon it, e.g. e-commerce, wireless telecommunications. Not surprisingly, world-leading companies are moving fast to catch the lead of developing Internet based products and services, notably Microsoft has been re-structuring its business strategy from a software vendor towards Internet based services provider.

It has been accepted that, although theoretically fairly advanced, the current generation simulation software has not been able to fully taking the advantages of the technology that are available to date. The industry will soon be dissatisfied with the traditional ways of computing that the resources (software, CPU, memory, disk space, etc.) are tightly bound (installed) to a single computer. The New Technology should enable remote access, distributed computing, memory sharing, using broadband communication and be able to provide the design tools and services to citizens, utilities, local authorities and thus encouraging energy efficiency and sustainable environment. Attempt has already been seen in researches that simulation being used in Internet-based Energy support services [Clarke, 2003].

It is anticipated that the next generation simulation software tool should enable that the current generation simulation software be restructured to embrace the state-of-the-art technologies. The development of the next generation simulation software, named the Simulation Framework (SF), is underway. The Simulation Framework is a New Technology, a new generation of simulation software that differs significantly from the conventional products in the market. The design of the Simulation Framework (SF) is based on the client-server architecture implemented using the latest middleware technology to enable distributed computing and network services (Internet sockets and TCP/IP Transport Protocol).

The resulting software system is a powerful modern computing environment that each computer that has SF installed and running, the SF together with the simulation modules in it are no longer isolated. They are, instead, connected via the network (LAN or Internet). The daemon process of the Simulation Framework (SFd) on each computer acts as a 'super server' that listens to connection requests from the module-processes on the local machine, over the local network and/or the Internet and reacts with the corresponding server services.

For instance, during a dynamic thermal simulation, when light luminance information is needed to decide whether the window blinds need to be closed or not, the simulator, ESP-r, will spawn a thread (sub process) to start the light simulation using RAD to retrieve the information needed. Once the light information has been obtained through Inter Process Communication (IPC) and excessive information no longer needed, the process of RAD will be terminated. Here RAD can be started on the same computer or on another computer over the local network.

Equally, when the thermal boundary conditions are needed during an airflow simulation using CFLO3, a thread will be forked to start the dynamic thermal simulation using ESP-r, on the same computer, on a computer connected by the local network (LAN), or over the Internet. Once the information obtained through IPC, the sub-process will be terminated and the CFD simulation will continue.

Figure 9 shows the configurations and operations of the Simulation Framework (SF).

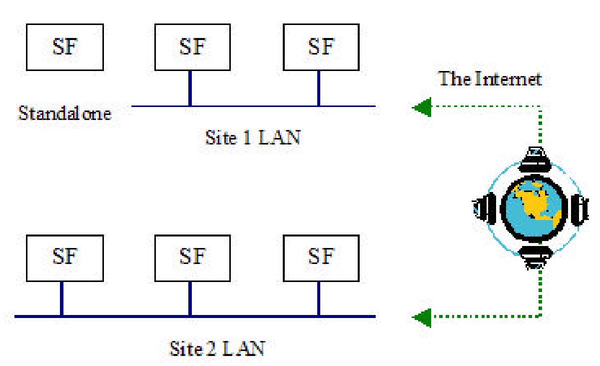

Figure 9 Application of the Simulation Framework

The Simulation Framework (SF) has the following distinctive advantages over the conventional simulation software:

1. The Simulation Framework is network operating system using modern communication technology.
2. Facilities of the Simulation Framework can be accessed remotely from the Internet.
3. Being a distributed computing environment, the Framework is highly scalable and suitable for different levels of users, e.g. software developers, designers, property owners, government auditors. It is able to provide solutions for complete business functions.
4. The Simulation Framework is able to support

future expansion to reflect changing business requirements.

5. The different user types have a single point of access for all business needs. Whether scaling up or scaling down, the user interface remains consistent while the application complexities are largely hidden.
6. The users are able to perform as much processing as possible during a project.
7. Enable centralised environmental monitoring, targeting and assessment of sustainability. For instance, developers are able to add new simulation modules to the Framework; designers are able to using the installed simulation modules to improve their sustainable designs; property owners and government auditors may install a minimal set of the Framework and use only the SQL (Structured Query Language) facilities to query the results for regulation compliance.

Conclusion

This paper has described the development of the software tools using simulation approach to support the sustainable design of buildings. The paper described the features of the simulator modules comprising the simulation environment and the applications in industrial design. The paper went on introduced the development for the next generation software tool, named the Simulation Framework that is being developed underway.

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