EXPERIENCE OF USING BUILDING SIMULATION WITHIN THE DESIGN PROCESS OF AN ARCHITECTURAL PRACTICE

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ABSTRACT

This paper documents work that follows on from a previous study [Morbitzer et al 2001] on the implementation of a simulation-tool into an architectural practice at outline design stage. The use of simulation is now pervasively and routinely undertaken by designers within the company to evaluate energy and environmental performance of their design concepts.

The paper documents the changes to the interface, based on the feedback from designers. It includes a case study of how these improvements have impacted on the degree-of-use of the simulation-tool by designers, the impact of the tool on the design process and the design outcome, a discussion on the development of the simulation-tool, and the issues facing the architectural practice with use of simulation.

INTRODUCTION

Historically, the use of simulation on practical problems is undertaken, predominantly, by specialised environmental systems engineers or research groups (commercial, government funded or academic), usually focused on specific problems [McElroy et al 1999]. This situation gives rise to simulation exercises being undertaken, generally, later on within the design process (scheme or detail design stages [RIBA 1995]) with the purpose of validating design decisions. This situation is due to the limited availability of resources for simulation work at early design stages and limited understanding of the benefits of using simulation by design team members. However, changes in procurement methods and legislation have provided strong incentives for the use of simulation within architectural practice.

The use of simulation facilitates better understanding of the design problem with respect to energy performance, often highlighting poor performance of design concepts: the need to change designs to mitigate this under-performance at the later design stages can be costly.

In order to address these problems, an Outline Design Stage (ODS) interface was developed [Morbitzer et al 2001] with ESP-r [ESRU 2003] as the core simulator. The interface was introduced and used within an architectural practice, with the intention of using the tool routinely on projects at the outline design stage when it can have the greatest influence on energy and environmental aspects of the design.

The adapted software is currently in its final phase of development as described by [Maver and Ellis 1982]: *where commercial exploitation and development of user training and support procedures* is being undertaken.

Providing the analysis software is only part of the requirement. In order for the use of simulation to be exploited, significant investment of resources [Clarke 2001] in some crucial areas is required:

- obtaining an appropriate level of knowledge of the issues of computer modelling within practice;
- development of a robust understanding of how, where and when simulation can be used; and
- development of collaboration between key individuals within practice.

In this particular case (within the architectural practice) the requirement for increased resources has been facilitated through the UK government's TCS project. Funding from this provided the additional resources required for development of software.

The paper focuses on three core issues relating to the use of simulation in practice:

- Potential drivers for the increased use of simulation.
- Interface/software development to increase functionality and ease of use.

- Business control for quality assurance and user training

These issues have been highlighted through practical application of the ODS Interface within an architectural practice.

The ODS Interface is a bespoke interface to an advanced simulation tool. The interface facilitates straightforward creation of the geometry model through links with the existing CAD tool within the practice and enables easy attribution of the geometry model through support databases which hold construction, operation, and control files.

Currently the software is capable of determining the annual energy consumption and thermal comfort conditions.

It is the belief within the architectural practice that significant benefits are available to clients in using simulation at the earliest design stages, predominantly in explicit evaluation and quantification of the design parameters. This improved design concept evaluation methodology is believed to facilitate better design-decision making, leading to improved design entities and an improved service to clients.

Information and knowledge increase as the project progresses. At the earliest design stages, information and knowledge pertaining to the design problem may be significantly restricted which emphasizes the importance of understanding the assumptions made within the simulation model. This requires a high level of control by management.

It has been found through the application of the ODS interface by architects within the practice that control of any simulation exercise, particularly those undertaken by non-specialists, is of vital importance in limiting the liability of the architectural practice: clients often assume that the predicted annual energy consumption for example, indicates how the actual building will perform. It is therefore necessary to highlight the assumptions made within the simulation model to demonstrate that simulation is not infallible.

The following sections of the paper discuss:

a) the barriers to the use of simulation that have been addressed and those remaining;

b) the issues facing the construction industry with respect to sustainability and associated legislative changes, how simulation will play a crucial role in demonstrating sustainability, and how this has been interpreted by the architectural practice in its strategy for sustainable building design utilising simulation;

c) changes to the interface to improve architect take-up of the software; and

d) the issues of quality assurance and training.

BARRIERS TO THE USE OF SIMULATION IN PRACTICE

Initially the barriers to the use of simulation were attributed to:

- complexity in creation of the simulation model;
- poor understanding of simulation by architects.

These barriers were addressed in the development of the ODS Interface and its implementation in the company.

Through the experience of using simulation within an architectural practice further barriers to its use have been identified through user surveys and feedback as:

- increased risk of liability of the architectural practice;
- unfamiliar working methods;
- lack of knowledge of energy modelling;
- perceived increase in workload.

These barriers have been addressed in the following ways:

Firstly, in the development of comprehensive management procedures to control the risks associated with architects undertaking simulation.

Secondly, in appropriate communication through training to ensure that the architects have an appropriate level of understanding to undertake simulation.

Finally, the significant barrier of the ‘perceived increase in work load’ has been mitigated through recent developments of the software interface to incorporate a Building Regulations Compliance checker and other additional functionality. The hypothesis was that the provision of additional functionality, specific to the way an architect works, would give an added incentive for building the geometry model to check compliance to Building Regulations. Having built the geometry model for the Building Regulations check, the attribution stage is achieved in a straightforward manner enabling energy and comfort performance results to be obtained for the design concept.

Since the initial implementation phase of the ODS Interface within the architectural practice, a variety of external factors have been highlighted by the architectural practice as important drivers for increased use of simulation within the design process. These are highlighted in the following section.

THE DRIVERS FOR INCREASED USE OF SIMULATION

Since the architectural practice first started implementing thermal simulation into its design process, there have been several developments that have resulted in increased need for its use, and also additional requirements to its capabilities.

The root of many of the drivers for increased use of simulation in practice comes from the drive for energy efficiency, and in the broader context, the drive for sustainability. The impact of sustainability on governmental policy and legislation is significant. The drivers towards sustainability include:

- International/National/Organisational policy, such as Rio and Kyoto agreements, the UK government's *Building a better quality of life,* and the NHS Estates and Defence Estates Policies for sustainable development; [DETR 2000, NHS Estates 2001]
- Planning policy (Local Agenda 21) - this has led to changes in the Structure and Local Plans by Local Authorities;
- Legislative changes such as the recent update to the Building Regulations in the UK and the EU Directive on energy performance of buildings [CEC 2001];
- Changing types of procurement such as PFI/PPP (Private Finance Initiative/Public Private Partnership) where the focus is on the life cycle of the building and on improvements to public services.

The *triple-bottom line* [EEA 1997, CIRIA 2001] of sustainability or sustainable development can be seen as the integration or optimisation of social, economic, and environmental objectives in Figure 1.

The circles represent the domains in which the aspects of sustainable development exist. The use of simulation could help in quantification of the impact of the operational energy and the impact of the building components within the environmental domain at the building scale. It could also be useful in quantification of the degree of comfort within spaces within the societal domain.

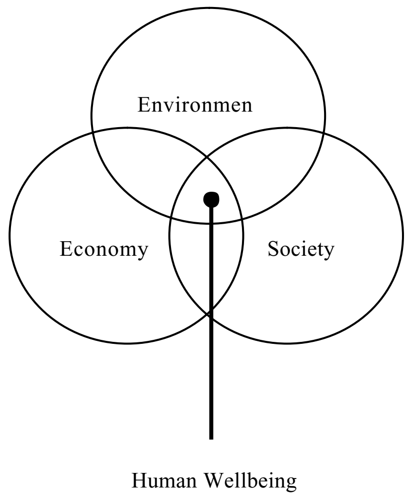

Figure 1 – Triple-bottom line model of sustainability

Changes to the UK Building Regulations Part L (Conservation of Fuel and Power)

Recently in the UK the Building Regulations Part L [DTLR 2002] have undergone significant changes. The Building Regulations in the UK now allow the designer to carry out an energy performance assessment in three different ways.

- Elemental Method
- Whole Building Method
- Carbon Emissions Method

The *Elemental Method* compliance is achieved when components of the building such as window sizes, insulation level, plant efficiencies and ventilation performance specification comply with the specification set out in the Regulations.

The *Whole-building Method* of compliance is achieved when the proposed building is simulated and its performance is compared with benchmarks.

The *Carbon Emission Calculation Method* of compliance is achieved when the proposed building is simulated and the carbon emissions are calculated and assessed against a notional building of the same size and shape as the proposed building designed to comply with the Elemental Method.

The introduction of the Whole-building Method and Carbon Emission Calculation Method is a significant change in the way the Building Regulations address energy efficiency. Firstly, they remove the design restrictions that the Elemental Method imposes on the design, such as the construction used or window sizes. Secondly, the methods embrace all the energy consumers in the building. This allows a trade-off approach between different energy consumers, hence further increasing the flexibility of the designer (e.g. lighting energy consumption vs. heating energy consumption). This trade-off also includes an assessment of the energy type used (hence the use of electricity rather than gas as an energy source would be penalised).

The case study described later highlights the use of simulation to assess compliance to the new building regulations of a building that fails to achieve compliance when using the Elemental method.

The European Directive on the energy performance of buildings

The European Directive on energy performance of buildings is likely to be a significant driver towards the increased use of simulation in two main ways:

- In the establishment of a general framework for calculating the integrated building performance:
- The certification of buildings means that new building performance will need to be evaluated and guarantees given that the predicted and actual performance of the building will be the same within an acceptable boundary. The most sensible way of achieving this would be in the use of integrated simulation.

The directive's main objective is stated as:

The basic objective underlying this draft Directive is to promote the improvement of the energy performance of buildings within the EU, ensuring in so far as possible that only such measures are the most cost-effective are undertaken.

Although this objective doesn't explicitly indicate how costs are determined, it remains to be seen whether only energy costs are considered or whether other considerations of the triple-bottom line approach are included in the accounting procedure.

Changing Procurement Routes

Under PFI/PPP procurement methods employed by the UK government there usually exists a situation where the occupier of the building pays for the energy use of that building, and therefore a reduction in energy consumption is a tangible benefit. This may not be the case in the situation of speculative building development facilitated through more traditional procurement routes (e.g. Design and Build). In this situation the focus is more likely to on the minimisation of the capital cost of the development. Energy savings may not be perceived as important in this situation as the developer will not be responsible for the energy cost. Admittedly, reduced running costs may enhance the chances of leasing any speculatively developed space; however, there exists no framework, as yet, for demonstrating energy performance to potential tenants/buyers. [Hobbs 2003].

Currently the ODS Interface enables quantification of annual energy consumption and comfort conditions. The architectural practice is focused on developing the evaluation capabilities of the software to increase the use of the tool in practice in direct response to the external drivers.

The following section describes the framework for enhancements to the ODS Interface to improve degree of use, to respond to the external drivers and to ensure that the associated risks of using simulation are kept to minimum within the architectural practice.

DEVELOPMENT OF A SUSTAINABLE DESIGN ENVIRONMENT (SDE)

[Clarke 2001] introduced the concept of the Computer Supported Design Environment (CSDE), as a way in which the use of simulation could be developed to aid in the design process. To address the long-term requirements of the architectural practice, a framework (Figure 2.) for such an environment has been constructed in order to guide the gradual change in design approach to incorporate explicit design concept evaluation, facilitated to provide *feedback on all aspects of performance and cost in terms meaningful to the designer.* [Clarke 2001]

It is believed this approach within the practice will aid in the production of sustainable design outcomes, by allowing designers to quantify their design decisions with respect to sustainability at the pre-design and concept design stages, where the impact of the design-decisions is greatest.

The Sustainable Design Environment includes:

- Qualitative Sustainability Assessments [BREEAM 2003, LEED 2003, SEAM 1996]
- Window Designer (daylight level calculator)
- Thermal analysis for thermal comfort and energy consumption.
- Environmental Impact Assessment (Life Cycle Analysis tool)
- Whole Life Costing Tool
- QA/Training Material

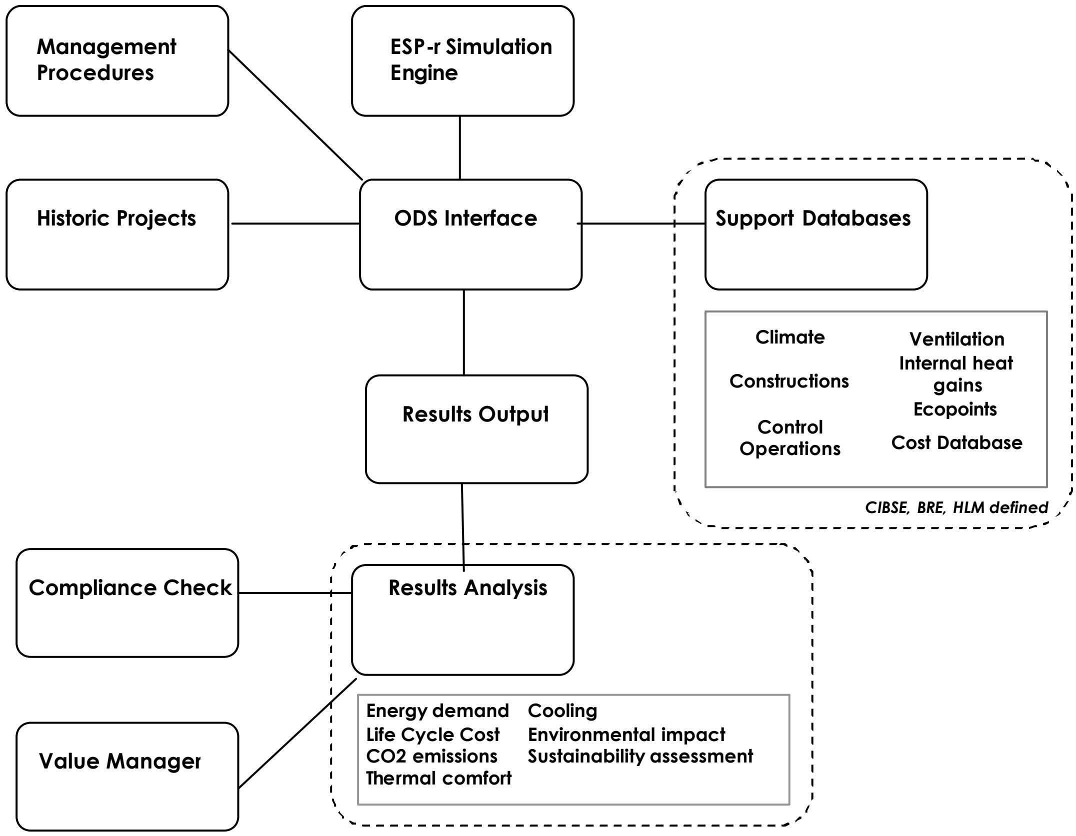

Figure 2 – Sustainable Design Environment

INTERFACE DEVELOPMENTS

The ODS interface described in [Morbitzer et al 2001] has been developed in a number of ways to extend capabilities and embed it within the framework described in the previous section.

The developments that have been achieved so far to the interface are as follows:

- Window Designer (daylight level calculator)
- Building Regulations compliance checker
- Operations and control specifier

The developments to the support databases are underway to include cost and environmental impact fields. The qualitative sustainability assessment tools are still to be incorporated along with the value management tool.

Probably the most significant adaptation to date is the Building Regulations compliance checker that has enabled designers to check compliance of their design concepts early within the design process and enabled them to change things when compliance was not achieved.

QA AND TRAINING

The use of simulation by architects within the design process requires a level of control for a variety of reasons. This has led to the development of management procedures in order to:

- Provide a checking mechanism as to whether or not a simulation exercise is necessary – a simulation exercise should only be carried out if it provides an answer to a design consideration that cannot be answered in an easier and quicker way (e.g. by contacting a building services engineer).
- Ensure that financial and human resources required for the exercise are available.
- Agree deadlines that can be met by all parties and provide performance predictions in the time frame required by the design team.
- Ensure that either an external or internal party approves data used for the model creation and that data sources (as well as the person(s) who approved the data) are documented.
- Ensure that verification and validation of the simulation model are applied.
- Ensure that performance predictions are reported in an understandable way and that the report with the performance predictions explains the basis on which

they were produced (e.g. input data used, model accuracy applied).

These procedures have been developed to limit the risks associated with using simulation by architects at early design stages.

The procurement and design processes are complex processes involving varied and often disparate individuals/organisations. The information available at the early design stages is limited and therefore contains a significant degree of uncertainty; the procedures limit the effects of that uncertainty.

QA checks of the simulation model form a vital part of every simulation exercise to ensure that the information produced is reliable. Performance predictions need to correspond to the actual behaviour of the building. This check should be carried out as a combined verification and validation exercise. Verification and validation is defined as follows [Robinson 1994]:

Verification: ensuring that the designer is solving the *problem correctly*. This deals with the accuracy of transforming a problem formulation into a model.

Validation: ensuring that the designer is solving the *correct problem*. This deals with the model behaving with satisfactory accuracy consistent with the study objectives.

Generally the use of management procedures can slow down the speed with which a simulation model is created (additional work required to fulfil the tasks involved, waiting for response from person carrying out a QA check), but it has to be ensured that they are always applied. One way to ensure this is by linking them to the simulation tool (management procedures open up automatically in a text document when a designer starts the simulation interface). This feature is currently under development for the ODS Interface.

The situation where simulations are routinely undertaken by non-specialists will occur only with substantial training being implemented: an appropriate level of training of the architect carrying out a simulation exercise is required to ensure the efficient use of the tool and the creation of an appropriate simulation model. From experience with architects within the company, it was found that basic training in the operation of the CAD tool for the specification of a model geometry as well as the model attribution in the ODS can be carried out within a day. Training is currently carried out by in-house training, support during project work as well as through an extensive user manual.

CASE STUDY

A case study is given to demonstrate how the adapted ODS interface has been used in early stage design by architects. The interface has been used on many projects ranging from prison and hospital design to commercial and residential building design. The example given here focuses on how it has been used to check compliance against the new UK building regulations and reflects the impact of the QA procedures developed.

The case study describes a simulation exercise that assessed whether or not a proposed building design could achieve compliance under the Carbon Emission Calculation Method of the British Building Regulations Part L.

Simulation model

The simulated building comprised 13 floors. The bottom floor was used as a retail area. The floor above was used as the lobby of the building. On top of this were 11 floors that were used as office spaces. Each floor comprises of an occupied space with a height of 2.75m and a void space 1.1 m high. For the model representing the proposed building the glazing area of the occupied space was specified as 90% and for the notional building as 61.1% (equivalent to 40% overall façade area). The windows in the proposed building were attributed as double-glazing, in the notional building as glass with a U-value of 2.2 W/m^{2}K (required by the Building Regulations). Fresh air was supplied at 16 l/s per person, assuming a 50% heat recovery. Internal heat gains were specified as typical for an office building [CIBSE 1998].

Results

The study was carried out in two steps. First the building was simulated with the ODS Interface to determine the heating and cooling energy requirements as seen by the building plant as well as the required capacities. Table 1 shows this data for the notional and the proposed building design.

It can be seen that the notional building has a lower heating energy consumption than the proposed building but a higher cooling energy consumption. This was a surprising finding because it was initially assumed that the higher solar gains caused by the larger glazing areas of the proposed building would result in higher cooling energy consumption.

Table 1: Heating and cooling energy requirement as seen by the building plant and required plant capacities

	Notional Building	Proposed Building
Heating Energy Consumption [kWh/m^2a]	7.5	11.1
Cooling Energy Consumption [kWh/m^2a]	63.2	60.5
Heating Capacity [kW/m^2]	30.5	35.5
Cooling Capacity [kW/m^2]	61.8	70

Figure 3 displays a first finding from this analysis. The graph displays the heating and cooling loads in the zones on the level that was simulated as representative for most of the office spaces within the building. It can be seen the building has a significant cooling load throughout the year, whereas the heating load is generally low. The glazed areas with their lower thermal resistance are an important heat flow path. In this particular case the large glazing area therefore reduced the cooling load of the building. This finding was also confirmed by a detailed analysis of the energy breakdowns that occur in the different zones during various climatic conditions.

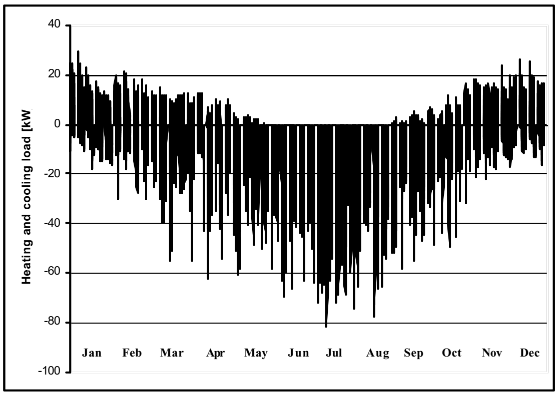

Figure 3: Heating and cooling loads in selected office spaces (perimeter and core location) of the proposed building over an annual period

Although the building envelope did not negatively influence the energy performance of the proposed building the notional building still had marginally lower energy consumption. This was a result of the plant system that was specified for this particular building (See Table 2). In consequence the proposed building failed to achieve compliance through the carbon emissions method. However, the building achieved compliance through the *Whole-building Method* because its overall carbon emissions were lower than the benchmarks specified in the Building Regulations.

Table 2: Annual delivered energy consumption (kWh/m^2a) and capacity (kWh/m^2)

Building type	Heat-ing	Hot water	Cool-ing	Auxiliary plant	ACMV[1] fans	Lighting	Office equipment (small power)	Total
Notional	7	4	33	11	47	43	30	176
Proposed	11	4	38	38	60	39	30	220

Discussion of case study

The case study showed how the integration of simulation into an early building design stage resulted in a more informed decision process. It was shown that for this particular building large glazing areas did not cause higher energy consumption than a notional building with smaller glazing areas. This was a finding that contradicts best practice advice as well as the design approach that the Building Regulations try to encourage with the elemental method. Using simulation thus informed the designer that in this particular case it is possible to make the preferred aesthetic design choice and still comply with the Building Regulations.

CONCLUSIONS

- Policy for Sustainability, Changing Legislation (UK Building Regulations, EU Directive on the performance of buildings), and use of the PFI/PPP procurement route is likely to increase the use of simulation within the construction industry.
- It is important to have appropriate control of any simulation exercise undertaken in practice, particularly by non-specialists.
- Quantification of the design parameters is an important aspect: simulation is utilised to facilitate this quantification within practice in order to improve design-decision making.
- The adoption of comprehensive Quality Assurance has reduced the risks associated with the use of simulation in practice.
- Training has improved understanding within the architectural practice of when and how the use of simulation should be undertaken

1. Air Conditioning and Mechanical Ventilation

- Training and the interface developments have led to an increase in use of simulation within the architectural practice.
- The use of simulation by architects at the early design stage has facilitated improved understanding of the design problem and improved design outcomes.
- The political drivers for sustainability are likely to encourage the take up of other tools within the design process for quantification of other important design parameters.
- There is need for additional appropriate tools to be made available for designers in order to improve design concept appraisal.

FUTURE DEVELOPMENTS

Future developments will include the further development of the SDE. Post Occupancy Evaluation (POE) should also be undertaken to compare predicted and actual performance against key parameters such as client and user satisfaction, energy consumption, efficacy of control systems and comfort conditions. POE has the capacity to:

- improve benchmarking of new design concepts; and
- improve understanding of design of sustainable buildings.

Post occupancy evaluations are considered by the company as crucial to their provision of an unrivalled service. However, it is understood that the development of a framework for POE will occur in the mid to longer term.

It is envisaged that the in-house training will aid further implementation and expand the possibilities for the use of simulation throughout the architectural practice.

Finally, the issues of procurement and contractual arrangements within any design process impacts significantly on whether simulation is used and how it used within the design process; these issues need to be investigated. For example, an important use for simulation is in quantification of energy consumption; however, in situations where the client is not the owner or occupier this has little relevance. Suitable assessment of the need for simulation and the degree of quantification of the design parameters is likely to be required.

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