SIMULATION ON THE EDGE

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ABSTRACT

Consider the following scenarios:

The WWW page describes the tool as "a general first-principles solver for multiple domain assessments" and the practitioner says "the project is an aluminium smelting plant so what's the problem with 3kW/m^2 of casual gains?" Tool developer raises eyebrows - simulation at a newly defined edge.

Gripe from simulationist to tool developer - "we just finished a project with 100,000m^2 floor area and found it difficult to QA the project files". Tool developer imagines scenes from Dante's Inferno - simulation as an endurance contest.

Conversation between tool developer and simulationist - "how do I model stair treads? - where are they? - in the fire escape - why do you think this is important? - they are included in the building section". Simulation drowning in needless complexity.

Planning discussion "the client wants to know how many minutes they have before environmental conditions deteriorate if there is a catastrophic failure of the HVAC on a sunny summer day - if it goes above 26C a collection of rare artifacts will suffer irreversible damage. How shall we approach this?". Gasp - truly simulation at the edge.

This paper reviews some of the singularly amazing, useful, and sometimes misdirected work that practitioners attempt with simulation and the technical and software support which ESRU (the Energy Systems Research Unit) and SESG (the Scottish Energy Systems Group) in Glasgow have recently provided.

The paper will deal with issues such as:

- What was done to support substantial simulation questions and who is well placed to attempt such work?
- How does one gain confidence in projects which are exploring untested uses of a tool?
- What duty is it of the vendor to deprive the practitioner of their chaos and complexity? Sometimes it is necessary to build models which are at the compositional limits of a tool. But does the practitioner realize the incremental cost of such complexity?
- How do those entering the profession develop the skills to deal with issues of model abstraction in realistic design projects?
- What about when the practitioner has a different idea of what the tool is capable of from that of the tool developer?

INTRODUCTION

Simulation tool developers have made great strides in extending tool functionality, they have invested much in tool ease-of-use and are proud of their "better mousetraps". Some even entertain thoughts that these efforts will help pay the rent. So what do practitioners go and do? They apply these tools to real-world projects, unencumbered by the developers inside knowledge of best-practice, successful strategies and "things-to-avoid". Now and again practitioners push the limits of simulation in ways that surprise tool developers.

Whether this results from the ingenuity or naivete of the practitioner, the simulation community can learn much from the radically different views that developers and practitioners hold of simulation tool capabilities. Few developers combine the skills of application coding and application use within the constraints of the design process. Practitioners who successfully explore new facets of design performance and who leverage existing tool facilities will define a new market for their skills and, eventually, influence others in the simulation community. Simulation owes much of its maturity to the random mix of design questions in projects which continually stress tools in hitherto unthought of ways.

Of course, tool developers are not immune to excesses of ingenuity in the design of their tools and naivete regarding those who use their tools. Developers get caught up in facilities which owe more to the dictates of a particular library of interface widgets then on a careful reflection of user requirements. Jargon still masquerades as conventional dialogue, inappropriate interface conventions and arbitrary assumptions abound. Clarity for the developer is often anything but clear to a practitioner who has a 14h00 deadline.

This paper is particularly interested in occasions where practitioners define new frontiers in simulation. The practitioners working in such areas tend not to be prolific writers, perhaps because of client confidintiality or the intensity of their work, and thus there is little in the literature which addresses this issue.

In the following sections the author will explore some aspects of simulation at the edge which have influenced the evolution of simulation tool design and support which ESRU and SESG have recently provided. Although the case studies were drawn from real projects, for the purposes of this paper some project and participant details have been obscured.

The initial stages of each case study follow a similar pattern. Vendor X advertises their better mousetrap as "a general first-principles solver for multiple domain assessments in the built environment". The web page shows a range of example projects, enumerates the facilities their tool offers and options for skills-acquisition. After careful consideration, Firm Y acquires the tool, allocates resources for initial training and begin to use the tool on the periphery of projects. Gradually they evolve an impression of what they can do with the tool as well as a list of things that they wish they could change about the tool. They develop in-house procedures, they usually, but not always, invest in further training and support. And then...

SIMULATION AT A NEWLY DEFINED EDGE

In a simulation based consultancy, a project arrives that is only moderately challenging in terms of model composition (it is a industrial shed) but operationally complex. The tool interface (in this ESP-r) balked at accepting an internal gain in one zone of 1.5GW. Staff phone the author and the conversation went something like: "Wow, that is a big number...try expressing the load as W/m^2...still to big, try subdividing the main processing hall...ok...and what do the performance reports say...they say ‘********‘, ok try to integrate over a shorter period". At the edge irritants cluster. But hang on, there might be a very good reason the interface rejected the initial number. "What sort of temperatures are being predicted?"...Wow..."What’s the wall composed of and is there a radiant component to the load?"... "Ok, we need to confirm additional details of the performance metrics and energy balances, but this output indicates that a) surfaces temperatures are going to be high and b) thermal expansion could be a problem if that load is intermittent."

So why would a model of a smelting plant be cause for concern? Well, the intuition and experiential references which simulationists use to calibrate models might be difficult to acquire. The radiant loads and surface temperatures might lie outside the experimental and theoretical studies underlying the correlations used within the tool. There is uncertainty in the predicted values.

How does one acquire confidence in such a situation. Paranoia (as in "we need to confirm additional details") is a useful guide. What does the CIBSE Guide/ASHRAE Handbook say about this? Each performance metric evolves from the interactions of specific flux and flow paths: Do these make sense? Has zone and surface energy balance been maintained? What is the pattern of longwave radiant exchange within the zone? Where is there thermal mass in the zone and how does it react? What is the sensitivity of the predictions to the magnitude and radiant fraction of the internal gain? Does altering the thickness, conductivity or surface properties of the constructions change the nature of the predictions?

Such questions are predicated on access to a range of performance data (esp-r offers many facilities in this regard) as well as user opinions as to the processes involved and pattern matching skills to find where these overlap. In this case, initial investigations confirmed that the predicted trends were indicative rather than absolute.

Reviewing scores of UK and European consultancy projects, it is as often the case that design questions demand simulations that focus on aspects of performance which are particular to that project. What happens if the exposed ceiling structure is 100mm deeper or the thermostat is moved to a different location or a different crack width is assumed for the doors or the tree near the entrance is removed? Sometimes it is the form of the assessment metric. What is the frequency of predicted mean comfort votes or the rate of change of humidity or the incidence of condensation or the correlation between infiltration rates and wind direction?

Where the focus is narrow and deep there is a chance that it involves simulation facilities which have not been explored by the practitioner. It might involve a simulation facility which has been infrequently used or which has not been used to do exactly what the practitioner demands.

For example, a researcher wished to model an experimental solar drying facility. Measured data from a number of points within the experiment as well as equations representing theoretical moisture losses were available. The intent of the work is to calibrate the simulation model and then conjecture and test different operational regimes to improve the consistency of the drying process and reduce drying time. The simulations would also provide a platform for evaluating and evolving the moisture transfer equations and the design of the drying facility.

The abstraction of the test facility into a simulation model was straightforward because the zones required were well defined and its design included few areas of complexity. Similarly, the flow network appeared straightforward. The researcher used an explicit geometric representation of the test facility and its contents with imposed heat transfer coefficients. This allowed each convective, conductive and solar and longwave radiant flux exchange within the assembly to be assessed. Code interventions were confined to the core moisture transfer issue.

In reality, the design was is a small scale low-to-medium velocity wind tunnel which had periodic injections of heat from a solar source and was filled with materials which slowly released moisture into the air stream.

During calibration of the model it became apparent that pulses of heat being injected into the collector space were not being "noticed" by downstream zones. This artifact disappeared if the flow rate was reduced below ~1000 ac/h and the simulation timestep increased to one second or longer. This poses some interesting simulation issues:

- How does one represent a solar collector made up of dark course rock layer over a concrete roof in which the total surface area is high and the concrete roof mass is also significant?
- Similarly, how does one represent wood stacked into drying racks within the chamber where the total surface area is high and a complex moisture transfer is active depending on the air stream moisture content?
- What boundary conditions apply when the time constant of the problem is two magnitudes less than the usual lower timestep limits of the simulation tool?
- If the timestep equals the time constant, a three month drying cycle equates to 1.9x10^7 timesteps (give or take a million). This presumes serious computational and data storage resources even before contemplating how one might might approach the analysis of sub-second performance metrics and long term trends.
- How does one calibrate a model against a limited set of measurement points and uncertainties in the composition of the test facility?

There is a generic simulation issue in the need to understand high frequency performance metrics (say system control feedback loops) in conjunction with long term performance issues. The practitioner must judge where it is acceptable to assess the control response at courser time intervals and the uncertainty this introduces.

SIMULATION DROWNING IN COMPLEXITY

So... "how do I model stair treads? - where are they? - in the fire escape - why do you think this is important? - they are included in the building section".

For any number of reasons practitioners compose models which are not concise representations of the project and they carry out assessments which actually do little to clarify the performance of a design. Practitioners may be lead by the tool to attempt untenable levels of complexity. A typical case is a simulation tool which can import CAD files and the availability of a CAD model which includes items such as door frames, conduits, chairs and standing roof seams. Usually such items have a third order thermal impact but their inclusion in the thermal model requires the practitioner to invest scarce resources in removing them or in their attribution (Hand 1998).

Another classic case is a repetitious design (say 25 near-identical offices) where the user chooses to explicitly model each one (perhaps at low resolution) rather than consider the option to model one or two offices (perhaps at high resolution) and scale the predictions accordingly.

How does one judge how complex a model should be? One approach is to clearly define the performance metrics required by the project and then the related physical processes. Say the design team was concerned about occupant comfort near a west facing facade during the winter. The distribution of solar radiation within the space might contribute to localized discomfort so the model would benefit from addition geometric resolution and from a temporal analysis of shading and insolation distribution within the space. Longwave exchange might cause discomfort so explicit radiation viewfactors within the office would improve the resolution of the metric. One might also consider placing radiant sensors at several points within the office to check for position sensitivity.

Thus, after careful reflection is might turn out that stair treads as an important aspect of a particular design assessment. Required complexity is something which must, somehow, be managed.

SIMULATION AS AN ENDURANCE CONTEST

Having observed scores of projects, there are indeed some which, after sober reflection, demand models of extreme descriptive and/or operational complexity. Given that the use of simulation is hardly a trivial exercise for a constrained project how might one approach the management of large projects?

- Be brutally honest. The relationship between model complexity and project resources does not grow as a linear function. Beyond some nominal level of complexity (which depends on the simulation tool and the practitioners expertise) the resources and attention given to a project is better described as exponential growth. If the vendor offers an improved application or you acquire a faster machine the only thing that actually changes is that point where nominal complexity becomes exponential complexity.
- Have procedures. People loose scraps of paper with critical information, systems which depend on error-free performance invite failure. If it takes more than a few moments to identify the differences between two versions of a model, either the tool or the quality assurance procedure needs to evolve. If the random loss of a file delays the project for more than an hour then use a different archiving strategy.
- Know your skills. When you come to a bottleneck or a puzzle or a crash, is someone in-house or at the other end of an internet or phone connection that can sort it? Can you regularly and consistently build constrained models that work well? How accurate is you estimate of the resources they take? If you intentionally introduce a subtle error in a working model, how long does it take your QA process to find this? Well?
- Know your tools. How well do they accommodate additional complexity? Do simulation staff have strategies for tool use which successfully leverage existing facilities to accomplish their tasks? Do they have strategies for discovering critical performance patterns in large datasets?
- Know the project. Those who rush to the keyboard will be invited to return to it over and over and over. What metrics can you enquire about via simulation that help to answer the project design question(s)? What needs to be represented to deliver those metrics? What can be excluded? Can you design a model which supports these metrics and anticipates follow-on questions from the design team?

If the above questions yield uncomfortable answers what are your options? Can you alter your procedures, skills base or your support contracts to be in a better position to take on the project? Can you influence the tool vendor to adapt the tool?

SIMULATION AT THE EDGE

The catastrophic failure scenario is an excellent example of simulation at the edge. Edges are scary. Engineering almost becomes science. Answers, if they exist at all, have to be prised out of deep and hidden places and held up to the light of extreme sceptism.

The built environment is replete with difficult problems and needs practitioners who are equipped to evolve new methodologies and working practices and leverage the functionality of their tools to support their work. Here is the story of one such project and it began with one question:

The system died, how long have we got?

In the context of archives and museums, a catastrophic HVAC system failure presents a considerable challenge. If an artifact or exhibition is at risk under specific temperature regimes or overly rapid fluctuations in humidity, how can practitioners assess risk within an existing or proposed gallery space? For the majority of buildings without a fully redundant environmental system, contingency plans are a critical design constraint. A 24 hour response may be viable when a 3 hour response is logistically absurd.

This question arose within the planning process for a new exhibition in an English museum. The galleries under consideration had a southwest exposure and the exhibition would be open during the warmest period of the summer. Risk assessment was complicated by the massive construction of the galleries (walls over 1.5m thick were quite common), historic fenestration details and openings between gallery floors as well as an environmental systems design which was planned around a displacement ventilation system.

The exhibition included a mix of free-standing, board-mounted and chambered artifacts with clusters of multimedia terminals. Several displays created voids adjacent to fenestration which were subject to high solar radiation and bespoke lighting schemes were planned.

To find out the nature of environmental degradation it was necessary to understand local response characteristics (e.g. air and surface temperatures, air flow patterns), at a number of points in the galleries, the degree of structural cooling resulting from the raised floor of the displacement ventilation system and the exposed ceiling below it and the mixing of warm air from local casual gains and the display voids near fenestration.

It was also necessary to understand how the galleries would transition from an air-conditioned state to one driven by buoyancy and boundary conditions. What was the efficacy of the structural mass in delaying overheating? Would artifacts adjacent to the fenestration voids be at greater risk? To what extent would air temperatures stratify and how long would it take for elevated temperatures at the ceiling to extend down into the artifacts?

Clearly, a number of dynamic interactions were at play in the galleries and it would be difficult to perform a risk assessment based on a static analysis or by looking at facets of the design in isolation. The number of points at which performance metrics needed to be tested and the number of paths by which adverse environmental conditions might propagate argued for an integrated assessment of both thermal and air flow domains. This also argued for a degree of redundancy in assessments (i.e. multiple approaches to risk assessment).

In order to determine the onset of critical environmental conditions the following approaches were used:

a) The consultant knew that the project was complex and instituted a cooperative effort with the tool developer.

b) The simulation team prepared models for an integrated simulation tool which supported detailed thermal and network flow analysis and for a CFD package which had been optimized for building analysis.

c) Each model was designed to deliver the specific metrics of the project at critical points within the galleries and artifacts and was structured to support tests of the sensitivity of the model to possible design parameter uncertainty.

d) Assessments were carried out for a number of operational and climatic scenarios with the intent of delivering a "rule-book" for the exhibition managers.

e) Patterns observed in each assessment were cross-correlated with the other simulation tool and with analytical computations.

f) The results of the study would be critiqued by a 3rd party advisor.

Figure 1 shows the model used for the integrated thermal and network flow approach. Each gallery was subdivided into an occupied zone and a ceiling zone with the voids between the displays and the building facade treated as separate zones. A plenum zone for the displacement ventilation system extends under all of the galleries.

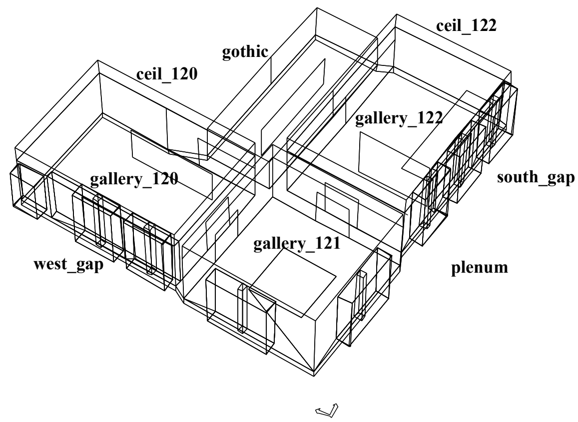

Figure 1: thermal model of museum galleries

This approach allowed the design team to trace the deterioration of environmental conditions and their causal effects before, during, and after system failure.

Figures 2 and 3 show a portion of one of the CFD models used in the study. Each of the display cabinets, internal obstructions and heat sources were included in the model. The stream lines shown are related to one of the extract vents just prior to failure.

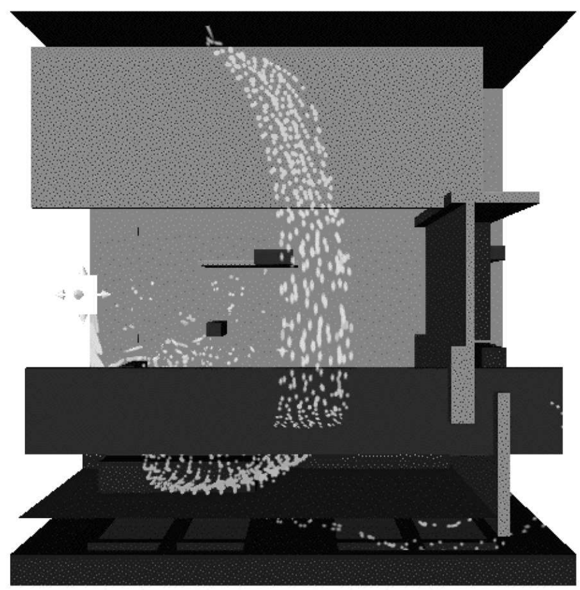

Figure 2: CFD model of gallery (view from above)

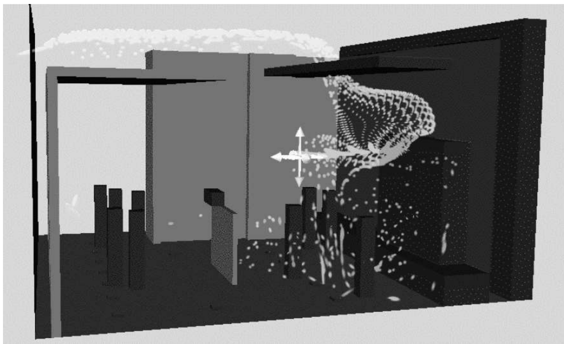

Figure 3: CFD model of gallery (view from side)

To have successfully addressed the catastrophic failure scenario is one measure of the maturity of available tools, practitioner skills and vendor-practitioner cooperation. It indicates that there are ways to approach even the most difficult of problems.

DUE CARE AND ATTENTION

The museum study demonstrated one approach to ensuring that the results of a project stand up to the most critical of analysis by the client and the courts.

The team had evolved working procedures which included robust project planning, model checking and calibration and quality assurance. They had invested the resources needed to become proficient with their tools. They knew that the project required an extension to their skills base and took steps to acquire these skills. This project was an exception only in terms of its intensity, the use of independent (as opposed to cooperative) assessments and the extended testing of uncertainties. Here is what they did:

- the project methodology built on established procedures,
- the metrics of the study were clearly stated and the models designed to deliver those metrics,
- they tested each simulation tool for robustness, sought the advise of the tool vendors and ensured the tool vendor was on call for clarification and advise,
- quality assurance was ubiquitous,
- all assumptions were stated and agreed with the client,
- the simulation team allocated time to evolve a clear understanding of the museum performance and from this communicate clearly with the design team.

Sound familiar? Be brutally honest. Have procedures. Know your skills. Know your tools. Know the project. If this does not sound familiar consult the *CIBSE Building energy and environmental modelling Applications Manual* (CIBSE 1998). It provides recommended QA procedures, guidance on the planning of projects, selection of simulation tools, sources of information. Practitioners who follow these procedures tend not to confront the legal professions and they tend to deliver useful information to their clients.

And sometimes clients want to hear the impossible (like warm air does not rise or that heat absorbing glass does not get warm). In a contest between physics and beliefs, sometimes it is wise to decline the battle. "We never turn down work" keeps the lawyers well fed. Know when to say no.

So what about the stair-tread practitioner? Excessive detail **does not preclude** delivering userful information to a client. Unconsidered detail is a successful strategy for limiting practitioner profits which can, occassionally, have adverse effects for the client. Such approaches can be indicative of a lack of understanding of the underlying interactions within a design.

And what about the smelting plant? Well, here the practitioner might be skating on thin ice without prior experience and/or a finely resolved intuition as to what conditions one might expect within an extreme environment. Paranoia and cynicism are useful vantage points for the use of a tool for an extreme design. Bottom line—don't enter uncharted territory without the skills and resources needed to calibrate the model and confirm performance predictions.

In the case of the material drying facility, it was not possible to identify the numerical problem within the timeframe of the study and pragmatic adjustments to the model were required. In terms of due care and attention this is a boarderline case. The trend was clear, however the absolute values included a degree of uncertainty. Indeed, the simulation community is currently better placed to report on relative performance issues than absolute performance issues. A useful rule for those who wish to use simulation to design experiments— design the simulation model in advance of building the experiment and positioning the instrumentation. This will expose potential unknowns within the model and the experiment. It is easier to change a model than an experiment.

EVOLVING TOOLS

A contributing factor to these case studies has been the continuing evolution of tools to the operational needs to practitioners. Each of these case studies, indeed almost every observation of and participation in such projects has left its mark on the simulation tool (sometimes as an immediate patch). Few of the interventions which were critical to these projects would feature in a vendors glossy brochure. "Even better QA reporting!"

"Now reports frequency of the rate of change of RH!" "Now provides more space for documenting operational strategies!" "Now keeps track of latent gains from wet surfaces!" "Now allows you to adjust small power loads on a minutely basis!"

CONCLUSIONS

The critical requirement in a number of the case studies was to identify the essential characteristics of the design and ensure that the descriptive entities used in the simulation model captured these characteristics. How does one do this? Find a clean notepad and answer the following questions:

- What do I wish to know, at what level of detail?
- Why do I (or the client/design team) want to know this?
- What is the quality and extent of design information that I can access?
- What is the essence of the design in terms of form, composition, operation and control and how might this evolve during the design process?
- What metric(s) signify acceptable performance and how can this be communicated to the design team and/or client?
- What are the essential interactions which need to be preserved within the model in order to deliver the project metrics?
- How can these interactions be represented? Can I sketch out the overall model and explain my approach to the design team (and if not why not)?
- What boundary conditions, over what period(s) would form a reasonable test of the design?
- How do I calibrate the model and arrive at an initial understanding of the design?
- How can I ensure the quality of the model as it evolves and my colleagues understanding of it?

A similar checklist can be found in (CIBSE 1998). Adding observations from simulation at the edge resolves to: **plan the project, find its essence, make a model that can tell the story of the design, be paranoid, live with it long enough to become less paranoid, pass it to someone else to try and break it and only then tell the design team how it works (in four part harmony if necessary)**.

A few "secrets" from simulation at-the-edge:

- Practitioners who are uncertain about how to approach an assessment task build quick and nasty disposable models and when they have learned enough they toss them out and use their new knowledge for the "real" model.
- Practitioners who need to see if their tool can deliver a particular metric in a particular way find this out sooner (i.e. they grab and existing model, run a quick simulation and explore data recovery and post-processing options) rather than later (i.e. when the real model is ready).
- (And here is the real secret) No matter how efficient you are at putting together a model and how fast your computer is in doing the calculations—it takes time to understand the performance of a design well enough to "tell its story" to the design team. The bigger the project the longer this tends to take. The closer to the edge you are, the more different views of the performance you need to check. Take the time you gain through good working procedures and staff skills and spend it getting the story.

Simulation is, in many ways, a disruptive technology. In Europe, practitioners working "at the edge" are doing so more frequently and are managing up to a score of simultaneous simulation based projects. The more conservative practices are beginning to notice this.

How will they adapt to this disruptive technology? Some will fail. Currently there is a critical shortage of staff with simulation skills. Few senior partners are in a position to manage simulation based projects. It will take time for new practitioners to work their way to positions of influence. In the interium, simulation based consultancies are thriving on a mix of subcontracted projects from established practices, and increasingly, by drawing clients away from established practices.

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