Keynote Address:
A View of Building Performance Simulation

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Building performance simulation is reviewed, with an emphasis on its role as a means to bring buildings into a better balance with the human and natural environments.

Introduction: Why Simulate Building Performance?

This conference is taking place in Australia, an island-continent that tends to be characterised as a place of landscape grandeur quietly isolated at the bottom of the world, with unique flora and fauna. Living in this land, the Australian Aboriginal people developed a unique technology: boomerang, woomera, management of the environment by burning. Their buildings (shelters) were small, temporary, and of little cultural significance compared with their paintings, artefacts, rituals and stories. Although their technology affected and changed the land, it was proved over tens of thousands of years to be a sustainable technology.

Around 200 years ago Australia began to be occupied by people of European origin as well as by the native inhabitants. The European tradition at that time seems to have been to first dominate and then exploit the environment as much as possible, and its technology was developed and employed to those ends. European buildings (including dwellings) were of great cultural significance, built to last, and set out to climatically modify large volumes of space. Two hundred years of European settlement in Australia have changed the landscape (and the ecosystem) far more than another 200 years of Aboriginal domination would have done.

Why begin like this? The purpose of a keynote address is to set the stage, to pose some questions, and to outline some ideas and issues that should relate in some way, however tenuous, to all of the papers that follow. The computer simulation of building performance is aimed at the prediction and understanding of the way a yet-to-be-implemented building development or modification will appear and behave. The behaviours of interest includes those which effect the comfort, health and safety of the building's future occupants, the energy, financial and other resources consumed in the building's construction and life, and the visual and microclimatic impact of the building on the surrounding environment; papers in this and previous International Building Performance Simulation Association (IBPSA) conferences address these issues. All these aspects have environmental, social and ethical dimensions, brought into greater prominence at a time of international concern about environmental degradation and risks to future economic well-being and personal welfare. In particular, building performance simulation is a tool towards bringing buildings and the built environment into a better balance with the human and natural environments, a tool towards sustainable development in building.

This need for sustainable development is unarguable: projections suggest that the total number of humans in the world will rise from around 5.5 to 8.2 billion by 2020; Western-type development seems to be attractive to much of the world's population; and at some time the combination of people and their technology, including their buildings, will come into balance with what the environment can sustain. However, the full nature of this sustainable development is far from clear. As well as assisting in the design of individual buildings, simulation can help in clarifying wider policy issues about forms for future buildings and cities.

This theme and this conference are particularly appropriate in Adelaide, our host city. Adelaide prides itself on being a particularly pleasant place in which to live, a multicultural, cosmopolitan community of around a million people with fine restaurants and rich cultural life, coupled with an interest in and record of achievement in technology. But it is a city which exists at the edge of the driest state in the driest continent, and questions of water supply, climate and land degradation are all very much issues in both popular and academic discussion. It is also a city which aims to develop a Multi-Function Polis (MFP) as a new and better model of building in a way that is responsive to and respects the natural environment. The simulation of the performance of new buildings as a part of the refinement of the relation between building and environment certainly has a place here.

I can confidently assert, then, that building performance simulation is an activity that matters. In getting from a position of need to a position of acceptance in the building development process we need to have:

(1) A building development industry that recognises this need and can organise itself to develop and use the necessary computer models;

(2) Performance simulation models that are validated, produce results that are meaningful to their audiences, and relevant;

(3) Results that can be used at those times in the design and development process when an understanding of the performance of a proposed building can have greatest impact on its improvement; and

(4) Much more experience of how to best use this understanding in the design of buildings.

Computers in the Building Design and Development Industry

The 1980's was a decade in which computers became a routine part of the work of the building design and development industry. This does not mean that the adoption of the technology was smooth or uniform; quite the reverse. In a 1986 paper, Steve Fenves related their use to the nature of the building industry itself: dispersed ("which almost guarantees that there is somebody somewhere who has written a program for some aspect of any conceivable task in building technology"), diverse ("which means that none of the above programs perform exactly the task desired by another participant"), detached ("with the participants belonging to many distinct organisations"; in Australia alone there are close to 100,000 organisations in the industry (Newton et. al. 1993)), and discontinuous ("with participants forming project teams and then disbanding,..[a computer program], even if located, is no longer used and maintained by its authors") (Fenves, 1986, pp1,2). Difficulties in achieving a wide acceptance and use of programs due to the nature of the building industry are exacerbated by continuing developments in computing; Fenves suggests that rapid changes in hardware and software causes many of the programs that have been developed "to remain frozen in time" and quickly outdated.

The position in the 1990's is similar. The industry is still dispersed, diverse, detached and discontinuous. In Australia it has also suffered greatly from a downturn in property values and development, so that investment in any technology has been subject to economic constraints. In computer-aided drafting and modelling a small number of systems have secured the greater part of the market in most countries and are found in at least the larger design offices, but there is no comparable general spread of other simulation programs. More designers, building managers, owners and government agencies are aware of the economic and environmental issues in building performance, and the need is certainly recognised. For example, Larry Degelman, in a paper called "Environmental Systems: Addressing the Real Issues", argued that "... architects are very concerned about producing responsible architecture - including the whole area of environmental control and energy accountability. The dilemma that architects face is that they simply cannot possess the knowledge in all the fields of expertise required to render a flawless and successfully integrated design solution. What architects need is a little help from the computer. This help needs to be in the form of "tools" and in the form of "expert advisers" (Degelman 1990 p160). The desire to "produce responsible architecture" is, however, coupled in many countries with pressure for architects to produce and develop designs quickly and cheaply. The deregulated, highly competitive architectural design market which now exists in most countries, where firms of architects are cut redesign and design development time in order to be able to offer competitive fees, does not encourage lengthy reflection and refinement in the performance of buildings. The "tools" and "expert advisers" need to be easy and quick to use.

The decision to use simulation may be imposed from outside. Government codes are beginning to require a demonstration of building performance in areas where public policy or public safety are involved, such as the behaviour of a building in a fire and its projected use of energy. Simulation then provides the evidence that required standards are being met. Increasingly, local government may also require a demonstration of the relation of a proposed building to its local urban environment: its shadowing effect on public space and nearby property, its influence on wind velocities at pavement level, and its visual impact on the street and neighbourhood. If information is demanded that can only be provided through simulation, then it will inevitably be increasingly used. The reverse influence also operates; as governments become aware that it is possible to provide new kinds of performance information, they are more likely to ask for such information in the development approval process.

In this address I am emphasising simulation in design, but its role is not limited to design. Indeed, one of the benefits long claimed for the increasing use of computer technology has been the closer linking of design, construction, commissioning and operation phases of a development's life. The existence of a computer model of a building facilitates the simulation of construction processes. Construction companies are also typically larger organisations than design offices, and perhaps better able to fund the development of software that is clearly beneficial to them. The simulation of the interaction of cranes, deliveries, material stockpiles and trade sequences, and of the behaviour of future construction robots, is a rich field.

But new buildings, however well designed and refined in their demands on the environment, will be dominated by the existing building stock for the coming decades. In seeking a more sustainable relationship between buildings and the environment, the better management of existing buildings is at least as important as new design. Here, too, there is now much greater awareness of both need and potential benefits as institutions strive to make their operations more efficient. The simulation of plant operating regimes, of the effect of possible building improvements in cost-benefit studies, and the subsequent computer-aided operation and control of building systems all have a role in bringing buildings and the environment into a better balance. Equally important are the uses of simulation outside the context of particular buildings, in the development of government policy and as a tool in education.

Simulation models: validation, forms of results, and relevance

In recent years there has been increasing emphasis on the validation of computer simulation programs and their comparison with other programs and 'traditional' models (see, for example, Birch and Frame 1991, p139: "the output from the computer is compared with measurements taken in a model of the school tested under an artificial sky, and both these results are judged against measurements taken in the real building.") I remember my own use of a thermal simulation program in the late 1970's. The results from the program were heavily dependent on the specified ventilation rate, the derivation of which which was not within the model and for which it was very difficult to justify a particular figure, especially if natural ventilation was assumed. Simulation demands a relative completeness, so that results give a true overall picture and not a constricted view of one aspect of behaviour which may, in reality, be dominated by other aspects.

Even given good models, results need to be available in a form that is meaningful to potential users who may not be well versed in the specialisms of energy, lighting, fire or other analyses. Attaining good performances in these various areas is a part of the craft of architecture, and I agree with Degelman that architects, in general, do seek a responsible architecture. That means that such performances need to be apparent for peer and self-critique, so that the bulk of what reflection and refinement does take place is not limited by lack of information to formal composition and aesthetic issues.

Writing about architectural criticism, John Whiteman draws a distinction between a notation and a representation. "A notation does not struggle to give again the experience in a different medium: it is not a re-presentation.... Instead, a notation, such as a plan or section graphic, is used to *identify* an architectural experience, and specialised skill with a particular notation system is required to know if the notation given is sufficient to to fix the identity of the experience intended. A re-presentation, on the other hand, is less concerned with identifying an architectural experience than with giving it again. In contrast with a notation, a representation aims for satisfaction. A representation of a building wants to re-awaken the architectural experience in a person, to give the same effect, but now in a different medium" (Whiteman, 1987, pp141-192).

The aspect of the computer simulation of building performance which has been most successful in gaining acceptance in practice has been representational: the simulation of the form and appearance of buildings. Indeed, in the architecture journals the most visible effect of computers in the whole design process has been the creation of renderings of projects. This may not always reflect a concern to simulate future performance; many of these renderings present the proposal in the (often literally) best possible light. Even if they are sometimes misleading (as were the 'artist's impressions' before them), such illustrations are understandable by architects, clients, planners, councilors and all the other players in the development process.

Representations, then, are accessible for everyone, while notations can only be understood by those skilled in and familiar with the notational system. The notations with which architects are most familiar are those cited by Whiteman: sections, plans, and the various symbol systems used in drawings. The notations used in building performance simulation are often different: numerical measures of heat flow rates, luminous intensity and annual energy consumption.

The exploration of options for refining a design, involves the architect, services engineer, cost accountant, and perhaps other specialists such as fire safety engineer in the intelligent judgement of how to proceed. For this collaboration to work best, all must be familiar with the notations adopted, with a shared understanding of the meaning or implications of the results. This shared understanding is difficult to attain; people do not have a common experience of relating energy use, for example, to environment since childhood, as they have with view, space and enclosure. The appropriate notations and relationships need to be learned.

Positioning the results of these non-visual building performance simulations more centrally in the design process therefore involves broadening the understanding of the notations used (a task, especially, for schools of architecture) and/or moving as much as possible from notation towards representation.

More accessible notations often involve the graphical presentation of information. An example is provided by Murray Milne and his colleagues in using three-dimensional graphs to express energy and daylighting performance in buildings. I quote from a paper on a graphic interface for daylighting design by Milne, Yuliatmo and Schilerin at the 1991 IBPSA conference: "The full potential of microcomputer design tools depends on finding more effective ways for architects and computers to exchange information in a graphic or visual mode.... A powerful design tool makes it possible to do something that is profoundly different from what architects could do before. They can bring their design to life, run it forwards in time, and watch how it behaves - not just what it looks like, but how bright or dark it looks, how warm or cold it feels, what it sounds like, and how well it accommodates human activities." (Milne, Yuliatmo and Schiler, 1991, p151). The further move from notations to representations leads to what is sometimes called "experiential simulations". Lighting again provides an example: rather than, or as well as, presenting numbers and graphs, the software can present images which accurately describe internal views given certain lighting proposals (see, for example, Perraudeau and Le Strat, 1991).

Along with accurate models and meaningful results is the question of the relevance of those results to particular circumstances. This question of relevance is not as straightforward as it first appears. It is tempting to assume an independence between technology and culture, and between building performance and the way buildings are used. This is not the case; one cannot transfer assumptions about buildng use between cultures, and people do not always respond as one would expect. I quote from a paper entitled "Aspects of thermal preferences in housing in a hot humid climate, with particular reference to Darwin, Australia" by my Adelaide colleagues Terry Williamson, Susan Coldicutt and Sam Penny: "Findings illustrate that mathematical models of thermal sensation... are of limited use as aids in the prediction of thermal preferences in Darwin housing. For example, they cannot answer the important question of whether or not air conditioning is 'necessary'. A major reason for this limited usefulness appears to be the lack of nay predicatable relationship between thermal preference and thermal discomfort or thermal sensation" (Williamson, Coldicutt and Penny, 1991, p251).

Simulation models in design

Assume we have mastered the art of producing validated simulation models which produce results in forms which are understood by their users who, in turn, have a good grasp of the cultural and geographic limits of their applicability. How do these models fit into design?

Since the early days of computer-aided design in architecture there has been a continuing, simple, and alluring vision of how this would work. An integrated computer model of a building provides both a geometric description and, with non-geometric attributes attached to objects and spaces, the basis for a concurrent description in terms of various performances. All those people involved in the design centre their work on this same model. As the design develops the model becomes more complete and the simulated performances more precise. Eventually, everything is known about the building's geometry, materials and services, and everything able to be modelled is known about its performance.

Using this model in design, simulation was seen as a fundamental part of an "analysis — synthesis — evaluation" sequence of design activity, where each cycle of this sequence occurs at a slightly greater level of detail. Aspects have been implemented in the pioneering work of ABACUS at Strathclyde University and in such building modelling systems as BDS, GABLE and laterly AES. The key was integration. The fact that all the players in the building design process based their work on the same building model ensured consistency and the availability of as complete information as possible about the design at any stage. In his 1986 paper that I have cited already, Fenves argued that "research is urgently needed to develop representations of designs of sufficient scope and completeness so that every participant in the design process can locate and evaluate those aspects of the design information that are relevant" to that participant (Fenves, 1986 p5).

We still wait for this vision to become the norm. There are a number of contributing factors for the apparent delay: the complexity and quantity of data in the necessary models, their sophistication, the inadequacy of some of the simplifying simulation models adopted, the complexity of the interfaces, and a mismatch between the interests, priorities and pressures on designers and the processes necessary to make these large models 'work'.

Much later research has, therefore, been rather less ambitious in scope, seeking limited but efficient tools to address specific needs, particularly at the early stages of design when the fundamental decisions that effect the performance of a building are taken. Lighting design will again provide an example: "Since extensive daylighting related input data are usually not available at a preliminary design stage, flexible and effective estimation procedures are needed, which would provide "magnitude of order" information derived from a small set of data.... these rules could be realised in terms of "intelligent" modules within the CAAD systems to enhance their interactive design supporting capabilities" (Mahdavi and Berberidou-Kallivoka, 1991, p137). The notion here of linking rules (as in expert systems) with simulation is important. My own experience of building expert systems in this area was that the available 'rules', if we sought to apply them generally, were simplistic. We had to resort to procedural simulations which took very specific situations into account to make the advice provided by the expert system relevant, and this still ignored the cultural and social issues mentioned above.

Experience in Use: A Small Case Study

The mode of design using computers as design media is and should be different from that without such technology. It is useful to describe a very small case study: a competition entry for energy efficient housing for an MFP - organised competition for medium-density housing at Osborne, a suburb of Adelaide, in which I and two colleagues at the University of Adelaide collaborated with the firm of Pacific Architecture in Sydney. I shall preface this by pointing out that what I will describe is not a winning scheme, so that I cannot claim that computers and computer simulations bring any guarantee of success. Indeed, our own agenda in using the competition to test certain ideas, and therefore being rather different to the competition agenda, may even have got in the way.

Our agenda included the modelling of building performance: the future character of urban design, solar access, shading, energy use, and building cost. We used various software: MiniCAD (a 2D and 3D Macintosh CAD system well suited to quick block modelling), CADDSMAN (as a 3D surface modeller suited to more detailed visualisations), and TEMPAL (an energy simulation program).

The computer modelling was a part of a larger agenda to demonstrate an explicit approach to formulating an urban design "language" expressed as rules (see for example Radford, 1992), and to link this with a non-hierarchical collaborative design process where these rules and their implementation in computer building models were the basis for discussion and design development.

In the event, the rules, the collaboration and the computers were closely linked. The rules associated desired characteristics of the development with building and urban design form, and linked together the detail and larger scale forms of the design. They provided a basis for dialogue, with a form of expression with which all the contributors were familiar. The collaboration focused on the rules, which were taken and developed and interpreted by the collaborators. The computer simulations provided a common image which could be readily understood by team, in a form that could be taken and developed. Without the collaboration, there would have been less impetus to formulate the rules. Without the computers, we would have had less facility in understanding the work of others or in taking on and adapting the work of others. The computer drawings and visualisations made it possible for a team member to take another's design, make a copy, and modify it in a way that would never have been done with each other's manual drawings. Noticeably, these exchanges did not eventuate to the same extent with the thermal and energy simulations because we did not have the shared knowledge of the energy simulation software among the team as we had with the visual simulation software.

In a postulated future computer-aided design environment we would have designed with a computational grammatical design system, defining rules for the form of houses and then exploring spaces of designs that followed these rules in a speculative, questioning process. We would have simulated the energy performance of these houses in a way which enabled us to ask "what if?" questions about assumptions of the way the occupants would live in them, as well as the design decisions made. We would have roamed the streets in a virtual reality but abstracted world where, all situated in this world, we could have discussed the urban design senses of enclosure, shelter, view, sunshine and shade. Using graphical feedback, we would have asked "what if?" questions about the climate and explored the microclimate that resulted about the buildings.

The description of, and learning from, case studies are of particular value at this stage in the development of the field; see, for example, a larger case study of geometric modelling and various performance simulation tools for CMU "intelligent Workplace" project in this conference (Mahdavi et al 1993).

Achievements and Directions

Looking at the literature, there is a sense of gradual, incremental, progress in the computer simulation of building performance, and through that a sense of gradual progress towards more accurate understandings of the way a building interacts with its environment.

The major concern of most researchers in the field has been the development of better simulation models, and the proceedings of all three International Building Performance Simulation Association conferences have contained a majority of papers which advocate and describe more accurate models for heat and mass transfer, air flow, natural lighting and so on. But interest in building performance simulation is demonstrated not only by the IBPSA conferences but also by others: examples are those of the Association for Computer Aided Design in Architecture (ACADIA), held every year in the United States, the European equivalent (ECAADE), and the biannual CAADFutures conferences. It is notable that whereas IBPSA papers generally reflect a technical emphasis (with many equations and flow chart diagrams), work reported in these other conferences often presents a 'users view' (with much more illustration of building designs).

It seems to be characteristic of all fields of computer-aided design research that aspirations consistently remain ahead of the ability of systems to deliver. The rhetoric tends to 'sell' the future; what *will* be possible *given* confidently expected developments in hardware/software/designer's attitudes. Looking towards this future, experience suggests that only a very few of the many models and systems that have been developed already will survive; most will fall into disuse, most without getting beyond the prototype stage. Nevertheless, many of these will influence the future, even though they are discarded themselves.

I shall end with three scenarios illustrating aspects of a future for building performance simulation.

First, consider a collaborative scenario. I recently watched "live" in a colleague's office a presentation at PARC Xerox in California on networks for electronic communications, distributed over the international computer links to participants in Europe, America and Australia. The workstation screen showed a video image of the speaker, a white-board, and the workstation's own speaker broadcast the sound. In Adelaide we could have drawn on the whiteboard and interrupted the speaker, although social convention would preclude such bad manners (and the other members of the audience could have turned us off). As an adjunct to shared models and networked CAD, it suggests a way in which the dispersed international building team can work together, allowing those with expertise in various very specialised areas of building performance to contribute.

Secondly, consider an "integrated model" scenario. Despite the difficulties, the notion of the integrated model is so simple and so attractive that it remains an image of the future and research on appropriate integrated models continues. In this scenario the performance of buildings will be checked as a matter of course as they are designed on commercial CAD systems. Generative models will assist in the process of building this model. We may use what we presently label 'expert system' techniques as a part of both generation and performance evaluation, but these tools will be recognised as essentially different in nature from that of human experts with their scope and limitations well recognised.

Thirdly, consider a 'virtual reality' scenario, with heat, light and sound simulated in experiential fashion, replacing notation by representation. But even such experiences of 'hot and cold', 'light and dark' are not sufficient; as demonstrated in the work of Williamson, Coldicutt and their colleagues cited above, decisions about how hot or cold it is are not independent of one's culture, activity, past activity and mood; decisions about whether to heat or cool are not independent of the cost of heating and cooling and alternative attractions for spending that money. How does one simulate all of these influences in the design process?

A sideline may be the design of simulated rather than real living environments, of building performance simulation without the prosaic limitations imposed by the expectation to turn the model into a 'real' building. An architecture unhampered by gravity, a sensual architecture of heat and cold, intense light and dark corners, soft music and bird song: architecture as a true performance, to be explored and enjoyed as a film or computer game.

Given that computers use very little energy and very little material, perhaps a sustainable architecture for an increasing world population will be one in which much of the need for buildings is replaced by electronic alternatives. I am reminded of the English novelist E.M. Forster's classic short storey written around 1910 describing life in an underground world of automated services and simulated experiences in which people needed only a small space to live and did not need or choose to travel. It begins: "Imagine, if you can, a small room, hexagonal in shape, like the cell of a bee. It is lighted neither by window nor by lamp, yet it is filled with a soft radiance. There are no apertures for ventilation, yet the air is fresh. There are no musical instruments, and yet, at the moment my meditation opens, this room is throbbing with melodious sounds. An arm chair is at the centre, by its side a reading-desk — that is all the furniture." (Forster, 1928). But the title of Forster's story was *The Machine Stops*, and the lifestyle he described is essentially impoverished. His story continues: "And in the arm-chair there sits a swaddled lump of flesh — a woman, about five feet high, with a face as white as a fungus. It is to her that the little room belongs. "

Perhaps we are better advised to continue working towards a sustainable 'real' world rather than 'virtual' world, with building performance simulation playing its part in this endeavour.

References

Birch, S. and Frame, I. 1991. "The Use and Evaluation of a Computer Program for the Investigation of the Daylight and Sunlight Performance of Buildings." In *Building Simulation '91*, J.A. Clarke, J.W. Mitchell and R.C. Van de Perre, eds. IBPSA (The International Building Performance Simulation Association), pp139-144.

Degelman, L.O. 1990. "Environmental Systems: Addressing the Real Issues." In *From Research to Practice*, Proceedings of the ACADIA'90 Conference (Big Sky, Montana, Oct. 5-7), ed. by J.P. Jordan, ACADIA, pp159-160.

Fenves, S.J. 1986. "Present and Future Role of Computers in Building Technology." In *Proceedings of CIB.86: Keynote Presentations*, CIB.

Forster, E.M. 1928. "The Machine Stops." In *The Eternal Moment and Other Stories"*. Harcourt Brace Jovanovich, Inc, New York.

Mahdavi, A., and Berberidou-Kallivoka, L. (1991). "Simulation of natural lighting: From geometrical configuration to occupancy evaluation." In *Building Simulation '91*, J.A. Clarke, J.W. Mitchell and R.C. Van de Perre, eds. IBPSA (The International Building Performance Simulation Association).

Mahdavi, A., Hartkopf, V., Loftness, V. and Lam, K.P. 1993. "Simulation-based Performance Evaluation as a Design Decision Support Strategy:

Experiences with the "Intelligent Workplace"." In *Buiding Simulation '93,* this volume.

Milne, M., Yuliatmo, U. and Schiler, M. 1991. "An interactive graphic interface for daylighting design with superlite." In *Building Simulation '91,* J.A. Clarke, J.W. Mitchell and R.C. Van de Perre, eds. IBPSA (The International Building Performance Simulation Association), pp151-157.

Newton, P.W., Wilson, B.G., Crawford, J.R. and Tucker, S.N. 1993. "CAD Conferencing", *Technical Computing,* No.77, pp24-27.

Perraudeau and Le Strat. (1991). "A Design Tool for Interior Daylighting Description of Luminous Environment with Image Synthesis". In *Building Simulation '91,* J.A. Clarke, J.W. Mitchell and R.C. Van de Perre, eds. IBPSA (The International Building Performance Simulation Association), pp145-148.

Radford, A.D. 1992. "Local Architectural Language as a Context for Design Review." In *Design Review,* B.C. Lightner and W.F.E. Preiser, eds. University of Cincinnati, pp187-197.

Turner, J.A. and Hall, T.W. 1990. "An application of geometric modelling and ray tracing to the visual and acoustical analysis of a municipal open-air auditorium." In *From Research to Practice,* Proceedings of the ACADIA'90 Conference (Big Sky, Montana, Oct. 5-7), J.P. Jordan, ed. ACADIA, pp173-186.

Whiteman, J. (1987). "Criticism, Representation and Experience in Contemporary Architecture: Architecture and Drawing in an Age of Criticism." *Harvard Architectural Review,* vol.6 pp137-141.