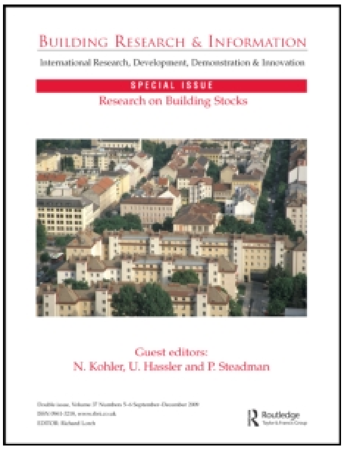

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Predicting building performance: the ethics of computer simulation

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INFORMATION PAPER

Predicting building performance: the ethics of computer simulation

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A responsible architect or engineer taking sustainable design seriously will aim to create a built environment that exhibits cohesion in the contexts of environmental, social/cultural, and technological realms. In addition, the very notion of sustainability extends an actual (or implied) duty of care to peoples and environments now and into the future. Advanced computer simulation of environmental and technological performance offers one way of tackling this obligation. However, claims about simulation can lead to a spurious impression of accuracy and therefore legitimacy. Likewise, inappropriate applications of simulation may result in wrong decisions and an erroneous allocation of resources. Almost all discussions of the validity of computer simulation for decision-making focus on its quantitative accuracy; however, the problems addressed are often far from well defined. Two concepts from the social sciences, 'trustworthiness' and a taxonomy of 'ignorance', are introduced as ways of assessing the appropriate use of simulation. Simulation applications should not be seen as surrogates of reality and interpreted as logical answers to substantive problems. Although simulations have potency as perspectives to support wise human judgements, a more mature approach is needed when applying these tools and outputs to decision-making.

Keywords: building performance, decision-making, ethics, modelling, simulation, sustainable design

Un architecte ou un ingénieur responsable, prenant au sérieux la conception durable, visera à créer un cadre bâti manifestant de la cohésion dans le contexte des domaines environnementaux, socioculturels et technologiques. De plus, la notion même de durabilité implique une obligation réelle (ou implicite) d'attention à l'égard des personnes et des milieux dans le présent comme à l'avenir. Une simulation informatique évoluée des performances environnementales et technologiques offre un moyen de s'attaquer à cette obligation. Néanmoins, les affirmations relatives à la simulation peuvent conduire à une fausse impression d'exactitude et par conséquent de légitimité. De même, des applications inopportunes de la simulation peuvent entraîner de mauvaises décisions et une attribution de ressources erronée. Presque toutes les discussions relatives à la validité de la simulation informatique pour la prise de décision se concentrent sur son exactitude quantitative ; cependant, les problèmes abordés sont souvent très mal définis. Deux concepts empruntés aux sciences sociales, «la crédibilité» et une taxonomie de «l'ignorance», sont introduits en tant que moyens d'évaluer l'utilisation appropriée de la simulation. Les applications de la simulation ne devraient pas être considérées comme des substituts de la réalité et interprétées comme des réponses logiques à des problèmes de fond. Bien que les simulations aient la capacité d'offrir des perspectives permettant d'appuyer des jugements humains judicieux, une approche plus mûre est nécessaire dans l'application à la prise de décision de ces outils et des résultats obtenus.

Mots clés: performance des bâtiments, prise de décision, éthique, modélisation, simulation, conception durable

Preamble

Advanced computer performance simulations provide techniques aimed at predicting, with certain assumptions, future states of the physical environment that may have a direct impact on the issue of sustainability. A recent conference of the International Building Performance Simulation Association (IBPSA), held in Glasgow, UK, in July 2009, included papers that

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described numerous computer programs aimed at modelling the built environment from the micro to global levels. The simulation techniques and application being described covered a wide range including modelling the potential for mould growth in bathrooms, modelling indoor air flow, hot water boilers and air-conditioning systems, modelling occupant behaviour that may determine energy consumption, modelling the urban climate, and even modelling future weather. Many of these types of simulation models are now routinely used by many designers and their consultants to guide and assess design decision-making. Increasingly, these simulation programs are also employed by analysts to develop policy formulations such as codes and regulations. However, claims made by simulationists can often lead to a spurious impression of legitimacy, with 'accurate' predictions of some aspects of built environment performance being used to legitimize certain design decisions at the building level and regulations or similar mechanisms at a policy level. This paper considers the use of simulation, in particular building performance assessment simulation, and how one might judge appropriate use.

Introduction

Probably the most important concept in human understanding to emerge in the late 20th century is the recognition that humans can threaten the existence of its own species, and indeed all other species, on Earth. This new awareness is at the heart of the call to invoke sustainable practices – in our case a sustainable built environment. In *Understanding Sustainable Architecture* (2003), Williamson *et al.* suggest that fundamentally sustainable architecture is a:

> revised conceptualisation of architecture in the light of contemporary concerns about the impact of human activity on the environment.
>
> (p. 1)

If the practice of building performance assessment simulation is to be part of this project, then it follows that one should ask the question: Does the practice of building performance simulation need to be (re)conceptualized to support the aim of producing a sustainable built environment? To answer this question, first some of the basic notions behind the idea of a sustainable built environment require examination to ascertain what place simulation might play.

In the last 30 years or so various writers including Hans Jonas and Zygmunt Bauman have argued that with the utilization of modern technology there is a radical departure from everything previously known, so great that it has affected the balance between humans and nature and social arrangements in ways not previously encountered. These changes are likely to be long-term, cumulative, irreversible, and global in scale. Jonas was perhaps the first to suggest that this condition raised issues of an ethical nature that no previous thinking on the topic had to deal with (Jonas, 1984).[1] Writing in the late 1970s he explained that all traditional (Western) ethics are anthropocentric, belonging to dealings between man and man. The non-human world was considered ethically neutral, with all consequences that one needed to consider effectively situated close to the act in both space and time.

> Proper conduct had its immediate criteria and almost immediate consummation. The long run of consequences beyond was left to chance, fate, or providence.
>
> (Jonas, 1984, p. 5)

In attempting to deal with this new imperative, Jonas, remaining firmly entrenched in the anthropocentric tradition, suggested that as an ethical principle one should always ascertain the 'truth' concerning future conditions that might result from one's decisions and actions in accordance with the maxim:

> In your present choices, include the future wholeness of Man among the objects of your will.
>
> (Jonas, 1984, p. 11)

In other words, there is an obligation do to nothing that might risk the permanence of human life. To this end, practical knowledge should be employed to discern the trends of one's actions as certain, probable or possible. This should apply as much (or even more so because of resources implications) to the design of the built environment as to any other aspect of human endeavour.

Built environment performance assessment simulation may offer a small means of satisfying this demand, but it is not necessarily straightforward. Concerns expressed about the utility of simulation to inform decision-making provide some insight into the complexities in accepting such an approach. Bannister (2005) identified some of the problems when he pointed out that:

> evidence does not support the existence of a general relationship between simulated performance and absolute performance [... there is] a knowledge gap in the understanding of the correct use and interpretation of simulations [... and there is] a gap between how they [simulation developers] think simulation tools should be used and how they are being used.
>
> (p. 39)

This situation contains all the elements of what Strauch (1974) described as a 'squishy' problem, where advocates of simulation worry about the technical competence of their tools and worry far less, or not at all, about how the methodology unambiguously captures the problem.

Some background to simulation

Built environment performance simulation had its beginnings in the 1950s with the development of computers that could be used to solve complex mathematical problems. Most early uses were little more than extensions of standard engineering design methods and were employed to estimate temperatures and the interactions between elements of mechanical air-conditioning systems. A pioneer of the technique, Tamami Kusuda, in his Keynote Address to the 1999 IBPSA Conference in Kyoto, Japan (Kasuda, 1999), described the early days of developing computer programs for refrigeration system performance, psychrometric calculations, and building thermal environmental calculations (including energy performance analysis after the oil embargo of the early 1970s). Kusuda explained that one of the first successes for performance simulation was to calculate the likely environmental conditions in nuclear fallout shelters.

The early 'voice' of performance simulation was formed essentially around solving a one-dimensional problem sponsored often by commercial interests. As Shove (2003) points out, it is no accident that the stimulus to develop building thermal performance simulation went hand in hand with the growth of air-conditioning, the marketing of comfort conditions, and the 'need' to undertake engineering calculations that could not easily be handled by traditional manual methods. Choices in these matters are culturally as well as technologically framed.

Even though a conceptual understanding exists that in a situation of multidimensional design decision-making the compartmentalization of knowledge is more likely to lead to suboptimal or even non-sustainable outcomes, single-problem applications of building performance assessment (for example, the thermal performance of a building) are the norm in all areas of built environment performance analysis. In 1979, at the time when the techniques of simulation were being refined, Jonas pointed out this dilemma:

> For just as it is only through science that those enterprises are made possible whose later consequences we are told to discover by extrapolation, so this extrapolation in turn clearly demands at least the same degree of science as is embodied in those technological deeds themselves. In fact [...] it demands a still higher degree. For the degree which suffices for the short-range prediction intrinsic to each work of technology by itself – the engineer's prediction of its working – is on principle inadequate for the long-range prediction of the combined working of all of them: and at this, the ethically required extrapolation must aim.
>
> (Jonas, 1984, p. 29)

How then is it possible for building performance simulation with its origins in engineering calculation to satisfy the expanded criteria necessary to address the ethical demands of designing a sustainable built environment?

The meaning of simulation

Building performance simulation can be defined as 'the science of estimating future states of single or multiple physical phenomena within an existing or proposed built environment'.

From any review of the literature on methods of enquiry, it becomes clear that views about the criteria one might apply to judging how built environment performance assessment simulation should be applied will be heavily influenced by the philosophical assumptions of the person making the judgement. It is evident that these paradigms and assumptions influence which particular principles and criteria are favoured in making judgements. While addressing this issue is far from easy and rarely if at all discussed, confronting this problem is fundamental to a mature understanding of built environment performance simulation.

To understand the meaning of simulation, first there must be recognition that there are different ontological positions or views about the nature of the world and in addition there are different epistemological beliefs, or views, about the nature of knowledge and how it is possible to know about the world.

Built environment simulation is steeped in an empiricist/positivist tradition which assumes that the world 'out there' is essentially knowable and that the 'true' nature of an external reality is discoverable through the application of the methods of science. The assumption on which building performance simulation is predicated is therefore the notion that it is possible for knowledge produced through the application of simulation to approximate closely an external 'reality'. Knowledge in this case equates with the accurate representation or a surrogate of that which is outside now and in the future. But if, as many assert, the empiricist project is dead, can a contemporary interpretation of simulation practice and theory be provided outside of a scientific or realist framework?

A post-modern view posits there is no possibility of theory-free foundational knowledge and therefore no special epistemic privilege can be attached to any particular method (simulation or otherwise). Likewise, no external referent is available that would allow one to adjudicate from among different knowledge claims. (This should not be interpreted as relativism or 'anything goes'.) In a constructivist paradigm, knowledge of the world is provisional and context dependent, *i.e.* there are only alternative, subjective constructions of reality produced by different individuals. Shared knowledge is acknowledged as a social and historical product.

These views have significant implications for thinking about and assessing the use of performance simulation to inform the design of a sustainable built environment. The pragmatist philosopher Richard Rorty gives a hint as to how progress might be made when he says that in the pursuit of knowledge an:

> account of the value of cooperative human enquiry has only an ethical base, not an epistemological or metaphysical one.
>
> (Rorty, 1991, p. 24)

That is, the truth of a matter is that which a group has worked out from within; it is not relative to any truth that is 'out there' in an epistemological or metaphysical 'reality'. Accordingly, a project to assess the appropriate truth of simulation could begin with criteria that a reflective judge could use to characterize good versus bad enquiry and good versus bad applications of simulation.

Simulation to inform sustainable design

As discussed above, an *end* in designing for a sustainable built environment revolves around the issue of accounting for the effects of one's decisions – encompassing the realms of environment, social and economic issues, in the short-term and especially in the long-term. The question then is what *means* should be used to bring about this end and what attributes would such means exhibit? Ultimately, it is argued that the use of such means should become an integral part of the process and practice of built environment design, *i.e.* the ethical practice of architecture should be re-conceptualized to account for this.

Godfried Augenbroe, in his address to the 2001 IBPSA Conference in Brazil, outlined a 'tool function wish list' to facilitate quick, accurate, and complete analysis of candidate building design alternatives as (Augenbroe, 2001):

- Design as a (rational) decision-making process enabled by tools that support decision-making under risk and uncertainty.
- Incremental design strategies supported by tools that recognize repeated evaluations with slight variations.
- Explicit well-posedness guarantees that check embedded 'application validity' rules and are thus able to detect when the application is being used outside its validity range.
- Robust solvers for non-linear, mixed and hybrid simulations, going beyond the classical solving of a set of differential algebraic equations.

While from a simulationist's point of view this list seems sufficient, looking at the notion of applying simulation to inform decision-making something more is needed. There is a need for a way to distinguish not only sound from spurious 'results' (addressed by the Augenbroe wish list), but also the sound from spurious 'applications' that may prompt an erroneous legitimacy.

These requirements can be captured in the notions of simulation accuracy/validity and simulation trustworthiness.

Accuracy/validity

Accuracy or validity of a simulation model is described as the degree to which it corresponds to a matter of fact in reality and is concerned very much with a correspondence principle of truth. Three methodologies are adopted by simulationists in order to satisfy the accuracy/validity criteria to approach a truth standard in predicting real behaviour:

- Empirical validation, which compares simulated results with measured data in the real world, *e.g.* a building, a test cell or a laboratory. The ultimate validation test would be a comparison of simulation results with a perfectly performed empirical experiment with all simulation inputs perfectly known. Because of the complexity of the built environment, such an experiment is all but impossible.
- Analytical verification, which compares simulation output from a program, subroutine, algorithm or software object with results from a known analytical solution or a set of quasi-analytical solutions.
- Intermodal comparison, which compares the output of one program with the results of other similar programs.

Each technique has some logical difficulties. Most simulation programs consist of scientific law-like statements of interacting and interwoven computational routines whose behaviours are not all measured in an empirical test. A validation experiment that results in a successful matching of a measured and simulated variable may well be the chance interaction of two or more incorrect operations. Analytical verification, on the other hand, usually relates to highly constrained boundary conditions (*e.g.* constant temperatures) that may be useful in identifying programming errors but generally bear little resemblance to the real physical world. Satisfying an intermodal comparison may be a necessary condition among similar programs, but it is not sufficient to guarantee a depiction of physical real-world behaviour.

Just as Karl Popper has stated:

> the criterion of the scientific status of a theory is its falsifiability, or refutability, or testability
> (Popper, 1972, p. 37)

so the 'accuracy' of simulation tools can be established only by efforts at whole system validation. In the positivist world of the sciences and quantifiable measurements, this would mean that the results from simulations would be tested against the established criteria of accuracy (reliability and objectivity) and validity (internal and external). If it were only necessary to establish the truth or non-truth of a computer model, evaluation would be relatively easy. The problem, however, is not that simple, particularly if one accepts the notion that knowledge cannot be value free. At least three questions need to be answered: first, the degree of correspondence to reality; second, the severity of any tests; and third, whether the result is sufficient to provide confidence that the model can be used in any given context for decision-making. No single framework seems to be available to address these issues fully. The first question concerns the rigor of the naturalistic (or quantitative) knowledge produced by the simulation and may be addressed by scientific verification strategies as outlined above. The other two questions are concerned more with rationalistic (or qualitative) knowledge for decision-making; in particular how uncertainties are dealt with. To address these issues, the set of 'trustworthiness' criteria of Guba and Lincoln (1989) mapped onto Smithson's (1989) taxonomy of ignorance can provide useful ways of looking at the problem. This mapping emphasizes that in making judgements about the 'goodness' of simulation information in describing future states, not only should consideration be on what information is presented (knowledge – awareness and/or understanding), but also notice should be taken of what is missing (ignorance – the absence of knowledge).

Trustworthiness and ignorance

The criteria for 'trustworthiness' for qualitative evaluations suggested by Guba and Lincoln (1989) are credibility, transferability, dependability and confirmability; they parallel the tests for rigour in a quantitative paradigm. Trustworthiness criteria are closely related to purpose or problem definition. Problem definition in the use of built environment performance simulation always presupposes some more or less coherent structure of beliefs amongst those producing and those using the knowledge created by a simulation, *e.g.* an understanding that a level of occupant thermal comfort is important, or that energy costs should be kept to a minimum. It can be argued that a serious engagement by all stakeholders in a built environment project to establish shared beliefs (project aims in the environmental, social and economic realms) becomes an ethical obligation in the practice of sustainable architecture. In this stakeholder discourse, consideration of the future consequences of the design decisions and criteria to measure the probable trend of outcomes become important elements of a process. While trustworthiness criteria can inform the potential approach to investigations of a problem, it remains unknown if the right problem or the right questions are being addressed. Here an approach to structuring problems based on a consideration of ignorance is useful.

In Smithson's taxonomy, reducing ignorance relates to identifying absence and uncertainty related to an incomplete or inadequate definition in the nature of the problem or entity that is being sought (disinformation), while confusion and inaccuracy relate to distortions or misrepresentations (misinformation) where the outcome is most likely a deception. Absence and confusion are an error in kind, while uncertainty and inaccuracy are an error in degree.

In essence, Smithson suggests that any problem can be addressed by asking four questions about irrelevance:

- Absence: should that kind of knowledge be absent (or present)?
- Confusion: is there a distortion in the definition of knowledge?
- Uncertainty: what degree of certainty is relevant?
- Inaccuracy: how accurate does the knowledge need to be? Is it irrelevant because it is not accurate enough: or is it needlessly accurate?

A mapping of the trustworthiness criteria with Smithson's taxonomy of ignorance is shown in Figure 1. This can be used as a conceptual framework for discussing the appropriate application of building performance assessment simulation.

Questions on problem definition and relevance

Problem definition is central to the application of knowledge informed by simulation, and relevance is

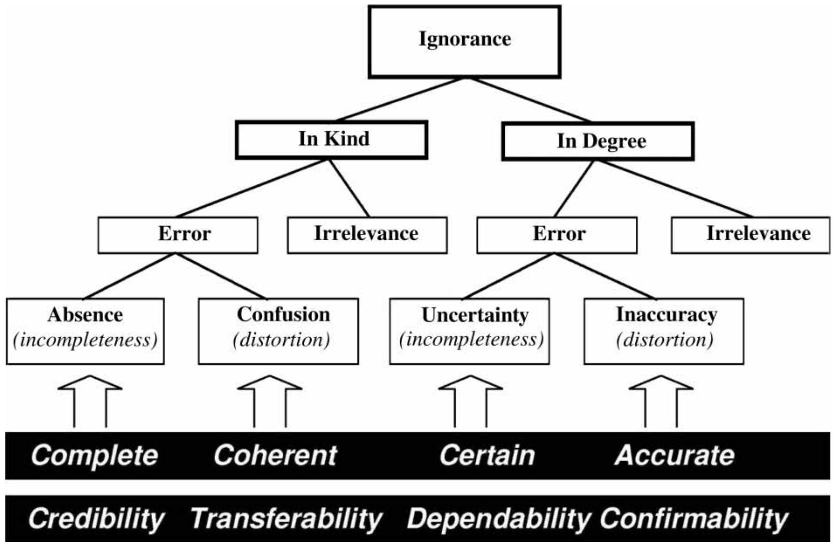

Figure 1 Mapping of trustworthiness and ignorance

central to problem definition. Strauch (1974) points out that many problems:

> have no well-defined formulation. Or, if they look like they do, it remains well-defined only as long as we don't lean on it too hard or question the assumptions too strongly.
>
> (p. 4)

Earlier Rittel and Webber (1973) described this type of ill-formulated problem as a wicked problem.

Therefore, in the process of addressing the assessment of building performance design decisions informed by simulation (or wider policy issues), the four questions of trustworthiness (and their converse reducing ignorance) need to be asked with an eye to relevance.

An analysis of trustworthiness criteria and ways to check ignorance shows the necessary nature of the enquiry process, but it can never give unambiguous, definite answers. The central point is that for each unique problem, these questions must be asked, always with the understanding that the goal is relevant approaches, rather than the unattainable goal of being certain of making no error of any type.

Credibility (and absence)

The credibility of an application of simulation will be derived by reference to an appropriate authority to establish the match between the constructed realities of the simulation and those realities that will be the built environment in the real world. Credibility will be lacking when key elements of a problem definition that reflective judges would agree should be included are missing or a simulation tool is used inappropriately, *e.g.* to represent systems that the tool is not actually capable of representing.

The questions to test credibility are: Is there incompleteness in the objective (stated or assumed) that the simulation application is addressing so that some relevant matter is absent?; and Does the simulation means address the ends in a relevant way?

Taking into account the contingent nature of the world, establishing the credibility of the system(s) data that provide input to a simulation will add credibility to the results, as will acknowledging the uncertain nature of the output. However, credibility relates not only to the simulation means, but also to the use of simulation results. A distinction can be made between the simulation models *per se* and the machinery that translates a model output into design decisions or policy. Credibility will be lacking if moral responsibility (if not legal responsibility) in applying the results of simulation is not accepted at all levels. For example, when design decision-making in a regulatory context is informed by simulation, the outcome would be expected to have some objective interpretation in reality.

An examination of the current application of simulation in the current Building Code of Australia (BCA) energy-efficiency provisions that have an overall objective of reducing greenhouse gas emissions shows this expectation is not achieved. Within the BCA, compliance may be demonstrated by achieving a specified Star Rating as determined by the Nationwide House Energy Rating Scheme (NatHERS) based on the results of a thermal performance simulation of the proposed building.

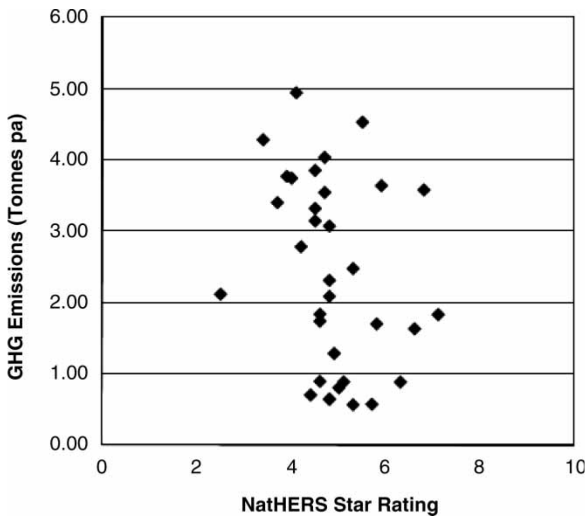

Figure 2 Nationwide House Energy Rating Scheme (NatHERS) Star Rating versus measured greenhouse gas emissions per annum for heating and cooling of 34 houses in Adelaide, Australia. *Source:* Williamson *et al.* (2007)

Figure 2 shows for a sample of 34 houses in Adelaide, Australia, the results of a comparison between simulated and actual performance derived from several years of recorded end-use energy data. There is no significant correlation between the Star Rating and actual greenhouse gas emissions produced by the heating and cooling systems.

One reason for this result is that the simulation in a holistic sense is incomplete because consideration of the heating and/or cooling appliances is absent in NatHERS. The Star Rating is calculated from a simulation of the aggregate heating and cooling loads taking into account certain assumptions about the use of the building. In order to achieve a 'policy' requirement of fuel neutrality, an estimate of potential energy consumption or greenhouse gas emission is not part of the simulation: the heating/cooling appliances are not considered.

Transferability (and confusion)

Transferability is a cue for checking that appeals to the appropriate authority are indeed relevant: in Guba and Lincoln's (1989) words, that 'salient conditions overlap and match' (p. 241). The use of simulation results beyond the intended range of contexts (explicit or implicit), or applied to aspects beyond the proposed scope of the underlying analytical model, is more likely if the problem addressed by the simulation is not made clear or is confused.

In assessing transferability, the complexities of the relationships between authority, responsibility and uncertainty mean that the assessment of risk is too important to be purely the preserve of scientific analysis – there are too many societal implications. Key questions on transferability therefore include the extent to which authoritative knowledge should be scientific, to the exclusion of other forms of knowledge, and related to this, the problem of how to bring together different knowledge into a coherent decision-making rationality.

The NatHERS example above may also introduce confusion and a distortion in decision-making. A responsible designer (and the client) may wish to achieve a Star Rating for the design beyond the minimum in the belief that this will further reduce greenhouse gas emissions. Because of distortion in the use of the simulation results, significant resources may well be expended without achieving the desired aim.

Dependability (and uncertainty)

Dependability relates to the uncertainties in using simulation results. It depends on how changing conditions of the phenomena being simulated are taken into account, as well as how changes in the design created by an increasingly refined understanding of the setting are handled. The stability or applicability of the simulated knowledge over time should be considered here. This can be illustrated by a simple example. Bulk thermal insulation is known to deteriorate over time. Fibreglass insulation in an attic space will compress and anecdotal evidence suggests that the material could be as much as 30% less effective within say a decade. The implications for energy consumption could be significant, yet, because this is not a well-researched issue, no thermal simulation program probably takes this or other known unknowns into account.

A review of the proceedings of the IBPSA (International) Conference shows almost no authors have addressed issues of the uncertainties inherent in simulation analysis. Of the few, Macdonald (2003) says:

> The quantification of uncertainty in the design process is necessary when applying simulation in practice to assess the risk in design decision making [...].
>
> (p. 769)

At the 2009 IBPSA Conference in Glasgow, no papers addressed this important problem.

Confirmable (and inaccuracy)

Confirmability is concerned with the constructions, assumptions, and facts (data) behind a simulation model and the use of the model to draw general conclusions.

Inevitably, there are many uncertainties and 'inaccuracies' in the application of simulation. For example, researchers (Bloomfield, 1986; Guyon, 1997) have consistently found large differences of around ±50% in total building energy consumption when operators are asked to simulate the same building with the same software, with no consistent variation depending on the expertise of the user, either occasional or expert consultant. Discarding input errors, the differences often arise because of the way the simulation operators interpret the building to construct the necessary input data.

The scientific formulations fundamental in a simulation (*e.g.* in thermal performance assessment these include surface resistance, sky emissivity and discharge coefficient) have accepted values that can be orders of magnitude different, yet rarely are these variations and therefore uncertainties acknowledged in simulation results. Likewise, generic or standard values for the exogenous variables to a simulation, such as climate factors (*e.g.* wind speed, temperature), environmental factors (*e.g.* soil conditions) and building material properties (*e.g.* conductivity, emissivity) are usually adopted without the 'built in' uncertainty of results ever being considered. While it is possible that with sufficient resources physical parameters can be specified with a higher degree of accuracy for a particular instance, the same is not likely to apply to variables concerning the human occupancy factors. Adopting stereotypical or average human behaviour assumptions as a simulation input (or worse, obscuring such assumptions in complex computer software) will result in a likely distortion of knowledge so that good sustainable design that depends on the blending of a multitude of factors into a coherent whole may not be realized. When simulation developers suggest that these issues are only partly about the techniques of simulation and pass the responsibility for 'correct' implementation down the line to the users, distortions in knowledge are likely to occur.

Discussion and conclusions

> What we and other people do may have profound, far-reaching and long-term consequences, which we can neither see directly nor predict with precision [...].
>
> (Bauman, 1993, pp. 17–18)

The issues and requirements for a sustainable built environment are likely to extend well beyond a reliance on existing conventions and empirical knowledge. However, employing simulation as 'responsible decision-making' in the hope of achieving a truly sustainable built environment is, as seen above, problematic. These problems should be acknowledged. Researchers, practitioners and policy-makers must realize that simulation can never pretend to offer the kind of certainty which experts with their scientific knowledge and with greater or lesser credibility claim to offer. At the foundational level, both modellers and the users of simulation must also be mindful of the problem highlighted by Jean Baudrillard that simulation may blur the distinctions between the real and unreal; the model becomes the determinant of our view of (a certain) reality (Baudrillard, 1994). The language in much of the simulation literature exposes this muddle because often no distinction is made between instances in simulation and instances in the physical world.

It should also be noted that the issues raised here have implications for the uses of simulation of the future states of the physical world in general and that these could also have implications for built environment design decision-making and wider policy formulations. For example, the important issue of climate change is based almost entirely on the predictions of simulation models and potentially these results may have a much more significant effect on design decisions than building assessment simulation *per se*. Figure 3 shows the

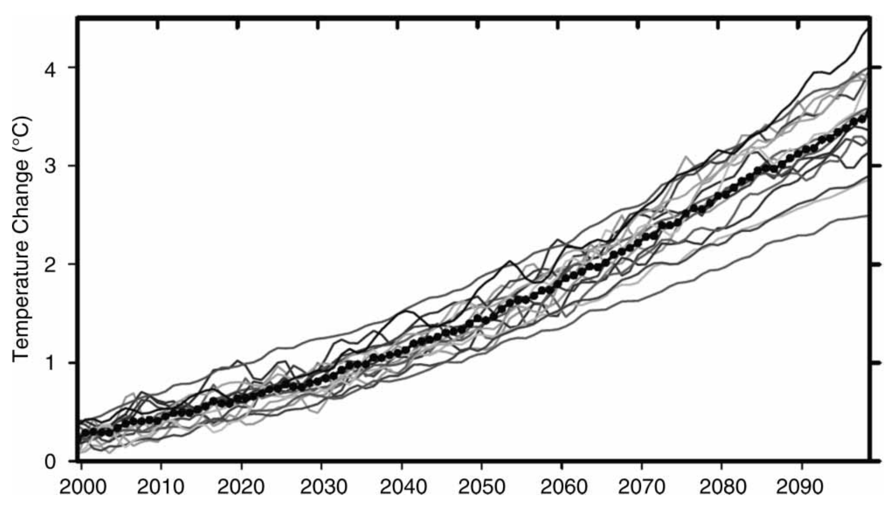

Figure 3 Future global warming simulated by 17 global circulation models, International Panel on Climate Change (IPCC) Scenario A2. Multi-model mean series are marked with black dots. *Source:* Meehl *et al.* (2007, p. 763)

results of 17 global circulation climate models as reported in the 2007 Fourth Assessment Report (AR4) of the International Panel on Climate Change (Meehl *et al.*, 2007). Not all these predictions can be right or likely equally wrong, yet the average is presented as a deterministic value of the most probable future state.

Räisänen and Palmer (2001), when examining the use of climate change simulations, have expressed concerns regarding the use of these models for decision-making. They concluded:

> Because of the inherent uncertainties that exist in climate prediction, the notion of providing users only with deterministic forecasts is a misguided strategy. More informed decisions can be made given a reliable probability forecast, as compared with a deterministic forecast of uncertain accuracy. In terms of the potential economic value, a probabilistic interpretation of climate change simulations has a distinct advantage over the deterministic interpretation of treating the ensemble mean of model results as the truth. This is most clearly the case when the scatter between different model results is substantial, as is generally the case [...].
>
> (p. 3225)

The same could be said regarding, for example, thermal performance or lighting simulation of buildings. By framing a discussion of these simulation models (and all simulation) beyond the normal scientific concerns to include different knowledge perspectives that focus on the treatments of uncertainty, one could begin to understand their true value for decision-making. Rather than surrogates of reality, the simulations would best be viewed as perspectives that are incomplete and non-unique ways of looking at a problem that provide the basis for wise human judgements to be made (Strauch, 1974).

Bauman (1993) stated that one has a duty to

> visualize the future impact of actions (undertaken or not undertaken) [...]

and that while doing this:

> the moral stance consists precisely in seeing to it that both uncertainty and responsibility are neither dismissed nor suppressed, but consciously embraced.
>
> (p. 221)

Simulation has a potential to contribute to this obligation. The ability (and indeed obligation) to predict future consequences of present decisions with any degree of confidence is a relatively new means in the history of human undertakings. However, a mature understanding of the implications of applying these tools to built environment design decision-making is still to emerge.

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References

Augenbroe, G. (2001) Building simulation trends going into the new millennium, in R. Lamberts, C. Negrao and J. Hensen (eds): *Proceedings of the BS'01 Conference*, International Building Performance Simulation Association, Rio de Janeiro, Brazil, pp. 15–27.

Bannister, P. (2005) The ABGR validation protocol for computer simulations, in I. Beausoleil-Morrison and M. Bernier (eds): *Proceedings of the Conference Building Simulation '05*, Montreal, Canada, International Building Performance Simulation Association, Montreal, Canada, pp. 33–40.

Baudrillard, J. (1994) *Simulacra and Simulation*, University of Michigan Press, Ann Arbor, MI.

Bauman, Z. (1993) *PostModern Ethics*, Blackwell, Oxford.

Bloomfield, D.P. (1986) The influence of the user on the results obtained from thermal simulation. Paper presented at the 5th InternatoalSymposium on the Use of Computers for Environmental Engineering Related to Buildings, Bath, UK.

Guba, E.G. and Lincoln, Y.S. (1989) *Fourth Generation Evaluation*, Sage, Newbury Park, CA, pp. 236–243.

Guyon, G. (1997) Role of the model user in results obtained from simulation software program, in J.D. Spitler and J.L.M. Hensen (eds): Proceedings of the 5th IBPSA Building Simulation Conference, Prague, Czech Republic, International Building Performance Simulation Association, Prague, Czech Republic, Vol. 1, pp. 377–384.

Jonas, H. (1984) *The Imperative of Responsibility: In Search of an Ethics for the Technological Age*, University of Chicago Press, Chicago, IL.

Kusuda, T. (1999) Early history and future prospects of building system simulation, in N. Nakahara, H. Yoshida, M. Udagawa and J. Hensen (eds): Proceedings of Conference Building Simulation '99, Vol. I, Kyoto, Japan, International Building Performance Simulation Association.

Macdonald, I. (2003) Applying uncertainty considerations to building energy conservation equations, in G. Augenbroe and J. Hensen (eds): Proceedings of the 8th International IBPSA Conference, Eindhoven, the Netherlands, pp. 769–776.

Meehl, G.A., Stocker, T.F., Collins, W.D., Friedlingstein, P., Gaye, A.T., Gregory, J.M., Kitoh, A., Knutti, R., Murphy, J.M., Noda, A., Raper, S.C.B., Watterson, I.G., Weaver, A.J. and Zhao, Z.-C. (2007) Global climate projections, in S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds): *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge.

Popper, K.R. (1972) *Conjectures and Refutations: The Growth of Scientific Knowledge*, 4th Edn, Routledge & Kegan Paul, London.

Räisänen, J. and Palmer, T.N. (2001) A probability and decision-model analysis of a multimodel ensemble of climate change simulations. *Journal of Climate*, **14**, 3212–3226.
Rittel, H.W.J. and Webber, M.M. (1973) Dilemmas in a general theory of planning. *Policy Sciences*, **4**, 155–169.
Rorty, R. (1991) *Objectivity, Relativism, and Truth*, Cambridge University Press, Cambridge.
Shove, E. (2003) *Comfort, Cleanliness and Convenience: The Social Organization of Normality*, BERG, Oxford.
Smithson, M. (1989) *Ignorance and Uncertainty: Emerging Paradigms*, Springer, New York, NY.
Strauch, R. (1974) *Squishy Problems and Quantitative Methods*, The Rand Corporation, Santa Monica, CA (available at: http://www.rand.org/pubs/papers/2006/P5303.pdf) (accessed March 2010).
Williamson, T.J., Plaves, Y. and Hart, R.L. (2007) An evaluation of the Nationwide House Energy Rating Scheme (NatHERS), in J. Coulson (ed.): *Proceedings of the 41st Annual ANZAScA Conference*, Deakin University, Geelong [CD-ROM].
Williamson, T.J., Radford, A. and Bennetts, H. (2003) *Understanding Sustainable Architecture*, Spon, London.

Endnote

[1]This book was first published in German as *Das Prinzip Verantwortung: Versuch einer Ethik für die technologische Zivilisation* (Frankfurt: Insel, 1979).