

## Note on editors

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## Note on Think Lab

# THINKlab

This book arises from debate within the internationally leading University of Salford 'Think Lab'. This state-of-the-art facility has been developed for research into Information and Communication Technologies in many fields, including design and construction. It provides a forum for leading figures across the world to participate, both in person and through virtual collaborative technologies, to discuss topics relating to future developments in ICTs applied to various topic areas. For further information visit [www.thinklab.salford.ac.uk](http://www.thinklab.salford.ac.uk)



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<sup>1</sup> The RICS Foundation is a charitable body established by the Royal Institution of Chartered Surveyors to seek to improve the quality of the built and natural environment.



# Foreword – Virtual worlds, virtual prototypes and design

*William J. Mitchell*

Architects and other designers inhabit a curious borderland between the virtual and the physical. They have always been concerned with conjuring up things that don't exist but might, imagining them in detail, and eventually finding ways to translate these visions into physical reality. Over the last half-century, computer-generated virtual worlds have played an increasingly crucial role in this process.

The first virtual world I ever saw was called Spacewar. It ran on early DEC computers in the 1960s and 1970s, and was later reincarnated as one of the first arcade games – more accurately, a bar game, since there weren't yet any arcades. A Spacewar 'world' had two inhabitants. You controlled one spaceship moving in the gravitational field of a star, your opponent controlled another and you tried to shoot each other down with missiles. It was very simple – limited, of course, by the available processing power and graphic display capabilities – but it had the essentials: a simulated spatial environment, simulated physics, control of something that represented you and multiplayer interaction.

Four decades later, we have entered the era of Second Life – which, when I last logged on to check, claimed to have 4 523 218 residents. Second Life describes itself as 'a 3D online digital world imagined, created and owned by its residents'. It runs over the internet, and its operators just keep adding servers as it grows. It presents itself in coloured, shaded perspective, with real-time motion. Players control avatars that can interact via text messages, buy and sell virtual artefacts, acquire virtual real estate and design and build virtual things. Numerous organizations, such as the *Reuters* news agency, have built sites in Second Life to transact business there.

Furthermore, Second Life and its competitors are beginning to blur familiar categories. As virtual worlds rapidly expand their capabilities, they increasingly overlap the established and hitherto fairly distinct domains of videogames, computer animation, computer-aided design systems, geographic information systems, engineering simulation systems as well as remote interaction and collaboration systems. As a result, architects and others can now design for the physical world, for virtual worlds and for hybrids of the two. And they must begin to take careful account of the varied and complex relationships that may exist between the physical and the virtual.

## Connections of the virtual and the physical

A virtual world may, for example, function as a *mirror* of a fragment of the physical – perhaps by means of movement sensors on dancers that drive the motions of avatars, or thermal sensors on buildings that drive 3D digital models showing energy flows.



In principle, this is much like live television, but it allows much greater flexibility in defining the functions that map from physical to virtual.

Alternatively, a virtual world may serve as a *utopia* – that is, an ‘improved’ version of the physical. This seems to be key to the appeal of Second Life. Tremendous effort has been devoted to making it look like the physical world, and to function like it in some carefully selected respects, but avatars are generally richer, thinner and better looking than their physical counterparts. It never gets cold or rains. And you don’t get sick and die.

A virtual world may, of course, simply present a *fiction* – showing things that do not exist in the physical world, never did and never will. Second Life has a great many wholly fictional environments that function much like stage or screen sets, within which avatars act out roles.

Physical and virtual worlds may also operate in parallel, but with *cross-linked* dynamics. The flourishing economy of Second Life, for example, is cross-linked to the economy of the physical world through mechanisms for the exchange of Second Life dollars for US dollars. Taxation departments are beginning to take note of this.

Looking to the past, a virtual world may present a *reconstruction* of something physical that no longer exists – of Rome at the time of Julius Caesar, for example. Or it might present something that was once proposed but never made physical, such as Tatlin’s tower for Saint Petersburg. In this case, it is presenting a *counterfactual conditional*: if the tower had been built, *then* this is what Saint Petersburg would be like.

Looking to the future instead, a virtual world might present a *prediction* or *conditional prediction*. Thus an architect may build a virtual version of a project and say to his/her client, in effect: ‘If you invest in making this physical, *then* this is what you will get.’ More strongly, it could function as a *promise* to the client, and even establish a contract.

Construction contract documents for buildings once took the form of drawings and specifications, and served as *prescriptions* of what was to be done. More recently, 3D digital models created by CAD (computer aided design) and BIM (building information modelling) systems have played this role. As the distinctions between CAD systems and virtual worlds become less rigid, it is not hard to imagine virtual worlds becoming repositories of construction documents. Architects would deposit them there, and contractors wanting to bid on projects would need to visit them.

Of particular interest to designers are *virtual prototypes* of products, buildings and urban settings. These are digital representations of design proposals – ideas put forward for exploration, analysis and evaluation, with the intention that they might one day be physically realized if they stand up to scrutiny. The emerging practice of virtual prototyping is beginning to connect virtual worlds, in a powerful way, to the long tradition of prototyping in design and construction.

## Traditions of prototyping

A prototype is usually thought of as a partial, approximate, or abstracted realization of a component or system that is constructed before the real thing in order to advance the design process. It differs, by virtue of its particular, antecedent, functional relationship to the real thing, from superficially similar artefacts such as movie-set fictional buildings, historical reconstructions and art works. Over the centuries, prototypes have taken diverse forms and have served a wide variety of specialized purposes.

A full-scale clay model of an automobile, for example, allows designers to sculpt surfaces, check form and appearance and, eventually, seek approval from management before proceeding to tooling and production. An experimental prototype version of a nuclear weapon can be tested, at some convenient desert location, to see if it works – and perhaps to announce a threat to potential targets. An example of a key structural component of a building can be set up and loaded to destruction to demonstrate that its counterparts will be safe in use. A pre-production motorcycle engine can be run in an instrumented acoustic chamber to determine exactly what sort of noise the proposed product will make and whether it is acceptable. A lightweight, non-functional mockup of a building façade, erected on site, can serve the political purposes of informing nearby residents about what is proposed and convincing them that it will be good for the neighbourhood. A running prototype of a new software product can be demonstrated to potential investors to convince them that it has a market.

## **The economics of prototyping**

The goals of prototyping are, in some mix: to provide information needed for further refinement and development of a design; to identify any design errors or potential failure points; to provide a basis for choosing among options or deciding whether to proceed to the next stage; and (in a less scientific spirit) to persuade decision makers. Achieving these goals comes at a cost, and the art of prototyping is to produce the required information with minimum expenditure of time and resources. A prototype fails if it is too incomplete or inaccurate to yield the information required in the relevant context. On the other hand, it slows down the design process and wastes precious resources if it is unnecessarily elaborate and costly for its purpose.

The economic imperatives that frame prototyping practices vary with stage in the design process and type of end product. In particular, there is generally a progression from quick, approximate, inexpensive prototypes that provide rough guidance at early stages to more carefully crafted, detailed and costly prototypes at later stages. A product design might, for example, initially take the form of rapidly constructed foam or paper prototypes, proceed to carefully crafted wood or plaster and then – as confidence in the design and commitment to it grow – eventually develop to precisely fabricated, fully functional metal and plastic.

The length of the expected production run also makes a difference. Where many physical instances will be produced from a single design, as with automobiles, the cost of a prototype may be multiples of the cost of a finished product. But, where just one finished instance will be produced, as with a building, the cost of prototyping usually must be limited to a small fraction of the cost of the singular product.

Some of the information that can be gained from prototypes is of particularly high value. Where design failure would be catastrophic – perhaps resulting in injury or death – it makes sense to invest heavily in prototyping. But, where the consequences of failure would be less severe, this may not be so necessary.

In general, a designer contemplating the production of a prototype confronts a set of cost-benefit questions. What sort of information or rhetorical effect do I need? What is the quickest and cheapest way to get it? What effects will this have on schedule and budget? Will the benefits justify the costs?

## The rise of the virtual

In the past, the only option was to create, test and evaluate physical prototypes. During the nineteenth and twentieth centuries, before they were largely displaced by computer methods, careful model testing techniques played an indispensable role in many design domains (Cowan, 1968). Where designers needed to economize in this sort of process, they resorted to scaling down from full size (for obvious reasons, a particularly common practice in architecture and urban design) and to substituting inexpensive, easily worked materials for the intended actual materials.

Over the last couple of decades, though, the ongoing development of information technology has made the alternative of virtual prototyping increasingly feasible and attractive. In the manufacturing industry, the virtual prototyping of the Boeing 777 in the early 1990s was a particularly significant milestone in the application of this new approach (Sabbagh, 1996). In this case, digital models of the aircraft were used extensively throughout the design process, and the first physical prototype was a fully functional one that flew. In architecture and construction, the steadily increasing adoption of three-dimensional, computer-aided design systems has generated growing interest in the virtual prototyping of buildings.

Sometimes a virtual prototype will be less expensive to create than its physical equivalent, but this is not necessarily the case; production of careful, detailed digital models can be time-consuming and extremely costly. But part of the attraction of virtual prototyping (at least in principle) is that digital models typically need to be created *anyway*, to serve as design documentation. So, why not build digital models that can support documentation, visualization, engineering analysis and various forms of performance simulation? Then, the cost of modelling will be justified by numerous, varied benefits. This is the old dream of integrated computer-aided design, which has been around since the 1970s (Mitchell, 1977), and is finally approaching fruition in current building information modelling (BIM) systems (Goldberg, 2006).

A second attraction of virtual prototypes is that they are (when properly structured) relatively easy to edit and change, and thus provide designers and their clients with an enhanced ability to explore ranges of variants on design concepts. Part of this capability comes from standard CAD editing tools, which are typically easier to apply to a digital model than, say, saws and chisels to a wooden model. Increasingly now, parametric models – which are built from the beginning with variation in mind – support this kind of exploration even more effectively. Parametric modelling is actually a very old idea – it was a key feature of Ivan Sutherland's pioneering *Sketchpad* CAD system in the early 1960s (Sutherland, 1963) – but it had little impact on design practice until, much more recently, commercial software vendors began to integrate useful parametric tools with CAD products, and to market them heavily.

A third attraction is that virtual prototypes enable the substitution of virtual experiments – conducted by applying analysis or simulation software to digital models – for the slow, painstaking, costly, sometimes dangerous process of instrumenting physical prototypes and running actual experiments to generate data. Instead of subjecting a physical model of a structure to load testing, you can now run a finite element analysis; instead of carefully instrumenting a physical model of an auditorium for acoustic testing, you can run an acoustic simulation; instead of placing a scale model of a building in an artificial sky, you can run a lighting simulation. The development of useful analysis or simulation software may be a slow and costly process, but once the software exists

the marginal cost of each application is typically very low compared to that of physical modelling, instrumentation and experimentation. Furthermore, while physical prototyping and test facilities tend unavoidably to be expensive to create and maintain, and generally are not widely accessible, analysis and simulation software is, in principle, available to anyone who can download it. Hence, as our stock of analysis and simulation software grows, the advantages of virtual prototyping become increasingly overwhelming.

Overall, then, the effect of virtual prototyping has been both to expand the range of benefits to design processes that can be achieved through prototyping and to transform the economics of prototyping. Until now, this has been accomplished through the use of computer-aided design and engineering simulation software. But this may change as more general virtual worlds, such as Second Life, continue to grow, expand their modelling and simulation capabilities and attract investment. My guess is that designers will increasingly see virtual worlds as attractive outsourcing sites – places where the local conditions and economies make it quick, cheap and easy to build prototypes.

## Translation, abstraction and elaboration

It is tempting to think of virtual prototyping as a replacement for physical prototyping, but in practice the two often coexist and are inextricably interconnected. Automobile design, for example, still entails the use of both clay and curved surface CAD models, and there is little sign of this changing. The reason is that the affordances of clay and CAD overlap to some extent, but do not mutually substitute. Clay models of automobile bodies are not precisely mathematically defined, but they are tactile – which means a lot to craftsmen who are used to receiving information through their hands, and they offer more to the experienced and sophisticated eye than the most advanced raytraced rendering. Conversely, CAD models *are* mathematically defined, and they support a wide variety of analyses, simulations and visualizations, but they abstract away from tactility. Clay and CAD, it turns out, are complementary.

This complementarity has been reinforced, in recent years, by the emergence of techniques for efficiently translating between physical and virtual prototypes. Laser scanners and three-dimensional digitizers can be used to convert physical models into corresponding digital ones, while computer-controlled, rapid prototyping devices – laser cutters, 3D printers, multi-axis milling machines and the like – render digital models into material, tactile form. In architecture, the office of Frank Gehry has been an important pioneer of design processes grounded in both physical and digital modelling of form, with the use of sophisticated techniques to translate back and forth (Mitchell, 2001).

These physical/virtual translations are special cases of the translations among representations that occur continually in most serious design processes – from two-dimensional drawings to physical scale models, from building plans to circulation network diagrams, from detailed drawings of buildings to simplified urban massing models, from point clouds' output by scanners to structured CAD models, from non-functional foam and cardboard mockups to functional metal prototypes, and so on. These translations are rarely mechanistic or neutral, but are occasions for exercising design judgement. In some cases the task is, for a particular design purpose, to abstract away from detail that is unnecessary and distracting in the current context. In other

cases, it is to carry the design to a higher level of elaboration by adding detail and structure.

Design processes benefit from the availability of diverse prototyping techniques, together with tools and strategies for translating among prototypes by abstracting and elaborating. As a result, virtual prototyping techniques have had a complex and somewhat paradoxical effect on design practice. They have partially displaced more traditional, physical techniques whilst – simultaneously, and probably more importantly in the end – they have also complemented them and thus enhanced their value.

## The future

At this point, the future of virtual prototyping seems very bright. The technologies that support it continue to develop rapidly, to migrate from research laboratories to commercial software products and to move from there to practice. There are promising efforts to reduce impediments to adoption and effective application by establishing useful standards and by moving away from closed, proprietary software systems towards more open-source frameworks for software development and dissemination. Increasingly stringent demands to assure life safety and sustainability will motivate architects and other designers to invest more time and resources in careful prototyping.

Concurrently, virtual worlds are rapidly growing in scale and sophistication, attracting investment to support research and development, and increasingly becoming sites for everything that can benefit, in some way, from taking place in online virtual environments – mirroring, role playing, reconstruction of the past and many useful forms of prototyping. This is shifting much of the burden of software tool development from the relatively small and specialized domains of computer-aided design and engineering simulation to a much larger and better-funded community. Furthermore, it is producing effective combinations of modelling and simulation with social interaction and exchange capabilities. It seems likely, then, that virtual prototyping will become a specialized interest of sub-communities within the larger communities supported by virtual worlds.

The moment has come. Following some important pioneering work in the 1990s, the 2000s will be the decade of the virtual prototype – perhaps to be found in a larger virtual world. This book presents a comprehensive, up-to-date overview of this crucial topic in design and construction, with contributions by some of the leading theorists, researchers and practitioners.

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# Introduction – Virtually there...?

*Peter Brandon*

## 1. Context

Most people close to retirement in construction have spent a working lifetime which has broadly followed the advent and development of commercial and electronic computers. Looking back for them, it has been a fascinating journey. It started with computer bureaus which took basic information, punched it on to cards and then processed it before sending it back to you to undertake the corrections! The bureaus charged about one farthing (this is about one-tenth of a current new UK penny) for every character and this just about paid the firm to have Bills of Quantity, for example, prepared in this way. Unit quantities followed, whereby standard units, such as a door, could have all its components and decoration computed by the machine automatically, specified and costed. Computer-aided drafting developed alongside, but it was not until the microcomputer, as it was often called (now the PC), was developed that CAD and other programs under the control of the user began to make serious inroads into the market-place.

Computing then moved from the domain of the enthusiast to that of commerce. The rapid rise in the power of such machines and the parallel reduction in cost enabled the machine to come within the scope of the general public, and with the advent of the internet the machine was transformed from being just another tool to an essential aspect of daily life for most people in the developed world.

The process has been one of exponential growth in both the power and spread of the machine, which has seen the behaviour patterns of people changed out of all recognition through its influence. The dependency on the computer has increased in the developed world to the point where our manufacturing plants, our homes, our energy supplies and our mechanical devices could not work without the support of microprocessors. This has been extended still further to the point where the primary source of our knowledge and the way it is managed and presented is now found through the internet, and a massive explosion of knowledge has occurred. During the Clinton Presidency in the USA the number of internet sites rose from less than a hundred to over 350 million and is now well over one billion. This has created what Malcolm Gladwell (Gladwell, 2001) identified as a tipping point, a place where an epidemic of change occurs in the social, technical or cultural aspects of life similar to that of an epidemic in the health domain.

These developments are well known and do not need amplification, but where do we go from here?



## 2. Prediction and foresight

For many years people have been engaged in the process of predicting what would happen in the foreseeable future. As the speed of change increases then people want to know where they should place their investments, what they need to learn and where they can direct their efforts for maximum advantage. Increasingly, the predictions about the kind of life people will lead have been dominated by the power of technology and in particular the power of the computer. Many of these predictions have come true and there is now considerable dependence on the machine in nearly all aspects of daily living. Consequently, issues such as security of information have become of major importance (see Grahame Cooper, Chapter 16), and this, coupled with governance and intrusion into people's lives (often triggered by malign use of the technology or significant external events, e.g. terrorism), has opened up the likelihood of Orwellian possibilities for the future (Orwell, 1949) – Orwell just got the year of 1984 wrong!

At a more mundane level the construction industry has tried to predict what could, and in some cases should, happen to its structure and performance in the light of the technological revolution that surrounds it (see Nashwan Dawood *et al.*, Chapter 19). It would be true to say that construction has been one of the last major industries to fully embrace the technology. Whereas the large scale engineering industries such as aerospace and automobile manufacture have raced ahead with the adoption of computing technology, construction has remained stubbornly resistant. The technological developments have been progressing fast in other industries but construction has for some time fought off the challenge, as exemplified by the cartoon prepared by the author in 1998 (see Figure 1).

Nevertheless, various studies have identified the potential for harnessing the technological developments for construction (CICA Report, 1992; Hannus *et al.*, 2003; Rezgui and Zarli, 2006). Some of these are reflected in this volume. The industry itself is aware of the need to respond and, in a large scale study undertaken by the author in 2004, the construction industry in Australia placed developments in IT as the second most important factor to influence the industry over the next 20 years, after sustainable development (see Figure 2).

However, the industry seems hidebound by its present structure, the educational standard of much of its workforce and the lack of investment required to transform its working practices. These problems are often described as 'cultural' and there is some merit in looking at them in this way. They have arisen after centuries of adopting a particular kind of behaviour, and, in an industry that is so diverse and so geographically fragmented, it is going to take many years for this to change.

One of the problems might be that construction is often considered to be one large monolithic and homogeneous industry. But if the methods adopted for, say, free form structures together with the personnel employed were compared with the average house builder, then a major gulf would appear, certainly in the UK.. The former uses three dimensional modelling, laser scanning, high level mathematics and CAD/CAM systems for manufacture with a highly trained and informed personnel. The latter uses the craft technology of another era, admittedly now with many preformed components, but with a workforce that is under-educated and which has little knowledge of the potential of computer-based methods. Both sectors may have similar aims but their ability to use new technologies could not be further apart.

Other industries

Construction

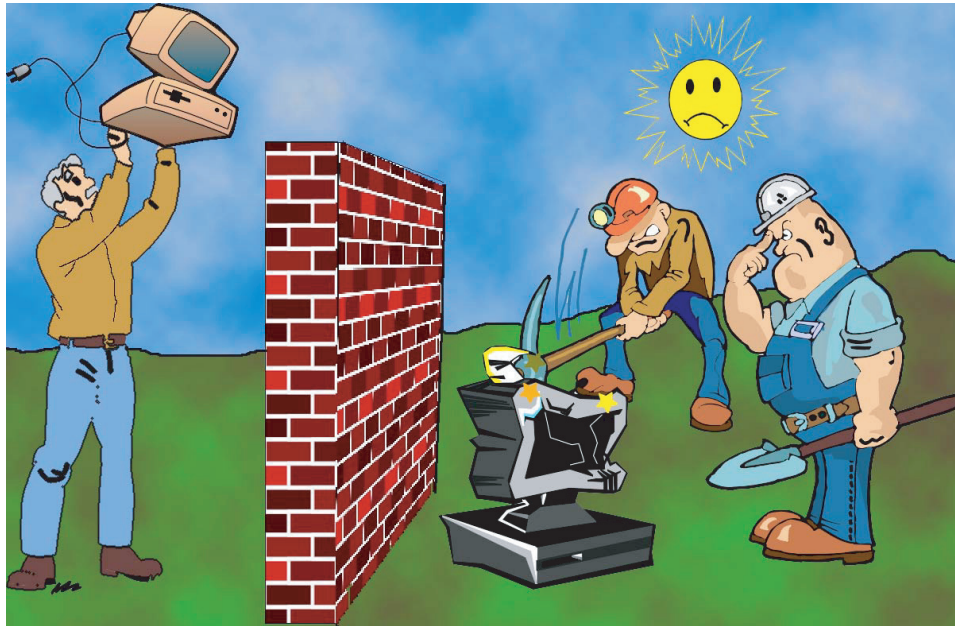


Figure 1 Construction's response to the transfer of Information Technology? (Brandon 1988).

Global Trends Affecting the Industry

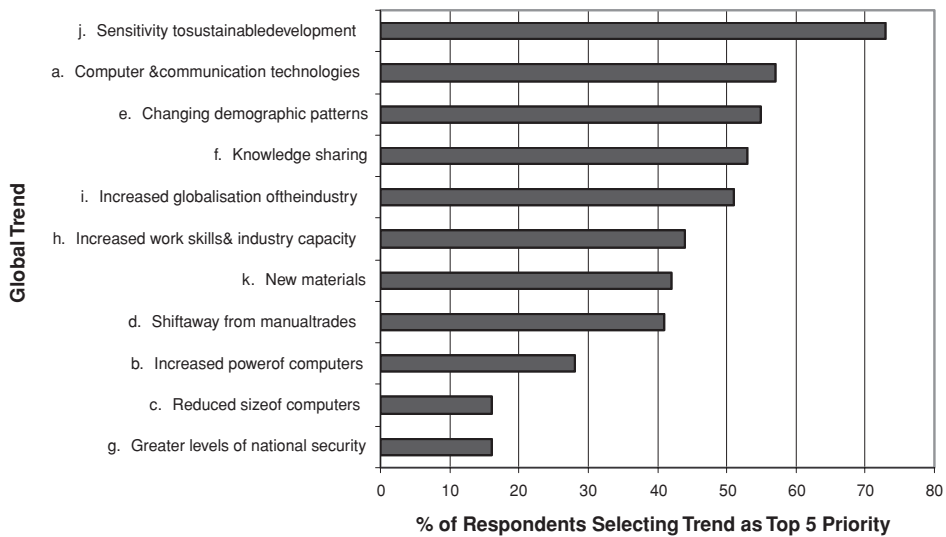


Figure 2 Global trends affecting the Construction Industry. 'Construction 2020 – A Vision for Australia's Property and Construction Industry'. Report CRC Construction Innovation, Australia 2004.

Despite this recognition of the influence of the information and communication technologies (ICTs) to change the industry, when the members of the industry had to choose the highest priority for the industry to address, changing the business environment came top. By this, the industry means the cut throat competition and procurement. The two are linked, of course, but it is not obvious to most individuals in the industry.

There is a difference between prediction and foresight. With prediction the event will happen and the recipient has to decide what his or her reaction might be. With foresight a desirable scenario for the future is developed and the person has to decide how they might make this scenario become achievable. In one the person is a passive receiver, whereas in the other the person can attempt to create and shape the future.

Flanagan and Jewell (2003), in a comparison of foresight studies in construction, identified similarities between the predictions of ten countries and found that four countries (France, UK, Singapore and USA) had not included information technology as a major issue. This is slightly misleading as the assumption of these countries was that information technology permeated everything and that progress in any area could not develop without it. They did not see a need to identify it as a separate issue worthy of addressing. This in itself is quite interesting as it may mean that the assumption of the industry in these countries is that the industry would continue in the way it always has but would be merely enhanced by ICT developments. If this is true then the mind set of the industry is not one of revolution (as has been seen in other manufacturing industries) but of incremental change within the existing paradigm. This is not a recipe for major advancement. The power of ICTs to revolutionize what is done in the industry is so strong that it cannot surely be left to a supporting role?

To some extent this may be the result of the timescale over which the study was expected to look. It is difficult to see a vast industry which is fragmented into sectors with a complex supply chain being able to change radically within 5–10 years. Consequently, incremental change becomes the horizon of the day. If, however, we go beyond the 15-year horizon then much of the immediate focus on current problems begins to fade away. The political and structural issues and the current barriers are perceived to no longer be as relevant.

### **3. The changing scene**

This book and its authors have chosen to look at this longer horizon and beyond, to examine what might benefit the industry of the future. Some of the chapters provide case study material of advanced applications, existing now, since it is unlikely that there will be a ‘big bang’ change across the whole industry. There will be pioneers, and the case study material provides an indication of what will eventually become common practice.

There are clear signs that things are changing and this provides the context for this book. At the moment the revolution seems to focus around the use of 3D modelling of the design and process, and the use to which the model can be enhanced to be utilized throughout the construction and operation phases of development. This could, of course, span several decades. If the information can be used several times and a legacy of knowledge and intent produced for future users then the model becomes an organic repository for the history and development of the project, able to be mined at will for those who wish to adapt and develop the building in the future. This has been

put forward as a major motivator for many years. Some have taken this concept much further on real-life projects towards 4D and nD modelling (see Ghassan Aouad *et al.*, Chapter 12 and Martin Fischer, Chapter 8), and the result is an integrated database of knowledge built around the 3D design model to which all the participants can contribute.

The potential of this approach is at last being recognized. Some major clients (see Martin Riese, Chapter 5) are beginning to demand that 3D modelling is used on their projects, and if the design teams and the contractors are not able to operate this technology then they will not be employed by that client. It is a strong incentive! This level of commitment usually means there is a 'champion' in the directorate of the company who has a vision for the future that encompasses computer approaches at the highest level. Some clients are already claiming that such technology is saving them more than 10% of the total cost of the project in design/construction and substantially more within the operational cycle. These are significant sums of money and as such provide significant competitive advantage to the firms concerned. An interesting project would be to see how these champions arise and what level of knowledge they require to provide the level of commitment needed to instigate change and provide the investment needed.

In other instances the nature of the building demands a much higher level of technology support. These buildings simply could not be built without the use of 3D modelling and the supporting knowledge structures. Conventional processes using 2D drawings will not allow the design forms to be represented for construction, let alone set out on site or checked for regulatory requirements. However, one of the problems that these buildings pose is that regulatory authorities have not yet adapted to the new approaches and are trying to interpret designs for conformance using tools from another era. 2D drawings, for example, do not allow a full understanding of, say, fire regulation requirements for a building which is free form with multiple floor levels within an irregular structure (see Nicholas Nisbet *et al.*, Chapter 17). Glymph has expressed this succinctly with regard to the buildings of Frank Gehry in which he was the senior partner responsible for the management and technological support (see Gehry, 2002).

It would appear that at last we have reached a watershed where at least some sectors of the industry will move forward, driven by client demand, and the knowledge that interesting forms and systems cannot be implemented without the use of advanced CAD/CAM models. The next step is to get the business-to-business models developed so that the interface with the supply chain is improved. One follows from the other in an integrated system, and the full benefits will not be felt until such time as the integration is complete. It is a case of 'the whole is greater than the sum of the parts', and this includes the regulatory systems and techniques which are used for evaluation.

#### 4. Market pull or technology push?

But where is the motivation for change to come from? Is it to be driven by the inventiveness of the IT research community, or is it to be driven by the demand from the practitioners for assistance to solve their current problems? In some countries, particularly the UK, the prevailing view of government research funding agencies has been that it should be industry which pulls through any new technology into the market-place since the main aim of these funding agencies is to increase economic competitiveness. 'Relevance' is the order of the day. This approach is understandable

as industry and commerce provide much of the *raison d'être* for the research and these sectors want to see quick results. However, this emphasis tends to skew the research towards current problem solving and quick wins at the expense of attempting to shape the future and preparing an applied sector for the technological future – hence the lack of preparedness for the expected virtual futures. Consequently, those countries which are less enslaved by long traditions may find themselves at the vanguard. It is no coincidence that Gehry, for example, finds it easier to work in less developed countries than in those with a strong professional and regulatory environment.

It must be wrong to polarize the situation in this way, i.e. market pull or technology push. If the industry does not understand the potential of the technology both now and in the future then it is likely to invest poorly and shut its eyes to future innovation which can transform its performance. This requires education throughout the industry, particularly of those in positions of power, and it requires experimentation to ensure that the appropriate technologies are adopted and adapted for the sector concerned. A long term view is helpful in providing continuity of development and to avoid too many blind alleys. However, the need to reflect and adjust to changing business conditions is equally important because predictability is notoriously difficult in the area of information and communication technologies. This may change as the subject becomes more mature and stable, but for the foreseeable future this is unlikely to happen.

## 5. The changing technology

The past three decades have seen significant movement in the focus of the applications that have been attempted with electronic computers. In the early days the software was developed to either enhance or replicate human activities. Most of these activities were developed to deal with the inadequacies of the human mind and human limbs. These were summarized by Broadbent as long ago as 1973. Humans were not too good at calculating in a reliable manner, got tired quickly and were slow at writing things down. The machines were targeted at improvements in these areas, without changing the manner of the activity, to provide a more effective solution. As time went on, the power to hold data and manipulate them provided new forms of analysis and insight, which allowed a more informed decision to be made. Visualization of data then developed to aid understanding and communication, and the infrastructure for communication changed radically with the internet and mobile devices. Indeed the power of visualization has transformed how we present and interpret data (see Richard Boland *et al.*, Chapter 18) in the context of aspects of management and it is now an expectation for much of our routine decision-making. In many ways the technology is in advance of the human issues, and it is they which hold back the advancement (see Mustafa Alshawi, Chapter 21).

At various times different groups of researchers have explored the use of machine intelligence as a way to aid human decision-making. In the 1980s, in response to the Japanese 5th Generation Project, many countries invested in what were then called 'expert systems' and methods of knowledge representation. An example was the ELSIE expert system for construction pre-design planning, which in several real case studies outperformed human experts (Brandon *et al.*, 1988). Again, this exploration followed the pattern of most computer developments and largely focused on replicating human



behaviour – in this case ‘intelligence’. This would, of course, be a superb achievement, but it does also raise questions as to whether this is appropriate or whether a different focus might provide better service for future human use. These are not trivial issues and may well dominate our thinking for the next working lifetime.

## 6. The disappearing computer

The next step is probably the use of ambient technologies, where the computer is possibly not even visible to the user but nevertheless is communicating, monitoring and analysing as and when required in a more natural way than we expect today from our keyboards and other devices. Already, firms such as Phillips have designed computers which could, and do, reside in the wallpaper as a natural part of the building construction/finishing and through which communication with the outside world is facilitated. This facilitation does not have to be through conventional devices but through speech picked up from our key fob or through projection devices direct onto our retina or even, in the long term future, through our brain patterns.

Terrence Fernando and his colleagues across Europe (see Terrence Fernando, Chapter 20) are developing their work in the University of Salford ‘Think Lab’, investigating how ambient technologies might impact on future workspaces in a number of key industries. This work, sponsored by the European Union Framework Programs to the amount of 12 million Euros, has just started and includes construction and planning as industry sectors. It will be interesting to see how this work reveals the potential for the future.

This ‘disappearance’ of the machine has, of course, its downside. How will the user know it exists? What else is it picking up beside our messages and signals, and how is it manipulating what we provide for it? What is it doing to our privacy and our sense of self? Are we drifting into a position where we are integrated into a massive network of knowledge in which we are just a small (but dispensable?) part? How can we make our lines of communication secure?

Like all technologies ICTs can be used for good or ill, and do we really have the power in a globalized society, where the computers are linked together in a potential grid of knowledge, to protect the values of independence and freedom which we prize so highly? We use democratic mechanisms to adjust and balance our behaviour, but where are these within the confines of the integrated computer networks which we see developing today? This may seem a million miles from the operation of a CAD system or the preparation of a programme schedule, but they all contribute to the whole.

In the early 1980s the author was concerned that when writing FORTRAN programming for construction he would include statements which said that IF such an event occurred THEN the following action should be taken. These statements contained within them the value system of the program writer as he, first of all, had to determine which events should be considered before action was taken and then he had to decide what that action should be. These were often his viewpoint or the perceived wisdom of the day. The statements were encapsulated in the software routines and then those routines were embedded in others until it was difficult to find the original without much effort. Unlike normal human interaction there was no challenge to the assumptions because it was too difficult or even impossible to find the original. By its very nature computer software is designed to be used by many people (in general software it can be

over a billion users) and therefore the values of one individual becomes an imposition on the many. It is extremely difficult to design systems which are transparent.

Grady Booch, the Chief Scientist for IBM, in the 2007 Turing Lecture at Manchester University, UK, suggested that the next three decades could be labelled as follows as far as software development is concerned:

- The first decade would be one of greater transparency in software development (although it is not clear upon what basis this statement could be made, but it sounds promising!)
- The second decade would reflect even greater dependence on the machine (so that we could not exist without its support)
- The third decade would be the decade of the rise of the machine (and presumably the decline of the independent human mind)

By themselves none of the developing technologies are harmful, but without control and devices for ensuring equitable performance attuned to the needs of the human race (something we cannot achieve yet even without machines) we are in danger of creating a potential disaster. Can we have the bright positive future without releasing the monster lurking beneath the surface?

For example, can you imagine trying to devise a system for evaluating sustainable development upon which all the world's nations could agree and which they and their machines will comply and from which they will exercise control? At the moment we cannot agree on a common set of measures. It is unlikely we could agree on how to change these measures as more knowledge becomes available and our mistakes become visible, and it is unlikely that we could agree as to how our machine would or should interact with that of another country with its own set of assumptions even if the concept of 'country' and national boundaries remain intact.

## 7. Technology supporting construction

In the light of the above, the problems of construction seem almost insignificant, but it is worth noting that accommodation is one of the most important aspects of how we judge our quality of life alongside food and health. If we get it wrong it has enormous impact. So what can technology do for us?

Two of the major problems often quoted as faced by construction are firstly, the separation of design from manufacture, and secondly, the inability to test and simulate the design and the processes of construction and occupation in advance of the building assembly. The size, complexity, expense and one-off nature of large building and civil engineering structures has made it economically impossible to provide physical prototypes which allow the examination and testing of design and processes in a way that some other high technology industries can achieve.

This is now beginning to change. With the advent of commercial 3D modelling of buildings now beginning to permeate the market-place it is now quite commonplace to provide 'fly-throughs' in real time with fairly realistic visual imaging of the building. At the moment the design approach has not changed dramatically with the technology, and it does appear that some traditional techniques employed by humans for centuries are still the most able way of being creative in the visual fields.



However, a new form of 'digital craftsmanship' is emerging which may allow new methods of designing that have not yet been fully defined by the design and construction community. The use of distributed objects, which can be gathered together from around the world, laid out for assembly in a virtual environment and moulded at will, may be one approach. Another may be the use of 'agents' within the virtual worlds (see Joe Tah, Chapter 15) that exist, which will seek out information, as and when required, acting as a kind of 'knowledge slave' for the design and construction professional. Indeed Lawson (2004) has suggested that this kind of support might be the way forward to enable true computer-aided design – at the moment it is a misnomer.

The communication of ideas through new ambient technologies and the monitoring of performance as design and construction develop will bring new thinking to the methods adopted for design. It will also transform the design process itself, and the digital environment has yet to be explored and examined as a new paradigm for design (see Rivka Oxman, Chapter 1). The new media may change the way designers think and develop their creative acts.

These technologies will also provide a rich environment of knowledge where the traditional boundaries between the professions will become almost meaningless. The interrogation of models for examination and investigation is one of the real assets of the computer-based approach. It enables designers (in the broadest sense) to test and examine what they are proposing before the commitment to build. It not also allows clients and other stakeholders to examine in a similar way, but also to take the model into the operation phase of the development cycle in a continuous and seamless transition. Knowledge capital is now a key ingredient in the search for improved solutions (see Chimay Anumba and Zeeshan Aziz, Chapter 11; Yacine Rezgui and Simona Barresi, Chapter 13; and Matthew Bacon, Chapter 14) and its power is only just emerging. This is changing the way we perceive design and the manner in which support for design is constructed, and it is by no means clear what formalisms may yet appear for this purpose (see Tuba Kocatürk, Chapter 4)

One of the most significant aspirations in construction in recent years has been the desire to build a building in a virtual environment before starting the procurement process, thus enabling the buildability of projects to be tested. In the past two years this has become a reality, and Heng Li and his team at Hong Kong Polytechnic University (see Andrew Baldwin *et al.*, Chapter 7), working with CATIA, have developed a visual simulation of the construction process which has enabled significant savings to be made by contractors and enabled design solutions to be tested for their viability and efficiency. This is a major step forward and challenges the existing models of evaluation that are often locked into a historical precedent which is no longer applicable.

Designers (see Manfred Grohmann and Oliver Tessmann, Chapter 2; Martin Simpson, Chapter 6) have experimented with the new visualization approaches which can give a much improved understanding of the aesthetic of the construction and also its structural integrity and its method of construction. The result is some stunning architecture which would just not be possible without the engagement of the machine. The direct link to computer-aided manufacture (also pioneered by Gehry and Glymph) is changing the relationships between members of the design team. On the Experience Music Project in Seattle, Glymph has stated publicly that the Project Manager had to stand aside and allow the negotiation of the structure to be held directly between the fabricator and the designer through the machine.

Others (see Robin Drogemuller, Chapter 9; Souheil Soubra, Chapter 10) have pushed the boundaries of evaluation and the integration of new priorities for assessment into the traditional 3D models to engage the agendas of sustainable development and whole-life cycle evaluation. Gradually the complete development life cycle will be represented in the model and the virtual development will have been complete. Of course, it will never be complete as models are always inferior representations of the real world and therefore they are always capable of refinement.

A big question that hangs across the whole of this development of technology is 'what are we prepared to allow the machine to decide upon?' To what level are we prepared to allow the machine to replicate the processes of our mind, and at what point will we recognize that the machine is better than us at undertaking creative acts? The automation of the mind, encroaching on our role as decision makers will be a key issue for many years to come. Already some routine decisions, largely involving calculation, are already trusted to the machine, but at what point are we prepared to allow our judgement, particularly those related to human behaviour, to be delegated?

This relationship between human and machine is being taken to what must be the ultimate link between the two. The 'jacking in' of the computer directly into the brain to enhance performance is being suggested. It is already underway for dealing with certain human physical disabilities such as hearing and visual dysfunctions, but the forecast is that it will eventually be used to stimulate the brain or enhance it for lifestyle requirements. There may come a point when we may have to decide the characteristics of the brain that we can place on a chip that will improve the performance of an architect or engineer! This may be a long way off but we should not allow this kind of technology to creep up on us unawares. The next generation will have a whole host of ethical issues to deal with as the technology begins to develop machine intelligence which may compete with human intelligence and be available to only a small sector of the population.

## 8. Learning from others

It is unlikely that construction will lead the way in exploring these technologies. It is already some distance behind other large manufacturing sectors such as the aerospace and automobile industries. The supply chain for construction is not yet sufficiently computer literate or developed, except for some very special cases, to engage in a technology-centred procurement and manufacturing process. Some CAD/CAM examples exist, largely associated with fabrication of the steel frame and cladding, but generally traditional craft methods prevail. These are, of course, broad generalizations and many professional firms in the more advanced building sectors are incrementally introducing elements of a seamless design and construction system.

One of the most interesting innovations being considered at the moment is the possibility of 'printing' buildings direct from a design (see Tony Thorpe *et al.*, Chapter 3). In this case the principles of 3D printing, where the machine lays down a succession of solid layers of material, has been transported to a large concrete pour creating a structure direct from the design model input. This concept is still in its infancy and others are being considered, such as direct extrusion of buildings with lasers creating voids and openings. It is possible that these experimental programs may transform the way in which we think of the act of construction.

Some major clients realize that something has to be done to improve industry performance, not only in embracing the technology but in changing the underlying structure of the industry so that the technology can be harnessed to improve efficiency and effectiveness. British Airports Authority are a good example where the construction teams for the Heathrow Terminal 5 have been formed under just a few headings, with a supply chain dedicated to each team enabling the development of systems linked by computer models to be introduced. It is no coincidence that when this type of innovation is introduced it is often driven by senior personnel from other industries taking a leading role. In the case of British Airports Authority it was Sir John Egan who came from the car manufacturer, Jaguar. Perhaps it is the role of enlightened large clients to provide the uniting vision and driving force to change the nature of the industry.

There is a sense that much of what we are able to achieve will be dependent on the technology infrastructures that are being developed and are available for any group to adopt and use. The internet has been such a vehicle which has changed the way we communicate and study and undertake our business. All industrial sectors, and construction is no exception, will have to take cognisance of what is happening in the wider world and test each development's suitability for its own use. However, in addition, the industry may attempt to shape the direction of these developments to suit its own ends and to secure its own future. It then becomes more than a technology watch – it is a technology driver.

In any case, the boundaries between industries/activities will become fuzzy and there will be migration of knowledge from one group to another. The introduction of knowledge grids, where several computers act together and share each others' knowledge (similar to an energy grid), is an interesting concept which may well impact on the way construction is perceived. Nobody quite knows what will happen when knowledge sharing takes on a new dimension beyond what we have seen even with the internet. It opens enormous possibilities for collaborative working across all participants in the development process.

## **9. The future and this book**

This book brings together some of the leading international thinkers and practitioners in a multi-disciplinary discussion about what the future might be for both information and communication technologies impacting on the design and construction industries, looking forward into the medium-term future some 15 years or more. We know that we cannot predict with any certainty what will happen, but we can suggest the priorities and shape of the technological infrastructure that will allow us all to perform our roles within the design and construction process in a more informed and effective manner. However, those roles are changing because of the technology, and this in turn may impact on the structure of the industry itself. Do we need the same professional infrastructure? Do we need the separation of design and manufacture? Do we continue with on-site manufacture? Does the new media mean that we think in a different way? These are important questions which arise out of this exploration. The authors vary, not only in their professional and academic backgrounds but also in their experience of the new technologies. They each provide a different perspective on the problem, and from the editors' point of view this has been fascinating and we are indebted to them for their willingness to put their views down on paper for us all to share.

We will all have a view of where the future might lead us and we hope this volume will play its part in stimulating discussion of not only what we should be doing as an industry to harness the power of the technology but also what we should not be doing. It encourages us not to sit back and be mere passive recipients of new technologies but to become active participants in the way these transforming technologies develop.

Some of the questions we might ask ourselves are:

- How do we build on what we have now?
- What can we expect from technological advances in the future?
- What impact are the new technologies going to have on the future of construction?
- What are the social and managerial impacts of such changes?
- What are the barriers to be overcome?
- What changes are needed in the industry?
- What changes can we expect in procurement and contract arrangements?
- What actions need to be taken now?
- What are the social impacts of such changes?
- What are the dangers of allowing machines to take more of a decision-making role?

Clues to the answers to these questions can be found in the book. There is probably no other significant development that is likely to change our industry so dramatically as the information and communication technologies. This collection of chapters provides new insights and directions for the future and prepares the wider community for the virtual futures which are to come.

It is a wonderful challenge but also an awesome responsibility for all of us engaged with design and construction.

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