Real-time digital modelling in design education and practice.

Murray Fraser[1]
Halli Bjornsson[2]

[1] School of Architecture and the Built Environment, University of Westminster
[2] Cadai Ltd, Guildford, UK

This is a post-peer-review, pre-copyedit version of an article published in URBAN DESIGN International, December 2004.

The definitive publisher-authenticated version of Fraser, Murray and Bjornsson, Halli (2004) *Real-time digital modelling in design education and practice.* URBAN DESIGN International, 9 (4). pp. 187-196, is available online at:

http://dx.doi.org/10.1057/palgrave.udi.9000126

Proposed paper for *Urban Design International* special issue on 'Design education in the global and digital age', guest edited by Professor Catherin Bull, University of Melbourne

---

REAL-TIME DIGITAL MODELLING IN DESIGN EDUCATION AND PRACTICE

Professor Murray Fraser,

Department of Architecture,

University of Westminster,

35 Marylebone Road,

London NW1 5LS,

UK

+44 (0)20 7911 5000 x.3368

(m.fraser@westminster.ac.uk)

&

Halli Bjornsson,

Managing Director, Cadai Ltd, Guildford, UK

(halli@cadai.com)

July 2004 (revised)

Abstract

Real-time modelling represents the first thoroughgoing application of the digital realm to architecture and urban design, and as such marks a clear advance on the partial applications that were previously the norm. The authors have pooled their combined expertise in architecture and computer games to adapt the principles and techniques of real-time environments from computer games to designing buildings. The outcome is proprietary software called Cadai, which allows architectural and urban design proposals to be modelled in realistic detail, both externally and internally, and then be 'walked' around in their entirety by viewers.

This paper argues that real-time modelling offers three advances on previous forms of 3D digital modelling: it enables digital modelling to be used from the earliest sketch stages of a design project; it allows collective online meetings of the project team inside the evolving design scheme, wherever the participants are in the world; and it enables greater user-participation in decisions about planning schemes, given that anyone familiar with computer game environments can now properly understand and experience architectural and urban design proposals. The paper explains the properties of Cadai and showcases some real-time models built by students at Oxford Brookes University and the University of Westminster, along with the first major commercial real-time model produced in Cadai for a brownfield development proposal in Northern England. Our contention is that real-time modelling will soon become the dominant way that computers operate in architectural and urban design, and will remain so for the foreseeable future.

Keywords

Architecture and urban design, digital design, immersive environments, real-time modelling, representation

1. Introduction

The digital tools that are now being used by architects and urban designers in their daily work have changed beyond recognition over the last few decades, and nowhere has the transformation been quite so dramatic as in the way that design is taught in educational institutions. With a stroke of good fortune, universities find themselves at the forefront of new technologies that are now shaping the future of digital design. Currently a variety of new avenues are being explored, spanning from the use of computers for the fabrication of physical models or building prototypes through to the creation of alternative worlds in which new concepts can be represented and debated. In particular, real-time modelling offers what is probably the first thoroughgoing application of the digital realm to architecture and urban design. In doing so, it marks a clear advance on the more partial applications that were the norm in the first era of digital design.

Before discussing real-time modelling as a design tool within education and practice, it has to be pointed out that much of the difficulty in dealing with the subject stems from general obfuscation about the role of digitalisation within architecture and urban design. All of us know what computers are, but the discussion of their precise relationship to the built, inhabited environment becomes problematic. Are we talking mainly about the observable changes that are happening in our everyday socio-spatial conditions, such as how we work or communicate with each other? Or is it actually about something that

is more intangible, almost metaphysical, given the arrival of parallel, symbiotic digital realms that are being added to our general perception of reality through the internet or what is known as ‘cyberspace’?

The obvious answer is that no-one knows as yet, and here it is significant that to date there has still not been a definitive text written on the subject of digitalisation in architecture and urban design. Yes, we have all read many opinions and ideas about the subject, and have seen some fascinating propositions, but beyond this, nothing has been proven convincingly. The condition of uncertainty is not helped by two extreme tendencies in thinking about issues like cyberspace or digital design. The first tendency is to over-exaggerate the extent of social changes that will arise from new digital technology, starting with canonical science-fiction writers such as Philip K. Dick or William Gibson and then hyped even further in the work of devotees like Neil Spiller (Dick, 1968; Gibson, 1987; Spiller, 1998; Spiller, 2002). We should not forget that science-fiction writers of the early-twentieth century had us today flying around with personal jetpacks, and other similar fantasies, whereas what we have actually got are mobile phones that take pictures. It is more likely that the changes that will occur will be smaller and more piecemeal, and might happen in ways and in places that we would not expect. The second unhelpful tendency has been to assume that the impact of computers on architecture and urban design will come primarily in terms of built form, whether this is by enabling complex and previously unrealisable double-curvature in surfaces, as in the Bilbao Guggenheim, or by allowing us

to envisage a dramatic new style or aesthetic for ‘digital architecture’, as in Peter Zellner’s call for hybridised digital spaces or in Greg Lynn’s ideas about animated forms (Van Bruggen, 2003; Zellner, 2002; Lynn, 1999). What these amount to is little more than what might be termed *architecture parlante* for the digital age, something that wishes (as did the most expressive practitioners of Classicism or Modernism in the past) to produce some kind of symbolic form to represent a new cultural condition. The fact that these efforts to achieve this goal only seem to limit the attractiveness and possibilities of new digital media seems not at all to discourage these latter-day symbolists.

In contrast to these limited approaches, it can be argued that digitalisation in architecture and urban design becomes far more interesting when it is not over-hyped or is assumed to produce specific forms in itself, but rather when it is becomes a means to rethink the process of three-dimensional creativity. It is only through this recognition that it will avoid becoming simply an add-on, or a fashion statement, or something that differentiates education from practice, and instead is conceived as integral to the way that we do things. What this recognition also suggests, hopefully, is that any type of architecture, any approach to design, any aesthetic that one might care or dare to imagine, can be designed with equal ease through the computer. Just as the use of a pencil or pen was never regarded as precluding or leading to any specific form of architecture or urban design, neither should the computer.

So if we accept this line, then how might the computer become a fluid and open-ended tool that is applicable across all of the processes of spatial design and representation? Here the assertion needs to be made that, to date, computers have not really been employed as extensively for designing as they might be. Students or architects and urban designers in practice still tend to make sketches or physical models to start off their design ideas, before turning them into CAD drawings either in 2-dimensions or 3-dimensions, or else produce structured animations that rely on proprietary software of increasing sensitivity to enhance the quality of representation. But in almost every case, the CAD drawings that result are still essentially all about the communication of design decisions that have already taken place 'outside' the computer. As such, computers are merely being employed as sophisticated tools to produce the same kind of representations that would have been done before computers were invented: technical drawings, rendered paintings, 3D-projections, video animations. The use of computers might well help to improve office productivity, but in terms of what is being done, there is nothing that is intrinsic to the computer about the process, no matter how skilfully the end products are executed.

2. Real-time modelling as an approach

It is at this point that real-time digital modelling enters the picture. Real-time is the term given to any instantaneous, constantly updated, immersive and interactive digital environment. A succinct dictionary definition is:

"Of or relating to computer systems that update information at the same rate as they receive data, enabling them to direct or control a process such as an automatic pilot." (American Heritage Dictionary, 2000)

As this definition suggests, there are already many applications for real-time digital technology in modern life, such as flying airplanes, targeting military weapons, mapping the movement of shoals of fish in the North Atlantic, relaying instant data from the body of patients to surgeons during medical operations, and more recently in London, for the reconstruction of a major crime scene. A website provides live feeds so that we can see, should we want to, of what is happening in Trafalgar Square, the Lloyds Building, or even a real-time dating bar called Belushi's that can be viewed continuously over the internet so that you can decide if there is anyone there you might actually like to meet (http://www.camvista.com/england/london). What is happening in different ways in all of these real-time applications is that information is being delivered to the computer screen interface within the same coordinated time-frame as the user of the computer is then interacting with it. Delays in information transfer are erased completely, and this then also allows the possibility of other data sources to be simultaneously

streamed in from the internet, or a dedicated web feed, or another peripheral device that is connected the computer. It is above all these alterations in the subjective experience and decision time-frame that are being altered by real-time technology, rather than the fundamental technological relations of the computer; what is new is that there is now software that is fast enough to be coordinated with the actions of the user.

Probably the most familiar form of real-time environment to us today is the 3D graphics in computer games, all of which rely on real-time engines to produce instantly updated models that are perceived instantaneously and seamlessly in a piece of parallel software known as the real-time viewer. A whole plethora of publications is now emerging on all aspects of 3D games design, largely fed by specialist developers in the USA (Eberly, 2000; Eberly et al, 2003; Hawkins, 2004; Olano, 2002; Partridge, 2001; Pipho, 2002; Steed, 2003). Further enhancements of these real-time environments are now being developed through the use of interactive headsets for certain gaming experiences, or else by incorporating the frequency of user choice in mass online games as a method to drive the sequence and narrative of play, or by relaying feeds from cameras and other sensors located in local or remote environments directly into the computer as something that the user can then interact with, as in the case of the I-Toy for Playstation 2.

Aware of this trend, and as a direct result of our own personal backgrounds in architecture and games design, what we have been doing together over the

last few years has been to try to apply this technology to architecture and urban design. In the past, CAD models have simply been too slow and cumbersome in terms of the processes and amount of data they have required, and so it was clear that a fresh approach was needed. What we have done in response is to create a proprietary software programme called Cadai; this is a trademark name of Cadai Ltd, a company that is based in Godalming, in the UK's mini-version of Silicon Valley (http://www.cadai.com). This programme offers a number of ways to produce real-time digital models, each of which depends upon the building of relatively simple polygonal shapes onto which textured surfaces are then applied as skins. The building blocks that one sees in a real-time environment are never built as 'solid' digital elements, but rather should be conceived of as exquisite paper lanterns that are then filled with interior spaces that can be entered and walked around in.

In Cadai, the cunning use of gaming software allows the number of polygons that the viewer perceives to increase as they move closer to the particular building block or textured surface, giving them a sensation of more detail as they encounter an element. Conversely, the number of polygons and the level of detail then decrease as they move further away. In this manner, real-time modelling is a fast and flexible alternative to the cumbersome and data-heavy techniques that are used to build the usual 3D digital models. Real-time technology uses computer power more cleverly in order to give required effects just when they are needed, all with the aim of greater manoeuvrability

and the ability to be immersed in an environment. As an article on Cadai in *Building Design* magazine explained:

"The program also uses the 'level of detail' technique familiar to games designers. Essentially, this means adding increasing levels of detail to a view as the user approaches. This is different from increasing the resolution; if everything was in view, the model would begin to slow down. In all, there are five levels of detail, allowing the model to contain 10 times as much information as a single-level system." (Littlefield, 2004)

All of this means that Cadai real-time models can be built and run easily upon the typical desktop or laptop PC, although it certainly helps to have one of the more advanced 128/256MB graphics cards that are now becoming standard in all new computers. A real-time model in Cadai occupies only about 30-300MB of memory, depending on its size and detail, which is proportionately far less than previous 3D digital models, and hence it does not eat up the hard-drive capacity as much. It also means that the model can easily be copied around on a single CD. The Cadai software itself takes up very little space on the hard-drive, and in an effort to make it as widely used as possible, we are offering it as a free license to students or at relatively low cost (£200 per copy) to practitioners. This is substantially less than the more famous real-time engines of computer games such as *Quake* and *Half-Life*, which come at astronomical cost at the moment if they are to be used for

architectural or urban design projects, since they need to be heavily customised to make them seem unlike the actual computer game that they are derived from. In our view, there should be no elitism of usage, either in terms of prohibitive software costs or of users needing to buy computers that are any more powerful than the norm.

There is also a great degree of flexibility in the way that surfaces that can be applied in real-time modelling software such as Cadai. The surfaces can be either made out of the usual digitally-created textures that are common in 3D modelling, or else taken from photographs of real building surfaces that are then pasted onto the basic polygonal blocks, which allows a remarkable degree of visual verisimilitude where required. In terms of manoeuvrability within the environment, the viewer in a Cadai real-time model is able to 'walk' around freely using a combination of the mouse and the direction buttons on the keyboard, allowing them to change viewpoints, walk up and down stairs, open and close doors, and such like. A new feature even lets the viewer switch off the effects of gravity so that they can float above the buildings, as if in a hot-air balloon; with a simple keystroke, they are back on the ground again as pedestrians. The beauty of this degree of flexibility compared to previous kinds of digital models is that personal movement and subjective experience get away from being predetermined. The real-time model instead offers an 'open field' around which each person can move in the different directions and at the different speeds that they desire, depending on what they want to see.

Cadai offers several methods by which to create such real-time environments. In one route, a typical 3D digital model is built using a standard software application such as AutoDesk's AutoCAD, and is then taken into 3D Studio Max to be rendered, before being imported into the Cadai viewer where it can be experienced as an immersive and interactive environment. A second method is to build the entire digital model in 3D Studio Max before importing it into the Cadai viewer. An even more direct way is to build the whole digital model within the Cadai engine itself before switching it over to the connected viewer, meaning that there is no process of importation. This last method has the virtue of offering complete and very rapid changeability of elements in the model, which can be very useful for the early stages of design, but the slight drawback is that as yet it cannot produce quite as fine-quality renderings for the real-time environment as are possible when the 3D Studio Max stage is incorporated. But having said that, an obvious general point to make is that real-time technology is still very much in the emergence, and remains almost untouched so far within the realms of architecture and urban design; thus there are bound to remain limitations on what can be done.

Perhaps the key limitation of all kinds of real-time modelling at the moment, not just Cadai, is that it is still impossible to achieve what is termed 'real-time lighting'. In other words, one cannot make the daylight or artificial light effects change as the viewer walks around in the same way and with the same

degree of subtlety as happens in the real world. This is because the sheer amount of instantaneous calculations needed for real-time lighting is beyond the current capacity of computer technology, but experts agree that it is just a matter of time, and that within a few years real-time environments will indeed have totally naturalism in their light effects. In the meantime, the best way to achieve realistic lighting in Cadai real-time models is to use a technique in 3D Studio Max that involves the 'baking on' of textures, whereby a carefully selected lighting effect on a real surface, with the actual shadows and gradations of light, is photographed and then pasted onto the surface of the particular building block. For most purposes, this 'baking on' produces a convincing enough effect once it is imported into the Cadai viewer.

3. The benefits of real-time modelling

But behind these technical details, the underlying question is what is so intriguing about the use of real-time digital modelling for architecture and urban design? In our view, there are three main areas of potential:

1. Real-time technology such as Cadai can be used as an extremely quick and rough-and-ready tool by which to make digital models of buildings or urban design schemes, meaning that designers can immediately 'walk' around inside the environment and experience it, before changing aspects as required. In this way, it is able to take on

the roles of the quick sketch and the early cardboard model as a means to test and evaluate as many different design possibilities as possible, as quickly as possible. Real-time modelling can thereby help to shorten and improve the quality of the design feedback loop. This stage could also be expanded so that an interactive database is directly linked to any changes that are made in the forms or sizes of the buildings, providing architects and urban designers with precise instant feedback as they make initial design decisions at the start of a project. It would of course be the task of the designers and software specialists to identify and isolate which particular factors should be included in the linked database in each case, in order that when the designers then make specific changes in terms of the size or placement of built elements, the effects of these changes on the specified parameters are instantaneously available to them.

2. Furthermore, because it is already easy to place immersive and interactive real-time environments on the internet, as is being done on a huge scale through global gaming networks, this would then mean that the many contributors who are involved in architecture and urban design projects are able to input into a simultaneous discussion of a proposal from the earliest stages onwards. And they could do so not within a boring meeting room, but actually within the environment of the actual design proposal as it then exists. The opportunity to meet collectively online would also infer that it is going to be increasingly possible for participants to be geographically remote from each other,

meaning that the design process can become entirely globalised, and yet highly intimate at the same time.

3. In terms of the way that finalised designs are presented for public scrutiny, we also believe that because real-time modelling allows a building or urban design scheme to be modelled in its entirety, and then ‘walked’ around, both externally and internally, at the control of every person who knows how to operate a simple computer, this will help to explain design proposals to a far wider audience than has been possible hitherto. It is widely admitted that the vast majority of the population do not understand architectural or urban design drawings and models at all, nor should they be expected to. Unless architects and urban designers are able to find better ways to explain their ideas clearly and attractively, then they will never gain wider acceptance for these ideas amongst the general populace. Current types of CAD presentations that are produced for public consumption, and which commonly take the form of elaborate animations or fly-throughs, tend to be visually impressive but in the end are alienating in their coldness. The recipients know instinctively that these representations have been carefully choreographed in order to ‘sell’ the particular scheme, and as a consequence they are often distrusted as explanations of what the proposal will be like. This latter danger might of course happen as well when using real-time modelling, but it will be far harder to do given the fact that every viewer will possess much greater choice and control over how they move around and inspect the scheme.

Thus the implications for real-time modelling seem to us to be far-reaching both for teaching and practice within architecture and urban design. Imagine a faster and more accessible method to create and assess spatial design proposals, something that can just as easily be understood by a child as young as 5 or 6 years old. Imagine a design tool that could even be used by schoolchildren or by adults who are not specialists, many of who already build their own levels in computer games, and who could now more easily conceive the spaces in which they might choose to live. Imagine that whenever there was a contentious proposal for a public building or for a major piece of urban design, it could be distributed to as many people as wished to look at it on a CD or on the internet, in order that they could walk around and experience and comment on it. Imagine that for architects and urban designers, they could have client meetings with as many participants as you wish, online, inside your emerging design proposal. These and many other possibilities seem to be on the horizon, and this is why real-time modelling suggests for us a new way of thinking about how one can design and communicate architecture and urban design, right from the outset. The technology is still developing, but we have little doubt that it will become the normal design mode for students and architects and urban designers in say 5 years time.

And it is not just us who are saying this. “Using these (real-time) techniques, which support all the stakeholders in the urban planning process, the way we

participate in shaping our environment is on the verge of being radically opened up," claims the much-respected Centre for Advanced Spatial Analysis (CASA) at University College London (http://www.casa.ucl.ac.uk). A team at CASA are engaged on building a massive, albeit low-resolution and visually simplified, virtual reality model of central London, in a project paid for by the Greater London Authority, which is then to be made available via the internet for planning issues and prospective tourists. What is being created there is a virtual version of London where multiple users can engage in debates about the consequences of certain rebuilding works, and all in real time. A few architectural visualisation companies, such as Tekuchi in London's media heartland of Clerkenwell, are starting to produce small real-time models for clients using an increasing number of applications, such as the Quest engine (http://www.tekuchi.com). The next few years will see a number of these different innovations breaking through. This observation then leads us to the issue of how we have been trying to develop the use of Cadai within education and practice.

4. Cadai in operation

Given that the specialised expertise and software for real-time modelling lies outside the purview of mainstream architecture and urban design, it is no surprise that to date we have focussed Cadai more on its development in universities, firstly in the school of architecture at Oxford Brookes University

and more recently at the University of Westminster. A few students with high levels of digital skills and an appetite for learning new approaches have been able to use Cadai for the design of a projects that range in scale from the arrangement of kitchen furniture, to a new-build individual house, to a museum refurbishment, and up to a major urban design proposal for the area to the south of the Tate Modern in Bankside, London. The latter project grew out of a group-working exercise whereby a team of four students built the basic wire-frame model in Softimage and Cadai, then took detailed photographs of the actual buildings around the Tate Modern area and pasted them into the corresponding blocks in the digital model. The process involved a strict division of workload and the management of digital content within the model, but in many ways this was analogous to the way that a team of design students might assemble together a large physical model of an urban area.

Having mapped accurately the existing urban infrastructure around the Tate Modern, the students in pairs then worked on a series of design proposals for the area. One focussed on dropping their own buildings into parts of the main model, which is easy to do given that the Cadai model is already built up in sections that can be removed, and others put in their place. A more ambitious ploy for the second pair was to try to rethink the whole aesthetic of the Cadai real-time model, turning it into a night-time environment that could form part of a proposed 24-hour city. An indicative selection of the environments that were created in these student projects is provided in Figures 1-8. All of them allow viewers to move around smoothly, and together they demonstrate a

balance between highly photo-realistic environments and other approaches that have been designed with a more speculative and subjective aesthetic, our aim being to show that there is not only one way to use real-time modelling. Rather, there ought to be seen as being as many ways as there are designers.

Our more recent efforts have involved us in looking for ways to connect this exploration of real-time modelling and Cadai into the professional sphere. At the moment we are trying to start up partnerships between the University of Westminster and architectural or urban design practices through the Department of Trade and Industry's 'Knowledge Transfer Partnership' scheme. This will hopefully fund us to place graduates in real project teams who will then create real-time models of these projects using Cadai, with specialist advice provided by us. Despite the complicated bureaucracy involved, what this initiative reveals is that the state seems willing to offer a generous subsidy to help the transfer of cutting-edge expertise in digital knowledge from university to the design professions. In addition, a specialised real-time model of an area of Oxford was created by Cadai Ltd to teach design to schoolchildren, as part of a project that is being run by a team of researchers in the Joint Centre for Urban Design at Oxford Brookes University, with funding from a semi-autonomous official body, the Commission for Architecture and the Built Environment.

And as for the next stage of technology transfer to the profession, we are now being engaged, tentatively, as consultants to create real-time models for architects and urban designers, again using Cadai as the tool. The largest model that we have built to date was requested by a major international architectural and urban design practice for a speculative project that they are producing for an enormous brownfield site outside Warrington, in the North of England. The site is a former US airbase in the UK, and the principal architects for the development are the US-based conglomerate, RTKL. The project is still very much at an early design stage, but selected screen-shots are shown in Figures 9-12. Already it has drawn press attention as in all likelihood the largest real-time architectural model possibly anywhere in the world (Littlefield, 2004). This real-time model covers a substantial area of over a square mile in total - at around 300MB it definitely weighs in at the heavier end of the scale - but nevertheless it has been built to give a realistic impression of what the final scheme might be like, yet without having to design each of the built elements in too much detail at this early stage. Given that there are nearly 50 blocks in the section of the scheme that has been modelled so far, that is probably just as well. What it also means in this instance is that, unlike the student projects mentioned above, the blocks in the model do not as yet have interior spaces, and so cannot be entered.

This massive Cadai model for Warrington had to be produced very quickly, taking only a matter of three weeks, and hence certain shortcuts were be taken in achieve the appropriate visual effects for the buildings and

landscaping. It is envisaged very much as a sketch model, rather than a carefully worked out final proposal, and as such is obviously more convincing when viewed as an overall effect rather than close up. Nevertheless, the visual impression and level of detail that it gives is remarkable within these constraints. This real-time model was recently taken by the developer involved, Miller Developments, to show at the leading annual property developers' convention in Cannes, where it was extremely well received precisely because of the ability of those who were viewing it to move around as they wish, and for them to be able to alter their viewpoint to see what the proposal would be like either from the air or down at street level. The main purpose of the model is to convince investors that this is indeed the type of huge brownfield regeneration project that they should want to become part of; whether it will be successful in this aim is still in the balance, yet the wider implications are clear. The model was successful also in the fact that almost no instructions are needed for even the more experienced user; the idea of navigating using the direction keys, and altering the view by rotating the mouse are fairly universal skills by now. The lack of programmed routes, and the ability of viewers to move around in any direction they would like, as in the real world, has an added attraction for the architects and developers. They now want to track how viewers move around the digital model, in order to try to gauge their feelings about the relative accessibility of areas of the scheme, and to predict spots in which there might be more public interest, and higher congregations of consumers, were the project actually to be built. The Cadai model is also a useful ongoing design tool; once specific architects are appointed to work up in detail various parts of the urban masterplan, their

alternative designs can simply be substituted into the main model, thereby allowing the scheme to develop over time.

5. Conclusion

It is precisely in this conjunction of speculative work, which takes place so frequently and so readily as part of the educational process in architecture and urban design, with the more open and complicated requirements of design practice that the full potential of real-time modelling emerges. Once this technology has been developed further in the near future, and once more and more young architects and urban designers come out of college with the knowledge and skills to use it, real-time modelling will become an essential component of digital design, allowing a seamless transition from the start of the design process through to the portrayal of the final proposal. Now at the University of Westminster we are beginning to develop an international digital research axis that will hopefully include partners such as the Royal Melbourne Institute of Technology in Australia, Gehry Technologies in Los Angeles, as well as others. This is being done because these developments in real-time technology, when they come, are more than likely to happen quickly and simultaneously across many of the developed countries in the world. Real-time modelling embodies a sense of diversity and openness that seem to fit so well with the conditions that we see around us in the contemporary world.

As such, it is going to form a key component in the teaching and practice of architecture and urban design for much of the foreseeable future.

Acknowledgements

We would like to thank the following students for their work in producing the various Cadai models that are cited in this article: Kristjan Gardarsson, Irena Hrabincova, Wolfgang Haak, Yiannis Mitropoulos, Bill Sands, Alkis Tzavaras.

References

Anon., (2000) *American Heritage Dictionary of the English Language: 4th Edition*. Boston, Houghton Mifflin.

Cadai Ltd, http://cadai.com

Camvista, http://camvista.com/england/london

Centre for Advanced Spatial Analysis (CASA), University College London, http://www.casa.ucl.ac.uk/research/virtuallondon.htm

Dick, P.K. (1968/1999) *Do Androids Dream of Electric Sheep?* London, Gollancz.

Eberly, D.H. (2000) *3D Game Design*. San Francisco, Morgan Kaufmann.

Eberly, D.H. et al. (2003) *Texturing and Modeling: A Procedural Approach (Third Edition).* San Francisco, Morgan Kaufmann.

Gibson, W. (1987/1995) *Neuromancer*. London, Voyager.

Hawkins, B. (2004) *Real-Time Cinematography for Games*. Hingham, Massachusetts, Charles River Media.

ID Software (PC)/Bullfrog (PS2) (1999/ 2001) *Quake III*. Los Angeles, Activision/ Redwood City, California, Electronic Arts.

Littlefield, D. (2004) Game plans, *Building Design*, 18 June 2004, 26

Lynn, G. (1999), *Animate Form*. New York, Princeton Architectural Press.

Olano, M. et al. (2002) *Real-Time Shading*. Natick, Massachusetts, A K Peters.

Partridge, A. (2001) *Real-Time Interactive 3D Games*. Indianapolis, Sams.

Pipho, E. (2002) *Focus on 3D Models (Game Development Series).* Rocklin, California, Premier Press.

Spiller, N. (1998) *Digital Dreams: Architecture and the New Alchemic Technologies*. New York, Watson-Guptill Publications.

Spiller, N. (2002) *Cyber Reader: Critical Writings for the Digital Era*. London, Phaidon Press.

Steed, P. (2003) *Animating Real-Time Game Characters*. Hingham, Massachusetts, Charles River Media.

Teckuchi Ltd, http://www.tekuchi.com

Valve (PC)/Gearbox Software (PS2) (1998/2001) *Half-Life*. Los Angeles, Sierra/Vivendi Universal Games.

Van Bruggen, C. (2003) *Frank O. Gehry: Guggenheim Museum, Bilbao*. New York, Guggenheim Museum Publications.

Zellner, P. (2000) *Hybrid Space: New Forms in Digital Architecture*. London, Thames and Hudson.

List of images (10 colour, 2 b/w)

1. Screen-shot of an element being manipulated in the Cadai real-time engine

2. Screen-shot from a Cadai real-time model of the existing area around the Tate Modern, London

3. (b/w) Screen-shot of a 3D Studio Max model for a student urban design project for an area south of the Tate Modern, London

4. Screen-shot from a Cadai real-time model of a student urban design project for an area south of the Tate Modern, viewed at night

5. Screen-shot from a Cadai real-time model of the existing Modern Art Oxford museum

6. (b/w) Screen-shot from a Cadai real-time model of a student project for an installation in the Modern Art Oxford museum

7. Screen-shot from a Cadai real-time model of a student project for a new-build house, showing the ‘baking on’ of sunlight effects

8. Screen-shot from a Cadai real-time model of the possible arrangement of proprietary kitchen units for a client

9. Screen-shot from a commissioned Cadai model of a large urban design proposal for a brownfield site in Northern England, at early sketch design stage, viewed as if floating in a hot-air balloon

10. Screen-shot from a Cadai model of a proposal for a brownfield site in Northern England, also from the air

11. Screen-shot from a Cadai model of a proposal for a brownfield site in Northern England, on the descent to the ground

12. Screen-shot from a Cadai model of a proposal for a brownfield site in Northern England, viewed as if walking around at street level