DESIGN SYSTEMS, ECOLOGY, AND TIME

ABSTRACT

Discussion of architecture in ecological terms usually focuses on the spatial and material dimensions of design practice. Yet there is an equally critical temporal dimension in ecology that is just as relevant to design. At the micro scale is the question of "real-time" feedback from our design systems. At the macro scale is the issue of sustainability—in other words, long-term and potentially disastrous feedback from terrestrial ecosystems. In between are numerous different units for quantizing time in design and computation. In this paper, we examine some of these units—"real time," "design time," "development time"—to suggest how they interact with the ecology of design technology and practice. We contextualize this discussion with reference to relevant literature from the field of ecology and to our work applying custom design and analysis tools to architectural projects within a large interdisciplinary design practice.

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1 INTRODUCTION

Competition is the most fundamental parallel between architecture and ecology. Architects engage in formalized competition for client work in a manner that is uncommon among the professions (Lipstadt 2003). It is not only different practices that compete, but within a practice or a design team, individual design proposals must compete against one another in order that the best may be realized. Competition is only one of the parallels between natural evolution and business enterprise that has long been recognized, but more recent understandings of enterprises look at them in the context of ecosystems (Moore 1993) in which the types of relationships are more varied (symbiotic as well as competitive) and the dynamics of process are more complex (coevolution, succession).

In architecture, as in ecology, much of this owes to resource scarcity. In particular, the time required to propose feasible and satisfying solutions to design briefs is nearly always in scarce supply. Design technologies address this scarcity of time in many ways: parametric design addresses the need to study variations in like options quickly; building information management addresses the need to understand the trade-offs between design decisions and business data associated with design elements; building analysis addresses the need to understand building performance in the context of site, climate, and program.

This paper focuses on the latter—analysis—to understand computational design systems ecologically. While similarities between natural systems and parametric geometry have already been established (Cache 2002), these parallels are usually focused on the ability of technology and geometry to produce variations in a manner likened to the process of biological differentiation. Analysis complements these activities in parametric design by introducing the concept of ecological fitness—the criteria by which a design proposition might flourish in its environment. This notion of fitness, in turn, supposes a whole complex of criteria which have to do with time: the ability of an organism or design system to respond to immediate stimuli in its environment in order to survive, as well as the longer-term notions of sustainability and resilience in entity populations.

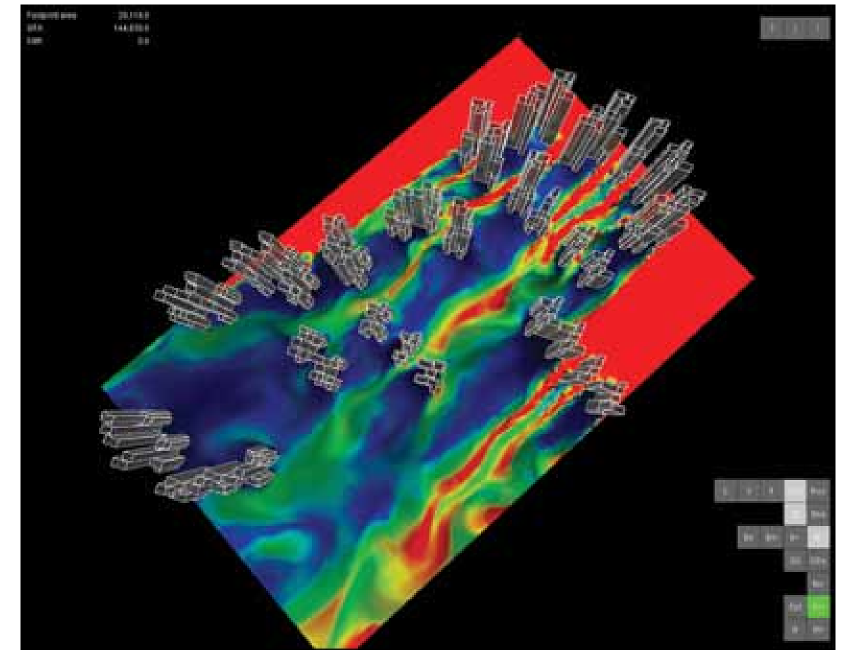
The authors of this paper are all members of a research and development team within a large, interdisciplinary design practice incorporating architecture, structural engineering, and environmental engineering. This paper examines specific applications of computational design systems that the authors have designed and created, which incorporate analysis in the generation and evaluation of architectural schemes and projects. Collectively, this research highlights some of the ways in which time is a critical factor in the ecological functioning of design practice.

2 REAL TIME/DESIGN TIME

2.1 Decision Support and Response Time

The response time of analytical tools has been highlighted as a critical aspect of performance-driven design. In this context the trade-off between accuracy and speed is an essential consideration in the development of building performance tools. It has been argued that the modeling and simulation of building physics phenomena entail a certain amount of complexity and uncertainty as they depend on noisy and often conflicting input data (Hong 2000). Looking into the performance metrics of animal decision making, we can clearly draw a parallel with speed-accuracy trade-offs. Animals must sample a noisy sensory and spatial environment, and their response to such stimuli is often dictated by the difficulty of the task and the resulting speed cost in relation to the error penalty associated with that task. The level of accuracy of received stimuli that an animal will anticipate before reacting to it has been observed to be directly related to the importance of the given task, while speed-accuracy trade-offs are in some cases needed to build a more accurate response mechanism over time (Chittka et al. 2009).

In the context of architectural design, speed-accuracy trade-offs are quite relevant in the early conceptual stages of design, where decision support of architectural choices critically defines the successive course of a project. Information on the effect of design manipulations is usually scarce at this stage, where the time available for decisions is minimal. Current research is rigorously focusing on this problem through various advancements such as novel simulation algorithms, interoperability frameworks, and human-computer interaction developments (Malkawi 2004). However, in mainstream architectural practice the need for faster response times remains. Designers, the end users of the developed performance tools, are often expected to respond in real time to design questions. Moreover, they are in need of an integrated overview of the effect that each manipulation has on all aspects of building performance in the long term. In that sense, for simulation tools to be useful in an early-stage design context, their response times need to meet those of the design cycles, which in most cases are very restricted.



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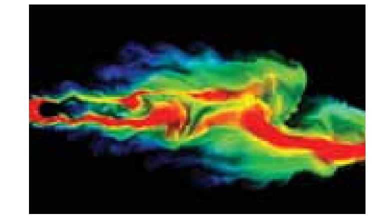

figure 1

2.2 Real-Time Fluid Dynamics

Among the performance tools available to the contemporary architect, the most time-consuming ones are those that involve computational fluid dynamics (CFD). CFD simulations are notoriously resource consuming, and therefore their application has mostly been restricted to the evaluation and validation of finalized design solutions. Despite exponential increases in computational power and the continued development of CFD applications, their speed has not yet met the expectations of researchers (Chen 2009). This is commonly justified by the complexity of the physics involved. However, there is also an argument with regard to the accuracy that is required to inform design decisions, in relation to both the given task as well as the current stage of the design process. It is generally suggested that the level of accuracy of a CFD simulation needs to be compromised with the turnaround time requirements of its application (Lomax et al. 2001). This can be significantly different, for example, between a sizing exercise for an HVAC system and a large-scale massing configuration. The turnaround time of the latter would in this case be so great that the results of the simulation could have become obsolete by the time they are available.

Given the increasing application of the authors' design and analysis tools to large-scale master plans, the incorporation of a less accurate and much faster CFD solver was considered a valuable

figure 1

Study of a Karman vortex using the fast fluid dynamics (FFD) solver.

figure 2

FFD study of a large-scale master plan.

approach in our development framework. The real-time CFD (or FFD for fast fluid dynamics) solver (Figure 1) is based on a lower-order numerical scheme that was first introduced in the computer graphics industry (Stam 1999).

Although the solver suffers from some numerical dissipation, the accuracy of the FFD solver has been validated and assessed as adequate for a number of cases (Zuo and Chen 2010). However, the speed of the solver far exceeds that of typical engineering-oriented CFD applications, reaching real-time feedback rates in two-dimensional cases even in large-scale massing exercises (Figure 2). Initial three-dimensional tests carried out with the solver have also been very promising, providing informative analysis results in a fraction of the time that would be required by conventional CFD packages.

3 REAL TIME/DEVELOPMENT TIME

3.1 Mature Systems and Adaptability

Attempting to provide real-time feedback to accommodate rapid design responses presents an interesting paradox: the faster and more accurate the results required, the longer the development time is. This is not dissimilar to ecological systems, where even short-term processes, such as ecological succession, build up strategies of long-term evolutionary development of the biosphere, so as to achieve maximum protection from its perturbations (Odun 1969). In the same way, design systems strategies have a temporal span that can be significantly broad, in order to ensure the creation of tools that are adequately homeostatic, unperturbed, and—most importantly—adaptable within their design environment. Thus, development time is increased as the aspiration is not only to respond to a specific niche design requirement, but also to identify and try to solve a general class of problem.

In another parallel to ecosystems, while quantity production characterizes the young system, it is quality production and feedback control that are the trademarks of the mature systems (Odun 1969). It can be argued that although the speed-accuracy trade-off in design systems follows a somewhat analogical relationship, the development time rate-of-change needed to achieve real-time feedback is usually convex: changes are initially numerous and quite varied, while, as the strategy develops, they become fewer, more accurate, and feedback driven. Most significantly, as long as the general framework is formulated as described, the time required to achieve adaptation to specific contextualized needs or platforms in later stages of the development process is logarithmically minimized.

3.2 Near-Real-Time Solar and Daylight Analysis

Sustainability has increasingly become a critical driver to design. It comes as no surprise, then, that design firms would support the development of a new daylighting design guide that would provide, among other things, more advanced daylighting design tools (Galasiu and Reinhart 2008). As the use of more precise solar design tools actually helps to broaden the range of architectural form (Otis 2011), software capable of near-real-time environmental analysis can be of great value to molding a design strategy. It is within the context of developing such a tool and adapting it for different platforms that the correlation between real time and development time, as well as its aforementioned intricacies, will be further described.

The initial creation of such customized software was spurred by the need of design teams to rapidly analyze the solar/daylight aspects of design proposals, preferably within the CAD platform used officewide. Current software, such as Autodesk's Ecotect, requires model conversion and long analysis times, which posed the problem of feedback time being disproportionate compared to current design cycles.

This new near-real-time solar and daylight analysis software, like Diva before it (Lagios et al. 2010), was developed using the Radiance ray trace engine (Ward and Shakespeare 1998; Mardaljevic 1995),

as well as the GenCumulativeSky method (Robinson and Stone 2004), and is capable of calculating seasonal radiation maps, daylight factor, and vertical sky component (Figures 3 and 4). Furthermore, a set of extra capabilities was exposed in a user-friendly manner, such as the calculation of sunlight hours relative to different local codes. This software offers tremendous performance gains, as it is orders of magnitude faster than other software. As an example, cumulative solar radiation analysis was run in Ecotect with a 5×5 sky subdivision and a 1×1 surface sampling on models comprising 1,000 and 10,000 panels, taking 9 minutes 45 seconds and 13 hours 40 minutes, respectively. When the Fast Calculation mode was chosen in Ecotect, the times dropped to 57 seconds and 1 hour 13 minutes. In our new tool the same models ran in 16 seconds and 29 seconds, respectively—over 50 times faster than Ecotect's fast mode and 1,700 times faster than its normal mode.

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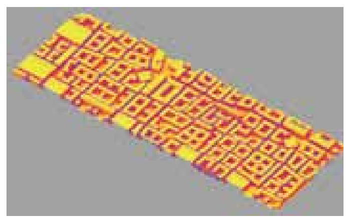

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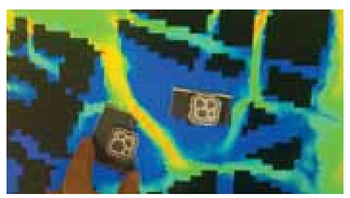

figure 5

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4 TANGIBLE INTERFACES

Minimizing the analysis turnaround time is a significant step toward providing a real-time response framework to the designer. However, what is also quite significant is the development of equally responsive user interfaces or interaction interfaces. A rapidly increasing number of studies have been involved with the development and incorporation of new interfaces, including augmented reality (AR) and tangible user interface (TUI) systems, in design systems (Seichter 2007). With the advent of new technologies, such as the Kinect device, the trend to substitute the mouse and screen with an immersive design environment has been continuously growing. Studies show that low-cost immersive design systems based on these technologies are expected to have a significant impact on design communication and decision making (Pak et al. 2011).

4.1 Marker-Based Touch Interfaces

Initial research into application of touch-based user interfaces exploited fiducial markers, placed on a horizontal LCD display and tracked by a camera above. The display allowed for dynamic presentation on the interaction surface, so that events could be modeled to respond in real time to the movement of the fiducial markers. Initially this system was used to test the feasibility of interactive design using the real-time fluid dynamics analysis environment mentioned above, though certain properties of a persistent, physically based marker system limited the utility of the interface for this particular task (Figure 5).

The marker was more useful in the context of visual site assessment. A design team working on a large coastal master plan in a former quarry wanted to assess views to the sea as well as planned amenities on-site from each of several hundred plots. In the system we developed, two LCD displays were used: one placed horizontally, displaying a site plan, and the other placed vertically, displaying the view from a point given by a fiducial marker placed on the plan display. Movement of the marker caused the vertical display to update dynamically. The plan display showed the terrain colored according to slope gradient so that users could visually identify and avoid those areas that are too steep for building (Figure 6).

4.2 Touch-Screen User Interfaces

Further development incorporated the real-time fluid dynamics and other rapid analysis tools into a comprehensive, interactive computer environment for master planning, developed in collaboration with an in-house urban design team. Compared to the marker-based interface, the use of touch screens allowed a very different quality of interaction, one which is becoming increasingly familiar to designers and clients due to the proliferation of touch-screen mobile devices.

Where the fiducial markers had allowed for movement of static building forms within an overall plan, the touch-screen interface allowed for manipulating building form rapidly, changing angles of walls and deleting or adding corners quickly. As these changes occurred, the real-time CFD solver was able to respond instantaneously. In fact, this is one example where real-time feedback is in some

figure 3

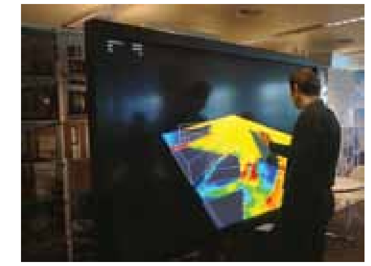
Rapid cumulative solar radiation studies.

figure 4

Cumulative solar radiation analysis at master plan scale

figure 5

FFD implemented on a fiducial marker-based touch interface.



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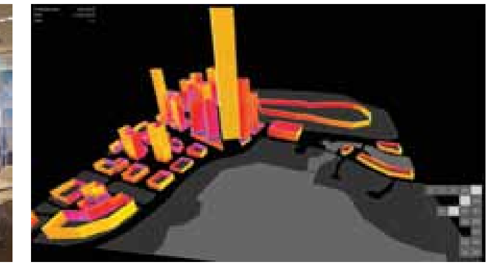

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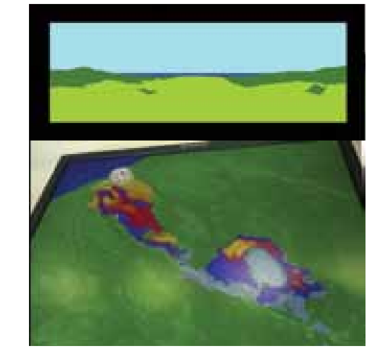

figure 6

sense too fast: the fluid solver reflects sudden changes to model configuration before it settles into a steady flow reflecting the new design state (Figure 7).

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4.3 Evaluation of Interactive User Interfaces

In general, the later touch screen–based applications offer a more robust and universally applicable design experience. The hardware for touch screens is relatively simple to set up, especially in the case of applications developed for mobile devices. Furthermore, the fact that the display can register points of interactivity ("hot spots") makes the technology more flexible than the use of physical markers.

Yet returning again to ecological principles, there are compelling reasons to have a diversity of entities that fill some niche, rather than a monoculture (Altieri 1999). The use of physical markers allows for three-dimensional and haptic interactivity for which there is currently no direct equivalent with touch-screen technology.

Additionally, touch screens are better suited as single-user devices. Both single-touch and multi-touch screens pose challenges for multiple users (Russell et al. 2002, Peltonen et al. 2008). Even when very large multi-touch screens are available, the quality of interaction encourages a single user to interact closely with the screen, making it difficult for other users to be equally involved with the design.

5 CONCLUSIONS

This paper has looked at specific innovations developed during the course of architectural practice that significantly change received notions of time for a designer. In certain cases, analyses that once took overnight or longer to run can now be done within minutes or quicker. This increase in speed is not simply a change in degree but rather a change in kind—analysis becomes an integral part of design, rather than a separate activity.

As nearly all contemporary designers are considering the long-term implications of sustainability in their projects, the near-term exigencies of "getting it right" are being felt ever more acutely. In thinking ecologically about design practice, such analyses can give competitive advantage to those projects or design ideas that "get it right." We find in practice that achieving the best performance from the use of such rapid analysis does not mean eliminating the role of consultants and adjuncts

figure 6

View assessment using an LCD screen and a fiducial marker.

figure 7

FFD study on a large touch-screen interface.

figure 8

Solar radiation analysis implemented in the interactive touch-screen interface.

to the design process. In fact, these qualitative changes in the time required to design and analyze make it critical to involve engineers, environmental designers, and architects in using these tools together in a collaborative fashion.

5.1 Future Research

We are actively engaged in research to improve the responsiveness of the design tools mentioned here, as well as others under development. We are increasingly looking into parallel processing on multiple cores, heterogeneous processing environments, and networked cluster computing to achieve not only quantitative improvements in responsiveness, but also the sort of qualitative shift mentioned above regarding what sorts of activities can be considered an integral part of the design process. At the same time, we are also looking at new ways to exploit the potentials of tangible interfaces and other user experiences in order to maximize the efficiency and immediacy with which designers can understand the impact of their choices across a range of time scales.

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REACTIVE LIGHT DESIGN IN THE "LABORATORY OF THE STREET"

ABSTRACT

This paper presents and discusses results related to a full-scale responsive urban lighting experiment and introduces a light design methodology inspired by reactive control strategies in robot systems. The experiment investigates how human motion intensities can be used as input to light design in a reactive system. Using video from three thermal cameras and computer vision analysis, people's flow patterns were monitored and sent as input into a reactive light system. Using physical as well as digital models, four different light scenarios are designed and tested in full scale. Results show that people in the city square did not engage in the changing illumination and often did not realize that the light changed according to their presence. However, from the edge of the city square people observed the light patterns "painted" on the square, as some people became actors on the urban stage, often without knowing. Furthermore, the experiment showcased power savings of up to 90 percent, depending on the response strategy.

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