The Impact of Information Technology in Architecture Design

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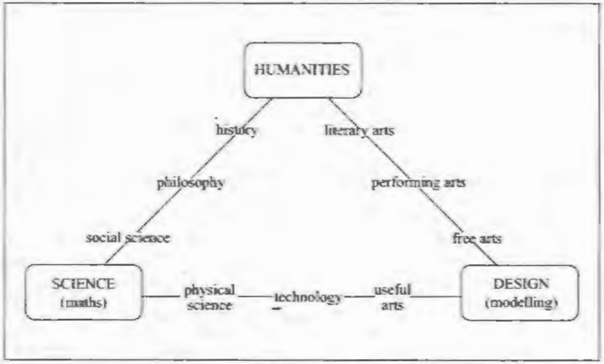
The Design Research Society (DRS) in the United Kingdom and the Design Methods Group (DMG) in the United States came into existence around the same time in the 1960s. For the first time, intellectual endeavor was focused on the complex human activity of design decision making. John Christopher Jones established at Manchester University a master's course in design and published the influential book *Design Methods* (Jones 1970). He later became the first professor of design in the innovative Open University in the United Kingdom.

Rittell in Germany, and Jones, along with Bruce Archer, Sydney Gregory, and others in the United Kingdom, began to develop what Herbert Simon, in his 1968 book *The Sciences of the Artificial*, called "a science of design, a body of intellectually tough, analytic, partly formalizable, partly empirical, teachable doctrine about the design process" (Simon 1968).

The notion that all academic thought lay along an axis from the *sciences* to the *humanities* was challenged. Instead, it was suggested by Archer (1976) that academic thought could be plotted as a triangle with *humanities*, *science*, and *design* at its apexes (Figure 1). For science, the prime language is mathematics, and for humanities, it is *natural language*; the language of design, it was proposed, is *modeling*.

Figure 1
The Argument to Elevate Design as a Discipline Equal to the Sciences and the Humanities



Around the same time—the mid-1960s—interest was growing in the idea of what is now know as "post occupancy appraisal" (POA) of buildings. The building boom in the United Kingdom after the Second World War had produced some disastrous outcomes, and there were clearly lessons to be learnt by studying the performance (or rather the lack of performance) of existing buildings.

The building industry, at 12 percent of gross domestic product, was Northern Europe's second largest single industry employing (directly or indirectly) one in twelve of the working population. Yet, despite its scale and importance in the national and regional economy, the building industry was underdeveloped and disaggregated. In the United Kingdom, for instance, only 6 percent of contacting firms employed seven or more people; 50 percent of architectural practices employed two or fewer professionals. The research and development budget of the industry was, and remains, a meager half of one percent of turnover. The professional education provision was highly fragmented and continuing professional development opportunities were very limited. Overall, the labor force was poorly qualified.

This had a serious consequence for the quality of the built environment. Conservative estimates suggest was that remedial treatment of building

defects costs the United Kingdom upward of £1,000 million per annum (excluding normal maintenance); about 50 percent of these defects, it is judged, could have been obviated by better *design*. In a high proportion of post-war buildings, energy consumption was profligate; UK Department of Energy figures suggested a potential saving of up to 50 percent through better design of new buildings and an additional 25 percent through appropriate design intervention in the existing stock of buildings.

In 1967, Professor Tom Markus set up, in the Department of Architecture and Building Science at the University of Strathclyde, a multidisciplinary research team—the Building Performance Research Unit (BPRU)—to develop tools for the appraisal of buildings in use. These tools, and their use, for "post occupancy appraisal" (POA), were described in the seminal book *Building Performance* (Markus 1972).

While the value of POA was recognized, a bolder notion emerged: could the design methodologies from the DRS and the DMG be deployed during the course of the design activity to achieve an outcome that was more fit for purpose, more cost-effective, and more sustainable?

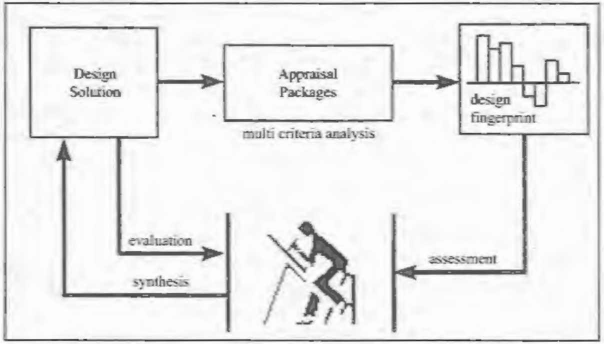
Although building design has much in common with product design, there is a significant difference. In product design, the *modus operandi* is to construct, and progressively refine, a *physical prototype* prior to the production run—a methodology impractical in large capital items such as buildings. What was needed, then, was a new paradigm: what we would today call a *virtual prototype*.

In the vanguard of efforts to achieve such a paradigm was the Architecture Machine Group (and subsequently the highly influential Media Lab) at Massachusetts Institute of Technology (MIT) and the Architecture and Building Aids Computer Unit, Strathclyde (ABACUS) in the University of Strathclyde. Nicholas Negroponte's book *The Architecture Machine* (Negroponte 1970) was inspirational: he dedicated the book "To the first machine that can appreciate the gesture." In the same year, Maver, Director of the ABACUS, a research group that had grown out of the BPRU, published *A Theory of Architectural Design in Which the Role of the Computer is Identified* (Maver 1970).

The *virtual prototype* paradigm proposed by ABACUS was captured in a simple diagram (Figure 2). Here, the designer proposes a design solution; appropriate computer-based modeling software predicts the cost and performance characteristics (the "fingerprint"); this is assessed and evaluated, thereby informing the next design iteration.

At that time (1970), Strathclyde University had only one mainframe computer; programs and data could be entered only in the binary form

Figure 2
A Diagram Representing the Virtual Prototype Paradigm Proposed by ABACUS



using paper tape or punched cards. Therefore, any prototype building had to be "described" in terms of the *x* and *y* coordinates of every geometric vertex (for plan layouts) or *x*, *y*, and *z* coordinates (for 3D forms); explicit instructions (in a language called FORTRAN—short for Formula Translation) specified which coordinates were joined by lines, which lines formed planes, and which planes made up volumes; there was neither graphical input nor output.

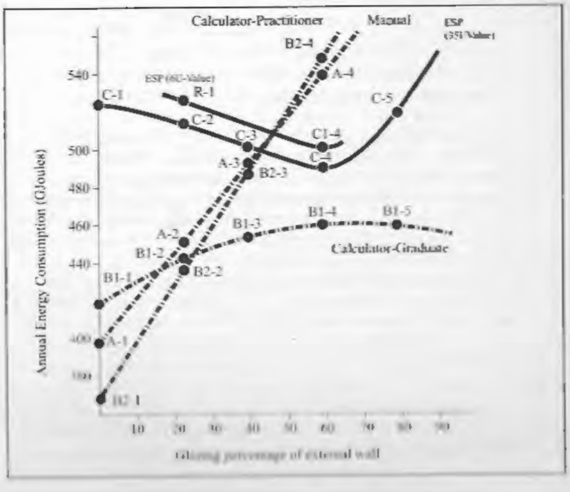
Nonetheless, against the odds, by 1970, papers were being published that described the process of appraising a simple building in terms of its cost (capital cost, recurring life-cycle cost) and its performance (daylight levels, energy consumption, plant size, etc.). By 1973, the emergence of pen-plotters, combined with innovative algorithms, made it possible to prodnce drawn plans and 3D ("wire-line") perspectives; affordable graphical input devices were also becoming available. Overnight, the architectural profession—highly suspicious of the idea that computers could have anything less than a deleterious influence on design quality—embraced the technology as a means of automating production drawings; the emphasis for the next five or six years, shifted (some would regret) from better *product* to more efficient *production*.

The 1980s and 1990s saw the evolution of increasingly sophisticated models of the energy behavior in buildings (Clarke and Maver 1991).

It became possible to demonstrate that the simplistic calculations in currency at that time were, at best, woefully inaccurate and at worst positively misleading. Figure 3 compares the outcome of calculations made of the energy consumption in a standard building by the simplistic hand calculations at that time approved by the Royal Institute of British Architects (the "broken" lines) with those calculations using the sophisticated computer-based model developed by ABACUS (Clarke and Maver 1991). Because the simplistic calculation was unable to take account of the varying solar gain throughout the year, it suggests an optimum solution of zero glazing; or, in the hands of a more intelligent user, a maximum consumption of energy at 60 percent glazing.

The sophisticated computer-based model, based on the new generation of energy models, deals in first principles with thermo fluids and thermodynamic flux, shows exactly the opposite—*minimum* energy consumption at 60 percent glazing.

Figure 3
Comparison of the Results from a Simplistic Hand Calculation (Broken Lines) with Those from a "First Principles" Computer-Based Model (Full Lines)



Based on the new generation of energy models, an energy design advice scheme for architects, pioneered by the Royal Incorporation of Architects, yielded certified annual and recurring saving in energy equivalent to millions of euros (McElroy et al. 1997).

The success of advanced computer-based models of the complex energy behavior of buildings spurred the development of computer-based models of how light (and subsequently sound) from multiple sources could be traced within complex building geometries to provide realistic experiences of the *quality* of the built environment.

This period also saw rapid development in software for photorealistic color imaging of both the exterior and interior of buildings and the subsequent animation of these images to afford virtual "journeys" around and through buildings that were still on the drawing board. Increased computing power allowed groups of buildings, settlements, and ultimately entire cities to be modeled.

The early pioneering work of the MIT Media Lab had led to the now-ubiquitous multimedia computer-based documents seamlessly combining text, drawings (hand and computer generated), photography, video, animation, and sound. Multimedia software with user-friendly interfaces was instrumental in bridging the gap between technologists and historians in architectural education.

It can be argued that the coupling of design methods with the power of computing has brought about the first radical change in how we design buildings since the renaissance discovery of perspective geometry.

The impacts can be summarized thus:

- Of all the design professions, it can be argued that architecture has led the way in the effective adoption of the emerging information technologies; just as developments in artificial intelligence, however primitive, have informed an understanding of the sophistication of the human mind, so computer-aided architectural design (CAAD) has informed our understanding of the complex human activity of design.
- The application of the technologies to the cultural issues that are central to the concerns of the profession (e.g., virtual heritage), and to our understanding of the relationship across the range of scale of operation of the profession—from interior design to the design of individual buildings, through neighborhoods to cityscapes offers, in the words of Frank Ghery in his acceptance speech on receipt of the Royal Institute of British Architects (RIBA) Gold Medal, "a great opportunity for architects to become master builders again."

- The extraordinary advances in verisimilitude of the still and animated imaging of the visual characteristics of interiors and exteriors of individual building and entire neighborhoods, surely gives, as never before, confidence to practitioners and their clients that what is intended, esthetically, is what will be delivered.
- The power of advanced dynamic models of the thermodynamic behavior of buildings, in response to diurnal and seasonal variations in weather and climate, has the potential to save millions of euros, and more importantly, in the long run, dramatically reduce atmospheric and stratospheric pollution: these models have the potential to provide us with a new *vernacular of sustainability*.
- The recent emergence of robust and powerful decision support systems that allow synchronous design across continents, time-zones, professions, and agencies will enable the next generation of architects and engineers to design from within the virtual world, which links virtual reality to rapid manufacture and shape grabbing technologies in a seamless transition amongst modeling options.
- The establishment of a number of hugely effective and interrelated initiatives to secure and promote communication within and across academia and practice, namely the formation in Europe of eCAADe (http://www.ecaade.org); in North America of ACADIA (http://www.acadia.org); in South America of SIGRADI (http://www.sigradi.org); in SE Asia of CAADRIA (http://www.caadria.org); in the Arab Regions of ASCAAD (http://ascaad.org); and internationally, of CAAD Futures (http://www.caadfutures.org), complemented by the meticulously maintained CUMINCAD database of over 10,000 abstracts/papers in the subject area (http://cumincadscix.net); and, last but not least, the initiative to bring into existence the International Journal of Architectural Computing (http://www.architecturalcomputing.org). These initiatives are quite unprecedented in the architecture profession, and herald a new model for cooperation and consensus in the academic and professional community.

Not withstanding the remarkable development in little more that four decades, there remain issues that the CAAD community needs to address:

- Little objective evaluation is made of the benefits (or for that matter the perceived threats) that have accrued, and will potentially accrue, from developments in the field; if the building industry is to raise the investment of R&D funding from the paltry half of one percent of the turnover (compared to 40 percent in the computing industry), the community has to get better at evaluating the efficacy of what has been achieved (through a rather random process) and estimating what could be achieved through a more coordinated and focused R&D endeavor, which excites the funders of sustainable futures.

- The virtual prototype tools that currently exist to predict the cost/performance characteristics of specific buildings are increasingly being adopted by progressive architectural and engineering practices, yet they are not being used, as they might be, to systematically explore generalized relationships between design decisions and cost/performance consequences; establishment of these causal relationships could provide an invaluable educational resource and move the profession and its clients toward the notion of "performance specification."
- Explicit appraisal of design options through virtual prototyping helps inform design decision making, but as Simon eloquently stated, taking a design decision involves subjective as well as objective value judgments; a recurring theme in some of the most interesting research over the last three decades has been the degree to which virtual prototyping—and the power of virtual reality (VR) and multimedia—can facilitate the effective participation of the clients and users of buildings in the forming of these value judgments; it is high time that this issue came to the top of the CAAD research and development agenda.
- It is difficult to shake off the suspicion that, had not our best students got mightily excited about, and made significant contributions to, the field, many of our colleagues (some of whom recently appear to be desperate to take over ownership of the topic) would still be resisting the "heretic" notion of computer-aided design (CAD); the profundity of the notion of virtuality, and in particular, virtual environments cannot be overestimated and our biggest challenge is to ensure that, in partnership with our students, the challenges and opportunities are addressed; we would be at great risk in the advancement of what is surely a fundamental shift in the education paradigm if we were to forget that we are all learning, even those of our colleagues who failed to see the writing on the screen. Two quotes, by Lev Manovich and Marcos Novak, respectively, are relevant:

> The architecture of cyberspace will succeed where modern architecture failed. Utopian imagination is no longer limited by physical reality. Its only limitation is the speed of rendering engines. The dream of transporting people through the experience of space can finally become a reality.
>
> . . . an architecture without doors and hallways, where the next room is always where I need it to be. Liquid architecture makes liquid cities that change at the shift of a value, where visitors with different backgrounds see different landmarks, where different neighbourhoods vary with ideas held in common, and evolve as the ideas mature and dissolve.

In conclusion, it can be said that members of the CAAD community—academic staff, students, and practitioners—have been privileged to share, over four exciting decades, a part in a truly transformational change in architectural research, teaching, and practice. What has taken place may, however, represent only the first faltering steps in our amplification of the intellect. Those who choose to take the subject forward in the next four decades will be privileged indeed.

Charles Babbage, who worked in 1833 on the first mechanical programmable computer with his muse and colleague, namely the mathematician Ada Lovelace, prophetically offered to give up the rest of his young life if he could come back in one hundred years' time for only one day, to see how the idea of computing had worked out; the application of computing to the complex and important areas of sustainable, innovative, and virtual architecture would surely have convinced him that the deal was worthwhile!

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