What Good is a Computer to an Architect?

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What good is a computer to an architect? Palladio found pen and paper perfectly adequate, after all. And it is hard to imagine Frank Lloyd Wright at a keyboard. (It just doesn't go with a cape and cane.) The most sophisticated piece of technology on most architects' desks, even today, is an electric pencil sharpener.

The salesman for CAD systems will tell you that you can increase professional productivity by replacing drawing boards with graphics workstations, and they will probably quote impressive productivity ratios. They may be right. But it is notoriously difficult to measure productivity, in any meaningful way, in a service profession; and it is certainly absurd to apply the industrial notion of productivity to artistic activity (and I take it that architecture should be at least partly that). In any case, we have an oversupply of architects in most developed Western countries, and every year there are more people trying to get into the profession than there are places. It could be argued, as a matter of social policy, that it would be better to create employment opportunities by decreasing individual professional productivity.

You might take the view that achieving higher architectural quality, rather than doing projects more quickly and cheaply, is the proper end of computer use. That is an attractive ideal. But there is no extensive body of distinguished computer-aided architectural design work to point to - at least not yet. At best you can find a few isolated tours-de-force to offset the leaden banalities that many firms are proudly popping out of their shiny new CAD systems.

We will not, in fact, find the answer by looking for ways in which computers can perform traditional design functions more quickly, or cheaply, or thoroughly, or accurately, than a human architect. There are some ways, but that is largely beside the point. The real importance of computer graphics for architecture is that it provides new ways of representing buildings, of manipulating those representations, and of interpreting them in various useful ways. A design process supported by a computer graphics system is qualitatively different from one carried out with pencil and paper; it has an altered pace and sequence, brings information to bear on decisions in new patterns, renders the visual effects of geometric, color and lighting decisions with unprecedented speed and precision, and so allows architectural ideas and effects to be explored in ways that were unimaginable before now. Computer graphics promises architects an aesthetic adventure...one that is just beginning.

Composition of Lines

What are these new ways of representing buildings? We can best begin to understand them by considering some canonical definitions of architecture.

One traditional way to represent a building design, for example, is by means of lines - usually drawn on paper. When we use this method of representation, architectural design becomes (at one level of consideration) a matter of manipulating lines. In his ***Ten Books of Architecture,*** the great Italian Renaissance architect L.B. Alberti defined architecture, in these terms, as follows:

We shall first lay down, that the whole art of building consists in the design, and in the structure. The whole force and rule of the design, consists in a right and exact adapting and joining together the lines and angles which compose and form the face of the building.

By "lines" Alberti meant straight segments (vectors) and circular arcs. Operations of "adapting and joining together" lines to produce compositions were performed by executing Euclidean constructive procedures (for parallels, perpendiculars, bisectors, tangents, and so on) with straight-edges and compasses. Lines could be projected from three-dimensional space onto a two-dimensional surface by the newly invented (or rather, reinvented) method of perspective.

But the architect's traditional tools for constructing line drawings are now being replaced by computer drafting systems, which provide greater speed and convenience. (See figures 1 - 4.)

Composition of Surfaces in Light

Another way to think of a building is as a collection of surfaces, bounded and divided by lines, and made visible by light. This focuses attention on surface qualities of color, reflectivity and texture, and the creation of relationships between these. In his polemic ***Vers une Architecture,*** the young Le Corbusier set forth a stirring definition of architecture in these terms:

Mass and surface are the elements by which architecture manifests itself...Architecture is the masterly, correct and magnificent play of masses brought together in light.

This is not merely an esoteric matter of aesthetic theory; it has direct technical implications for computer graphics. If we conceive of an architectural composition as a collection of surfaces, a "wire-frame" vector representation of a building will not serve us adequately; we will need to work with some kind of surface model. The simplest way to do this is to take closed planar polygons as data types. The shape of each polygon (normally specified by giving vertex coordinates in anticlockwise order), then, becomes a low-level design variable. To define a composition, polygons must be located in space, and assigned surface qualities, such as color.

Not all surfaces found in buildings are planar, of course. Cylindrical curvature is found on vaults and moldings, and spherical curvature is found on domes. Much more rarely, warped and spline surfaces of various kinds are found as well. So the surface modeling techniques that have been given so much attention in computer graphics have some role to play in architecture, though not so central a one as they play in automobile and aircraft body design.

Le Corbusier emphasized that the elements of a compostion are "brought together in light." An architect is vitally interested in the lighting conditions, both natural and artificial, that will exist in and around a building, and how light will paint surfaces to create a visual experience. So a necessary adjunct of a surface model is a lighting model, which allows the characteristics of light sources to be specified, and effects of light on surface to be displayed.

The simplest useful lighting model is based upon the cosine law for diffuse light incident upon an opaque matte surface. The light source is modeled either as a point in space, or as a direction, together with an intensity value. The reflected light from a surface, then, is a function of the reflectivity of the surface and of the cosine of the angle that the incident light makes with the surface. This elementary lighting model, together with hidden-surface perspective software and a raster display device, provides an architect with a very useful way to study building massing.

Architects are interested in sunlight; the ways that the sun casts shadows on and around buildings at different times of the year, the patterns of sunlight penetration (insolation) through openings, and the thermal effects of sunlight incident upon the exposed surfaces of buildings, are all vital architectural issues from both technical and aesthetic viewpoints. Two basic kinds of calculations are required to determine sunlighting effects: calculation of sun position as a function of latitude, longitude, date, and time of day; and calculation of the pattern of cast shadows as a function of sun position and building geometry. Calculation of sun position requires evaluation of some complicated trigonometric functions, while calculation of cast shadows is isomorphic to the problem of generating a hidden-surface perspective of the building from the viewpoint of the sun. Both these calculations can be carried out by hand (indeed there is a traditional architectural subject, sciagraphy, that is concerned with them), but they are extremely tedious and time-consuming. Use of a computer saves a great deal of time and effort, and allows more thorough explorations of sunlight and shadow effects to be carried out.

Much monumental architecture of the past (from the pyramids onwards) was essentially a matter of opaque volumes, and the shading and shadowing effects of natural light. But Gothic cathedrals and Baroque churches also made important compositional use of natural light transmitted through translucent and transparent planes of glass. Then the Industrial Revolution of the Nineteenth Century made possible spectacularly transparent steel-and-glass structures like the Crystal Palace, and the intense artificial illumination of interiors. Since then, the revelation of form through layers of glass, and the night-time effects of internally illuminated transparent buildings, have been major concerns in architectural composition. It is fairly straightforward to extend a lighting model to deal with transparent as well as opaque surfaces, so that an architect can use computer simulation to explore transparency effects. Essentially, the illumination at any surface point is calculated by considering both reflection and transmission effects.

Not all surfaces used in buildings are smooth and matte. Some are shiny, so that highlights become part of the visual experience. Some have a metallic luster. Some act as mirrors, so that reflections appear. Many have texture. Visual simulation techniques can now be extended to encompass many such effects.

Furthermore, a building, or a space within a building, may be illuminated by multiple light sources, and the effects of interreflection within a scene may be visually important. Where accurate rendering of complex lighting effects is required, the technique of ray-tracing may be employed. This is computationally expensive, but it can produce extraordinarily realistic results.

It is sometimes suggested that use of computer graphics forces an architect to deal in barren computational abstractions, and places the emphasis in a design process upon technology rather than upon the subtleties and complexities of visual experience that enrich and enliven architecture, and give it the capacity to touch our hearts. But the techniques for simulating light on surface, and effects of color and texture, actually bring architects closer to the qualities of visual experience by rendering these quickly and accurately. These techniques have the same potential for liberating the architectural imagination that the technique of perspective construction had for the architects of the Renaissance, and the technique of graduated watercolor wash had for the architects of the Beaux-Arts. (See figures 5 - 7.)

Composition of Volumes in Space

You can see, now, that we are building up a geometric hierarchy. A vector is bounded by its end-points, and you can construct a plan, elevation or wire-frame three-dimensional model from vectors. A plane polygon is bounded by three or more vectors, and you can usefully represent a building as an assemblage of colored and shaded polygons. The next step is to recognize that a polyhedron is bounded by four or more polygons, and that you can represent a building as an assemblage of polyhedra. If we want, we can also admit curved as well as straight lines, curved as well as planar surfaces, and solids bounded by curved as well as planar faces.

Just as a polygon may be opaque or transparent, a polyhedron may be a solid construction element such as a column, or an enclosed void such as a room. Architectural theorists traditionally have emphasized that an architect composes both the solids and the voids. The Beaux Arts theorist Julien Guadet, for example, wrote:

...just as you will realize your conceptions with walls, openings, vaults, roofs - all elements of architecture - you will establish your composition with rooms, vestibules, exits and staircases. These are the Elements of Composition.

When a building is represented as an organization of polyhedral solids and voids, the designer needs operators for generating polyhedra. An extrusion operator, for example, can be used to generate a prism from a plane polygon. By rotating a plane profile about an axis, instead of translating it along an axis, a solid of revolution can be generated. By connecting the vertices of a plane polygon to a point, a pyramid form can be generated. There are others, but these are the most useful to architects.

Extrusion generates the basic architectural form of the cube and its variants. Extrusion or rotation (depending upon how you want to look at it) generates the cylinder. Rotation generates the sphere. And connection to a point (or rotation, if you like) generates the cone. In a famous passage, Le Corbusier pointed out the central role of these basic forms in architecture:

The light plays on pure forms, and repays them with interest. Simple masses develop immense surfaces which display themselves with a characteristic variety according as it is a question of cupolas, vaulting, cylinders, rectangular prisms or pyramids.
(See figures 8 - 9.)

Composition of Buildings in Urban Settings

Just as surfaces are built by composing edge lines, volumes are built by composing enclosing surfaces, and complete building masses are built by composing interior volumes and construction elements, urban form is eventually put together by composing building masses. The great French neoclassical architectural theorist J-N-L Durand expressed the point this way:

Just as the walls, the columns, etc., are the elements which compose buildings, so buildings are elements which compose cities.

Of course it is rare for an architect to design a complete city. More commonly, the task is to insert a building mass appropriately into an existing urban fabric. Thus urban form evolves in step-by-step fashion, as individual buildings are constructed, demolished, and replaced.

In order to see the effect of a proposed building in its urban context, an architect needs some kind of three-dimensional model of that context. Elaborate city models of wood and plaster have often been made to serve this purpose. (Mussolini made a famous one of Rome to guide the reconstructions that he had in mind, and the University of California at Berkeley has a beautiful model of downtown San Francisco for use in producing filmed simulations of proposed developments.) But such physical models are bulky, cumbersome, collect a lot of dust, and are difficult and expensive to keep up to date. An increasingly attractive alternative, now, is to maintain constantly updated form databases, which can be used to produce perspectives and animations showing proposed new buildings in context. (See figures 10 - 12.)

Conclusions

The Italian Renaissance drove a wedge between the computational and graphic aspects of design that has remained until the present day. Renaissance architectural theorists, such as Alberti, assimilated architectural design (along with painting and sculpture) to ***disegno,*** carried out through drawing. But Renaissance scientists (particularly Galileo in his investigations of structural member sizing) began a tradition of design by manipulation of mathematical models. Computer graphics, finally, is beginning to bring the two sides together again.