

## Seeing By Numbers: A Short History of Computer Renderings

Roberto Bottazzi, *The Bartlett, UCL*

The history of the relation between representational techniques and digital design is a complex, slightly deceiving one as, superficially, it lends itself to a rather linear account. If Artificial Intelligence (AI) or digital simulations mark clearer breaks between with pre-digital approaches, the digitisation of spatial representation appears as a straightforward absorption of prior knowledge. The mathematics of perspectival construction are still largely those codified since the beginning of the fifteenth century with only a substantial transformation that digital tools have made all these operation much easier. Speed is however an essential characteristic of the digital and quantitative changes are the preconditions for qualitative leaps. Easily constructed perspectival views allowed designers to directly work in three-dimensional space bypassing the traditional design process which rigidly moved from simpler orthographic representations to three-dimensional ones.

Underpinning this process of removal is the very architecture of the digital, the base code of (binary) numbers to which data and algorithms comply with. Such process has made translation between different media possible and has deeply changed how we apprehend reality and redesign with computers. German artist Hito Steyerl well registers this transformation by pointing out that in the digital age *how* we see is more important than *what* we see. The thick and often inaccessible layer of algorithms is both separating user and machine and the very space in which architectural ideas and design narratives can be injected *because of* the numerical, systematic, and, ultimately, abstract logic of the digital.<sup>1</sup> This layer is therefore not neutral as it implicitly frames the domain of what it can be imagined. These initial remarks already suggest that to recapitulate the history of computer-generated images (CGI) – the objective of this paper – we ought to engage the very architecture of computation as its logic has been propelling changes in this field. To chart how more technical transformations have impacted designers' ideas, we must also acknowledge that this is not a task which we can leave to technical literature. The effect of CGI on architecture can only be observed by acknowledging that design is complex and a hybrid which juggles technical, historical, intellectual, and material concerns. There is in fact a gap between the expectations of CGI in which the quest for realism and concerns of commercial profitability drive development and the conceptual and aesthetic instances that informed the construction of digital tools. The former obscures the latter: not only do CGI form a clear field of research, but they also constitute one of the sources of creativity for digital designers.

As for many other aspects of CAD, drafting tools draw inspiration from nature: rendering tools, for instance, are modelled after the physiology of sight. Such mechanism broadly divides between sensing spatial information (the equivalent of the eye) and elaborating them through algorithms to form the final image (the brain). The history of digital sight is a long attempt to perfect these two complementary activities based upon speculations on how the eye-brain pair may function. The language of mathematics modelled advancements in the science of vision (mathematisation of reality) which gave rise to techniques and processes forming both the tool sets of the digital designer and in this discussion, the very place from which critically examine the relation between CGI and

---

<sup>1</sup> Evens, A. (2015). *Logic of the Digital*. New York, London: Bloomsbury Academic.

design. What is of interest here are the very possibilities this process engenders such as the ability for artists and architects to capture aspects of reality not accessible to the human eye.

This was the case for wireframe visualisations or voxel rendering which not only generate images by diverging from the natural model of the eye, but also elicited new forms of representation and design. CAD, therefore, is entangled in a complex, dynamic web that different techniques, concepts, and disciplines have been morphing. As the mathematics of image construction changes, so does the range of things we can represent; it is through such prospective that we can assess with greater precision the impact of CGI on architecture from Alberti's *Prospectiva artificialis* to volumetric representations based on voxels. Whether these innovations were merely absorbed by CAD or digitally-native, they only acquire relevance if able to dislodge assumptions on the nature of design and its process. The formalisation of sight passed through two successive inventions: mathematical tools and physical machines which literally reified into contraptions mathematical principles. These two lines of development have been conflated by digital computers engendering the unification of two problems: that of geometry by finding precise rules to reconstruct surveying objects, buildings, an even landscapes, and that of the treatment of light, shadows, and colours through ray casting.

### **Invariants and Variables: numbers and geometry.**

The genealogy of computer rendering finds its ultimate foundation in the invention of mathematical perspective in the first half of the fifteenth century. If the techniques introduced by Leon Battista Alberti's *De Pictura* (1435) were to be interpreted according to contemporary CAD culture, we could speak of devices to store and compute spatial data to construct perspectival views. In many instances such techniques were actual machines that would physically translate geometrical principles into various contraptions. In the case of Jacopo Barozzi da Vignola (1583), the machine consists of two distinct parts which neatly map the eye-brain divide: through this clear break between observation and computation, Vignola's perspective machine could survey entire landscapes (Fig. 1). New images such as orthographic drawings could be derived from views by applying mathematical principles to re-compute the initial data. This possibility had immediate application for military purpose as it allowed to obtain plans of fortresses through simple observation. More conceptually relevant is Alberti's observations on the power of mathematics in synthesising reality as it allows to generate abstract views only displaying edges which are inaccessible to human senses by showing the profiles of objects not directly visible. In today's digital parlance we refer to such images as wireframe visualisations, a common feature of any CAD software. In the first book of the *De Pictura* (1435) Alberti warned the reader that his approach to the subject of painting was that of an artist rather than mathematician as "...Mathematicians measure with their minds alone the form of things separated from all matter."<sup>2</sup> It is nevertheless such ability to see things beyond their perceptual reality as intellectual constructions to enable the production of drawings of objects in which all edges are represented. This is the case for drawings of mazzocchio – an accessory to the hat usually worn in the renaissance – which was often the object of choice for virtuoso perspectival constructions (Fig. 2). Wireframe views are intellectual constructions resting on a rigorous mathematics which endows drawings with the ability to exceed reality and therefore become instruments for speculation and invention. Amongst the many examples of creative use of wireframe visualisations in design, OMA has been employing this mode since the 1980's: first for the competition entry for Parc La Villette in Paris (1982) in which such technique enhances the design concept based on overlaying different programmatic layers. These

---

<sup>2</sup> Alberti, L. B. (1991). *On Painting*. Translation by C. Grayson. London: Penguin Classics, p. 5.

techniques were re-explored with greater emphasis for the design of the concert hall *Casa de Musica* in Porto (1999-2005) in which the Rotterdam-based office produced dazzling and beautiful wireframe views of the final building by superimposing all the plans (Fig. 3). The technical ability to hide objects sitting in the background also represents one of the cornerstone of computer graphics. The invention of the “hidden lines” algorithm by Lawrence G. Roberts in 1963 was not able to remove parts of covered objects, but marked the moment in which mathematics could automatically draw things “as they are seen” removing the major criticism moved by Alberti to mathematicians’ view of reality.

Alberti’s polemics also opens up two separate strands of research that will run in parallel for a long time before being reunited under the abstract logic of binary computation of digital computers. The first is concerned with mathematical and geometrical notions to reproduce, or better re-compute, the datasets surveyed to generate new drawings. Alberti had himself developed some of these techniques for his survey of the city of Rome captured in the *Descriptio Urbis Romae* (1450). It is however with Piero della Francesca’s *Other Method* (c. 1470-1480) that we fully appreciate the creative use of mathematics in drawings. Whether ever employed by Piero, his method proposed a proto-version of Gaspard Monge’s descriptive geometry to recast a set of points directly surveyed from an objects which were no longer bound to what measured at the time of the survey. Piero gives many examples of this method, but the most compelling is its application to the depiction of the human head – surveyed in 128 points. By experimenting his method, Piero was eventually able to create the first view of a human head seen from below (Fig. 4). Here mathematics allows a complete separation between the perceptual experience of the object and drawing which, again, becomes a mental re-elaboration of the data. Furthermore we can see how mathematics allows to divide between data gathered which become invariants and their apprehension through mathematics (algorithms) which are variables. This is still how CAD operates: for instance, whenever we rotate the viewing angle in a perspective, the original coordinates describing the vertexes of objects are passed through a matrix which outputs the new positions of the points on screen, still playing with invariants and variables. CAD software also appropriated these techniques for modelling operations such as scaling, moving, rotating, etc. demonstrating how the basic numerical logic of the digital encouraged tools transferring, generalisations, and confluences of tools (in this instance, by merging representational and editing commands) (Fig.5). Not only can we see how numerical, quantitative transformations eventually became qualitative ones, but also how the mere quest for realism, CGI also offer opportunities for richer conversations involving disciplinary, narrative, and aesthetic considerations.

Alberti’s work on *prospectiva artificialis* also implied the possibility to automate the operation of survey and adding mathematical knowledge to surveying techniques. Albrecht Dürer’s engraving of the process of surveying a lute (*Underweysung der Messung mit dem Zirckel un Richtscheyt*, 1525) shows a process that almost automatically draws perspectival views of objects without human intervention (Fig.6). This etching not only explicitly takes advantage of some of the principles already illustrated by Alberti, but also opens up a long series of inventions and machines to automate drawing that will drastically change with the arrival of photography in the nineteenth century. The digital re-unites these two lines of experimentation through the development of scanners and the automation of photogrammetry.

## **Beyond Perspective: Numbers and Light.**

The development of techniques to compute light and shadows is equally long and complex. As for our considerations on geometry, we will foreground how the digital has triggered qualitative changes out of quantitative ones. The smooth elegant plateaux of binary computation allowed the translation of any media into numbers and the possibility to edit them via logical operations. If, on the one hand, the digital lowered the skill level required to interact with images; on the other, it also opened up profound questions on the legitimacy and legibility of images which impacted society well beyond architecture.

This complex story finds a first major transformation with Roberts' "hidden line" algorithms inaugurating a long period of discoveries driven by academic research which first impacted the movie industry than design disciplines. The 1960's were the decade in which the formula "computer graphics" was coined by William Fetter at Boeing whilst developing the first software for flight simulation. In parallel new types of software packages took full advantage of the transformation of the image from a chemical trace to a numerical field: first *SuperPaint* designed by Richard Shoup with a team of experts that included Alvy Ray Smith (who would eventually co-found PIXAR), and then, much later, the omnipresent *Photoshop* introduced by Thomas and John Knoll in 1987. University of Utah under the guidance of Ivan Sutherland led the research on algorithms to calculate the reflection and refraction of light on objects. Most of these algorithms are still in use and named after their inventors: French computer graphic Henry Gouraud devised the first algorithm to smoothen the faces of curved surfaces, which was subsequently improved by Edwin Catmull, James Blinn, and finally Bui-Tuong Phong. Blinn is also credited for the invention of "bump mapping" which inaugurated a series of tools which extended the possibilities of image editing tools (introduced by pieces of software such as *Adobe Photoshop*) to three-dimensional modellers. Architects would only enter this domain in the 1990's when a young generation of designers began to work with workstations that could run software able to model and render complex geometries. In about a decade, architectural representation moved from wireframe visualisations of SOM's proposal for *875 Third Avenue* in Manhattan to full coloured rendering of the Frank Gehry's *Vila Olimpica* (1989-1992) in Barcelona (Fig.7).

In the case of "bump mapping" we begin to observe the recombination of properties generally belonging to image editing software and surface modellers. Again, the unifying abstraction of binary computation allows recombining elements and, perhaps, more importantly here, exploitation through algorithms. These have their own rules which determine what and how will be computed. Algorithms are therefore active components which can extract radically different images from the same dataset. This is new condition is a consequence of Turing's architecture, one in which hardware, software, and data are all handled through a single logic, that of binary numeration. The complex interplay between invariants and variables is therefore possible and with it the possibility to radically challenge not only the status of images and objects but also the notion of creativity. When Carlo Sini examined such automatic processes, he turned to Nietzsche's account of how knowledge always emerges by moving something from the domain of the unknown or stranger into that of the known or familiar.<sup>3</sup> Such process does have similarities with algorithmic apprehension and is of use in framing how digital images and design interact. Two steps characterise it: "exteriorisation" of data and individuation of a unit of measurement. With the first step, Sini identifies the extraction of a particular dataset from the totality or flow of data, a process of discrimination between what will be

---

<sup>3</sup> Nietzsche, F. (1975). *Frammenti Postumi 1885-1887*, Italian translation, *Opere* vol.8, Milan: Adelphi. Cited in Sini, C. (2009). *L'Uomo, La Macchina, L'Automa: Lavoro e conoscenza tra future prossimo e passato remoto*. Turin: Bollati Boringhieri, p.48.

computed and what will not. The second operation pertains to algorithms as they apprehend a dataset according to the instructions scripted in them. This process eventually returns a new image of the initial dataset. In Piero's example 128 points are selected from the totality of possible points surveyed which are then algorithmically recalculated to generate infinite new drawings of the human head from the data rather than the original model. Despite the massive distance in time, similar conversations took place at the US National Bureau of Standard where Russell A. Kirsch developed the first digital scanner in 1957. Whilst working on the project, the team led by Kirsch confronted the new numerical nature of digital images when they had to script an adequate algorithmic process that acknowledged the non-perspectival nature of an image generated by a scanner. The image (on a picture of Kirsch's son) emerged not from geometry but from the bounce of beam of light. The model of reference was still the human sight except that rather than concentrating on the "eye", it was the "brain" (i.e. the algorithm) to focus the teams' efforts. Kirsch looked at the cognitive sciences for his algorithm and came up with a model that equated neuronal activities to binary inputs. The result could only be composed of a series of black and white pixels which immediately appeared to be excessively oversimplified. Rather than a purely technical the issue was intellectual, the algorithm was not sufficiently advanced in setting adequate processes of "exteriorisation" and measuring.<sup>4</sup> The re-writing of data by algorithms also affects CGI: amongst the many excellent examples are the renderings produced by Richard Voss in the early 1980's of different mountainous landscapes generated through fractals. Incremental tweaks in the algorithm's parameters gave rise to substantially different landscapes despite these were all based on similar initial datasets (Fig.8).

### **Computer Renderings: Designing in a Field of Numbers.**

The cumulative effects of these innovations merging both pre-computer and digitally native ones brings us to consider the role of CGI in contemporary design discourse and examine what they afford designers with. Though these effects may impact on different and possibility unrelated areas of design, they are held together by the common ability to more than technical developments and provide designers with opportunities to rethink both output and working methods.

As already mentioned, the computational architecture of CAD has provided a platform for techniques which had been running on parallel trajectories for several centuries to re-encounter. Computer renderings combine scientific technologies such as surveying, optics, and descriptive geometry which played a key role between the fifteenth and the eighteenth century, as well as photography for its ability to record light and colour, and cinema enabling the introduction of time. Today most CAD packages provide tools that seamlessly merge techniques coming from all these fields. This is a new aesthetic condition in which designers can easily interact with at least four different artistic disciplines, borrow from them, and apply them to their work. This also extends to the mode of fruition which is no longer bound to the screen: Virtual and Augmented Reality (AR and VR) allow volumetric and interactive interactions with the objects modelled. Such technological convergence allows designers to work simultaneously with data, algorithms, and space and venture once again into the representation of elusive qualities of space such as architectural effects.

---

<sup>4</sup> Bottazzi, R. (2018). *Digital Architecture Beyond Computers: Fragments of a Cultural History of Computational Design*. New York, London: Bloomsbury Academic. p. 112.

Similarly, AR and VR moves the point of view of the designer (and later on, user) in the digital space which can be read as either simulations of actual spaces or end products in their own right.

This technological convergence marks a distinct feature of the digital and our contemporary culture in general: synesthetic properties of spaces can not only be conjured up, but also find in the plasticity of algorithmic thinking a fertile infrastructure for expression. The ease with which designers manipulate a complex three-dimensional space has also changed the way in which they interpret the role of their work in the city. Many parameters can be altered in the settings menus of rendering engines to test different lighting conditions and simulating many different environments an object or a building may encounter in its future life. More radically, they provide an ideal testing platform to capture the ephemeral and perceptual qualities of architecture which may both exceed and add to the formal qualities of a piece of architecture. A point in case here are the rendering techniques employed by Jean Nouvel who deliberately deployed these tools to deviate from the codes of architectural representation. For instance, orthographic drawings of his buildings are situated in more extreme, subtler, in other words, less normative conditions such as night life to emphasise the ephemeral, complex interaction between buildings and cities. In his words "...We should be able to take advantage of the emerging poetic dimension of technology. It is ridiculous to see that schools still study the buildings through the production of 45 degree shadows...For me is also important to study a building as it will appear the fog, under the rain, or at night...I think that the coloured red lights and signs of a commercial street are one of the most astonishing architectural spectacles."<sup>5</sup> What computer renderings are challenging here is the solidity, permanence of architecture which is progressively eroded by portraying buildings as dynamic objects in dynamic environments affected by variations in the lighting conditions or by mutating technological and socio-economic qualities of their context.

From a strictly technical point of view, CGI take place in two distinct digital spaces. Objects are modelled in the vector space of CAD, whereas renderings materialise as collections of pixels arrayed in a grid in the raster space of the screen. Vector space is by definition a scale-less environment: objects are described by coordinates, etc., transformations are governed by mathematical operations of addition/multiplication, etc. of vectors. The collection of objects populating such space is an invariant in regards to the choices users make to visualise them: operations of zooming or rotation of the point of view do not alter the objects in the space, simply re-compute their position on screen. On the other hand, the space of the screen is bound to its resolution and therefore to issues of scale: altering resolution has tangible effects on what produced or visible. In their work Michael Hansmeyer and Marjan Colletti have been able to entangle both spaces to create formal compositions that explore and by pass the limitations of raster space by working on the vectorial (formal) resolution of their designs. In Colletti's work, these possibilities are explored in 2D drawings, 3D compositions, and animated space. The spatial complexity of the final composition is such that the fragment no longer appears as a simplification the whole (Fig. 9). By taking advantage of the properties of vector space, his design aesthetic no longer seeks reduction as it does not need to confront the potential loss of resolution imposed by raster display. When observed in its totality, the composition can subsequently reach stunning levels of complexity by exploiting such abundance of information unencumbered by preoccupations of top-down order and legibility (Fig.10). In order to better appreciate the innovative qualities that raster manipulation of space has brought to architecture, it is useful to compare Colletti's work to Voss' which was based on fractal algorithms. The ability to maintain unaltered levels of resolution when moving from whole to a part of it does

---

<sup>5</sup> Zaera-Polo, A. (1994). "Incorporating: Interview with Jean Nouvel". In *El Croquis: Jean Nouvel 1987-1994*, n.65-66, p.35.

remind of fractals as self-similarity is one their principles. The comparison however does not go further as, equipped with exponentially more powerful machines, Colletti conjures up spaces that are no longer bound by predetermined notions of order, not even self-similarity. The technological possibilities of CAD's vectorial space allows designers to morphologically articulate objects *ad infinitum* by closing the gap between data and form to establish connections and mutual transformations between the two. One of the elements of novelty of this line of research is its ability to blend the rigour of computation with perceptual effects which are digitally-native. Therefore, the natural comparison to Baroque architecture is also limiting: if Baroque architects often expressed similar cultural concerns by employing spirals in their buildings – an open, disorientating geometrical figure without beginning or end – here it is the exploitation of the properties of software modellers and renderers that allows contemporary designers to overcome inherited models of order.

Finally, the digitisation of images prompted by their numerical translation supersedes the visual paradigm of modern perspective and the lenticular culture behind it. Computer vision finds a key turning point with the invention of the digital scanner developed at the US National Bureau of Standards by Russell A. Kirsch in 1957. This invention, which came at the end of almost a century of research, moved the image acquisition process beyond both mechanical (perspective machines) and chemical (photography) paradigms as it utilised electrical signals to both scan and transmit data. We saw how this differs from, for instance, Piero's *Other Method* and the new role algorithms acquired in this process. As we pointed out in the introduction, seeing through numbers constitutes a new paradigm in which how we see increasingly coincides with what we see, a decisive difference with historical precedents. Kirsch's team immediately experienced first-hand a condition which we all confront now. The centrality of algorithms is today only more obvious and redefines what seeing altogether means: computer vision in military drones "see" humans not as geometries but as warmer areas (through heat maps) by passing visual semantics. Architects increasingly survey cities or landscapes through LIDAR scanners which "sees" through a laser beam: no lenses and therefore no need for light to act as a conduit of information to be recorded on a medium. As perspective is abandoned as a "symbolic form", another mathematics takes care of the synthetic apprehension of reality, no longer directly accessible by humans but rather interpreted by algorithms. Because of its pervasive application, computer vision represents the frontier of digitally-generated images, the liquefaction of medium into numerical fields apprehended by algorithms. It is on this level that architects and designers in general will have to develop a new form of digital literacy, one that may broadly look like the historical overview provided here: that is, to perform a complex dance between history and technology to tease out and exploit creative opportunities.