The Hidden Territories of the Digital Line

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Abstract

Since the Renaissance, the geometries used within image production have influenced built form by cross-pollinating with architecture's techniques and tools. This cross-pollination constructs new representational schemas that, upon becoming projective, have unique spatial and formal consequences. However, the contemporary digital image profoundly transforms the application of the Cartesian grid. Where previously the grid served as a spatializing device that positioned material edges, the pixel now transforms the Cartesian coordinate system into a boundary where each pixel "cell" demarcates a shift in colour and intensity so that form is delineated through a numerical assignation of colour. Digital images can therefore be used to produce images with the same ambitions as linear geometry, but to do so masks a visual conceit based on vast oppositions operating within a binding paradox. Any silent quotation of linear perspective within the digital image simply continues the embedded ideology found within the formal strategies and applications of linear perspective. The value in seeing beyond this paradox is that it affords very specific and diverse spatial and formal possibilities engendered by digital images. By extension, the political agency of the image can be modified by embracing the mathematical logic of digital geometry. This paper will unmask the inherent conceit of the visual interplay between digital and linear perspective representation. The paper will compare selected geometric, optical and political intersections of these two representational models in order to describe a new instrumental role for the digital image. The aim is to reveal how pixel assemblies, operating through colour and contrast, become the principal projective mechanism for the delineation of spatial depth. The ultimate purpose is to dismantle the projective imprint of linear perspective and to recast the image as a new generative mechanism acting within contemporary "envisioned" urban space.

Introduction

> In the last analysis the sole purpose of 'symbolic forms', their sole *product,* is just this: *the conquest of the world as its representation.*[1]

Brunelleschi's 1425 demonstration of linear perspective in Florence served as a proof of the geometric logic governing the organisation of form in the real world. Drawing on optical science, this highly rational and repeatable procedure organised physical space according to a visual schema. Reinforced by Alberti and Durer, this technique founded a new visual orthodoxy based on a visual continuum between the corporeal space of the viewer and the imaged space in the picture. If previously the image had been questionable for being a representational artifice, then geometry gave the drawing a transcendental authority. Significantly, the ability to reconstruct reality by means of geometry allowed this transcendental authority to work in reverse. The drawing became speculative; it could image both lost and new worlds. Initially co-opted by the Church as a powerful promotional tool by which to give substance to biblical narratives, this new model of pictorial representation became a new visual language within the broader secular world. Engineers, surveyors, artists and scenic designers used perspective machines to construct the Renaissance city three-dimensionally. Moreover, as Ruben's Strada Nuova in Genoa and Sixtus V's 16th-century refurbishment of the Piazza del Popolo in Rome show, urban form became political. Realistic images were constructed to transmit social status by controlling the gaze within tightly orchestrated perspectival views (Gorse 1997).[2] In Genoa, the Strada Nuova was transformed into a *scaena frons* (front of stage) for the Genoese nobility and a courtly centre within the larger city, where it served as a signifier of wealth and social aggrandizement. In Rome, the accelerated perspectival effect created by the scalar domination of the piazza's façade by the twin churches of Santa Maria dei Miracoli (1681) and Santa Maria in Montesanto (1679) was used to direct the viewer's gaze deliberately within a highly controlled space.

The addition of Cartesian coordinates and Desargues' projective theories during the Baroque further reinforced the transcendental status of linear perspective. The Church's desire to establish itself as the arbitrator of singular truths exploited geometry's position as a rational, mathematical procedure. Works like Andrea Pozzo's 1694 *The Transmission of the Divine Spirit* engaged the viewer in a metaphor of optical dynamics, using geometry to conflate the utopic ideal of the church and infinite space. Linear perspective marked "the moment of an epiphany, the revelation of meaning and the God-given geometric order the world."[3] Arguably an exemplar of the culmination of this technique, this work operates according to highly constrained viewing geometries that discipline the viewer to a single "ideal" station point where the "possibility of 'real order' for mortal existence appears".[4] The fine margin of optical error involved in this image provoked sufficient perspectival chaos to initiate a geometric mode of figural "excommunication". Refuting the bodily constraints imposed by the representational adoption of the Cartesian grid, Minim monks Jean-François Niceron and Emmanuel Maignon developed anamorphosis by conflating the viewing and distance points of projective linear perspective geometry. This controversial technique not only released the viewer from a predetermined viewing experience by setting the body back in motion in front of the picture plane, but it questioned the very representational intent and capability of applied mathematics. However, it is the digital colour array that takes the contestation of linear perspective projection one step further.

The digital image stands at the latter end of the diverse history of the application of linear perspective to representation. The technological shifts from analogue to digital image production cannot, of course, be encapsulated in a single paragraph. Nevertheless linear perspective is an ever-present paradigm that continues to affect today's urban form as much as it did in the Renaissance. The continued influence of linear perspective reflects numerous intersections with what digital images attempt to show. Fields of perspectival geometry, optics and politics all underpin the delivery, reception and impact of digital imaging upon the presentation of urban form. These similarities mask significant differences in the application of the Cartesian coordinate system. These similarities and distinctions between the application of geometry, optics and politics within these two interrelated representational models describe the opportunities presented by the technological change from analogue to digital in dismantling the ideological imprint of linear perspective within contemporary “envisioned” urban space. Applied formally as the principal mechanism of spatial depth, the productive aspect of digital technology is that its reconfiguring of Cartesian geometry provides a new strategic and tactical basis for disciplinary agency.

The Affective Data of the “Third Dimension”

> There is a third way of thinking about geometry that stands alongside the visual and the logic-based approaches: the algebraic treatment. Here algebraic structures such as vectors, matrices, and equations are used to form a kind of parallel world, in which each geometric object and relation has an algebraic manifestation.[5]

Descartes’ 17th-century coordinate system united geometry and algebra into a single system of analytic geometry. In effect Descartes’ algebraic application of Durer’s gridded picture plane enabled Euclidean space to have a measurable relationship with the physical world. The assignation of numerical values to coordinates, where each point has an *x*-coordinate representing its horizontal position, a *y*-coordinate representing its vertical position, and a *z* for three-dimensional space, prescribed a reductive representational system devoid of qualitative properties. In the Cartesian coordinate system, the values at any particular point are intertwined with the coordinates themselves: there is a direct relationship between the values at any given point and the location of that point. In a digital image or bitmap array matrix (“map” of locations and values), a particular value has absolutely no relationship to the value at that point. In other words, the value at any location is divorced from the numeric representation of the location itself, thus adding another dimension to the array matrix model, which is unavailable to Cartesian coordinates. Digital geometry, on the other hand, is a particular modelled response to the Cartesian coordinate system,[6] which quantifies the representation of physical space according to an array matrix (screen image) in which each pixel has an intensity value (represented by a digital number) and a location address (referenced by its row and column numbers).[7] However, the alignment of each of these two closely related geometric models belies intriguing inconsistencies, which in turn release new and very different representational possibilities.

Figure 1. Two “ideal” city views: Piero della Francesca’s *Ideal City* (top) and Internet webcam “glitch” image of New York City (bottom)

Extrapolating digital geometry from the rhetoric of the “ideal city” into a contemporary context means that any represented urban scene, such as the ubiquitous public urban webcam view, locates the extra capabilities of the digital array at the forefront, rather than retrospectively at the end of the image-making process, as in an analogue image-making procedure. It also means that a combination of the assigned "three-dimensional" values and the automated technology deliver a product that is intrinsically uncontrollable, in the sense that it is subject to network errors and cannot be constrained to the predictable outcomes of predetermined linear system (Figure 1).

Nor does the act of publication initiate a corresponding moment of closure for the digital array.[8] Invasive imaging protocols such as smoothing or averaging, "noise" removal or filtering, edge detection and contrast enhancement all reflect promotional decisions made to ensure control over image quality and content. Yet while these post-capture procedures, like their earlier analogue counterparts, are designed to curate reception, it is nevertheless both the assignation of values at the image's inception and the fact that it remains active indefinitely across the digital platform that resists the limitations of traditional linear perspective image-making procedures. Perhaps contrary to William J Mitchell's thesis, these features ensure that the digital array produces a more responsive and flexible, rather than "trustworthy", visual record.

> A non-algorithmic image, which is the product of many intentional acts …reveals a lot about what was in the artist's mind. An algorithmic image gives away much less about the artist but provides more trustworthy evidence of what was out there in front of the imaging system.[9]

All of this opens up a conversation about the nature of the digital "three-dimensional" value of the digital array matrix. If each pixel has a real counterpart, then it needs to be represented by more than a number or Cartesian coordinate to provide a comprehensive account of the captured scene.[10] As well as locating each pixel according to an *xy* coordinate, the value of each pixel in a digital array is its colour. In addition to this, the appearance and quality of a digital image is determined by the depth of the pixels, or in other words, the deeper the pixel the more values that can be assigned to it. In 256 digital colour schemes, or indexed colour, a component of each pixel is assigned to the description of brightness. This means that unlike traditional analogue imaging processes, the numeric structure of digital geometry has the capacity to assign highly specific, layered qualitative data to its components, thus forming a dynamic data structure that is not only complex but affective. The inclusion of two of the principal HVS (human visual system) cues of colour and brightness at the very inception of the scene capture thus positions the digital array in a representational arena which not only privileges a comprehensive, qualitative understanding of a captured scene, but forecloses the opportunistic gap between the line and any retrospective addition of ornament.

The representation of shape completes the suite of HVS perceptual cues acknowledged by the digital array. To return briefly to linear perspective projection, this geometry transforms the Euclidean proposition that parallel lines do not intersect into one where they intersect at the point of infinity. Digital lines, on the other hand, can cross without intersecting. This is because, unlike linear perspective lines, which literally cross over each other, digital lines are composed of sequences of pixels that can intersect in segments and at the point of intersection there is no pixel in common (Figure 2).

The pixel also favours certain types of combinatorial arrangements that connect by means of compositional groups or patterns within the image. These types of groupings, unlike either the basic continuous line element of analogue linear perspective representation or the uninterrupted tonal gradation of the photograph, coincide naturally with particular powerful Gestalt groupings of individual elements according to conditions of either similarity or proximity. Because pixel groups occur in strictly finite and mathematical increments according to their properties of similarity, they naturally align with Gestalt principles and therefore privilege the perception of the discrete object. Furthermore, the propagation of these individual elements is based upon information gathered from the neighbouring pixel, or by the interpolation process, which means that these elements create detailed contexts for each other based on similarity and proximity of form, colour, contrast and brightness. In this respect, if a pixel within a certain context has a value that is incongruent with its neighbours, then it is interpreted by the prevailing geometry as visual noise and therefore ignored thereby strengthening the tendency to associate into visible groupings.[11]

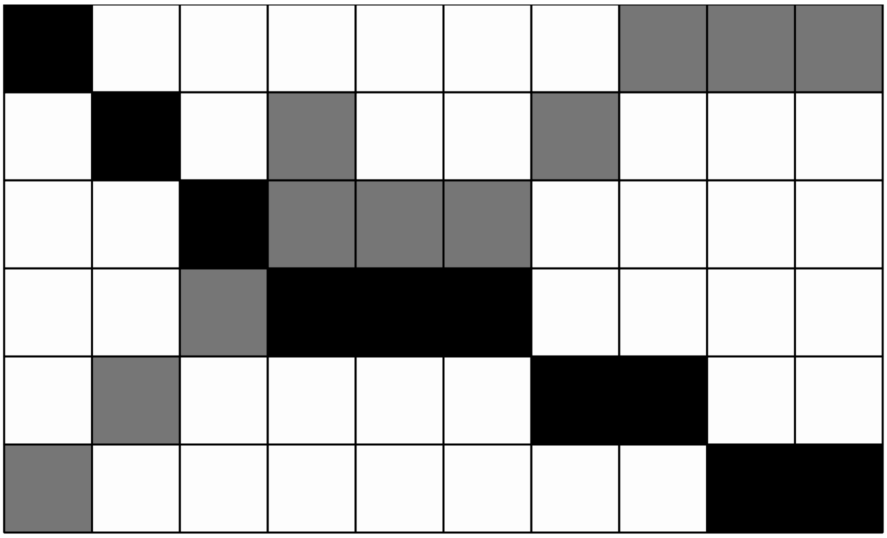

Figure 2. Representation showing two "arcs" (black and dark grey) and an "ellipse" (white) that have no common pixel. Adapted from an illustration by Klette & Rosenfeld.[12]

In terms of a digital array matrix or screen image, the alignment of pixels according to Gestalt principles can only take place when the relationship between the screen resolution, and thus the amount of visual information present within the pixel group, is sufficient to make the individual relations between the pixels evident, or put simply, at a close-up or "zoom" scale where the discrete pixels and their relationships become more prominent.

> Once a digital image is enlarged to the point where its gridded microstructure becomes visible, further enlargement will reveal nothing new: the discrete pixels retain their crisp, square shapes and their original colours, and they simply become more prominent. […] The continuous spatial and tonal variation of analog is not exactly replicable, so such images cannot be transmitted or copied without degradation….A digital copy is not a debased descendent but is absolutely indistinguishable from the original.[13]

In painting or photography, enlargement of the image through close physical proximity in the former case and an enlarger lens and condenser in the latter, degrades it by producing tonal gradients, which yield a fuzzier and grainier picture. However, the enlargement of the evenly distributed and finite geometric content of a digital image instead produces figural cohesion and strengthening. This compels the viewer to investigate different scales of the image by taking advantage of the zoom capacity of the Internet webcam. (Figure 3)

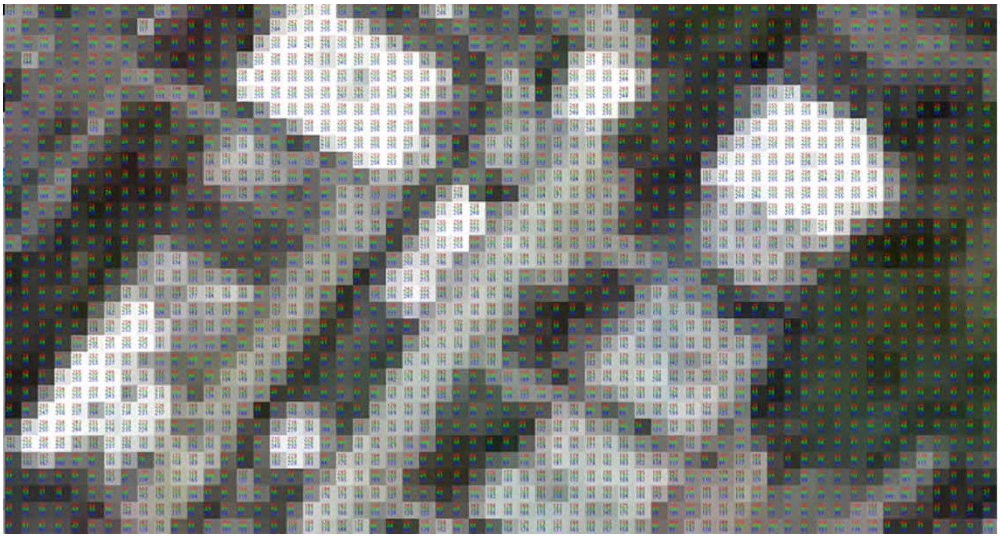

Figure 3. Image of New York generated using PixelMath software showing the distinctness of groupings of pixels arranged according to similarity of form, colour and brightness. [14]

Qualitative content as indexed space

If the act of rotating Durer's perspective grid in a ninety degree arc from a vertical to a horizontal position furnished architects with a means of formalising Renaissance space, then the additional assignation of colour values to the Cartesian grid seen in the digital array suggests a radically new approach to the design of the city's "viewed" surfaces.

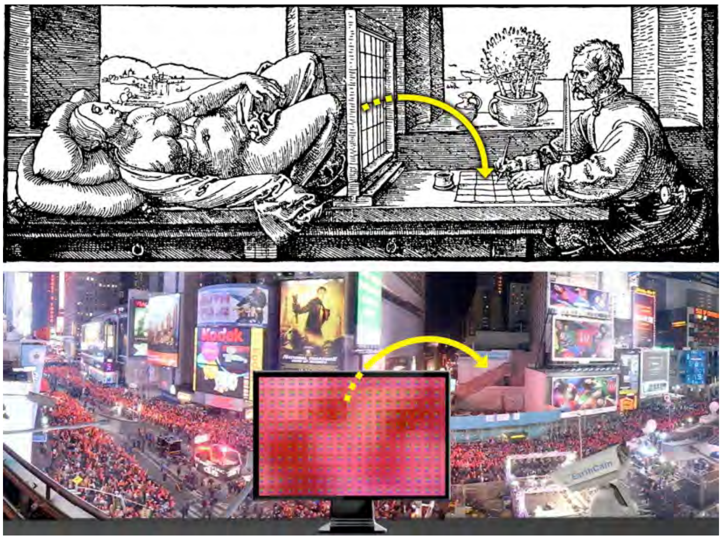

Figure 4. Top. Proposed rotation of the vertical Dürer grid into a projective horizontal plane. Bottom. Proposed rotation of the digital screen array, showing the numerical distribution of pixel values, used as a projective urban grid for Times Square, New York.

With pixel values determining the relationship of image content, it is consequently the assignation on the picture-plane grid of specific numerical values and locations associated with colour and brightness to urban conditions captured by digital arrays, such as public webcams, that provides the "projective" plan for formalising the city. This then establishes a reproducible platform that indexes the properties of the city according to a new range of qualitative criteria. Also, by extension, it means that because these properties are numerically manipulable, they can be strategically transposed into the urban fabric as a range of material relationships. The translation of these projective geometries can be seen in Figure 4, where a simple rotation of the numerical colour and brightness-based grid of the digital screen array to the horizontal ground plane serves as a projective formal grid for the city. Depending upon the desired effect of the intervention, the projective manipulation of this rotated grid could then work either to disrupt or to align with the urban narrative.

Optical Artifice: The Digital Marginalisation of Colour

Prior to the digitisation of the image, colour was always a secondary consideration in the image-making process. The dominance of line can be traced back through the long history of pictorial representation and to Aristotle, whose ideas initiated many subsequent attempts to marginalise colour. For Aristotle, clarity was of the highest value, a preference that persisted in the aesthetic thought of Alberti, Thomas Aquinas and the luminaries of the High Middle Ages, where line was regarded as being a more appropriate vehicle for representation than colour.[15] This was further reinforced by the reflections of Renaissance artists such as Leonardo da Vinci, who was unable to resolve his colour observations into a coherent theory, instead advancing light and shade as the primary visual components of representation.[16] Architectural form, on the other hand, seen in the notion of the *città ideale* in works such as the Urbino, Baltimore and Berlin Panels, was presented in the neutral tones of its own composite natural materials, and in the works of later Baroque and Rococo artists provided a blank canvas against which brightly clad figures were thrown into sharp contrast.

A continuation of the historical approach to colour as a secondary pictorial element and culminating in early 20th-century Modernism is also evidenced by contemporary digital representations of the city. With contemporary technology mediating colour permutations to the viewer, consideration is now given entirely to the proprietary interests of the camera and software manufacturers. This is evidenced by the fact that developments in the understanding of colour vision have far surpassed those made in colour perception theory. The number of colour sensations that can be distinguished by the HVS is numbered in millions, compared with the dozen or so terms used to classify these sensations. This number is further reduced to three or four “primary” colours that relate to the mechanisms of the eye, which translate incident light into perceived colour.[17]

In digital viewing and image-making devices, the specification of colour, or the way that the HVS measures the section of the electromagnetic spectrum is notated according to the idea of a “colour space”.[18] The addition of a particular mapping function between a colour model and a colour space produces a defining gamut or footprint within the colour space, which is constructed to the specifications of the software producer. These proprietary processes are often under-researched and exclusively product-driven.[19]

The processes associated with image reception and transmission, or the image “pipeline”, are highly deterministic simply because they are embedded in an opaque procedure. (An image pipeline or video pipeline is the set of components commonly used between an image source such as a camera and an image renderer such as a computer screen.) As part of the pipeline video transmission process, certain assumptions are made that attempt to bridge the gap between the image-making source (the camera), the image renderer (the computer screen), and the viewer. One of these, subsampling, is a filtering process that exploits the reduced human capacity for colour acuity relative to luminance and discards chroma samples at the video decoder, thus reducing the data rate of the video system to achieve higher speed and more efficiency.

As part of the “pipeline” process, CCD or CMOS sensors are image-sensing components containing grids of pixels, which are used in video cameras as light-sensing devices for image interpretation. Hundreds of individual pixels are arranged in horizontal and vertical directions over the sensor area with a Colour Filter Array (CFA) located above the pixel sensors to capture colour information and convert it to a full-colour image. Because of the location of the CFA above the image sensor, there is only one colour measurement available at each pixel: red, blue or green. However, image reconstruction requires three colours per pixel to output an image. Therefore the other two colours must be estimated using a demosaicing algorithm to complete the interpolation process to achieve a high-resolution image.[20] Put simply, this means that if there is no colour information available then the camera algorithm has to perform the task of interpolating the missing colour data to create three complete RGB colour image planes. This means that the translation of chromatic and luminosity-related data from one neighboring pixel to another remains a process of estimation in which the complete retrieval of the original signal is not possible. This procedural gap exposes the imaging process to all kinds of intervention, such as processes that work to minimise and normalise the digital visual information field leading to the erasure of numerous potentially interesting effects in favour of pre-determined enhancement criteria.

Releasing Colour and Brightness

The problem with these digital processes is not only that they are concealed from the viewer, but that they do not disclose the history of the interventions to which image data has been exposed. So in this respect, just like their earlier analogue counterparts, they too deliberately attempt to establish a continuum between the space of the viewer and the represented space of the picture by erasing the presence of either technology or artifice. Also, in line with this comparative historical context, it is ironically at precisely this "pipeline" locus of proprietary intent and technological difference that disciplinary agency can emerge.

There are numerous CFA pattern arrangements that could potentially out-perform the traditional Bayer CFA pattern that remain unexplored.[21] Further opportunities to vary the distribution of these patterns extend the geometry of the pixel beyond its traditional square form into hexagonal or round forms.[22] With this in mind, it is therefore the ability to intervene within and adapt the camera's CFA pattern that can modify the experience of viewing. In architectural terms, it suggests a very different type of formal approach to the urban surface, which is not only disruptive to these types of predetermined procedures, but which allows hitherto curated colour properties now to be released through a radical transformation and reinterpretation of the procedures that relay image data.

One such approach is to extrapolate commercial CFA patterns and transpose them into the architectural surface as scaled-up "mirrors" of the camera mechanism itself. This has been tested at scale by one of the authors of this paper.[23] the technique relies upon the production of a visible effect to the transmission and legibility of the Internet screen image by means of the mirrored surface pattern. The introduction of a secondary range of colours that affect image reception, in conjunction with the camera's zoom trajectory, would therefore alter the hierarchy of viewed content. This means that the CFA pattern can be deliberately used to disrupt the image's visual hierarchy and to modify façade visibility on digital display systems, or in other words, a building's level of Internet visibility can be determined by the manipulation of its surface colour properties (Figure 5).

Of the numerous artefacts to be avoided in the current approach to image-production integrity, the one considered to be most threatening is optical glare. Fraunhofer diffraction is formed by internal diffraction on the image sensor mechanism of the camera, which acts like a diffraction grating when the scattered light falling on the sensor exceeds the range of luminance that can be accurately measured.[24] Camera response functions are tuned to perform in low-contrast, uniformly illuminated scenes specifically to avoid an optical overload, or what is known as "glare spread function".[25] Contemporary digital camera lenses are explicitly designed to minimise the camera's production of this artefact.

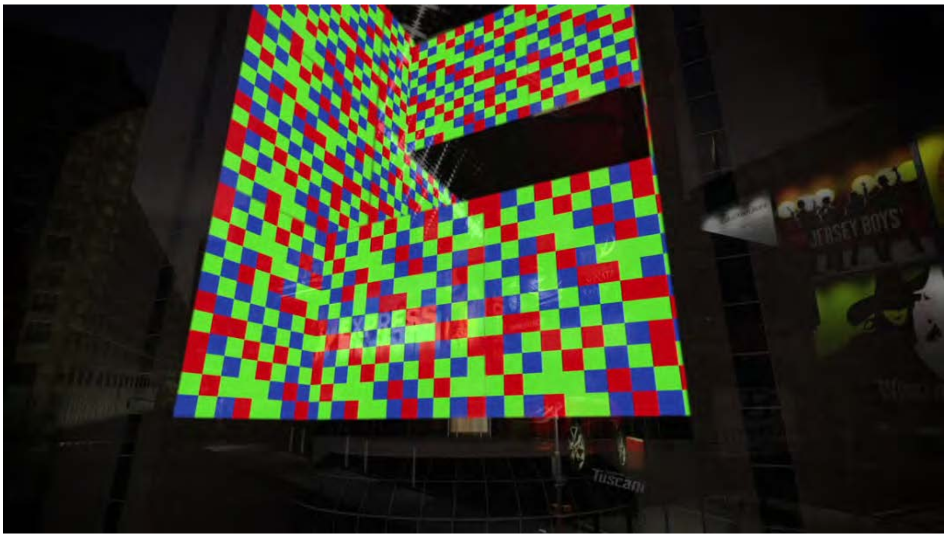

Figure 5. CFA pattern used as a speculative building façade showing a high level of colour and brightness emission to compete with adjacent media displays.

The brightness-related properties of the digital array can also afford similar formal opportunities to those of digital colour. The application of transposed Fraunhofer patterns at a vastly increased scale directly onto the material surface or "screen" façade of a building can produce a collision of optical and digital geometries.[26] This delivers a new material hierarchy that allows a building's visibility to be actively predicted and controlled through the intrinsic aberrations of digital geometry (Figure 6). Furthermore, it would contest the neutralisation of the city image brought about by pervasive acts of proprietary image-enhancement on the very terms by which it is is brought about, thus positioning the geometry of the digital array it as a central agent in both a re-thinking of the city's material qualities and new disciplinary agency.

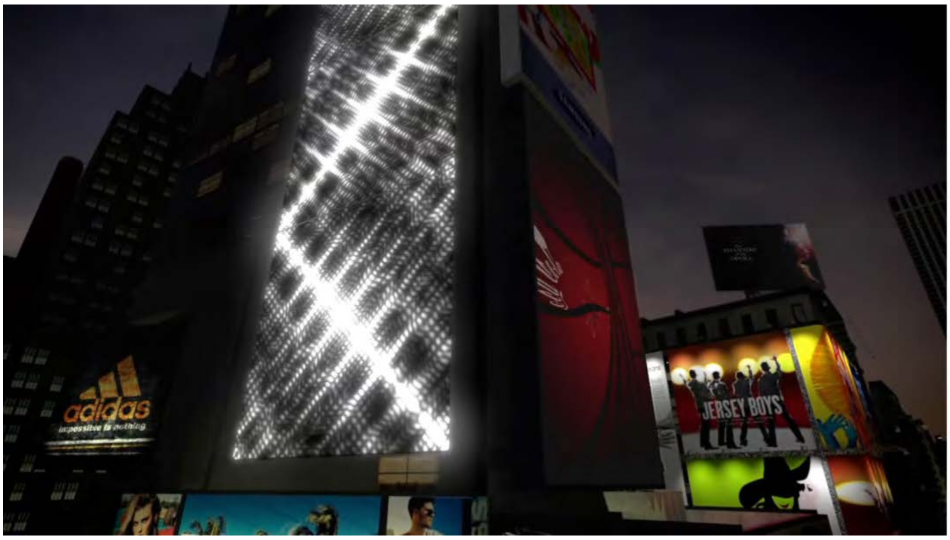

Figure 6. Fraunhofer diffraction pattern used as a speculative building façade "skin" showing a disruptive effect as the camera zooms in.

Conclusion

The pixel radically shifts the rules by which representation is both constructed and formalised. Positioning the qualitative properties of urban space as the operational fulcrum of the digital array shifts their translation into the city's material surfaces into a new realm of political agency because, by definition, digital imaging is an ongoing “open” process. In addition to this, the incorporation of affective data directly into the urban topology completely recalibrates the body’s experiential engagement with the city.

The digital array’s appropriation of the projective geometry therefore offers a very different set of formal opportunities from those of the Cartesian grid. Digital colour array technology has no use for the Cartesian correlation between a point value and its grid location. This type of numerical association of affective data therefore releases the image from the reductive locative constraints of the linear perspective grid. It also releases it from any entrenched procedural strategies designed to normalise image reception because this data is never stable. While the ever-adjustable nature of the digital image and its technological portability resist the production and maintenance of any single urban narrative, they also reposition the body in space. The potency of new formal strategies that either transform the hierarchy of the view or disrupt any iconic presentation of the city ultimately resides in the fact they contest the imposition of a single viewing space upon the viewer. In this respect, the digital array can release bodily experience to a new type of formal, affective terrain based upon ambiguity, and in so doing, it significantly repositions the agency of disciplinary drawing.

Endnotes

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