AND SHE BUILT A CROOKED HOUSE

From its first theoretical documents, *n*-dimensional space has fired the imagination. The mathematicians who began to allow a fourth dimension into their calculations to permit them more easily to solve certain problems, doing away with the experiential limitations of the three dimensions in which we live, could not escape the suggestive possibilities presented to them. Should we ever doubt that geometry itself is a creative discipline, describing forms and, at its origin, bringing them into being?

August Möbius, who first speculated that the fourth dimension might be useful for maths, is best known for his playful strip, a single 2d surface twisted in 3d. Felix Klein, who made significant discoveries regarding curves and "knots" in *n*-dimensional space, is likewise most popularly known for the bottle that bears his name: the Klein bottle takes Möbius's strip and ups the stakes, by making the surface into an impossible vessel. Sculptors, both. The great physicist, James Clerk-Maxwell, was moved to verse:

> My soul's an amphicheiral knot
> Upon a liquid vortex wrought
> By Intellect in the Unseen residing,
> While thou dost like a convict sit
> With marlinspike untwisting it
> Only to find my knottiness abiding,
> Since all the tools for my untying
> In four-dimensioned space are lying,
> Where playful fancy intersperses,
> Whole avenues of universes;
> Where Klein and Clifford fill the void
> With one unbounded, finite homaloid,
> Whereby the Infinite is hopelessly destroyed.[i]

These playful experiments in form made it possible to experience in words and objects aspects of the imperceptible new spaces. Scientists and mathematicians made the imagination central to their practice, and in so doing invited us into it. Such polymathic approaches were common in the nineteenth century, and are less common now. Gemma Anderson-Tempini's work, work that we experience throughout Burton Grange, radically transforms such creative practice for the age of string theory.

As the craze for four-dimensional geometry took hold in Britain in the 1880s – and it was a craze, winning mention in Boy's Own magazines, Oscar Wilde stories, news reports, and inspiring the novel *Flatland* – the possibilities afforded by an incredible form of space that allowed for the inversion of solid objects, or rendered them transparent, or allowed two beings to inhabit the same space at the same time, or objects to be moved from one portion of space to another as if teleported, were seized upon by metaphysical thinkers. This off-kilter house witnessed the period in which this rush of imaginative and intellectual activity occurred. Note the lintel on your departure: the threshold bears the date 1881.

In the years that followed, spiritualist journals were abuzz with reports of experiments that claimed to demonstrate that the communicating intelligences of seances were in fact reaching us from the fourth dimension. Great scandals and arguments erupted, as formerly respectable scientists – the chemist William Crookes, and the astrophysicist, Johan Friedrich Zöllner among them – lent their authority to such speculations.

In an effort to apply the brake to wilder speculations, the mathematician Willaim Spottiswoode urged people to think of higher space differently:

> Like a rainbow, if we try to grasp it, it eludes our very touch; but, like a rainbow, it arises out of real conditions of known and tangible quantities, and if rightly apprehended it is a true and valuable expression of natural laws, and serves a definite purpose in the science of which it forms part […] When space already filled with material substances is mentally peopled with immaterial beings, may not the imagination be regarded as having added a new element to the capacity of space, a fourth dimension of which there is no evidence in experimental fact?[ii]

The imagination, though, cannot be so easily contained. By the close of the decade, two significant movements further accelerated the spread of this mind-bending idea. The nascent scientific romance, as written by H. G. Wells, imagined time travel, trans-hemispheric vision and invisibility made possible through this form of geometry, well-known but little understood. The Theosophical Society, itself a trans-hemispheric, utopian enterprise, identified the fourth dimension with eastern spiritual concept of lôkas, or planes. Theosophists were soon travelling in their minds to the astral plane, from which they could view four-dimensional objects, assisted in their quest by the practices of yoga and meditation.

The art historian Linda Dalrymple Henderson detailed in her 1983 book *The Fourth Dimension and Non-Euclidean Geometry in Modern Art* how a range of such ideas reached the emergent artistic avant-gardes. Stopping short of asserting a direct causal relationship between the early cubist painting of Pablo Picasso and the work of the mathematician Ernst Jouffret, author of *Traite elementaire de gemoetrie a quatre dimensions* (1903), Henderson made a compelling case for influence simply by setting drawings and paintings side-by-side.

What is certain is that the Puteaux cubists, who included the poet Guillaume Apolinaire and the artists Jean Metzinger and Marcel Duchamp, encountered the fourth dimension in salons, through reading not just in Theosophical magazines, and popular squibs, but also, directly, in the work of mathematicians such as Henri Poincaré and Jouffret. “The fourth dimension was primarily a symbol of liberation for artists,” wrote Henderson.[iii]

For Duchamp, who had read both Jouffret and Poincaré, this method found its apogee in the *The Bride Stripped Bare by Her Bachelors, Even (The Large Glass)* (1915-1923). As he told Pierre Cabanne in 1967:

> Since I found that one could make a cast shadow from a three-dimensional thing, any object whatsoever – just as the projecting of the sun on the earth makes two dimensions – I thought that, by simple intellectual analogy, the fourth dimension could project an object of three dimensions, or, to put it another way, any three-dimensional object, which we see dispassionately, is a projection of something four-dimensional, something we’re not familiar with.
>
> It was a bit of sophism, but still it was possible. “The Bride” in the “Large Glass” was based on this, as if it were the projection of a four-dimensional object.[iv]

For the succeeding decade, the ideas of higher-dimensional space continued to circulate, reaching modernist writers, such as Gerturde Stein and Mary Butts, and further informing the work of abstract artists throughout Europe: Hilma af Klint, Wassily Kandinsky, Viktor Malevich, and Piet Mondrian.

What came next was Einstein. Henderson writes: “When the popularisation of Relativity Theory in the 1920s enshrined time as the fourth dimension and Einstein as supreme scientist and philosopher, both Poincaré and a purely geometric fourth dimension were soon largely forgotten by the public and artists alike.”[v] While high art might have neglected these mind-bending spaces, popular fiction, particularly horror and science fiction pulp magazines, kept

the notion alive. SF writers updated and experimented with H.G. Wells's "favourite motif" of the 1890s to allow for strange warpings of narrative spacetime, which themselves fed into comic books and TV shows such as *The Twilight Zone*. One such example, Roobert Heinlein's 1941 short story, 'And He Built a Crooked House,' describes an architect applying the principles of the fourth dimension to the building of a home. It was not so far removed from reality. The Rochester-based architect Claude Bragdon had worked such principles into his own practice.

This giddying cultural-historical account roars into the 20th century, towards Salvador Dalì, H.P. Lovecraft, the New Age, and imaginary spaceships powered by hyper-drives. But all the while another, quieter tradition, has existed alongside. Something more tactile, more domestic, but no less curious for that.

A young British mathematics teacher and writer called Charles Howard Hinton was also interested in the ideas of the fourth dimension, publishing his first essay on the topic in 1880. For Hinton, direct contact with such a space would enable a form of mind expansion that would be accompanied by a blossoming of altruism: in higher dimensions, we are all one. Taking his lead from the writings of Goethe, and specifically the idea of a "delicate empiricism," developed by Gemma in her book *drawing as a way of knowing in art and science* (2017) as "the effort to come to know natural form through prolonged empathetic observation, grounded in direct experience," Hinton sought direct contact with objects in space as a way of accessing the speculated fourth dimension. [vi] He wrote:

> There are two distinct ways of studying space - our familiar space at present in use. One is that of the analyst, who treats space relations by his algebra, and discovers marvellous relations. The other is that of the observer or mechanician, who studies the shapes of things in space directly. A practical designer of machines would not find the knowledge of geometrical analysis of immediate help to him; and an artist or draughtsman still less so. Now, my inquiry was whether it was possible to get the same power of conception of four-dimensional space as the designer and draughtsman have of three-dimensional space. It is possible.[vii]

To achieve this power of conception, Hinton developed a system of colour-coded cubes which, if reflected upon correctly, would train the imagination. He described his system in a series of books and essays. Despite his best efforts, it was extremely difficult to follow and did not catch on.

Hinton' sister-in-law, however, was an able student of his system. Alicia Boole had grown up with her mother Mary's instruction in mathematics at a time when women were excluded from formal mathematical education. Learning curve-stitching as a child – the same practice that feeds into Barabra Hepworth's stringed sculptures – she was already an able geometer, a constructor of parabola, before mastering Howard's cubes.[viii] By careful practice, moving the cubes through sequences devised by Hinton, Alicia learnt the modes of constructing four-dimensional solids.

Charles emigrated and Alicia became a mother and housewife before, in 1897, she sent some models she had made, cross-sections of the four-dimensional equivalents of the platonic solids, to the Dutch mathematician Pietr Schoute. Her brother-in-law's system worked, when the right mind had employed it. Alicia was able to make material the 3D shadows of 4D objects. She went on to co-author three papers with Schoute, and her models live in a store room in Pavilion E of the Mathematics Centre at Cambridge University.

Gemma's work turbo-charges this tradition. Her research has taken its lead from the same ideas of Goethe that inspired Hinton to mediate thinking the fourth dimension through sets of

kindergarten cubes.[ix] Goethe's morphology and philosophy of experiment inform both Hinton and Gemma at a foundational level. Gemma writes of her own development of a drawing method:

> The approach is not an illustration of his ideas, but a visual adaptation of Goethe's 'delicate empiricism' that combines imagination, intuition and observation […] Isomorphology builds on Goethe's morphology by establishing and visualizing a set of form species or Ur forms and symmetries that can be observed in animal, mineral and vegetable species.[x]

Embedded with Alessio Corti and Tom Coates at Imperial College, Gemma's "delicate empiricism" has expanded, and she has picked up the baton left by the avant gardes at a time when physicists and mathematicians working on string theory have become again invested in higher-dimensional space. Gemma is certainly the inheritor of Alicia Boole-Stott's mantle, making in paper, and by 3d printing, material models of the slice forms of irregular lattice polytopes identified by Alessio and Tom. Gemma's various constructions recall not only Alicia's models, but the wooden models of crystals that became popular pedagogical aids in the late-nineteenth century, and the gifts manufactured the educationalist Friedrich Fröbel to encourage children to encounter geometric forms in their play. Yet further models remain virtual: Gemma has made digital models of half a billion unfolded forms.[xi]

How has the dimensional picture changed for scientists, since Einstein? Gemma's story above tells us: "To begin to grasp the idea of nine spatial dimensions, imagine three levels of space. The outer level is our three-dimensional space, then curled up inside our big three dimensions are three smaller dimensions. At every point in our three-dimensional space we pass through them, but we do not know it… curled up again inside those, are three smaller dimensions still… the inner space of the strings… the last of the Russian dolls."

Alessio and Tom work as explorers in the higher realm, returning with samples, imaginary objects, which Gemma makes real in her artworks.

Gemma writes:

> Alessio tells me about how the Islamic mystics of Iran spoke of Hurqalya, the world of imagination, a place between the spiritual and the material and relates this to how the three of us together have carried an object from the immaterial world, where we could only have an intuitive grasp of it coming from our 'presence' in Hurqalya by means of our imagination, into the material world.[xii]

The shadows of higher-dimensional influence cannot be limited to straight lines. What has been astonishing when discussing her work with Gemma has been to discover how instinctively her imagination has alighted upon echoes and reflections of the rich cultural history of the fourth dimension.

Of all the concepts that have emerged from these conversations, two have resonated powerfully with Gemma's domestic life. Twinned objects, mirror-images of each other in our space, are staples of four-dimensional literature: we need only glance at our own hands to see left and right forms that cannot be made to coincide with each other. For Immanuel Kant, these "incongruent counterparts" were ample proof of the resilience of three-dimensional space; by contrast, they crop up in *Flatland* and in Hinton's writing, as demonstrators of how a higher space allows the "flipping" or lower-space objects. With the development of stereochemistry and the realisation that there existed molecules of the same substances which possessed mirror-imaged atomic structures, such twinned forms became important aspects of matter. Further, into the twentieth century, the morphologist D'Arcy Wentworth

Thompson identified such geometric “enanitiomorphs” in nature, in spiral shells and the horns of certain mammals. While developing Isomorphology during her PhD studies, Gemma worked in Thompson’s archive at the University of Dundee.

As the mother of twins, Gemma has described the experience of needing to be in two places at the same time, a form of bi-location that had she only physical access to the fourth dimension, would be available to her. She has dreamt of being able to use a wormhole in order to permit this. She writes that “the idea of turning inside out was a feeling I got close to… the way that parenting twins – especially when Nico broke his leg and I potty trained them alone – has felt like stretching beyond my human limit.”[xiii] This experience is reflected in the lyrics of her song/poem *4D Mother*: “I went to the bottom and I went through.” Gemma must satisfy herself with access to such abilities through the imagination.[xiv]

Wandering around this crooked house, we encounter mirrors, surfaces that fascinated another geometer, Charles Dodgson, and the artist Marcel Duchamp in his attempts to realise a 4d eye.[xv] We hear the song ‘Folding to Infinity’ by Plumm, with lyrics written by Gemma that closely recall James Clerk-Maxwell’s poem, unknown to Gemma when she wrote the words. We see origami forms emerging from wallpaper, models that simultaneously echo geometric craft practices and the model-making culture of the nineteenth century. We encounter a hologram, a sculpture in light; AI-voiced collage, and an AI séance, in which paranormal voices which have never had bodies will be able to answer questions on higher space.[xvi]

Gemma is, naturally, a practitioner of yoga, as popularised by the Theosophical Society in the west. She has even devised a four-dimensional yoga sequence, based on practices to activate the 3rd eye and ‘inner vision’ to prepare the mind screen to visualise a 4D object. I chuckled when I remembered that Charles Howard Hinton had reviewed a yoga manual. In her paintings of four-dimensional crystal forms, Gemma’s colour palette of pastels most frequently recalls to this eye that used by Annie Besant and C.W. Leadbeater in their experiments viewing “thought forms” from the astral plane. The parallels between these pioneers and how Alessio pictures his own mathematical work is striking.

Cross-references proliferate. Of course they do. Allow for more dimensions and you increase the number of connections possible. We can productively think of these interconnections as a form of four-dimensional travel, cutting across mundane time and space to connect categories, concepts and relations. Venture into these expanded spaces and you meet others returning backwards before you.

By containing these references, and enabling us to think and experience glimpses of the unseen higher-dimensional physical world we inhabit, through innovative techniques developed precisely for the purpose, this crooked house expands us all. It domesticates the impossible. In the dwelling Gemma’s work has possessed, the cross-references have included you, the visitors connected by being present in the space. Be sure to climb the frame, a cubic grid exploded, of a type first climbed by Hinton’s children.

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[i] James Clerk-Maxwell, ‘A Paradoxical Ode’, quoted in Daniel S. Silver, ‘The Last Poem of James Clerk Maxwell’, *Notices of the AMS*, 55 (2008), 1266–70 (pp. 1266–7). Silver reinstates the poem from Clerk Maxwell’s notebooks.

[ii] William Spottiswoode, ‘Presidential Address’, *Report of the Forty-Eighth Meeting of the BAAS Held at Dublin in August 1878* (London: John Murray, 1879), pp. 22-3.

[iii] Lynda Dalrymple Henderson, *The Fourth Dimension and Non-Euclidean Geometry in Modern Art* (Boston, MA: MIT Press, 2013), p. 492. First published by Princeton University Press, 1983.
[iv] Marcel Duchamp, as quoted in Pierre Cabanne, *Dialogues with Marcel Duchamp* (New York: Viking Press, 1971), p.40.
[v] Henderson, p. 494.
[vi] Gemma Anderson-Tempini, *Drawing as a Way of Knowing in Art and Science* (Bristol: Intellect, 2017), p. xxx. Gemma develops in her reading of Goethe the idea of the "urpflanze," the "ideal plant" that once seen in the mind would provide the observer with an archetypal form from which iteratively to invent further plants based on the logic of the patterns and forms of nature. These ideas have underpinned hybrid works produced with Alessio, to visualise a 4d tree, and a 4d embryo.
[vii] Charles Howard Hinton, A New Era of Thought (Swann Sonnenshcein: London, 1887), pp.85-6.
[viii] Gemma observes that Hepworth was the mother of triplets.
[ix] My own suggestion is that Hinton's cubes were also inspired by the German educator Friedrich Froebel, whose sets of geometric objects called "gifts" were advertised by Hinton's publisher.
[x] Anderson-Tempini, p.
[xi] It has taken Gemma and Andrew Macpherson over a year to curate a full library of polytopes unfolded in a variety of ways using Jupiter Notebooks.
[xii] Anderson-Tempini, notes from a conversation with Alessio Corti, February 2012.
[xiii] Anderson-Tempini, personal correspondence, August 2023.
[xiv] It should perhaps not surprise us that Charles Howard Hinton was also a parent to twins.
[xv] Alessio and Gemma have made drawings of a 4d eye, and also tried to draw 4d objects in perspective.
[xvi] The holographic principle is an important aspect of string theory, proposed by Leonard Suskind: "The three-dimensional world of ordinary experience — the universe filled with galaxies, stars, planets, houses, boulders, and people—is a hologram, an image of reality coded on a distant two-dimensional surface." *The Black Hole War – My Battle with Stephen Hawking to Make the World Safe for Quantum Mechanics* (Little, Brown and Company, 2008), p. 410