Bending the rules

Crystallography, Art and Design
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Science and art both attempt to represent reality and to imagine what could be as well as what is. A continuum stretches from the intellectual edifice of science which, we believe, is as objective a representation of the world as we can achieve, to the chaotic, sensual, emotional world of art, which selects particular parts of the human experience to illuminate. Later I will mention specific people, but there have always been individuals with interests in both camps. Crystallography as part of science has long had direct connections with art although no domain of science is more tightly constrained by the rules of space and of mathematics. We will begin from these rules and the "freedom of necessity" and move towards the apparently complete freedom of art. In art I will concentrate on the conventional two-dimensional rectangular "picture" and on conventional three-dimensional sculpture, but of course there are no limits to what can be termed "art".

I consider crystallography as connected with art in two main ways, firstly, in providing the rules of spatial geometry and of symmetry necessary for real objects and implicit in their representations. Secondly, crystallography deals with the problems of projection from higher to lower dimensionality and of restoration from lower to higher. I will deal with the idea of projection in the most general sense as the main topic.

The classic picture "Melancholia" by Albrecht Dürer (1471-1528), introduces the problem. It was etched by Dürer in 1514 (the date is worked into the magic square) and reflects his melancholy state of mind when struggling to develop the geometry of projection, although by that time he had largely succeeded. We see what is unmistakably a truncated rhombohedral crystal as the main subject of the picture - but what is it a crystal of ? To answer this question we must measure the inter-edge angle. However, the picture is only a two-dimensional projection of the scene. Can we restore the third dimension ? We can do this, but only at a price. The price is that we must bring to the problem some external knowledge or information of our own about the nature of the scene represented. If we pay the price of assuming that the crystal depicted has a three-fold axis of symmetry, then we can find the projection matrix, restore the three-dimensional coordinates of the vertices and calculate the inter-edge angle. In fact the angle is found to be 82.0 degrees and thus the crystal is not a cleavage rhomb of calcite (which would have 76.1 deg.) but is probably just a drawing exercise, since the axes are in the simple ratio of 3 to 2. We have also as confirmation Dürer's notebooks in which he was working out the mathematics of the drawing.

Let us consider first the rules of pattern.

The Alhambra palace in Granada, the highest achievement of the Moorish Kingdom of Andalusia (which ended in 1492), was a re-creation of paradise on earth (the Persian word 'paradise' simply means 'garden'). The Arabic paradise was to be staffed, somewhat contradictorily, by beautiful virgin girls of infinite experience, but in real life the Caliph would observe the women bathing and make his choices. One would expect that the walls of this enclosed paradise would carry erotic pictures, as do the walls of such structures in other cultures, and indeed the decorations of the courtyard walls of the Alhambra are world famous, but they are, in fact, covered with representations of the 17 crystallographic plane groups of symmetry. Early Islamic art had depicted natural forms but later tradition, in parallel with early Christian tradition, had become strongly iconoclastic and representation of living creatures was forbidden. Islamic decoration specialised in repeating geometric patterns which often used written words as motifs. There is evidence, furnished by carpets and other artifacts, that the Turkish regions of Islam were more concerned with geometric patterns than the Arabic.

Open lattice work in the Middle East was functional as well as decorative in permitting ventilation while it limited access. Craftsmen have described how they lay out the designs of screens, ceilings and vaults with strings and compasses. Recently there was even a modern company in Wales which specialised in producing traditional architectural lattices from silicone rubber moulds for customers in the Gulf. Anyone generating lattice patterns had to know something of the rules governing symmetrical tiling patterns and most artists needing this worked them out for themselves.

The whole question of the intrinsic appeal of symmetric designs, observed in even the earliest human beings, is one which deserves investigation and for which the tools, in the shape of the various scans now showing the operation of the brain, are only just appearing. A remarkable number of people, non-scientists as well as crystallographers, have become enthralled by the symmetry of the regular polyhedra and of repeating patterns. Sometimes they have produced useful and beautiful results. One such was Dr Ensor Holiday, a general medical practitioner, who came upon a remarkable Islamic tiling (in the collection of Bourgoin) in which almost regular polygons with 4, 5, 6, 7 and 8 sides were packed in a square lattice (of symmetry 4mm). With early plotting machines he drew out this pattern in various forms and marketed them (under the trademark of Altair) as colouring sheets for children.

Crystallographic patterns are so attractive that for the Festival of Britain in 1951, Helen Megaw from Cambridge, but earlier at Birkbeck College, with backing from Sir Lawrence Bragg, organised the Festival Pattern Group for the Design Council. Many commercial products like textiles and pottery were produced with design motifs based on the pictures (pre-computer graphics) then coming out of the laboratories. Restaurants on the South Bank were decorated in this way. Some products can still be seen, for example, glass with molecular designs is visible in the Chemistry Laboratories in Cambridge and I still have a necktie with a woven kaolinite structure.

Surprisingly, the explicit tabulation of the 17 crystallographic plane groups, the "wall-paper groups", came much later than that of the 230 space groups. In 1924, George Pólya gave examples of patterns in each group. Crystallographic theory provided the mathematical rules which governed the arrangements of identical motifs in identical surroundings. Around 1950 there was a drive to extend the plane and space groups to include other operations, particularly cyclic colouring patterns. Before 1939, the 46 black and white plane groups had been derived. In these, black and white objects were considered to be equal and opposite and elements of anti-symmetry related them. Russian crystallographers in particular worked on this idea and soon produced the 1651 black and white groups in three dimensions and also the 15 coloured plane groups. These symmetries were obviously apt for decorative purposes. Examples of commercially useful tilings abound and the Cement and Concrete Research Association had a tiling design group which produced interesting interlocking paving blocks that would not separate to leave gaps as the ground settled. It is fascinating to see how many different examples of actual pavings and tilings one can collect. Woven textiles and carpets are a special field where there are strong constraints imposed by the nature of the process. We cannot go into textiles but just mention tartan cloth, with square symmetry where the colour sequences of warp and weft threads are the same and specify the pattern, as the simplest examples. (We might recall that wearing the kilt was prohibited in 1746 by the Hanoverian regime and today tartan remains as a fossilised vestige of a formerly tribal society.)

Symmetry theory continues to develop and mathematicians in Bielefeld have produced elegant examples of 23 topological types of two-dimensional tilings by several motifs together. They have also developed a practical programme, 'Reptiles', now publicly available, which will generate very agreeable patterns in each of the 17 plane groups.

Culturally, some societies go for geometrical symmetry and some try to avoid it. For example, the formal French garden might be contrasted with the Chinese garden.

The work of Maurits Escher must, of course, long remain as the prime examples of the connection between crystallography and art. Although Escher is not well represented in major art galleries, he was popular in scientific circles and he was the guest of honour of the International Union of Crystallography at the Cambridge Congress of 1960. Crystallographers and mathematicians influenced his work but his treatment of their ideas is his own.

Escher's notebooks, edited by Doris Schattschneider, show how intensively Escher worked on the crystallographic groups. He had been shown Pólya's 1924 paper but found the theory prohibitive and preferred to develop it himself with remarkable results. I think that his "Horsemen" remains one of the most memorable tilings. It is surprising that now, even in Delft the home of tiles, Escher tilings are not commercially produced and works which Escher intended for public buildings were not implemented.

Here is one example of a curious cultural transmission. The Otovalo Indians of Ecuador had been weaving textiles with repeating patterns from before the time of Columbus. Quite recently travellers introduced them to Escher's work and his motifs were adopted, adapted and sold back to visitors as elegant modern rugs.

As soon as sets of rules for symmetry were discovered, people tried to break or extend these rules. Many artists have spoken of the effects of strong constraints on stimulating creativity. Igor Stravinsky said : "The more constraints one imposes, the more one frees one's self of the chains that shackle the spirit ... the arbitrariness of the constraint only serves to obtain precision of execution". The pressure to test the rules to the maximum and to find the limits of the permissible have promoted originality. This is the "freedom of necessity". Total freedom is deadening. Even Nikita Khrushchev is supposed to have said that 'they write better poetry in prison'. We might note that, after having blasted avant-garde artists, Khrushchev nevertheless invited the sculptor Neisvestny to make his tombstone which has a strikingly modern black and white anti-symmetric design, emphasising the contradictory nature of the subject himself. It is a test of significant art that it speaks to you, even if you do not like what it says.

It had been often noted that regular pentagonal and decagonal symmetry could not be worked into tilings of identical objects in identical surroundings. Five-fold symmetry did not figure in crystallography and in the International Tables, although sometimes five-fold twins were observed. This contrasted so sharply with the predominance of local five-fold symmetry in living objects that five-fold symmetry was almost the signature of life. Kepler, among many others, experimented with packing decagons. The Islamic tiling masters, the *maalem,* tried their best to work pentagons into their designs. In mosques they were sometimes challenged to work on surfaces doubly curved in space, which brought the new problems of a different metric which encouraged pentagons. In 1196, in Marageh in Western Iran, on the site which later became the Observatory of Hulagu (the Mongol ruler) with Nasr al-Din al--Tusi, the translator of Euclid into Arabic, as its director, a tower was built bearing a curious aperiodic pentagonal pattern, now seen to be closely related to that of quasi-crystals. There must have been some mathematical tradition in the place and perhaps a master designer was challenged - 'if you are so clever, now do it with pentagons'. Perhaps the general challenge to work new observations into one's total world view was paralleled in the restricted geometric model of how to accommodate a new kind of tile into one's wall decoration.

In 1974 Martin Gardner, in his renowned mathematical column in The Scientific American, discussed the new aperiodic tilings of Roger Penrose. In these, two different interlocking motifs, "kite and darts" were used together. Penrose was concerned to produce a jig-saw tiling where the local rules for joining pieces would force aperiodicity, but the same geometry resulted from a set of hierarchic packing rules which began with Bernal's suggestions for the hierarchic packing of icosahedra associated with the discovery that polio virus particles had icosahedral symmetry. Gardner's column generated great activity and many different mathematical aspects of aperiodic tilings were explored. This exploration culminated with the announcement in 1984 of the experimental observation of quasi-crystals, which set off a new line of crystallographic and artistic discovery with the production of thousands of papers. Penrose tiles, extended to three-dimensions, have the necessary diffraction properties. How they result from the interactions of atoms is still being investigated. The incident has been a clear illustration of Einstein's comment that "the human mind has first to construct forms, independently, before we can find them in nature".

In the West oil-painting has been the central graphic technique but the technology for producing two-dimensional pictures has developed rapidly and nowadays almost anything, real or imagined, can be made. What is the physical difference between the original of Van Gogh's 'Sunflowers' and the colour Xerox copy? We can even now replicate the irregularities of an oil-painted surface. Compare a picture, composed using a computer, with one painted by hand by a modern painter (Mark Rothko (1905-1970)) of high repute (at least in some parts of the art world) - The Tate Gallery has a whole room devoted to 'pictures' like this! There is a case for saying that two-dimensional painting is dead and must be completely re-appraised. Somewhat earlier, Malevich with his 'Black Square', a kind of no-picture, indicated that painting had negated itself. Did it represent ideas or what one saw? Part of the modern movement has been to produce pure pattern, with no representation of nature, exploring mathematical relationships and tentatively beginning to rise out of the two-dimensional paper into three-dimensional space. Victor Vasarely exemplifies this trend. The skill is minimal compared to that of the classical portrait painters and today it is trivial to generate this kind of pattern with a computer. Nevertheless there were still some surrealists, such, for example, the Spanish-Mexican painter Remedios Varo (1905-1963), who employed great skill and imagination, following the example of Hieronymous Bosch. In general I believe that, since the overthrow of traditonal pre-photographic representational painting, two dimensional art has not found a new tradition with sufficient constraints to require real creativity. Richard Feynman clearly stated the problem of science:-

"The whole question of imagination in science is often misunderstood by people in other disciplines. They try to test our imagination in the following way. They say, 'Here is a picture of some people in a situation. What do you imagine will happen next?' When we say, 'I can't imagine,' they may think we have a weak imagination. They overlook the fact that whatever we are allowed to imagine in science must be *consistent with everything else we know,* that the electric fields and the waves we talk about are not just some happy thoughts which we are free to make as we wish, but ideas which must be consistent with all the laws of physics we know. We can't allow ourselves to seriously imagine things which are obviously in contradiction to the known laws of nature. And so our kind of imagination is quite a difficult game. One has to have the imagination to think of something that has never been seen before, never been heard of before. At the same time the thoughts are restricted in a straightjacket, so to speak, limited by the conditions that come from our knowledge of the way nature really is. The problem of creating something which is new, but which is consistent with everything which has been seen before, is one of extreme difficulty. ("The Feynman Lectures in Physics", 1963).

The problem of working within a strict artistic tradition, such as ikon-painting for the Orthodox Church, is one of similar difficulty. Modern artists, having rejected all rules of tradition, face the opposite problem. With no rules, what rules are they going to rebel against?

Art deriving from crystallography at least has rules which can be explored and perhaps bent. Hans Hinterreiter (1902-) is a geometric painter who has started with crystallographic patterns but who has applied various transformation functions to remove exact identity and make the designs more interesting. This technique parallels what happens in growing organisms and corresponds to the tendency of mathematical crystallography to deal with the more general structures found in nature. The crystallographer A. V. Shubnikov, in particular, was early in exploring the mathematics of similarity transformations which, with the popularisation of 'fractals' have now become useful for actual structures, particularly those of quasi-crystals.

It must be mentioned, of course, that the instruments of science, especially of course microscopes, furnished images which, like the *objets trouvés* characteristic of a standard trend in art, are of aesthetic interest and bear also emotional appeal. The molecular graphics images of haemoglobin due to Max Perutz begin to answer the question of John Donne: "Why grass is green, or why our blood is red / Are mysteries which none have reache'd unto". György Kepes, I think, set up a laboratory at MIT to teach scientists how to convert by-products of their research into art objects. The work lies in the selection, just as a painter selects what brush strokes to make and what colours to use.

Albrecht Dürer visited Italy to learn about perspective, the projection of a three-dimensional scene on to paper, and in 1525 he wrote his great textbook developing the works of Euclid for the practical purposes of art. Euclid has always been the starting point and Dürer was in touch with the mathematicians of the time. The relationship between two and three dimensions has always been the challenge of painting. Picasso and Braque lived in a garret along with an academic drop-out, Le Mathematicien, who must have fed them ideas about the fourth dimension, relativity and such like, influencing the development of cubism, where space began to rise out of the canvas. Picasso, with his well-known bull's head, produced from old bicycle parts, demonstrated that 2 + 3 do not necessarily make 5 but may put the viewer on a completely different track and encourage him to reconstruct what he sees completely differently. This is the principle used by nature in symbiosis and called 'Bricolage' by Francois Jacob. Complex eucaryotic organisms seem to have developed from single-celled organisms in this way by chance association.

The art of the conjurer is to induce the viewer to reconstruct what is seen in the wrong way. We see some occurrence from one direction only and must reconstruct the reality by supplying information of our own. The conjurer uses our natural habits of perception to encourage us to think that the scene has been projected in one direction whereas it has actually been projected in another. We supply the missing information wrongly. Here I use the word 'projection' in a very general sense.

Shadow puppets exemplify this idea. Naum Gabo illustrated the reconstruction of a solid object from sections or projections just as crystallographers reconstruct ribosomes.

The actual science of vision is also exploited by painters. We have two eyes so that we have two two-dimensional views to combine into a three-dimensional object. The brain has a hard-wired arrangement for estimating the parallax, the third dimension, by comparing the signals from the two eyes at an early stage in signal processing. The brain operates with a three-dimensional model of the world. If you are going to be a spy, then you should always take two views from different viewpoints of your objective. We can illustrate this with a stereo pair of the new Secret Service Building on the Thames opposite the Tate Gallery.

The eye is non-linear and edge contrast is enhanced. This helped our survival as hunting and as hunted animals. Many physiological optical effects have been used, sometimes intuitively, by artists. Bridget Riley's picture "White Discs" appears to have the wrong title but, if you look intently, you will see the white discs, produced by the persistence of vision, flitting about among the black. Repetition of the same signal may overload the visual system producing nausea and paradoxical signals of depth. In the pre-computer days I once tried to make a diffraction grating photographically by first ruling 200 lines on a drawing board, but I had to stop because of nausea. Bridget Riley, I understand, gets an assistant to do the drawing.

René Magritte (1898-1967), in particular, has specialised in exhibiting paradoxes of visual interpretation. An earlier trend of virtuosos of painting has been to produce *trompes d'oeil* illustrations which use clues such as shadows, one object overlying another, acute perspective distortion and so on to give an illusion of an exact three-dimensional scene. Carlo Crivelli was an early master of reality. He produced an imaginary view with correct perspective. Viewing from a single viewpoint we have no alternative but to interpret what we see as a solid scene. A painting on a flat ceiling may demand to be interpreted as showing a deep vault in the sky.

Albrecht Dürer apparently invented folding cut-out models of polyhedra taking us from 2 to 3 dimensions. Polyhedra, as mentioned above, appeal particularly to the spatial imagination and are widely used industrially, as here for water tanks found on Mexican rooftops. They are clichés of the visual vocabulary on which more elaborate essays can be built.

I must now come to some personalities. Artists are always testing the rules to find the limits. In the time of Edouard Manet nude figures were appropriate for classical statuary and the bourgeois public also appreciated family scenes, but to combine these in the *Déjeuner sur l'herbe* caused serious scandal. Crystallography has its equivalent scene with this rather poor photograph of J. D. Bernal, the founder of the crystallographic laboratory at Birkbeck College, chatting up a young woman at a picnic on the grass during the first IUC Congress held in 1951 in Stockholm. Members of the 'invisible college' around Bernal and the Club for Theoretical Biology in Cambridge of the 1930s were closely in touch with artists. Barbara

Hepworth, Ben Nicholson, Henry Moore, John Piper, Victor Pasmore and many others discussed common interests with scientists. (Arthur Loeb, at Harvard, mentions in his memoirs that his mother used to dance with Mondrian, so that there is, in America, another connection involving crystallographers.) I must mention in particular C. H. Waddington, the biologist, who produced a magnificent volume, "Behind Appearance , the influence of science on art in the twentieth century" as the culmination of a lifelong interest. His opinions of Rothko, Jackson Pollack and others are far higher than mine, so that you should certainly consult his book. There used to be a rather poor picture of a crystal drawn by Barbara Hepworth around the Birkbeck laboratory which would not have got her through the crystallography examination. A better picture of Bernal invites comparison with William Blake's undignified picture of Newton which has recently been copied by Eduard Paolozzi as a twelve foot bronze image for the new British Library forecourt. Henry Moore is not one of my heroes and I think that his huge bronzes are a waste of good metal. In distinction to natural objects like a skull, they have no structure inside. The Tibetan bronze which I compared with the portrait of Dorothy Hodgkin exhibits a superior technique and more elaborate ideas. I am a Philistine, not in the sense of Yassar Arafat but in the sense of Matthew Arnold. Like my favourite painter Tom Keating, the scourge of the art critics, we should not miss an opportunity to mock the pretensions of the critics who do not themselves create. For example, the Penguin Dictionary of Art and Artists described the lost wax casting process: "The outer side of the wax is exactly what the desired bronze should look like; and molten bronze is poured through the top vent, melting the wax (which runs out at the bottom) and taking its place". The Tibetans knew better and this recipe seems to me to be a prescription for a face full of molten bronze.

If two-dimensional representation is about right in difficulty, then three-dimensions is really too difficult and artifacts cannot compete with natural objects for detail and significant organisation. One has only to look into the Tate Gallery. Nevertheless, the push must be in the direction of higher dimensionality. Up from flat tiles we have blocks of surprising sophistication for making a wall which needs no cement. Attempts to impose inappropriate three-dimensional crystallographic form lead to difficulties. In Rotterdam, houses made from cubes with their [111] axes vertical challenge the creative architect to defeat the arbitrary constraints and to make the interiors comfortable, in the way I mentioned earlier. The huge model of alpha-iron constructed for the Brussels Exhibition of 1958 furnishes the only example of an atom with a restaurant inside it. Some of the Islamic architects were more subtle and the cunning way in which the differently coloured blocks in the Sultan Hasan Mosque and in Al Azhar in Cairo proved so baffling that their descendants broke them apart to see how the dovetails were designed. The mosque by Sinan in Edirne has triple helix minarets and Western builders too produced spiral staircases of great ingenuity and beauty. Existence in three-dimensions is the strongest of constraints and evokes creativity both from organisms evolving and from human architects as they explore the configuration space available to them.

Cézanne said: "Treat nature in terms of the cylinder, the sphere and the cone, all in perspective". Now there are newer and richer stereotypes to use. Crystallography itself has recently been enlivened with new three-dimensional patterns involving curved rather than flat surfaces. The gyroid surface occurs as the interface between different polymer phasesid into Arabic, as its director, a tower was built bearing a curious aperiodic pentagonal pattern, now seen to be closely related to that of quasi-crystals. There must have been some mathematical tradition in the place and perhaps a master designer was challenged - 'if you are so clever, now do it with pentagons'. Perhaps the general challenge to work new observations into one's total world view was paralleled in the restricted geometric model of how to accommodate a new kind of tile into one's wall decoration.

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In the West oil-painting has been the central graphic technique but the technology for producing two-dimensional pictures has developed rapidly and nowadays almost anything, real or imagined, can be made. What is the physical difference between the original of Van Gogh's 'Sunfltness of Kepler was that he eventually ditched his *a priori* Mysterium Cosmographicum (the nested Platonic solids) in favour of elliptical orbits. People were continually trying to see *a priori* forms in Nature and this sometimes obscured their vision of what was actually there.

We have discussed projection and how it reduces dimensionality by making reconstruction or resurrection impossible unless extraneous information is supplied by the reconstructor. A symbol is a complex situation projected to zero dimensions. It is just a datum point or name, meaning nothing unless you knew before everything necessary. The Orthodox Church was using ikons many centuries before Microsoft. For example, this ikon represents St Catherine of Alexandria. The Catherine wheel is the label - if you do not know this beforehand then the ikon tells you nothing. It just reminds you of the story of the martyrdom of Catherine which you should have learnt elsewhere. If you want to construct an ikon then you have to put in characteristic labels.

Abstract concepts are related to each other and these connections can be shown in various ways by diagrams which connect corresponding ikons, using the visual apparatus developed by evolution for survival. The most important kind of diagram is the tree, developed by Ramon Llull (1235-1315) for theological purposes. We are familiar with trees because those of our ancestors who were not so good fell out of the trees and did not reproduce. We have, for example, highly developed brain algorithms which see branches as continuous even when they are crossed by other branches. On this basis we can confidently leap from one branch to another. This is why people are still necessary in making sense of the images of protein molecules produced by X-ray crystal structure analysis. They are better than computers at moving around in the protein trees. Both real protein molecules and real trees are structures obeying the strong constraints of existence in three-dimensional space.

Other abstract diagrams are the mandala and the matrix where ikons are arranged in hierarchic order or are laid out as a table. These geometrical diagrams were and are widely used. Every laboratory has the mandala of the periodic table of the elements to remind people of the cosmic order. Mandalas are very agreeable abstract designs but you have to know what they mean. Meaning is not self-evident as in a picture. If you don't know the story, you miss the point. Some ikons, as in this severed head, are quite realistic but we have to know the story, in this case of Salome asking for the head of John the Baptist, to appreciate the lesson that we should be careful what we promise at times of sexual excitement.

Some symbols are complicated, as in the alchemical pictures where feudal society and sexual relations are used to talk about chemical reactions, there being then no special terminology for chemistry. Chemical reactions are now represented by simple symbols but this statement emphasises that we can tell lies with symbols, as indeed with fabricated pictures. To get a true answer from the manipulation of symbols the rules must be carefully set up.

Still more dimensions can be added to pictures and sculpture, particularly the dimension of time. The famous picture by Marcel Duchamp (1912), the "Nude descending a staircase" indicates a time dimension, but he was long anticipated by a cave painting from Altamira which showed a nude boar descending a staircase. Just the same technique is still used today in showing the vibrations of molecules. More abstractly, Waddington developed ideas of the epigenetic landscape, an imaginary landscape in many dimensions through which a defining point moves to represent the various decision points in the evolution of a species or an abstract situation. These graphic pictures make catastrophe theory much more appreciable and they have even entered the vocabulary of "Gray's Anatomy", the textbook used by every medical student.

Adding motion to three-dimensional sculpture was introduced into art about 1930 by Alexander Calder (1898-1976) with his 'mobiles', which are now to be see above dentists' chairs and infants' cots. However, moving sculpture can do better. Calder's mobiles are trivial compared with a clock or steam-engine. A real steam-engine brings many emotional and intellectual connotations. It suggests the power of Jehovah and indeed the Society for the Propagation of Christian Knowledge, in the Victorian period, published a manual entitled “A Catechism of the Steam Engine” associating religion with technology.

In the time of the eighteenth century Enlightenment, (represented here by Denis Diderot, the author of the Encyclopaedia, who produced a still-interesting dialogue on the nature of living organisms), the idea of Man - a Machine was floated by LaMettrie, who caused such a scandal that he had to leave France. This coincided in time with the production of automata moving by clockwork, which was the high technology of the time. Vaucanson built very elaborate automata with programmes of motion stored on punched cards (invented by Jacquard for weaving patterns automatically) or by pins in drums, which stored information in bits like today’s hard discs.

Jean Tinguely has shown parodies of machinery but automata as an art form largely died out in the face of other media, although recently there was an exhibition at the Festival Hall of modern automata. They are not electronic but mechanical, because seeing the wheels go round is part of the excitement. Here were some examples of sculptures where motion with time is a new dimension added to those of space.

You may comment that any day now I may think of the cinema. Just so, but I venture to offer this idea as a direction which art may take in order to escape from its present period of relative sterility. I recommend to you Bernal’s advice on how to deal with generals and admirals. He said, that if you produce a written report generals will not read it; they will condescend to look at still pictures and they are very interested in models; but what really excites them is a full-scale demonstration. I think that this is a general principle and suggest that crystallography with stereo-graphics and physical models has lessons to offer to the art world and that correspondingly we ought to look out around the art world to see if they have methods of presentation which we might learn from.

Illustrations:

[1L] “Melencolia”, Albrecht Dürer, (copper engraving), (1514).
[1R] The Alhambra, Granada. [A.L.M., 1956]
[2L] Wall tiling from the Alhambra [A.L.M., 1978]
[2R] Transcript of Kufic decoration from the Bibi Khanum Mosque in Samarkand.
[3L] Stone lattice-work from Humayun’s Tomb, Delhi [A.L.M]
[3R] Brochure from Lattis Ltd., Wales, showing modern fabrication of traditional lattice-work.
[4L] Dr Ensor Holiday and one of his decorations based on an ingenious Islamic tiling by almost-regular polygons with 4-, 5-, 6-, 7- and 8- sides which was used in his Altair drawing sheets [A.L.M.].
[4R] Exemplars of the 17 crystallographic plane groups drawn by George Pólya (Z. f. Krist., 1924).
[5L] “Crystal Designs”, booklet produced by the Festival of Britain Design Group (1951) illustrating crystallographic motifs used in industrial design. (Initiated by Dr Helen Megaw)
[5R] do.
[6L] 2-D tiling produced by the programme “Reptiles” of D. Huson, O. Delgado and A. Dress (Bielefeld) [A.L.M.].
[6R] do. [A.L.M.]
[7L] Exemplars of the 46 Black and White plane tilings
[7R] Exemplars of the 15 Coloured plane symmetry groups (Belov et al.)
[8L] Application - a pavement tiling with the plane symmetry group pgg [A.L.M.]
[8R] Mackay tartan.
[9L] The 23 topological types of the Heaven and Hell tilings. (Huson, Delgado and Dress)
[9R] do.

[10L] Cultural differences in symmetry - French chateau garden Villandry, Loire).
[10R] Traditional Chinese garden.
[11L] The work of Maurits Escher (cover of book by Doris Schattschneider).
[11R] Escher's most famous picture "Horsemen"
[12L] Civic design by Escher, not accepted for execution (from Schattschneider).
[12R] Woven rug produced by the Otovalo Indians of Ecuador stimulated by Escher's work [A.L.M.].
[13L] Kepler's explorations of the packings of pentagons/decagons.
[13R] Islamic tiling with pentagonal/decagonal motifs (Isfahan) [N. Rivier]
[14L] Islamic tilings exploring pentagonal symmetry (Isfahan) [N. Rivier]
[14R] do.
[15L] The aperiodic "kites and darts" pattern of Roger Penrose [Sci. Amer. 1974] [A.L.M. will replace]
[15R] "The Blue Tower" , [Gonbad-é-Kaboud] (The tomb of the mother of Hulagu), (Maragheh, W. Iran, 1196) ["Islamic Architecture", p.100]
[16L] Commercial execution of Penrose's "kites and darts" tiling. [A.L.M.]
[16R] Tiling for an infinite mosque based on the Penrose pattern [A.L.M.]
[17L] Two tiles for the Penrose tiling with matching rules. [A.L.M.]
[17R] Jig-saw puzzle pieces forcing tilings in the 17 plane groups [A.L.M.]
[18L] Textile weave corresponding to the dualisation method of N. A. DeBruijn. [A.L.M.]
[18R] The pentagonal snowflake - illustration of the hierarchic nature of the Penrose tiling [A.L..M]
[19L] Computer processed picture from the Annual Report of Logica plc. (1995)
[19R] "Light Red over Black", Mark Rothko (1957). Tate Gallery T00275.
[20L] "Black Square" by Kazimir Malevich, [A.L.M.]
[20R] "Cheyt stri - tapisserie" (1971) by Viktor Vasarely (1908-) (Catalogue, Culan, France, 7 Sept. 1975).
[21L] "Harmony" (1956). Remedios Varo (1905-1963). [Kaplan, p. 190]
[21R] "Spiral Transit" (1962). Remedios Varo (1905-1963). [Kaplan, p. 170]
[22L] "Opus 164 C" (1962-1981) by Hans Hinterreiter (1902-). Szépmüvészeti Múzeum, Budapest, 1987. and Z. f. Krist., 150, 13-21, (1979).
[22R] Chance electron microscope picture from bent gold foil - extinction contours. [J. V. Sanders, CSIRO Tribophysics, Austalia][A.L.M.]
[23L] Albrecht Dürer, method of projection for picturing a lute
[23R] "The Elements of Euclid" by Oliver Byrne, (William Pickering, London, 1847) [A.L.M.]
[24L] "Bull", (from bicycle handlebars + saddle), Pablo Picasso (1881-1973)
[24R] "Portrait of Ambroise Vollard", Pablo Picasso (1881-1973) [Pushkin Museum, Moscow]
[25L] Indonesian shadow puppets
[25R] "Head no. 2" (1916) by Naum Gabo (1890-?). ["Naum Gabo, Constructions, Paintings, Drawings", The Arts Council, Tate Gallery, 1966].
[26L] Stereo picture (cross eyes) of the Secret Services building on the Thames [A.L.M.]
[26R] Stereo vision
[27L] "The Annunciation" Carlo Crivelli (ca 1430 - ca 1494) [National Gallery]
[27R] Trompe d'oeil. Vault of the Nave of S. Ignazio, Rome, by Andrea Pozzo (1642-1709)
[28L] "White discs I", by Bridget Riley, (1964). [A.L.M. can replace this]
[28R] Optical illusion with sine waves of changing frequency. [A.L.M.]
[29L] René Magritte (1898-1967), "Euclidean promenades", 1955.
[29R] Trompe d'oeil. "Cupboard", Domenico Remps (?), (17 cent.) Museo dell' Opificio delle Pietre Dure e Laboratori di restauro opere d'arte. [Darmstadt II, p.915]
[30L] Albrecht Dürer's diagram of a folding-up dodecahedron. [A.L.M.]
[30R] Application of polyhedra for domestic water tanks, Mexico. [A.L.M.]
[31L] "Déjeuner sur l'herbe" by Edouard Manet,
[31R] J. D. Bernal chatting up a young woman at the first IUC Congress, Stockholm, 1951. [A.L.M.]
[32L] J. D. Bernal (1901-1971)
[32R] William Blake's picture of Isaac Newton
[33L] Maquette for Paolozzi's statue of Isaac Newton after Wm. Blake for the New British Library.
[33R] "Three-way Piece (Points)" (1964) by Henry Moore (GLC Exhibition, Battersea Park, London, 1966).
[34L] Self-portrait (1950) of Barbara Hepworth (1903-1975). National Portrait Gallery, London.
[34R] "Three forms", (1935) by Barbara Hepworth, [Tate Gallery T00696]
[35L] "Dorothy Hodgkin (1910-1994)" by Maggie Hambling, (1985). National Portrait Gallery, London.
[35R] Tibetan bronze figure of Ushnishavijaya. Ukhtomski Collection, Hermitage, Leningrad. ("The Sacred Art of Tibet", M. M. Rhie and R. A. F/. Thurman, Royal Academy of Arts, London , 1991. p.318.
[36L] Interlocking wall blocks. Bad Nauheim, Germany. [A.L.M.]
[36R] Cubic houses with [111] axes vertical in the Port of Rotterdam [A.L.M.]
[37L] Interlocked blocks in the Sultan Hasan Mosque (1350), Cairo, [A.L.M.]
[37R] The Atomium (model of alpha-iron) at the Brussels Exhibition (1958) [A.L.M.]
[38L] orthorhombic CLP surface by J. Klinowski et. al. [A.L.M.]
[38R] Gyroid surface observed in liquid crystals (Monnier et al., Science, 261, 12199-1303, (1993))
[39L] "The struggle of oil and water", S. Takahashi (1996). [A.L.M.]

[39R] Laocoön and his sons, ca 25 BC, by the workshop of Hagesadndros et al. of Rhodes. The Vatican Museum.
[40L] I-WP surface as represented by S. Takahashi [A.L.M.]
[40R] Möbius object. S. Takahashi (1996) [A.L.M.]
[41L] Facade of church at Lambeth North [A.L.M.]
[41R] I-WP surface, J. Klinowski et al. [A.L.M.]
[42L] Symmetrical polyhedral objects from Scotland (Ashmolean) (Darmstadt collection)
[42R] Symmetrical (4) Pictish grave carving HMSO.
[43L] "The Durham Cassiodorus" (folio 172v). Celtic book page made in Jarrow. (ca. 7-8 cent.)
[43R] "The book of Durrow". Celtic book page. (7-8 cent.) (do.)
[44L] Luca Pacioli, "Divina Proportione"(1509).
[44R] Icosahedron by Leonardo da Vinci for "De divina proportione" by Luca Pacioli. (1509).
[45L] Geometrical pavement in Westminster Abbey, London.
[45R] Penrose tiling in the style of Leonardo da Vinci's drawing. [P. Kramer]
[46L] Icon of St. Catherine of Alexandria by Victor of Crete, 13 cent.
[46R] Icon for Linus Pauling [A.L.M.]
[47L] Mandala
[47R] Mandala of the Periodic Table of the (Chemical) Elements
[48L] "Arbre Exemplifical" (1505) by Ramon Llull, (Moll, Palma de Majorca, 1971).
[48R] Ramon Llull. Cover of "The Art of Memory", Frances Yates, Penguin.
[49L] Mandala/Matrix
[49R] Icon of the head of John the Baptist, by Ruiz de Peral. Granada Cathedral.
[50L] Alchemical picture. "In a castle which represents the philosopher's furnace, Lady Alchimia dwells in state with her consort the Athanor King... etc." 15 cent. Biblioteca Apostolica Vaticana. (from Klossowski).
[50R] Cu + Al = Cl + Au [A.L.M.]
[51L] "Nude descending a staircase", (1912), Marcel Duchamp (1887-1968)
[51R] Cave painting of moving boar, (Altamira, Spain).
[52L] Moving molecule of MangGlcNAc2OH, Structural Biology, 1, (8), 499, (8 Aug. 1994).
[52R] Epigenetic landscape, (catastrophe theory) Gray's Anatomy, (ca. 1975)
[53L] Portrait (1767) of Denis Diderot (1713-1784) by L. M. Van Loo (1707-1771). [Louvre]
[53R] Mlle. d'Espinasse on the cover of "The dream of d'Alembert" by Denis Diderot.
[54L] Exhibition of automata [A.L.M] Note: there is similar work by Marc van der Broek (1953-) of Wiesbaden (see Darmstadt 2, no. 193, 194)
[54R] Object at the exhibition of Automata at the Festival Hall, London, (), [A.L.M.]
[55L] "Staircase between Heaven and Hell", [A.L.M.]
[55R] "Staircase between Heaven and Hell", exhibition of Automata, [A.L.M.]
[56L] "Olympia", Edouard Manet. (1832-1883).
[56R] Parody of Manet's "Olympia", exhibition of Automata, [A.L.M.]

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Alicia Witt, Jennifer Esposito and Jessica Walter co-star in a story that proves that when the going gets tough, it's time to start Bending the Rules. -- (C) WWE.Â We want to hear what you have to say but need to verify your email. Donâ€™t worry, it wonâ€™t take long. Please click the link below to receive your verification email. We want to hear what you have to say but need to verify your account. Just leave us a message here and we will work on getting you verified. Bending the Rules is a 2012 buddy cop action comedy film directed by Artie Mandelberg, produced by WWE Studios, and starring Adam "Edge" Copeland and Jamie Kennedy. The film was released on March 9, 2012 in select theaters in the United States for a limited time. Detective Nick Blades (Adam Copeland) is a New Orleans cop on trial for corruption. Assistant District Attorney Theo Gold (Jamie Kennedy) is the man in charge of putting him behind bars. When these two unlikely partners from opposite sides of Bending the Rules is a mission in Saints Row IV . This mission is the first part of the "Time to Increase the Tempo" objective of the "Learn The Rules..." Quest. This mission consists of retrieving 4 Clusters , buying two Powers , and completing a training simulation. Upon completion of this mission, Blazin is auto-started, but this mission is not registered as completed until the Blazin is completed.