Structure and Form: A Design Theory Manual
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RATIONALE

The book presents a design science approach, accessibly explaining the relevant theories of design structure and form to undergraduates. The book aims at developing an understanding among readers of the fundamental geometrical rules governing structure (i.e. the underlying framework) and form (i.e. the constructed two- or three-dimensional resultant shape which is the outcome of the design process).

Although there appears to be a ready acceptance that the material proposed should be included in the design curriculum, its widespread acceptance on the basis of a dedicated module is not readily apparent, at least within the UK. Currently it seems that teachers are at a loss to find an appropriate text book which covers the range of relevant material in a way which is accessible to their students. As a result, at least within some institutions, it seems that students are occasionally left to fend for themselves, picking up snippets (e.g. relating to the various rules of composition, the golden section, pattern construction, tessellations, modularity or some other topic of importance to the designer). This is due primarily to the inaccessibility of the bulk of available texts which are considered to be too mathematical in terms of content. Further to this, those texts which are accessible to the intended market may either focus on only one aspect (e.g. Washburn and Crowe) or alternatively make a superficial review of many aspects (e.g. Lidwell, Holden and Butler). A more thorough treatment of a carefully selected range of material is proposed.

An important concern of the book is to connect as many topics as possible to real (historic or contemporary) areas of design, so that students can see that the material when considered carefully can be of use in a direct way to their own design work. It is anticipated that the book will be adopted as a core text book for design courses (as well as practice-based assignments and final-year dissertations). The book is relatively short in terms of text. This is due to the necessary reliance on visual material (which is more readily consumed by student designers often too impatient to wade through long text).

The book aims to cover the subject both broadly and accessibly. Formal mathematical content is kept to a minimum and appropriate literature is identified throughout. The text is extensively illustrated, concise and well-focused. The final chapter focuses on newly-developed techniques for geometric analysis; these may be of particular value in the development of material associated with final year dissertations. A series of appendices presents details of activities and assignment suggestions, selections of past student work, various workshop ideas, all of value to students in developing their own project ideas and probably also to teachers in developing appropriate curriculum material. An annotated guide to further reading is included at the end of the book.

Key Selling Points

- The only detailed overview of both structure and form for undergraduate design students
- Makes mathematical material accessible
- Highly visual and with additional pedagogic apparatus to enhance student learning

CONTENTS LIST

CONTENTS SUMMARY

1. Introduction
The subject is introduced, important literature is identified and the objectives are clearly stated. The layout of the book is explained.

2. Underneath it All: Elements, Constructions and Principles
This chapter is concerned with introducing certain elements and principles which form the core building blocks for all designers. Initially, several inter-related structural elements are identified. These include: *point*, *line*, *form and structure*. A selection of key principles is identified, including: affordance; alignment; the 80/20 rule; figure-ground relationships; rhythm and balance; importance of scale; consistency; constancy; continuance; convergence; form following function; framing; the golden section; iteration; law of Prägnanz; modularity; proximity; the thirds rule; self similarity and scale symmetry. The value of each to designers is explained. Some are dealt with in more detail subsequently. Various regular polygons and other constructions such as the so-called "sacred cut" the *vesica piscis* and the *ad quadratum* are explained and illustrated.

3. Minding the Gap: Tiling the Plane
This chapter is concerned with introducing various categories of tilings. A short historical review is presented, and the important characteristics of Islamic tilings are highlighted. The term *tiling* (or tessellation) is used when referring to a collection of polygons which cover (or tessellate) the plane, edge-to-edge, without gap or overlap. The construction of various types of tilings is explained and their characteristics discussed. During the latter part of the twentieth century, the British mathematician Roger Penrose developed what is known as an *aperiodic* tiling, that is a tiling which does not show formal repetition across the plane. The rules for constructing such a tiling are explained. Much attention has been given to Islamic tilings in recent years (e.g. those associated with the Alhambra Palaces in Granada, Spain). The characteristics of such tilings are discussed. Relevant applications and avenues for further research are also identified and various construction techniques are explained.

4. Symmetry: The Great Organising Principle

The concern of this chapter is with explaining the nature of symmetry, patterns, figures and motifs. Patterns, which are comprised of motifs which repeat on a regular basis across the plane, do not necessarily tessellate without gap or overlap. Often, both the repeating motif and the background are equally important constituent parts of the pattern. Motifs are the building blocks of patterns. The principal characteristic of a regular repeating pattern is the repetition of a motif by a given distance across the plane. Patterns are considered to have symmetry characteristics. In this case, the meaning of the term "symmetry" extends beyond its common every-day usage to cover geometric actions beyond bi-lateral symmetry. Patterns may exhibit one or more of four particular geometric actions (known as *symmetry operations* or *symmetries*. These are: *translation*, by which a motif undergoes repetition vertically, horizontally, or diagonally at regular intervals while retaining the same orientation; *rotation*, by which a motif undergoes repetition round an imaginary fixed point; *reflection*, by which a motif undergoes repetition across an imaginary line, known as a reflection axis; *glide-reflection*, by which a figure is repeated in one action through a combination of translation and reflection, in association with a glide-reflection axis. Symmetry can also be identified in three dimensional objects (and this is highlighted in chapter 8 when attention is turned to examining the nature of polyhedra). Border patterns comprise a regularly repeating unit, enclosed between two parallel lines forming a strip of finite width and infinite length. From the viewpoint of geometrical symmetry there are seven possible structures; of course each of these seven possibilities offers scope for infinite further variety through the use of alternative thematic, colour and textural qualities. So pattern symmetry is an indication of the underlying structure or skeleton of the pattern. The geometrical characteristics of such patterns are explained in this chapter. Relevant terminology and notation are introduced. All-over patterns or tilings translate (or repeat) in two independent directions across the plane. From the viewpoint of geometric symmetry there are seventeen possible structures. An explanation of the geometrical principles governing pattern construction is presented. Relevant applications and avenues for further research are also identified. It is now well established that different cultures and/or historical periods exhibit different symmetry preferences. A brief review of relevant empirical literature is presented. This could prove of value in the development of topics for student dissertations or theses.

5. The Stepping Stones of Fibonacci and the Harmony of a Line Divided

This chapter is concerned with various numerical series, especially the so-called "Fibonacci series", and its associated constructions. The measure associated with the series is known as "Phi" (ϕ) and it is claimed that the proportion ϕ:1 (or 1.618: 1) shows up in relationships throughout the natural, constructed and manufactured worlds. It has been "detected", for example, in architectural contexts, in proportions of the human body, other animals, plants, DNA, the solar system, music, dance, sculpture and other art forms. It should be stressed however that the evidence supporting detection is often rather limited and in some cases (at best) ambiguous. A review of the debate is presented. The measure was known to the Greeks as the *golden section* and to various Italian Renaissance artists as the *divine proportion*. The term *golden mean* is also used. The Fibonacci series and the golden section are intimately connected. It has often been declared that both the Greeks and the ancient Egyptians used the golden section when designing their buildings and monuments (though the nature of the evidence supporting these claims is not clear). The architect, Charles-Edouard Jeanneret (known as "Le Corbusier") developed a rule of design known as the "modular", a measure related to the proportions of the human body. Various constructions (including the golden section the golden rectangle and the golden spiral) are explained and illustrated. Relevant applications and avenues for further research are also identified.

6. Order in Chaos: Fractals and Scale Symmetry

This chapter is concerned with fractals and scale symmetry and in what way these may be of value to designers. A brief historical review of literature is presented and relevant terms are introduced and defined. A *fractal* is a geometrical shape made up of identical parts each of which is (at least approximately) a reduced/size copy of the whole. The term "fractal", from the Latin *fractus* meaning fractured or broken, refers to a unique type of geometric shape. Fractals have two distinct properties: they tend to exhibit infinite detail and they conform to the same shape at different scales, a property known as “self-similarity”. Fractals can be based on mathematical models, but are also common in real life. Examples of nature’s fractals are clouds, coastlines, lightning, various vegetables (e.g. cauliflower and broccoli) and mountains. This phenomenon of self similarity, or scale symmetry is exhibited in the Koch snowflake. The basic unit of the Koch snowflake, first constructed by the mathematician Helge von Koch (1870-1924), is the equilateral triangle which can be built up into a much larger structure while retaining certain similarities at the smaller scale level. Although the roots of fractal geometry can be traced to the late 19th century, it was the work of Benoit Mandelbrot, in the 1960s and 1970s that popularized the concepts. By 1975, Mandelbrot had developed a theory of fractals, and publications by him and others made fractal geometry accessible to a wider audience. Relevant applications and avenues for further research are also identified.

7. Variations on a Theme: Modularity, Stacking and Packing
This chapter is concerned with modularity and its applicably to design. Modularity embraces the concept of *minimum inventory and maximum diversity*. In other words, from a few basic modules or units (such as two or three tile shapes), a large collection of different structures (or solutions) is possible. The concept is of relevance to science, art and design, and can be detected throughout the natural world. It offers potential for innovation in the decorative arts and design, and is common in two-dimensional repeating patterns as well as architecture. Modular systems are comprised of the minimum number of components which can be combined alternatively to produce diversity of efficient structural forms. Such systems are efficient in their use of materials and energy resources. Probably the simplest expression of modularity is “close packing”, a concept which is explained in some detail. A series of illustrations (many taken from students responses to a modularity assignment) is presented. Applications are suggested and avenues for further consideration are identified.

8. Shaped like Crystals: Polyhedra, Spheres and Domes.
This chapter is concerned with various shapes known as *polyhedra.* These are objects formed from polygons. There are a particular set of five polyhedra, known as the *Platonic solids,* each comprised of combinations of one specific type of regular polygon. A further set of polyhedra (thirteen in total) are known as the *Archimedean solids*, and each is formed from combinations of two or more types of regular polygonal faces. A review is presented of the occurrence of such structures in nature, art, science, engineering and design. The difficulties encountered in attempting to apply two-dimensional repeating designs to regular polyhedra, avoiding gap and overlap and ensuring precise registration, are specified. The symmetry characteristics of importance to the process are identified, and the patterning of each of the five Platonic solids is explained and illustrated. Relevant applications and avenues for further consideration are also identified.

9. From Synthesis To Analysis
This chapter presents a tabulated list of structures, measures, proportions and ratios, all of which have been dealt with previously and are of use in the analysis of designs. Frequently-used measures: include: 1:1 (a simple square format); various triangular formats; various golden section constructions; the so-called “musical ratios” of 1:2, 2:3, 3:4, 3:5; 5:8, 4:5, 8:9; various formats/constructions associated with the square, circle and various rectangles and other polygons. The question of accuracy is debated and step-by-step procedures are explained. This chapter is designed to be of value to projects students in the development of methodologies appropriate to the structural analysis of designs.

10. Summary And Conclusions
On gaining a basic understanding of the geometrical concepts and constructions explained in this volume, the reader should be in a position to approach design assignments (and later professional design briefs) with a substantial armoury of techniques, based on the principles, concepts and perspectives dealt with in this publication. Further to this, graduate dissertations or theses students should be in a position to conduct structural analyses of naturally occurring

phenomena, human-made objects, images, paintings, sculpture, patterns, tilings and other forms of two- and three-dimensional designs.

Appendices

The appendices will include:

1. Guidelines on various geometric constructions. The emphasis will be on manual means of construction, using basic geometric instruments. For example, construct a series of golden rectangles or various regular polygons using only a pair of compasses and a straight edge.
2. Assignment suggestions. These will require students to generate original visual material. Where possible these suggestions will be grouped to relate to chapter headings. For example, construct two polygons which can be used in the construction of a Penrose-type tiling. Produce the tiling and colour it using the minimum number of colours with the proviso that no adjacent sides will be coloured the same. Several examples can be given from past student work.
3. Workshop Ideas. More substantial projects relating to professional-type design briefs will be included here. For example, produce a collection of tiling designs, coloured using a commercial palette, and for a specified end use. In the production of this collection, cut a square to dimensions of your choice. Cut into two or more unequal parts. Colour each tile with a colour of your choice. Make multiple copies (by scanning or photocopying each coloured tile). Use these two or more different shaped tiles (in any numerical proportion you wish) to create a collection of six periodic tilings, which cover the plane without gap or overlap. Each design must be original, precisely drawn, and distinctly different. Remember to decide upon an end use at an early stage in the process, and also not to relay solely on a change of scale as a means of differentiation. Feel free to use computing software of your choice.
4. An Annotated Guide to Further Reading

WRITING SCHEDULE / WORD LENGTH / ARTWORK

- 16 months from contract
- 20,000 words.
- 130 line diagrams and 20 B/W photos (50 of the line diagrams will be in the Appendices).

See end of proposal for artwork examples

READERSHIP

Primary	Undergraduate students in all aspects of Design in the UK & Europe (Graphic / Product / Communications / Textile / Interiors / Fashion) In the US it is anticipated that the Design courses taking this Design Science approach will be largely located in faculties of Engineering and Architecture
Secondary:	Lecturers/teachers in Design Postgraduate students in Design Undergraduate students of Architecture, Fine Art (mainly painting and sculpture) and Engineering (structural)

The book would be adopted on the Design Theory module at Leeds University: at least 250 students take the course each year. However, it should be noted that this module may well be unique in the UK at least.

RELATED /COMPETING TITLES

All the texts listed retail for under £30

- *Universal Principles of Design* Lidwell/Holden/Butler (Rockport Publishers, 2003, HB, 216pp) Edition II is planned for Jan 2010: $30.00/£18.99, 280pp, 400 photos & diagrams, large format. This would be the key competitor, certainly in the US where its breadth and lack of depth probably work well on freshman/sophomore courses. Outside the US, the breadth of this book seems a weakness, as it spreads itself thin in the attempt to cover everything. Outside the US, it is probably better suited as a basic reference source (largely for teachers) than as a course text book (for students). But it is accepted that the proposed book must have certain clear strengths compared to this work. By virtue of its focus my book will treat its subject in more depth so will work beyond introductory-level courses; also the text and the appendices will be written to encourage not only analysis but also practice, to encourage actual design activity. Beyond this, my work will take an international perspective (in terms of methods and case material)
- Lupton, E. and Cole Philips, J. (2008). *Graphic Design. The New Basics*, Princeton Architectural Press, New York, 247pp. A well produced text book, focused very precisely on a few of the needs of graphic design students. There is some overlap with this proposal, but this would account for no more that fifteen per cent. A justifiable criticism is that this book actually covers very little and only touches on a small proportion of the topics covered in the proposed book.
- Kapraff, J. (1991). *Connections. The Geometric Bridge between Art and Science*, McGraw-Hill, New York, 471pp. Renowned among scholars with interests covering the mathematical aspects of art and design. It is also well known to academic architects and engineering designers. The major drawback is that the bulk of design students feel the work is inaccessible due to the mathematical content and terminology used. The book is probably more appropriate to a more advanced graduate audience.
- Elam, K. (2001). *Geometry of Design: Studies in Proportion and Composition,* Princeton Architectural Press, New York, 106pp. A well produced, well focused text dealing with design analysis. It should be noted that the only overlap with the proposal is with one chapter only and that the author intends to present more fully developed procedures by which to conduct design analysis.
- Leborg, C. (2004). *Visual Grammar*, Princeton Architectural Press, New York, 95pp. This is a concise, cleverly presented monograph which relies mainly on well selected, simple imagery (with the minimum of text) to communicate some of the fundamentals of visual communication. There is a degree of overlap with the proposal, but the ground covered by this publication is addressed largely in chapter two of the proposed book.
- Hann, M.A. and Thomson, G.M. (1992). *The Geometry of Regular Repeating Patterns*. Textile Progress Series, vol.22, no.1, Textile Institute, Manchester, 62pp. This is a past work co-authored by the author of this proposal. The material presented is quite dated and the focus is simply on regular patterns which form only a small component of this proposal.
- Pearce, P. (1990). *Structure in Nature is a Strategy for Design*, MIT Press, Cambridge, Mass., 245pp. This is a very useful text aimed at architects as well as some of the curriculum needs of advanced architecture students. Parallels can be seen with some of the material in the proposed book (particularly chapters 7 and 8). The disadvantage of this text compared to the proposal is that it is largely too advanced.
- Stevens P.S. (1984) *Handbook of Regular Patterns: An Introduction to Symmetry in Two Dimensions*. MIT Press, Cambridge, Mass. This is a worthwhile textbook for undergraduate

students, but the focus is only on pattern geometry (again a small proportion of the proposal). A few errors are also evident.

- Washburn D.K. and Crowe D.W. (1988) *Symmetries of Culture: Theory and Practice of Plane Pattern Analysis.* University of Washington Press, Seattle, Wash.; London. This is a well known text book which is of value in understanding concepts relating to pattern symmetry. It also presents details of how patterns can be classified by reference to their symmetry characteristics (again this will form a small component of this proposed publication).

AUTHOR

M. A. Hann (BA, M.Phil, PhD, CText FTI), holds the Chair of Design Theory at the University of Leeds. He is also Director of the University of Leeds International Textiles Archive (ULITA). His teaching interests cover design geometry and geometrical aspects of art, design and architecture in different cultures. He has published across a number of subject areas, has made numerous key-note addresses at international conferences, and is an acknowledged expert on the geometry of patterns.

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ARTWORK EXAMPLES

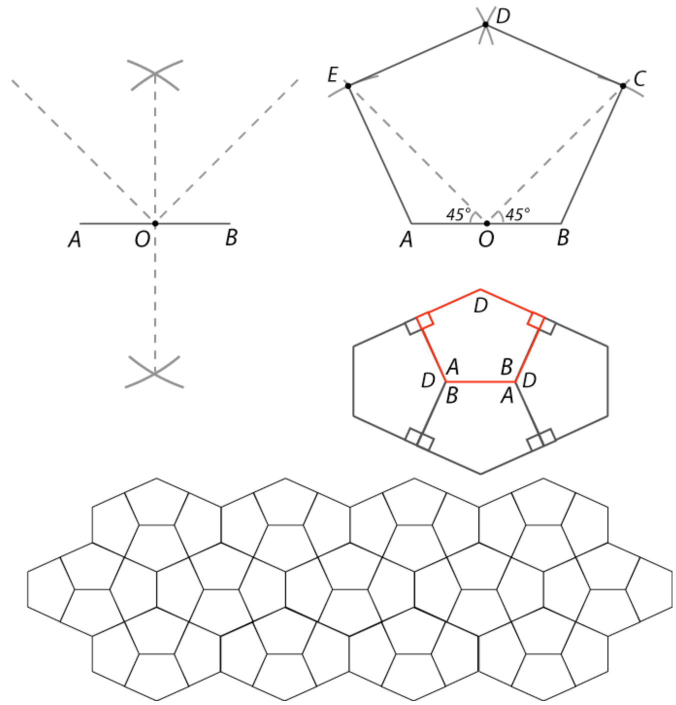

Figure 1 The construction of a Cairo tiling

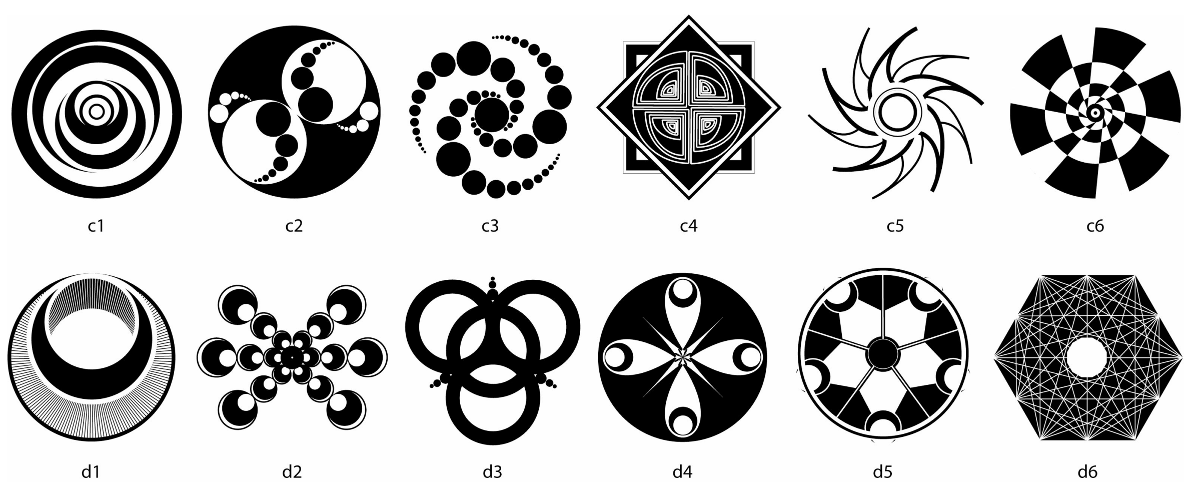

Figure 2 Various motifs with rotational and reflection characteristics

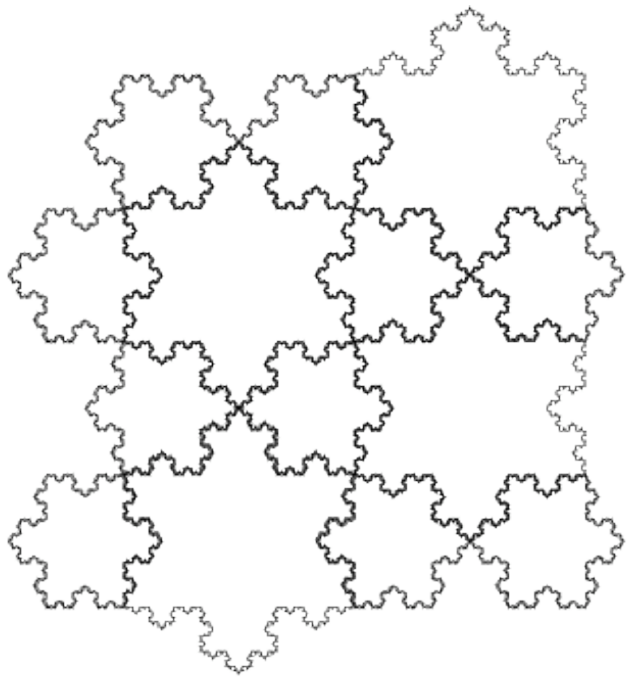

Figure 3 The Koch snowflake with 'six around one'

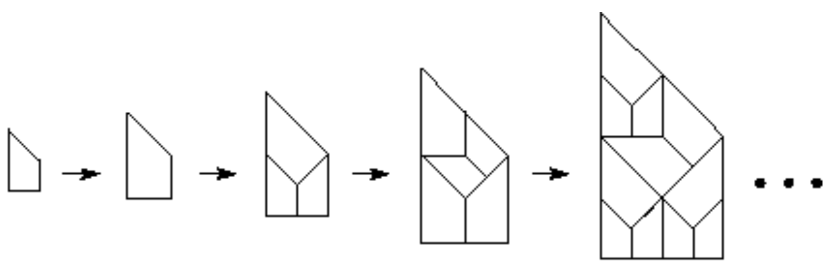

Figure 4 Geometric growth or scale symmetry

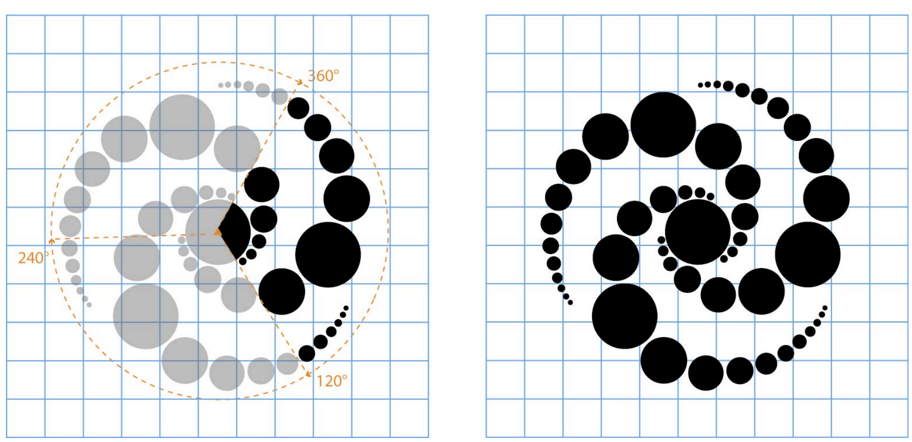

Figure 5 Three-fold rotation

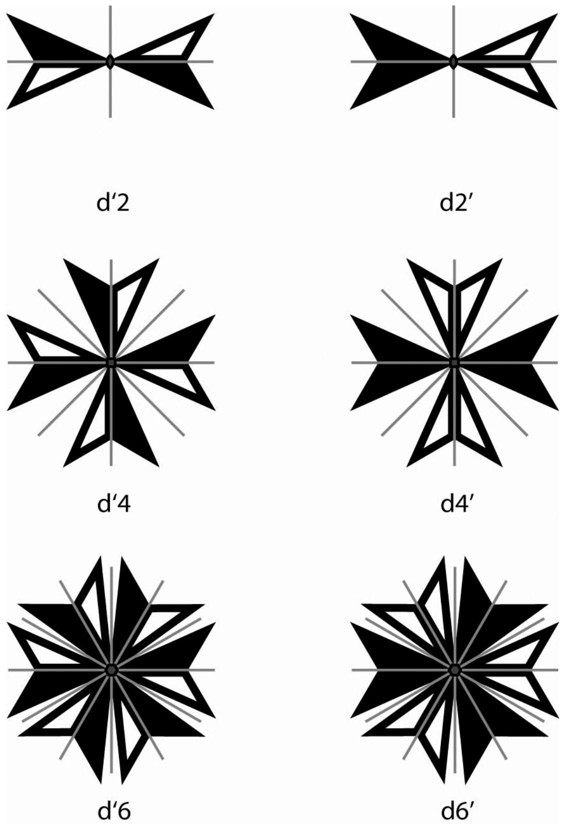

Figure 6 A few colour-counterchange possibilities on various motifs

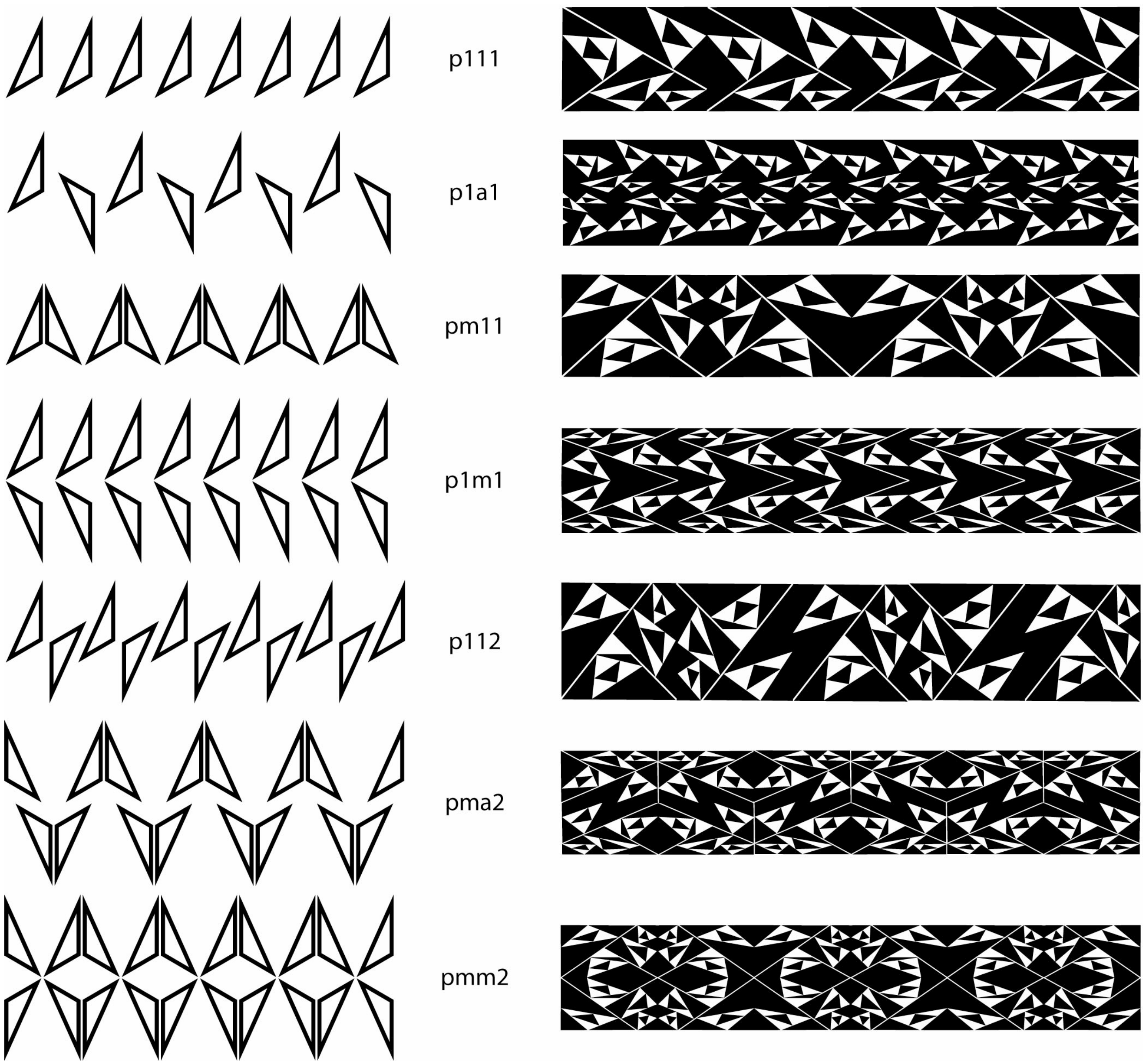

Figure 7 The seven classes of border patterns

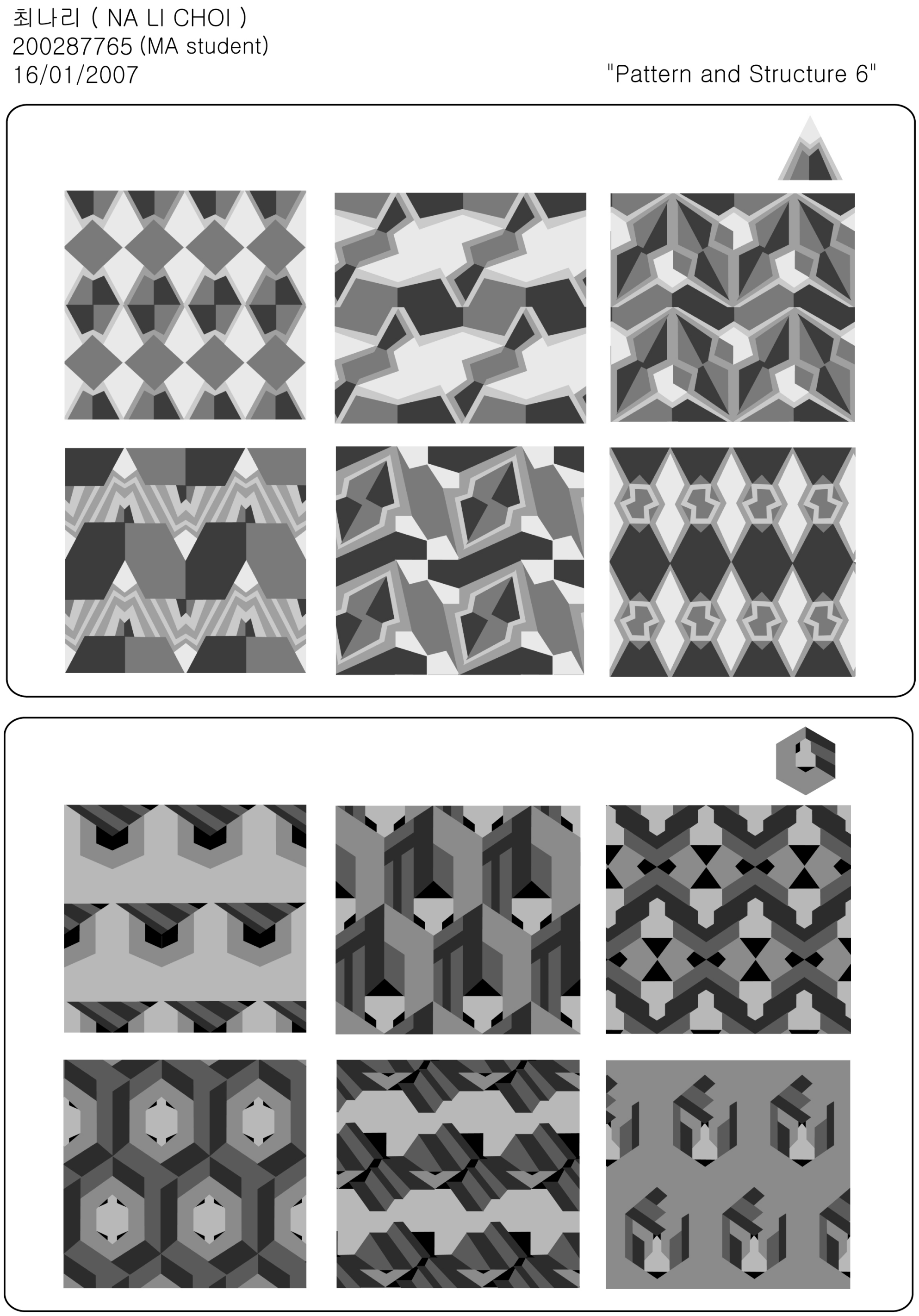

Figure 8 Examples of past student work relating to tilings and modularity

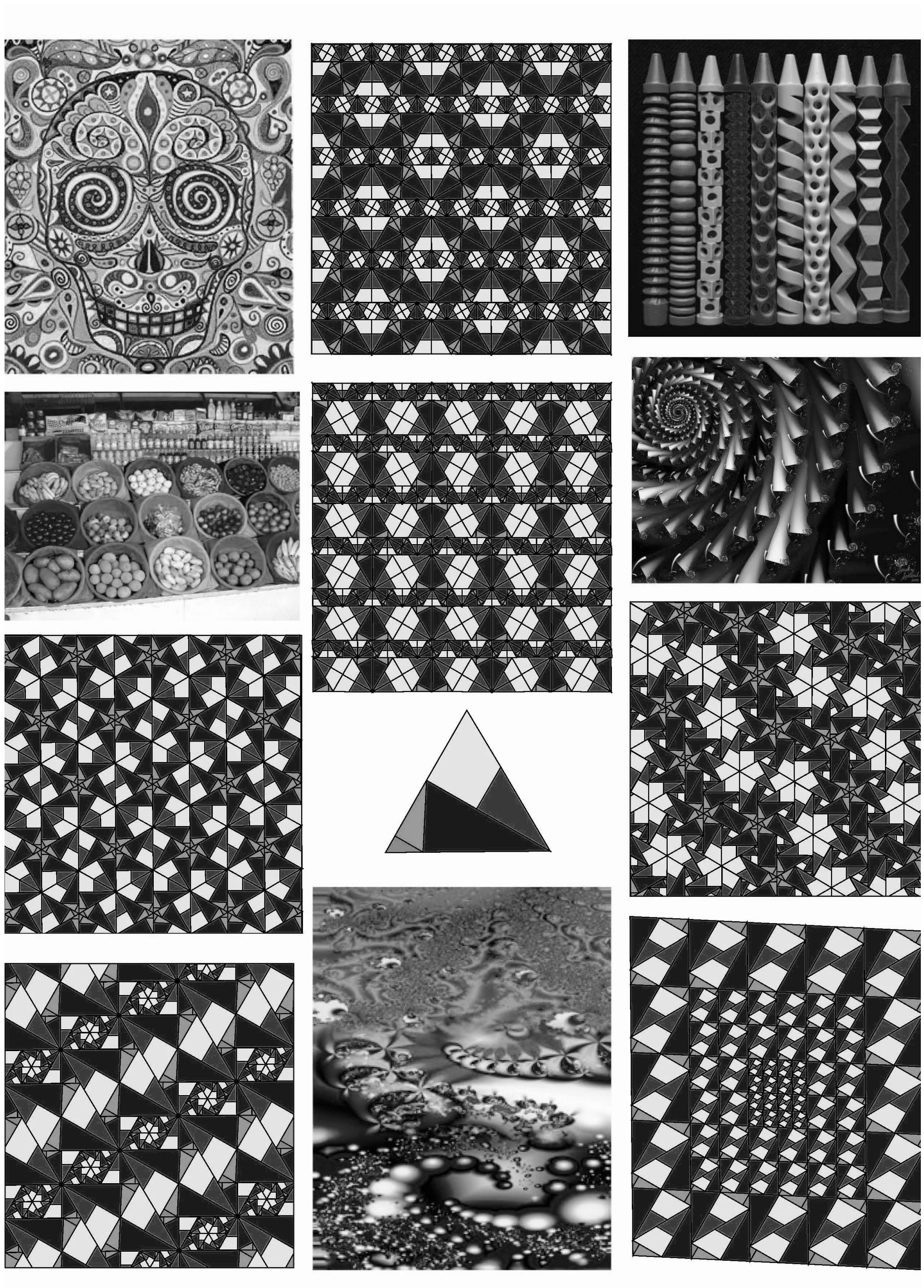

Figure 9 Examples of surface pattern designs developed from a project relating to fractals and scale symmetry