The Geometric Division of Space. Frameworks for Design Analysts

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The candidate confirms that the work submitted is her own and that appropriate credit has been given where reference has been made to the work of others.

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Abstract

This research aims to explore the persistence of geometric constructions and focuses on related issues such as proportions in the visual arts, design and architecture in both historical and modern contexts. Based on literature review, a comprehensive understanding on how geometric constructions function as (hidden) guidelines in design practice is developed.

This research adopts a qualitative research approach underpinned by the analysis of case study material. Five case study groups are selected and studied. They are: terracotta warriors, Xi'an (China); cathedral floor plans; Scottish clan tartans; posters; web-pages.

Novel analytical methods are developed based on certain geometric structures and related proportions and their use in the areas of human body proportion, architecture, textiles, graphic design and interface design. From the research, it is found that certain space division methods and proportions are found to be used frequently in more than one design discipline. There is an indication that certain proportions are more preferred by human eyes than others.

After analysis and summaries of the space division methods associated with each case study group, a range of frameworks of value to design analysts is proposed. Each case study can be considered to yield a unique framework of value to analysts considering similar case study material.

Thus the contributions of this study include: an explanation of why geometry structures are powerful compositional aids; a contribution to the scholarly debate; further knowledge which may be of value to analysts across the full spectrum of visual art and design.

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Chapter 1 : Introduction

This chapter introduces the background, aim and objectives as well as the research scope and the research methods. The thesis structure is given at the end of the chapter.

1.1 Background to the research

Geometric structures of various kinds have long been applied in design practice as compositional aids. As a design tool, the application of geometry can be found in ancient Babylon, ancient Egypt, Renaissance and even in modern times (Reynolds, 2001 p.113). Examples can be found in both two-dimensional and three-dimensional designs. Grid structures are often found in book-page and web-page design. Golden-section and root-rectangle proportions have seemingly been used to determine the position of key design elements. Brunes-star-type constructions have, it seems, been used to provide symmetrical balance. In the context of three-dimensional designs, cubes, pyramids, tetrahedrons and other polyhedra can be found in roof constructions. Spherical constructions and polygons (usually triangles) are often combined to create geodesic domes.

It appears that very little, if any, previous research has adopted an outlook best described as 'the geometric consideration of space division' though numerous past analytical studies have set out to discover the working methods used historically by craftspeople, painters, architects and builders.

In the development of designs or other visual compositions, it is often necessary for the practitioner to engage in a process of organization, selection and assembly. Decisions often make reference to an underlying structure or structural framework, which may take up one of many forms. Two or three-dimensional guidelines are frameworks, often referred to as grids, lattices, nets or matrices and often consist of familiar polygons and other geometric figures and constructions.

1.2 Research aim and research questions

This research only focuses on two-dimensional designs. The aim is to explore the persistence of geometric constructions and will focus on related issues such as proportion in the visual arts, design and architecture in both historical and modern contexts. The underlying research question is best considered as two sub-questions:

A. What geometric theories, outlooks or perspectives can be found to underpin design, both historically and in modern times?

B. In what way can knowledge of this geometrical underpinning be used to contribute to an analytical framework for use by future researchers and analysts?

In order to answer these sub-questions the overall objectives of the research are worth considering:

- To identify the characteristics of geometric structures in designs.

- To explore the different functions of geometric structures in different design practices and to ascertain (for example) the circumstances when a geometric structure may provide a (hidden) guideline in the final composition or construction, or may appear as part of the design outcome.

- To establish the relationship between the characteristics of geometric structures and their functions (e.g. if a hidden structure, how does it enable or help composition and, if part of the final design, does it have particular geometric characteristics?)

- To improve the understanding of how geometrical principles relate to space division in design.

1.3 Research methodology and research scope

This section reviews the research methodology and defines the research scope.

1.3.1 Research methodology

Qualitative research is chosen for this study as it aims to get a holistic understanding of the data context (Mason, 2002, p.3) to make analysis, explanation and arguments (Mason, 2002, p.3).

This is underpinned by case studies, which help to understand the relationship between the phenomenon and the content (Gray, 2009, p.247).

Data should be selected based on its availability (Mason, 2002, p.109) and reliability (Kumar, 2011, p.181). In terms of geometrical analysis, the accuracy of the data is vital for the later analysis as ‘the slightest deviation can result in a distorted ratio and an inaccurate analysis’ (Reynolds, 2001 p.115). The accuracy of the data can be achieved by measurements, calculation of ratios and data collection from reliable sources (Reynolds, 2001 p.114).

Analysis is a process which breaks down data into smaller units to reveal their characteristics and structure (Gray, 2009, p.499). There are some criteria of geometrical analysis provided by Reynolds (2001, p.114); for example, geometric systems have been used or studied before; canons (units) of measurement are found; purpose or meaning of the applied geometric systems is highlighted; historical developments of the geometric systems are traceable and symbolic meanings of certain constructions are defined.

1.3.2 Research scope

Case study groups in this research have been selected to ensure that they adequately represent the multifaceted nature of design.

Five case study groups were selected and analysed in this study. These groups are as follows: terracotta warriors, Xi'an (China); Cathedral floor plans; Scottish clan tartans; 20th and 21st centuries poster designs and web-page design. These were found to be fairly representative as they fulfill the following selection criteria: First, they are selected from different historical times, covering the time periods from BC 221 (terracotta warriors), to medieval times (Cathedral floor plans), to the 18th and 19th centuries (Scottish clan tartans) then to the most recent times (posters and web home page design), which reflect the aim that ‘proportion in design can be considered in both historical and modern contexts’. Second, the selected case study groups reflect different disciplines of design: terracotta warriors (human figure proportion); Cathedral floor plans (architecture design); Scottish clan tartans (textile design); posters design (graphic design) and web-page design (interface design). Thirdly, the sources of data selection are all based on key publications and official websites (detailed data selection criteria for each case group are given in chapter 4, section 4.2.2; chapter 5, section 5.2.2; chapter 6, section 6.2.2; chapter 7, section 7.2.2 and chapter 8, section 8.2.2 respectively). Last but not least, each case group contains a number of samples: terracotta warriors (35 cases); Cathedral floor plans (20 cases); Scottish clan tartans (22 cases); posters (46 cases) and web-page design (100 cases), which will benefit theory development.

1.4 Thesis structure

This thesis contains a total of 9 chapters, apart from this chapter, chapters are as follows:

Chapter 2: Fundamental concepts

This chapter reviews the fundamental geometric concepts associated with design. Attention starts with points and lines then switches to the geometric characteristics of structural frameworks. Further related geometric principles such as symmetry and grids are dealt with towards the end of this chapter.

Chapter 3: Case study group number 1 - Terracotta warriors, Xi'an (China)

This chapter deals with how square grids may have been used as guidelines to govern the proportions of terracotta warrior standing figures. The hypothesis was based on the previous literature of square grids used in ancient Egyptian paintings, ancient Greek sculptures and Assyrian sculptures, each indicating proportional reference points for parts of the human body.

Chapter 4: Case study number 2 - Cathedral floor plans

This chapter shows that cathedral floor plans were often constructed based on a square (the overlapping square of the nave, choir and transepts). Further to this, some simple relevant constructions included: golden-section rectangles; modular shapes ; sacred cut as well as root rectangles ($\sqrt{2}$ to $\sqrt{5}$ rectangles).

Chapter 5: Case study group number 3 - Scottish clan tartans

This chapter explains the nature of tartans, identifies typical surface structures, ratios and proportions, and suggests possible avenues of use for analysis. The principal sources of data were a collection of tartans held at ULITA – An Archive of International Textiles (University of Leeds, UK) and Stewart's 1974 publication The Setts of Scottish Tartans.

Chapter 6: Case study group number 4 – Posters

This chapter suggests some simple methods which have been used in poster design based mainly on the use of square derivative constructions, which can form the construction basis of the whole design without any further measurements.

Chapter 7: Case study group number 5 - Web-pages

This chapter aims to find common division methods, especially grid division of web homepages by analysing FTSE 100 (the 100 largest companies listed in the London stock exchange) homepage layouts.

Chapter 8: Design frameworks for analysts

This chapter presents summaries of the space division methods associated with each case study group and identifies a range of frameworks of value to design analysts. Each case study can be considered to yield a unique framework of value to analysts considering similar case study material.

Chapter 9: Conclusions

This chapter includes a further discussion of the aim and objectives; the contribution of this research; the limitation of this research and recommendations for future work.

Chapter 2 : Fundamental concepts

This chapter reviews the fundamental geometric concepts associated with two-dimensional designs.

2.1 Introduction

All designs are constructed by shapes and shape combinations (Arnheim, 1955, p.55). Shapes can be divided into points and lines, which are the most basic design elements. Good designs often arrange the design elements according to certain geometric theories. Symmetry operations and the laws of proportions are important principles besides others.

The objective of this chapter is to review the fundamental geometric concepts associated with two-dimensional designs. Attention starts with points and lines then switches to the geometric characteristics of structural frameworks. Further related geometric principles such as symmetry and grids are dealt with towards the end of this chapter.

2.2 Point, line, structure and form

Point, as the basic geometric element, has no dimensions and cannot be felt or seen (Poulin, 2011, p.12). Point, as a form, on the other hand, has been applied in various design contexts in both ancient and modern times (Hann, 2012, p.11).

Line is another basic geometric element. , it is defined as “the path traced by a moving point” (Poulin, 2011, p.20). All geometric shapes are constructed from lines (Poulin, 2011, p.21; Peterson, 2003; Leborg, 2006 p.11).In design practice and art creation, lines are usually used to give energy (Hann, 2012, p.15), direction (Oei and Kegel, 2002, p.77), texture (Peterson, 2003) or to create different emotions (Peterson, 2003).

The composition of forms can be divided into surfaces and edges and then subdivided into shapes, lines and points (Poulin, 2011, p.42). A form can be either a two-dimensional visible conceptual element, or a three-dimensional object. (Poulin, 2011, p.44).

Structure is the underlying order which governs the relationship between design elements (Wong, 1993, p. 59). It can be made formal or informal, visible or invisible to fulfil different design requirements (Wong, 1993, p. 59).

2.3 Various regular polygons

A polygon is a type of two-dimensional geometric form. It refers to a closed space bounded by straight lines (Rich, 1963, p.7; Hann, 2012, p.15). Triangles, quadrilaterals, pentagons and hexagons, etc. are examples of polygons. All polygons are formed by sides (or line segments), vertices (the joint points of sides) and interior angles (angles between sides).

A regular polygon refers to polygons which are equilateral and equiangular (Jacobs, 1974, p. 499). In other words, a regular polygon has the same length of sides and the same interior angles (Hann, 2012, p.17). The numbers of regular polygons are infinite. 3-sided regular polygons to 10-sided regular polygons are illustrated in Figure 2.1. It is obvious that when the side number of a polygon increases, its shape looks more and more like a circle (Jacobs, 1974, p. 499).

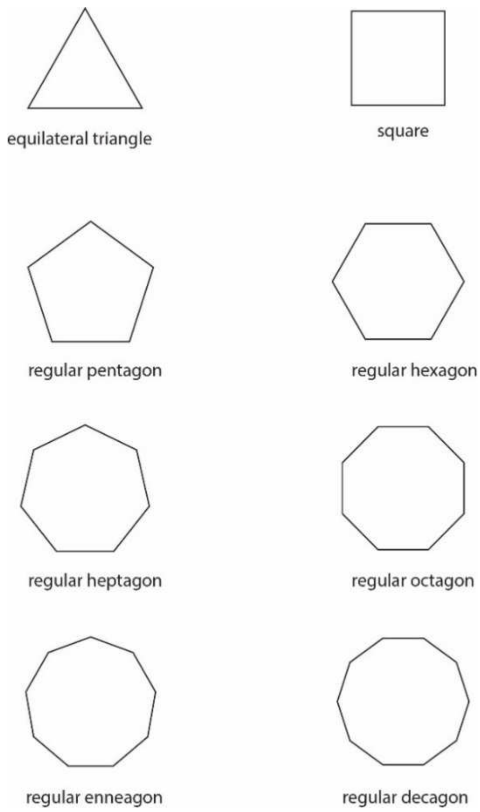


Figure 2. 1 Various regular polygons

Source: Drawn from Hann, 2012, p.17

A square is a four-sided regular polygon, as a regular polygon has the same length of sides and the same interior angles (Hann, 2012, p.17). It has four-fold rotation and four reflection axes also (for a detailed explanation of symmetry please refer to Section 2.4). This section mainly focus on the division of a single and multiple squares.

A square and one of its diagonal (as shown in Figure 2.2) can generate a 1: √2 proportion (Wu, 2002, p.83; Hiscock, 2007, p.201).

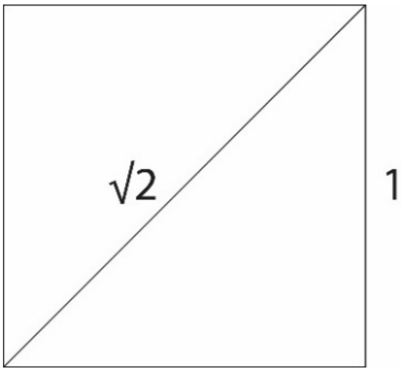


Figure 2. 2 A square and one of its diagonals

Source: Drawn from Hiscock, 2007, p.201

A square divided by another square inside it, set at 45 degrees, is known as the 'ad quadratum' (Hiscock, 2007, p.187). An example of a square divided by another square and its diagonals is shown in Figure 2.3. This is also explained in detail in Chapter 4, Section 4.3)

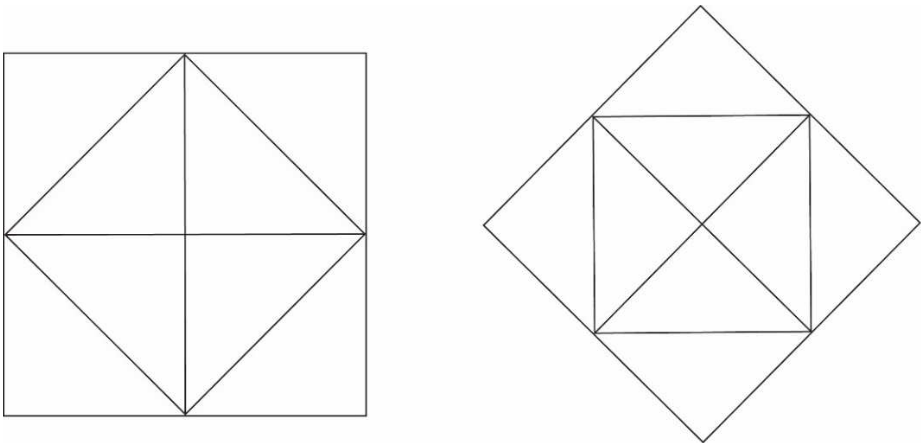


Figure 2. 3 Square divided by diagonals or other square

Source: Drawn from Hiscock, 2007, p.187

This type of division creates an isosceles right-angle triangle with its inner angles of 45, 45 and 90 degrees, and a proportion of 1: √2 between the lengths of the triangle sides (Hiscock, 2007, p.187).

Two equal-side squares with one rotated 45 degrees while being over laid on the other one, generates an eight-point star (Figure 2.4). The overlapping area of the two squares creates a regular octagon (coloured in grey in Figure 2.4). (This is a common construction in cathedral floor plans, which is explained in detail in chapter 4, section 4.3).

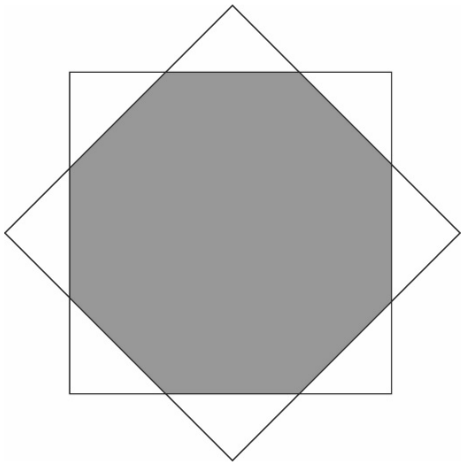


Figure 2. 4   An eight-point star generated by square rotation

Source: Drawn from Wiemer and Wetzel,1994, p.452

The gnomon is a construction obtained by drawing arcs which are centred at the corners of the square with the arc radius equal to the length of the square diagonals, illustrated in Figure 2.5. (Watts and Watts, 1992, p.309). It is a way to add to or subtract from a square to make it larger or smaller (Watts and Watts, 1992, p.309).

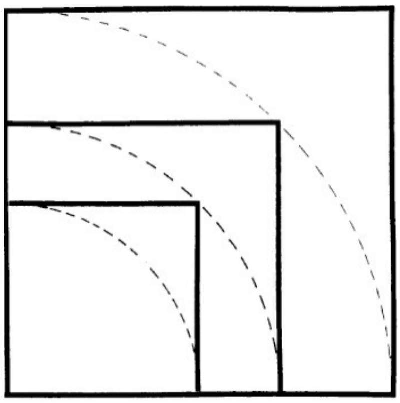


Figure 2. 5   The gnomonic progression of a square

Source: Watts and Watts, 1992, p.309

The 'sacred cut' refers to a construction of four arcs that are centred on the four corners of a square, with the half diagonal length of the square as the radius in each case, and those arcs intersecting each other in the centre of the square (Figure 2.6) (Watts and Watts, 1992, p309).When four lines are drawn which touch the arcs while parallel to the square edges, a nine-unit-grid is yielded (Figure 2.7) (Wightman, 1997, p.68). The inner square can be sacred cut again and this process can be continued.

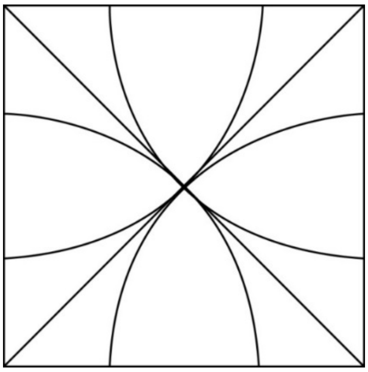


Figure 2. 6 'Sacred cut' construction

Source: Drawn from Watts and Watts, 1992, p309

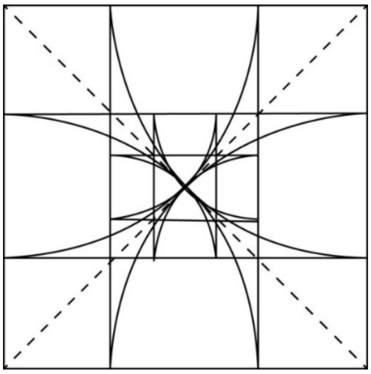


Figure 2. 7 The endless scared cut

Source: Drawn from Watts and Watts, 1987, p275

The sacred-cut process can be reversed, with the inner square defining the next largest square (Watts and Watts, 1987, p271). As shown in Figure 2.8, the inner square can be drawn first, and then it can be cut by four arcs centred at its four corners with its radius equal to its side length. Then with the four circles from the arcs completed, followed by the extension of the square diagonals the next largest square can be constructed. The intersecting points of diagonals and circles define the four corners of this next largest square (Watts and Watts, 1987, p271).

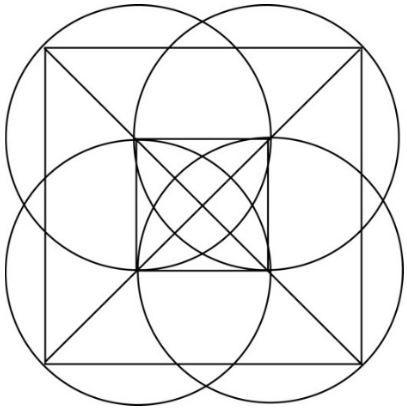


Figure 2. 8 The reversed scared cut process

Source: Drawn from Watts and Watts, 1987, p271

A circle is an enclosed space, which is constructed by a set of points in the same plane and each point has the same distance from the centre (Rich, 1963, p.68; Hann, 2012, p.33; Jacobs, 1974, p. 420).The point set is known as a circumference, which is illustrated in bold in Figure 2.9 and a part of the circumference is known as an arch. Thus arc AB and arc AC are illustrated in Figure 2.9. A line jointing the circle centre and a point on the circumference is a radius. Therefore, OA, OB and OC are radii in Figure 2.9. A line jointing two points on the circle is a chord. So AB is a chord in Figure 2.9. A diameter is a chord which passes through the centre of a circle (Rich, 1963, p.68).

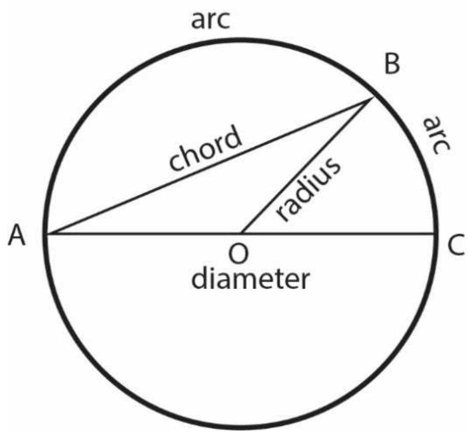


Figure 2. 9 Arc, chord, radius and diameter of a circle

Source: Drawn from Rich, 1963, p.68

All regular polygons are cyclic (Jacobs, 1974, p. 499), which means that any regular polygon can be placed inside a circle with all its vertexes touching the circle. Meanwhile, a circle can be drawn inside a regular polygon by touching its sides (Figure 2.10) (Rich, 1963, p.69). That is because all the distances from the centre of a regular polygon to its vertexes are the same, as well as the distances from the centre to the regular polygon sides (Rich, 1963, p.69).

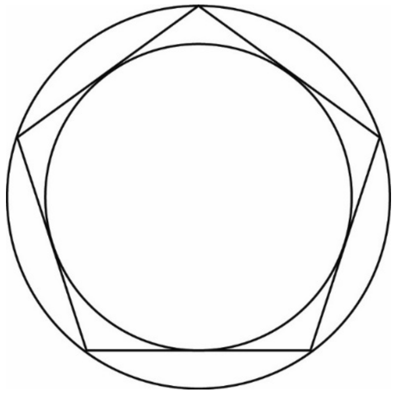


Figure 2. 1 0 Cyclic regular polygon

Source: Drawn from Rich, 1963, p.69

In summary, polygons are shapes bounded with straight lines (Hann, 2012, p.15). Regular polygons are special types of polygons which are cyclic.

2.4 Symmetry

Balance, as one of the most basic principles in design practice can be divided into symmetrical balance and asymmetrical balance.

Symmetrical balance is also known as formal balance which refers to a state of equilibrium (Poulin, 2011, p.123), that means that all the design elements are arranged completely ‘balanced’ or centred (Poulin, 2011, p.123) in a piece of design work. Symmetrical balance can be achieved by applying symmetry operations in the design process (which will be described in detail in this section) to achieve formal, stable, ordered and regular design outcomes (Poulin, 2011, p.126; Hann, 2012, p.73).For example, most book pages are designed symmetrical and most animals and human bodies are symmetrical as well.

Asymmetrical balance, on the other hand, is known as informal balance, which refers to ‘a state of lack of balance or symmetry’ (Poulin, 2011, p.130). In design practice, asymmetrical compositions are unstable, irregular and disordered (Hann, 2012, p.73). However, it creates more visual tension than symmetry compositions (Poulin, 2011, p.133). Some posters or paintings, for example, may use a small area of dark colour to balance a large area of light colour. This section, however, only focuses on symmetrical balance.

Symmetry can be further divided into two forms, static symmetry and dynamic symmetry (Hambidge, 1953, p. xii). Symmetry which has a fixed entity or state is called static symmetry (Hambidge, 1953, p. xiii). For example, the proportions of 1:1, 1:3, 1:4 and 2:3 have static symmetry (Hambidge, 1953, p. xiii). The proportion between the edges of a square is static symmetry.

Dynamic symmetry, on the other hand, is symmetry indicating life and movement (Hambidge, 1953, p. xii). Proportions like 1: $\sqrt{2}$; 1: $\sqrt{3}$; and 1: $\sqrt{5}$ are such examples (Edwards, 1967, p.4). These proportions can be found in dynamic rectangles, which will be discussed below in section 2.5. According to Hambidge, static symmetry and dynamic symmetry cannot be used unconsciously (Hambidge, 1953, p. xvi).

Symmetry can be achieved by applying symmetry operations (Hann, 2012, p.73) in design practice. Translation, rotation, reflection and glide-reflection are basic symmetry operations (Hann, 2012, p.74; Pearce and Pearce, 1978, p.14; Horne, 2000, p. 8). Each is discussed below and illustrated schematically in Figure 2.11.

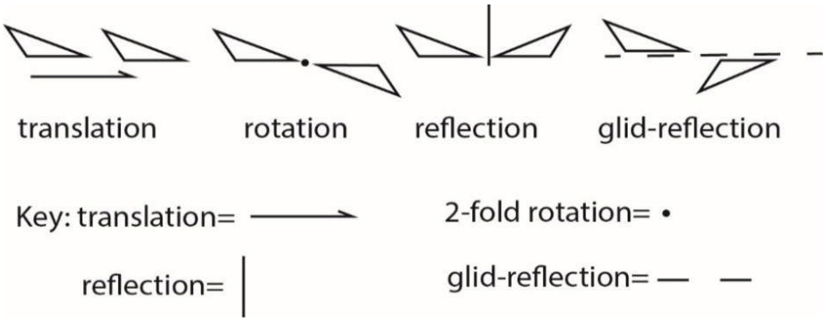


Figure 2. 1 1 Four basic symmetry operations

Source: Drawn from Horne, 2000, p. 8

Translation is where all parts of a figure or an object move the same distance in the same direction (Hann, 2012, p.75; Horne, 2000, p. 8). Here, the direction can be any direction, as long as the figure or the object is moved to an exactly same figure/object (Horne, 2000, p. 8). Translation geometry is commonly used in wall paper pattern designs.

Rotational symmetry refers to where a figure or an object repeats itself around an imaginary point (Hann, 2012, p.74) or around an imaginary axis (Pearce and Pearce, 1978, p.15). Rotational symmetry can be classified as divisions of 360 degrees (Hann, 2012, p.74). For example, if a figure or an object repeats itself once in a 360 degree rotation, this figure or object has one-fold rotation or is asymmetrical (Pearce and Pearce, 1978, p.15; Hann, 2012, p.75).If a figure or an object represents itself twice in a 360 degree rotation, it has two-fold rotation (Pearce and Pearce, 1978, p.15; Hann, 2012, p.75).Thus, if a figure or an object repeats itself 'n' times around a point or an axis in a 360 degree rotation, this figure or object has n-fold rotation. Rotation symmetry can be found in all regular polygons and Platonic solids, which will be described later in this section.

Reflection is known also as mirror symmetry, referring to figures or objects which are the same on either side of a line or a plane that divides it in halves (Pearce and Pearce, 1978, p.14; Hann, 2012, p.74; Horne, 2000, p. 8).Most man-made objects are reflectional.

Glide-reflection is a motion which combines translation and reflection along a glide-reflection axis (Pearce and Pearce, 1978, p.14; Hann, 2012, p.74; Horne, 2000, p. 8). The image of human footprints is an example of glide-reflection (Hann, 2012, p.75).

Therefore, translation, rotation, reflection and glide-reflection are basic methods in achieving symmetry in design practice.

Reflection and rotation symmetry can be found in all design structural frame works. In other words, regular polygons and Platonic solids are all reflectional and rotational. The following section aims to explore the geometric characteristics of regular polygons and Platonic solids.

Among regular polygons, the equilateral triangle has three-fold rotation and three reflection axes; the square has four-fold rotation and four reflection axes; the regular pentagon has five-fold rotation and five reflection axes, while the regular hexagon has six-fold rotation and six reflection axes (Pearce and Pearce, 1978, p.18) (Figure 2.12).

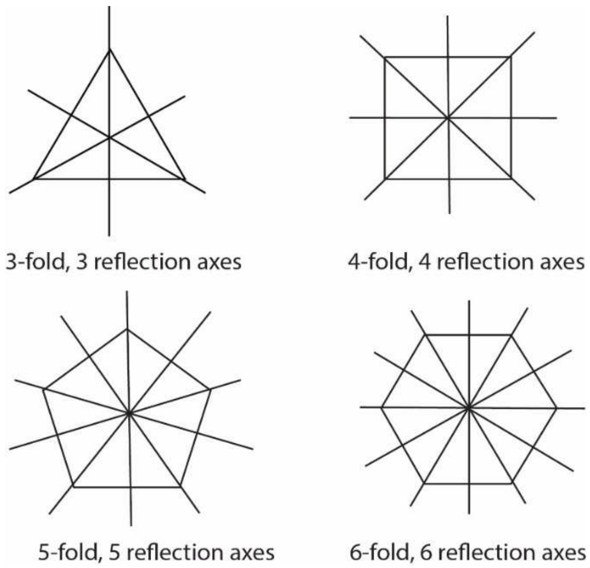


Figure 2. 1 2 Reflection and rotation in regular polygons

Source: Drawn from Thomas and Hann, 2007, p.44

2.5 Harmony, ratio and proportion

This section reviews the common constructions and proportions in two-dimensional design.

2.5.1 Golden-section proportion

Harmony, in design, refers to a satisfying relationship between the parts and the whole (Birkett and Jurgenson, 2001, p.255). The application of correct proportions or ratios can induce visual balance. Ratio is best considered as a geometrical progression (Hambidge, 1953, p.3), a comparison of two quantities (Poulin, 2011, p.223) and an abstract number without a unit of measure (Rich, 1963, p.87). For example, the ratio between 10 and 20 is 1:2. Proportion, on the other hand, can be described as a symmetric relationship (Poulin, 2011, p.219), a relationship between the parts and the whole (Birkett and Jurgenson, 2001, p.255) in regard to magnitude, quantity or degree (Poulin, 2011, p.218).Thus, both ratio and proportion are terms to describe a comparison relationship between one size and another. Proportion, however, is of a particular value as it expresses an integral relationship in a design (Poulin, 2011, p.219).

As mentioned in the previous section, proportions exist in both static symmetry and dynamic symmetry compositions (see Section 2.4). Ratios of rational fractions only exist in static symmetry, while irrational fractions can be found in dynamic symmetry (Elam, 2001, p.32). Static symmetry cannot produce harmonious ratios when subdivided (Elam, 2001, p.32). Because of this, attention will focus mainly on dynamic ratios in this section. In particular, the golden proportion, root rectangles and dynamic dividing methods will be discussed.

The golden proportion, also known as φ (phi), the golden section or golden ratio, represents a ratio of 1:1.618 that is believed to yield the most harmonious aesthetic beauty (Poulin, 2011, p.223). This ratio is believed to have been applied in almost all design disciplines. For example, the golden ratio has been found in Renaissance paintings, in the Parthenon temple and in most of the ancient Greek sculptures (Elam, 2001, p.6). Furthermore, it can also be found in line segments, some regular polygons and some Platonic solids.

As observed previously by Hann (2012, p.109), the golden proportion or golden section has been the subject of a vast range of literature, much of it fanciful, claiming the appearance of the measure throughout nature, the universe and the visual arts and design. There appears to be a belief that golden proportion measures can always be found, and it is only a matter of simple discovery to find them (Hann, 2012, p.109).

If a numerical series, such as the Fibonacci series (1, 1, 2, 3, 5, 8, 13, 21, etc), which displays the characteristics that each number is the sum of the previous two, the ratio between adjacent numbers is a golden ratio (Elam, 2001, p.11; Pough, 1976, p.8; Hann, 2012, p.109). In the context of the Fibonacci series, the proportions between 2 and 3, 3 and 5, and 5 and 8 are all close to 1:1.618 (Elam, 2001, p.11; Pough, 1976, p.8; Hann, 2012, p.109).

The golden ratio can be achieved in line segments if a line is divided into two parts such that the ratio of the shorter segment to the longer segment is the same as that of the longer segment to the whole (Poulin, 2011, p.223; Pough, 1976, p.8; Hann, 2012, p.110). For example, as shown in Figure 2.13, ‘a’ is to ‘b’ as ‘b’ is to ‘a’+‘b’, and when ‘a’ equals 1, ‘b’ will equal 1.618.

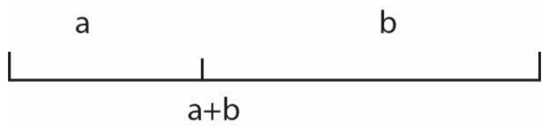


Figure 2.13 Golden ratio in line segments

Source: Drawn from Pough, 1976, p.8

When we consider an isosceles triangle whose internal angles are 36°, 72°and 72° or 108°, 36°and 36°, there will be a proportion of 1:1.618 between their shorter and longer sides (Pough, 1976, p.9). These are shown in Figure 2.14 a and b. In Figure 2.14 a, BC: AB =1:1.618, while in Figure 2.14 b, A’B’: B’C’ =1:1.618.

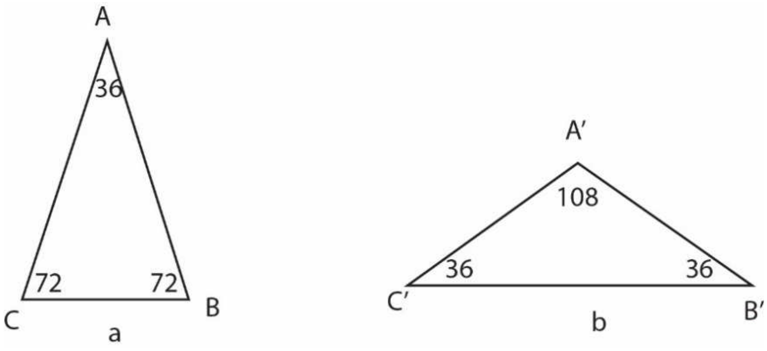


Figure 2. 1 4 Golden proportion in triangles

Source: Drawn from Pough, 1976, p.9

If a golden section is applied to a quadrilateral, which is a shape with four straight boundaries, then a golden-section rectangle is created (Pough, 1976, p.225; Hann, 2012, p.111; Raghubir and Greenleaf, 2006, p.96), in which, the ratio between the short side and the long side equals to the ratio between the long side and the sum of one short side and one long side (Figure 2.14) (Raghubir and Greenleaf, 2006, p.96).

A golden-section rectangle can be drawn from a square. As shown in Figure 2.15, ABCD is a square. Bisect CD, connect the middle point of DC and B, use that distance as a radius to draw arc BF that intersects DC’s extension at F, then draw line EF parallel to AD and extend AB to E, the resultant rectangle AEFD is a golden-section rectangle. The small rectangle BEFC is a golden-section rectangle as well since it has the same angles and proportions as rectangle AEFD. These two rectangles are called similar polygons (Rich, 1963, p.92). Also rectangle BEFC is known as the reciprocal of rectangle AEFD (Hambidge, 1953, p.30; Hann, 2012, p.111).

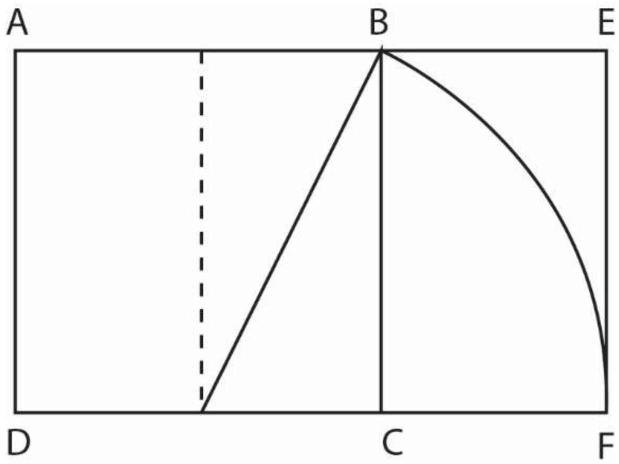


Figure 2. 1 5 The construction of a golden rectangle

Source: Drawn from Hann, 2012, p.111

Furthermore, a golden-section rectangle can be divided this way endlessly, and then a golden-section spiral can be drawn inside the rectangle. This possibility is shown in Figure 2.16 (Hann, 2012, p.111).

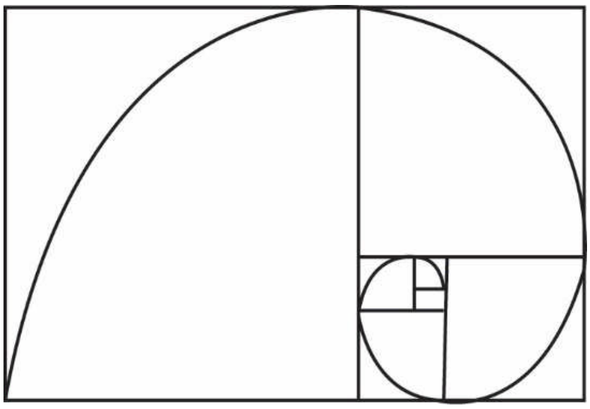


Figure 2. 1 6 Golden-section rectangle division and a golden-section spiral

Source: Drawn from Hann, 2012, p.111

As mentioned previously, an isosceles triangle whose internal angles are 36°, 72°and 72° has a golden ratio between its sides. As shown in Figure 2.14, triangle ABC is a 36, 72, 72, a triangle, in which BC: AB=1:1.618, so that a golden-section proportion can be found also in a regular pentagon and a regular decagon through sub-division (Pough, 1976, p.9; Hann, 2012, p.110; Elam, 2001, p.30).

Fibonacci squares divide a space into squares with side lengths corresponding to the Fibonacci series (Figure 2.17) (Landa, 2014, p.172). The characteristic of the Fibonacci series is that each number is the sum of the previous two, then the ratio between adjacent numbers is a golden ratio (Elam, 2001, p.11; p.8; Hann, 2012, p.109).Thus, this division is based on a golden-section proportion.

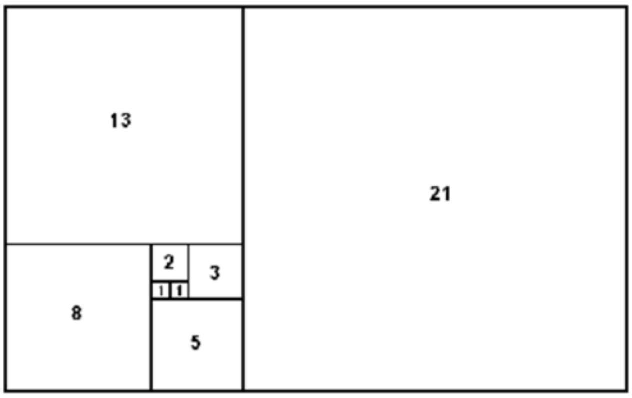


Figure 2. 1 7 The Fibonacci squares

Source: Drawn from Landa, 2014, p.172

A five-point star can be created inside a regular pentagon by its diagonal lines. This pentagon is called a star pentagram (Elam, 2001, p.31). A star pentagram ABCDE is drawn in Figure 2.18, in which, triangle ADC is a 36°, 72°and 72° triangle. AD:DC=1.618:1. Likewise, triangle AFG is a 36°, 72°and 72° triangle as well, where AF:FG= 1.618:1. This division can be continued endlessly (Elam, 2001, p.31; Pough, 1976, p.9).

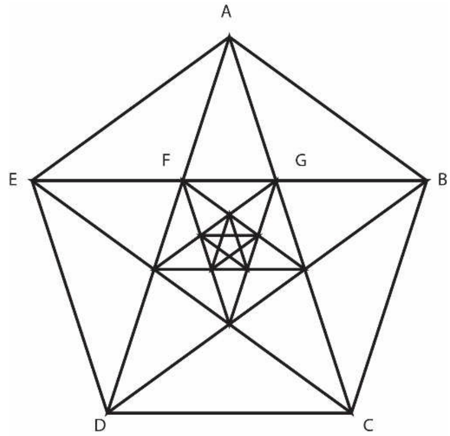


Figure 2. 1 8 Star pentagram division

Source: Drawn from Pough, 1976, p.9

A regular decagon can be divided into ten 36°, 72°, 72° triangles by connecting its centre and all the vertexes, which also has the ratio of 1:1.618 (Pough, 1976, p.9 Elam, 2001, p.30). This division is shown in Figure 2.19.

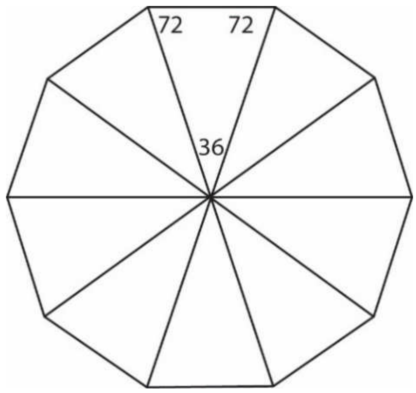


Figure 2. 1 9 Regular decagon division

Source: Drawn from Pough, 1976, p.9

Apart from regular polygons, the golden-section ratio can be found in some of the Platonic solids as well. Different from polygon divisions, golden-section rectangles rather than golden-section triangles can be found inside icosahedron and dodecahedron (Pough, 1976, p.10).

2.5.2 Dynamic proportions

Apart from the series of golden-ratio measures, dynamic rectangles can provide various dynamic proportions as well. The rectangle that is constructed based on a square and its diagonal is known as a root rectangle (Hann, 2012, p.39). All root rectangles can provide interesting proportions with or without sub-division (Hann, 2012, p.40). In design practice, root-two ($\sqrt{2}$), root-three ($\sqrt{3}$), root-four ($\sqrt{4}$) and root-five ($\sqrt{5}$) rectangles are used commonly as compositional aids. The following section focuses mainly on exploring the geometric characteristics of root rectangles.

The root-two rectangle is the most widely used structure in design practice (Elam, 2001, p.34). It can be constructed based simply on a square and its diagonal. As shown in Figure 2.20, ABCD is a square with the edge length of 1 unit (coloured by dark grey), so that the length of DB is $\sqrt{2}$. Connect DB and make DF=DB, the resulted rectangle AEFD is a root-two rectangle (coloured area) (Hambidge, 1953, p.18; Hann, 2012, p.39; Elam, 2001, p.34).

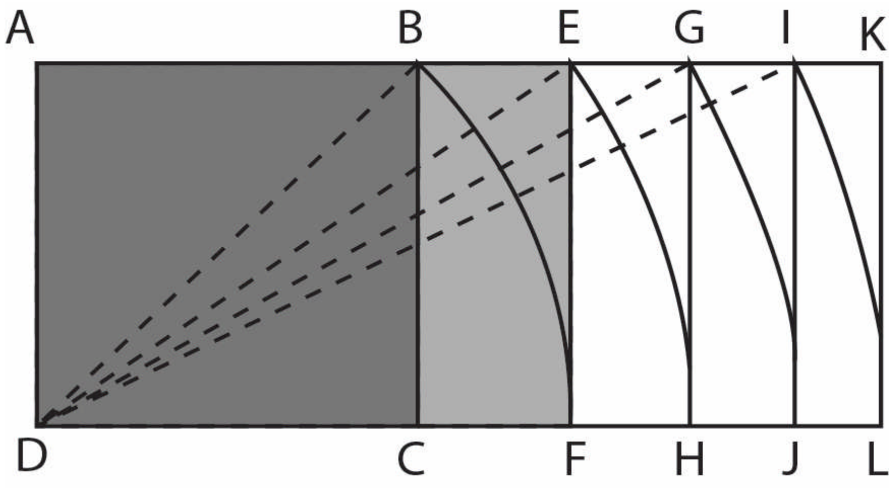


Figure 2. 2 0 The construction of root rectangles

Source: Drawn from Hann, 2012, p.39

The proportion between the edge lengths (AD: AE in Figure 2.20) equals to 1:√2. In other words, if the length of the short side is one, then that of the long side will be the root value (Hann, 2012, p.39).

Furthermore, root-two rectangles can be subdivided into two small root-two rectangles (Hambidge, 1953, p.18; Hann, 2012, p.39; Elam, 2001, p.34) and the dividing process can be continued endlessly (Elam, 2001, p.34). Root-two rectangles have also been found in ancient Egyptian and Greek designs (Hambidge, 1953, p.18; Hann, 2012, p.38). Nowadays, the DIN system of paper size is based on root-two rectangle sub-divisions (Elam, 2001, p.36). Figure 2.21 shows this case.

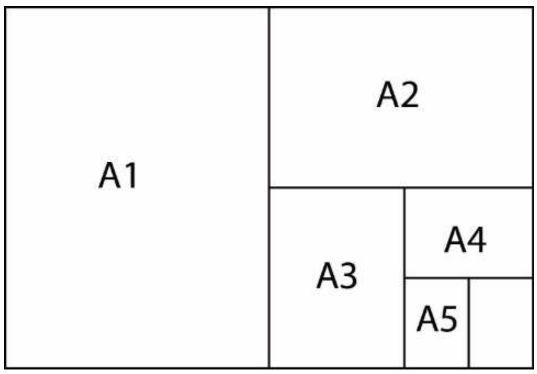


Figure 2. 2 1 The DIN system

Source: Drawn from Elam, 2001, p.36

Similar to the root-two rectangle construction methods, a root-three rectangle can be constructed based on a root-two rectangle and its diagonal. As shown in Figure 2.20, rectangle AGHD is a root three rectangle, in which, DE=DH, while AD: DH=1: $\sqrt{3}$ (Hambidge, 1953, p.19; Hann, 2012, p.39; Elam, 2001, p.38). Also, a root-three rectangle can be divided into three small root-three rectangles (Figure 2.34 b) and this process can be continued endlessly (Elam, 2001, p.38).

It is interesting to notice the relationship between the root-three rectangles and the regular hexagon. Precisely, by connecting the opposite points of a regular hexagon, three root-three rectangles are shown (Edwards, 1967, p.67). This is illustrated in Figure 2.22, in which, rectangle ABDE; rectangle FBCE and rectangle FACD are three root-three rectangles. In other words, a regular hexagon can be constructed by a root-three rectangle rotating around a centre axis until the corners meet (Elam, 2001, p.40). This construction process is shown in Figure 2.23. Rectangle ABCD is a root-three rectangle (Figure 2.23 a). After a first rotation, point A ends up in the position of point D; point D in Point D'; point C in the position of Point B; point B in point B'. This is shown in Figure 2.23 b. Then the rectangle ABCD can be rotated in the opposite direction. That is point D to point A; point A to point B'; point B to point C and point C to point D'. Figure 2.23 c illustrated this case. Thus, hexagon AB'BCD'D is constructed by the rotation of the rectangle ABCD.

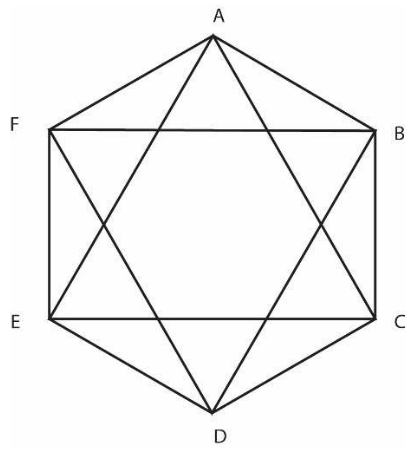


Figure 2. 2 2 A hexagon is divided into root-three rectangles

Source: Drawn from Elam, 2001, p.39

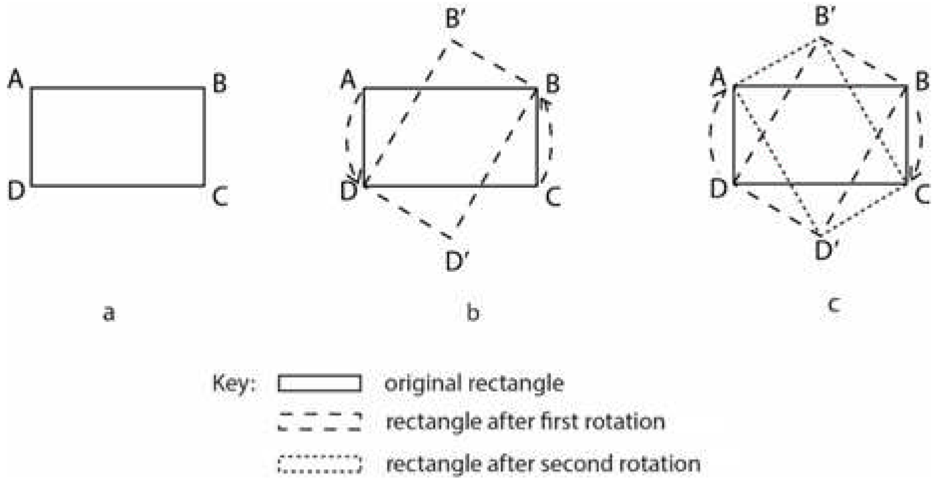


Figure 2. 2 3 A root-three rectangle constructs a regular hexagon

Source: Drawn from Elam, 2001, p.39

A root-four rectangle, on the other hand, can be drawn from a root-three rectangle by using the length of its diagonal. In Figure 2.20, rectangle AIJD is a root-four rectangle (Hambidge, 1953, p.19; Hann, 2012, p.39; Elam, 2001, p.42), and the proportion between the size lengths is 1:2. Thus, a root-four rectangle can be divided into two squares or four small root-four rectangles (Figure 2.24 c).

If the diagonal methods are applied to a root-four rectangle, then a root-five rectangle is produced. Rectangle AKLD in Figure 2.20 is a root-five rectangle, which has a proportion of 1: √5 between its shorter and longer edges. It can be divided into five small root-five rectangles (Figure 2.24 d). Again the subdivision can be repeated endlessly. Moreover, this is the highest root rectangle found in design practice (Hambidge, 1953, p.19; Hann, 2012, p.39).

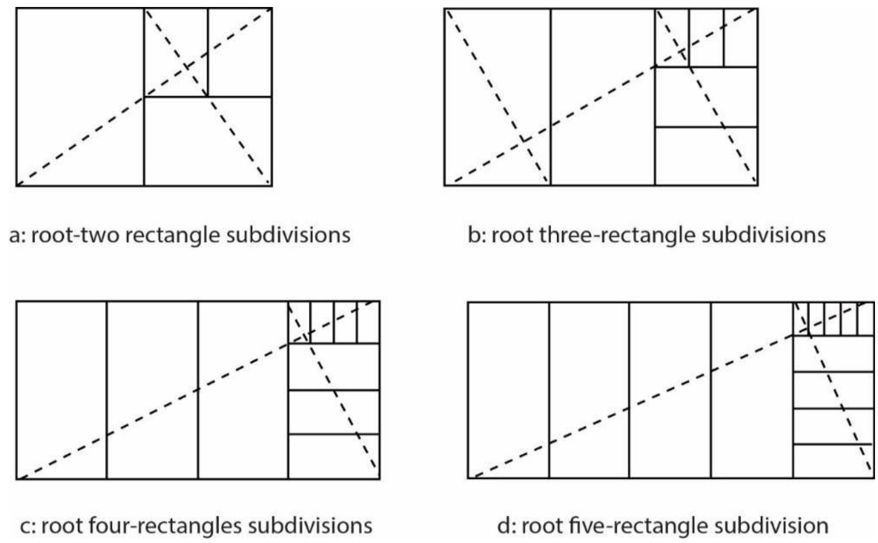


Figure 2. 2 4 Subdivision of root rectangles

Source: Drawn from Elam, 2001, p.42

Therefore, root rectangles are important structural frameworks to produce dynamic proportions. They can be obtained through square construction, and subdivision.

There are other ways to produce harmonic proportions. The diagonal division, the Brunes star and grids are methods to produce satisfying ratios (Hambidge, 1953, p.19; Hann, 2012, p.39).

If two golden-section rectangles are interlocking together, a √5 rectangle is then generated (show in Figure 2.25). ABCD is a square, with side of 1 unit length rectangle EBCH and rectangle AFGD are two interlocking golden-section rectangles. EFGH is a √5 rectangle.

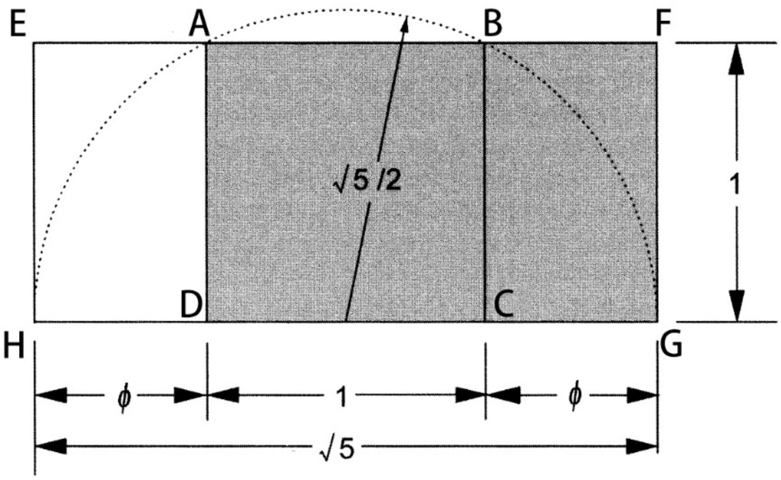


Figure 2. 2 5 The construction of a root-five rectangle

Source: Drawn from Birkett and Jurgenson, 2001, p.264

2.5.3 Diagonal divisions

Rectangles can be divided and then sub-divided by their diagonals (Hann, 2012, p.42; Elam, 2001, p.33). The Brunes star (Figure 2.26) is the most common type of diagonal division, which is shown when a rectangle is first divided into four equal parts and then the half and full diagonals are drawn (Hann, 2012, p.42). The intersecting points which are illustrated as black dots in Figure 2.26 are highly symmetrical and the parallel lines passing through those points divide the rectangle into various equal sections (Figure 2.26) (Hann, 2012, p.43). In design practice, the main elements are sometimes placed on the intersecting points of a Brunes star (Hann, 2012, p.43).

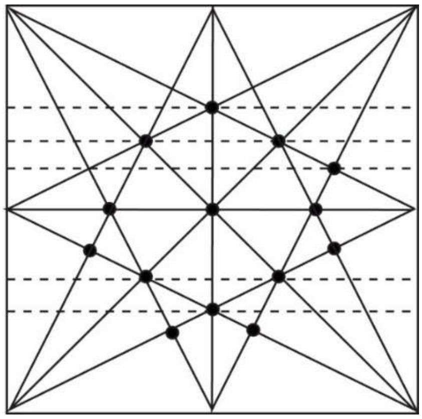


Figure 2. 2 6 The Brunes star

Source: Drawn from Hann, 2012, p.43

2.6 Types of two-dimensional grids and their use

The grid, as an assembly of lines (Hann, 2012, p.19), has been applied in various design disciplines. Examples can be found in pattern design (Collins, 1962), graphic design (Samara, 2003, p.24), architectural design (Chilton, 1999, p.2) and floor-plan structures (Hann, 2012, p.18).

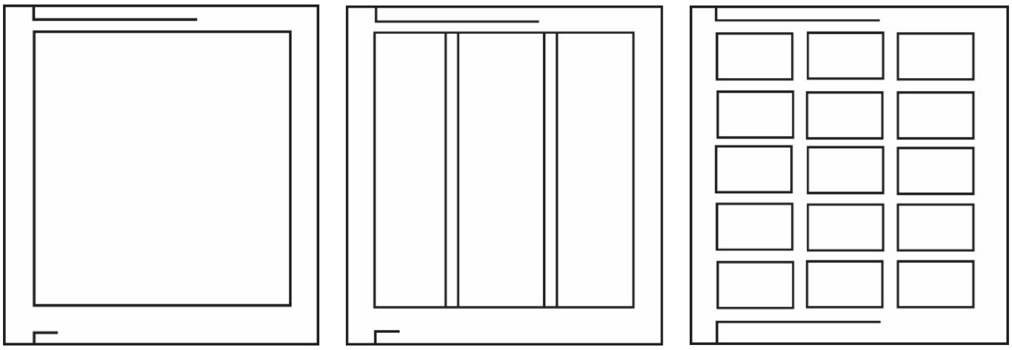
Grids can be divided into different types according to different reference systems. In two-dimensional design, there are six types of grids which are commonly used as guidelines. They are the base-line grid (Roberts and Thrift, 2002, p.26), the 3x3 grid (Elam, 2004, p.9; Hann, 2012, p.24), the manuscript grid (Samara, 2003, p.26), the column grid (Samara, 2003, p.27), the modular grid (Samara, 2003, p.28) and the hierarchical grid (Samara, 2003, p.29).

Horizontally, a page is structured according to a base-line grid. Vertically, it is divided into columns and margins (Roberts and Thrift, 2002, p.27). The column width, however, is based on the text type's size and the number of type within a line (Samara, 2003, P.27; Roberts and Thrift, 2002, p.18; Brockmann, 2008, p.31). Usually, the larger the text, the wider the columns required (Brockmann, 2008, p.31). After all, a comfortable column width has to be provided since either too long or too short columns can create an uncomfortable reading experience. According to Brockmann, too long columns can weary the readers, while too short columns force readers to change lines too rapidly (Brockmann, 2008, p.31). The number of columns depends on the print format and the size of typeface (Brockmann, 2008, p.49).

The manuscript grid (Figure 2.27a) is considered to be the simplest structured grid, and is comprised of a dominate rectangle occupying a page (Samara, 2003, p.26). In a book spread, it usually creates a mirror image, from left to right as well as the margins (Hurlburt, 1978 p.69). The margins, on the other hand, are particularly important in defining the appearance of the page (Samara, 2003, p.26).

The column grid (Figure 2.27 b) is largely applied to newspaper, magazine and book-page design allowing different information to be arranged in different vertical columns independent of each other (Samara, 2003, p.27). Furthermore, the column structure enables different information to be separated (Samara, 2003, p.27). For example, pictures and text are usually arranged in different columns in newspapers, magazines and webpage designs. Columns can work separately or can be combined to fulfill the requirement of the content. For example, a six-column grid is rarely used compared to six-column type; rather it is more commonly used to construct a three-column or a two-column make up (Hurlburt, 1978, p.55).

A modular grid is a column grid with horizontal subdivisions that appear as a matrix of cells (Figure 2.27 c) (Samara, 2003, p.28). Each module is a small information space (Samara, 2003, p.28). Similar to a column grid, modules can either work individually or combine together to form a larger grid field to fulfill special needs (Samara, 2003, p.28). For example, large pictures, illustrations and tables may occupy a number of modular spaces in a page (Brockmann, 2008, p.60). These table-like guidelines provide more flexibility as the proportion can be divided in any number of ways and the modules can be either vertical or horizontal in proportion (Samara, 2003, p.28). The control degree of grid system, however, depends on the size of modules. The smaller the grid unit, the more flexibility it can provide and the harder it is controlled (Samara, 2003, p.28).

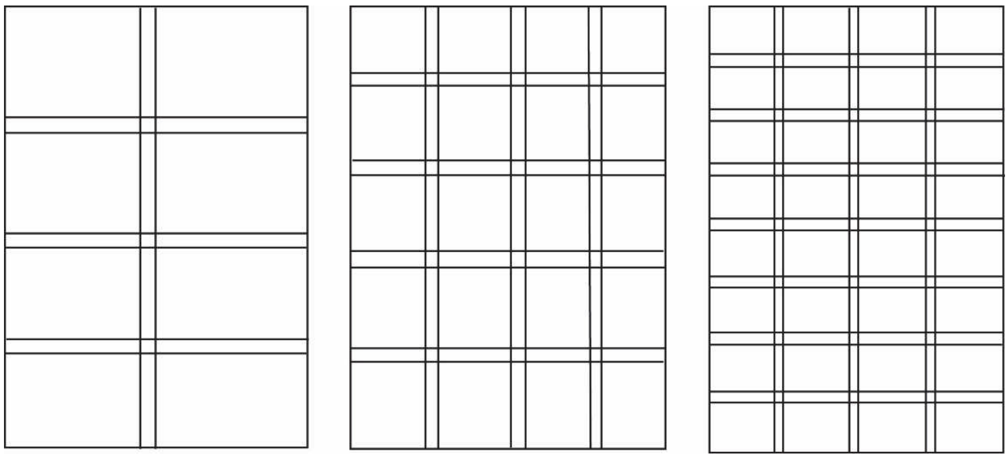


a b c

Figure 2. 2 7 a-c The manuscript grid, the column grid and the modular grid

Source: Drawn from Samara, 2003, p.26-28

Modular grids are usually divided into 8 fields, 20 fields and 32 fields (Figure 2.28 a-c) in design practice.



a b c

Figure 2. 2 8 The 8 fields, 20 fields and 32 fields grid

Source: Drawn from Brockmann, 2008, p.90

Grid systems discussed above, however, cannot fulfill all design needs. A hierarchical grid (Figure: 2.29) may be needed. Samara defined the hierarchical grid as “an odd grid that does not fit into any category” but it is still based on an intuitive placement (Samara, 2003, p.29). The column width and the spaces between them, however, can vary (Samara, 2003, p.29). Some web-page designs are examples of the application of a hierarchical grid (Samara, 2003, p.29). Also a hierarchical grid can be found to be used as guidelines in posters and billboard advertising design.

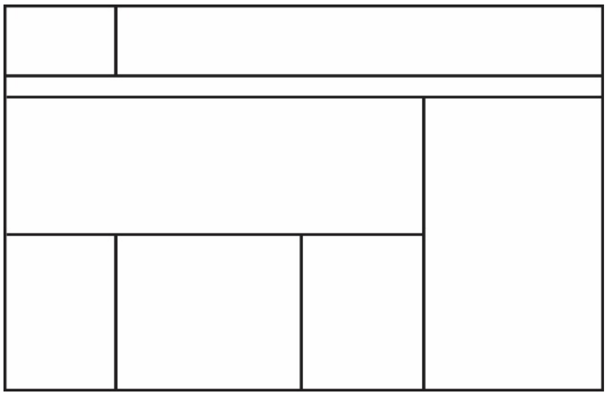


Figure 2. 2 9 The hierarchical grid

Source: Drawn from Samara, 2003, p.29

In addition to printing design practice, grids also play an important role in other design disciplines. Hann pointed out that, apart from squares, equilateral triangles and hexagons are usually used and tiling arrangements can also be used as units to create a grid (Hann, 2012, p.21). Examples can be found in some floor plans or building facade decoration. Moreover, the ratios of grid units can be flexible. Ratios such as 1:2, 2:3, 3:4 or 1:1.618 can also be used in creating a grid (Hann, 2012, p.21).

Therefore, grid systems have great flexibility and can be divided in different ways to fulfil different design needs. Among all the divisions, modular grids appear to have the most flexibility and have been applied in both two-dimensional and three-dimensional designs.

2.7 The division of square space

2.7.1 Square space divided by two lines

Geometric division of square space has long been a practice in human civilizations. Evidence can be found in pattern design (Özdural, 2000; Thompson, 1977); religious paintings (Popovitch, 1924); graphic design (Behrens, 1998; Elam, 2004); church or domestic floor plans (Wiemer and Wetzel, 1994; Betts, 1993) as well as in mathematics or geometry studies

(Bidwell, 1986; Yong, 1970). This section reviews the methodology of geometric division of square space as well as the proportions derived from different division methods.

Although a single line can divide a square space into certain proportions, in most cases, the minimum number of division lines for a square space is two. One of the common methods is to divide a square by its diagonal lines (Figure 2.30a). This division can be found commonly in Islamic pattern design (Özdural, 2000, p.175). A proportion of 1: √2 exists between the diagonal lines and the square edges, and the square is divided into four equal right-angled triangles. These highly modular subdivisions provide flexibility for pattern designs (Özdural, 2000, p.174). The re-arrangement of a divided square is shown in Figure 2.30 b.

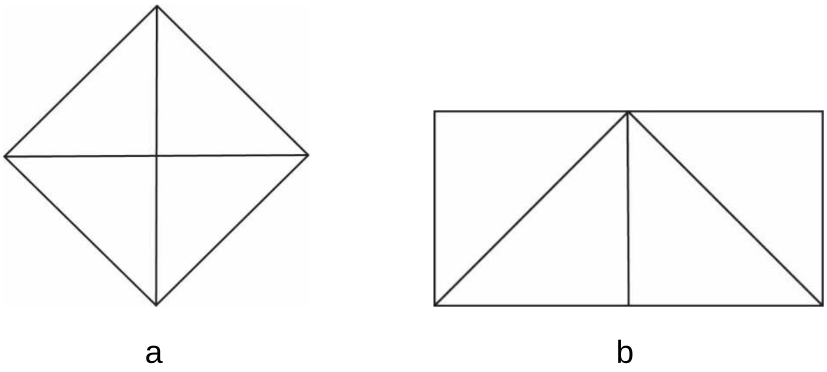


Figure 2. 3 0 Square divided by its diagonal lines and its re-arrangement

Source: Drawn from Özdural, 2000, p.175

Similar division is also found in many medieval church floor plans. Wiemer and Wetzel (1994) found the diagonal division of a square when analysing the geometrical structures of the floor plan of the chapel in Ebrach monastery church, a medieval church in Bamberg, Germany. Figure 2.31 reproduces this case.

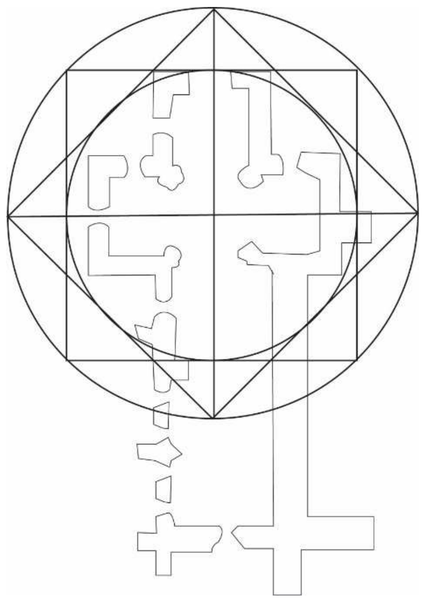


Figure 2. 3 1 The diagonal division of a church floor plan and its main division

Source: Drawn from Wiemer and Wetzel, 1994, p.456

In other cases, some of the division lines may be parallel to the square edges, as shown in Figure 2.32, in which, the middle square is divided by two lines which go across the middle point of its opposite sides, dividing it also into four smaller equal sized squares (Betts, 1993, p.17). The proportion between the original square and the sub-divided central square edges is 1:2.

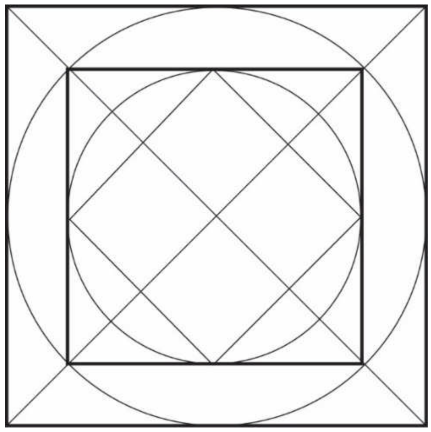
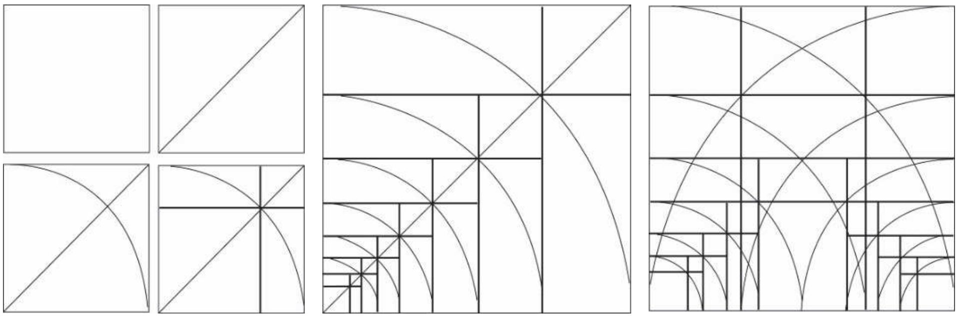


Figure 2. 3 2 Division lines parallel to square edges

Source: Drawn from Betts, 1993, p.17

Another method of sub-division of a square by two lines is known as 'gonmon', which refers to 'a shape or number that preserves the square and also makes it larger or smaller' (Watts and Watts, 1992, p.309) when added to or subtracted from it. This method has been applied to illustrate the space division in architecture (Coyne, Snodgrass and Martin, 1994). As shown in Figure 2.33a, a square is first divided by its diagonal, and then an arc centred at the bottom left corner of the square is obtained with the radius length equal to the side of the square. After that, two lines are made parallel to the square sides and these lines intersect at the diagonal-arch point. This produces a √2 proportion between the lengths of the sides of the two adjacent squares. This process can be repeated to obtain a series of scaled cuts as shown in Figure 2.33b, or it can be conducted in two corners of a square, to produce scaled grids, as shown in Figure 2.33c (Coyne, Snodgrass and Martin, 1994, p.115).This division was also found in urban plans by Watts and Watts (1992) in Gerasa (an ancient city near Jerash, Jordan).



a b c

Figure 2.３３ ‘Gonmon’ cut of square space

Source: Drawn from Coyne, Snodgrass and Martin, 1994, p.115

Referring to developments in mathematics, Yong stated that the ancient Chinese had no difficulty in root extraction to solve higher numerical equations, as early as the Han dynasty (206BCE-221CE) (Yong, 1970, p.92). The illustration presented in Figure 2.34 (reproduced from Yong, 1970, p.94) shows how the ancient Chinese calculated the square of 268, as a number involving hundreds, tens and single digits. Yong suggested the number 268 as this was deemed to be a convenient number to explain the relevant concepts and was not selected due to any further significance. The process is as follows: a square whose side length is 268 is drawn, then each side of the square 268 is divided into 200, 60 and 8, (as shown on the top and left side of the figure). Then horizontal and vertical lines are drawn from the points of 200 and 60. Through the division, the whole area is partitioned into three squares and four rectangles, marked as Square 1, Square 2, Square 3, Rectangle 1, Rectangle 2, Rectangle 3 and Rectangle 4 in Figure 2.34. Square 1 is a square of side 200, and an area of 40,000.Square 2 is a square of side 60 and an area of 3,600. Square 3 is of area 64. Rectangle 1 is a rectangle whose length is 200, width is 60, and area is 12,000. Rectangle 2 is the same as Rectangle 1 whose length is 200, width is 60, and area is 12,000. Rectangle 3 is a rectangle whose length is 260, with width of 8, and area of 2,080. Rectangle 4 is the same as rectangle 3, also marks an area of 2,080. So, when adding these numbers together, 40,000 (area of Square 1) + 3,600 (area of Square 2) + 64 (area of Square 3) + 12,000 (area of Rectangle1) + 12,000 (area of Rectangle 2) +2,080 (area of Rectangle 3) + 2,080 (area of Rectangle 4) = 71,824, the square of 268 is obtained. This method can also be applied in other numbers to calculate their squares (Yong, 1970, p.94).

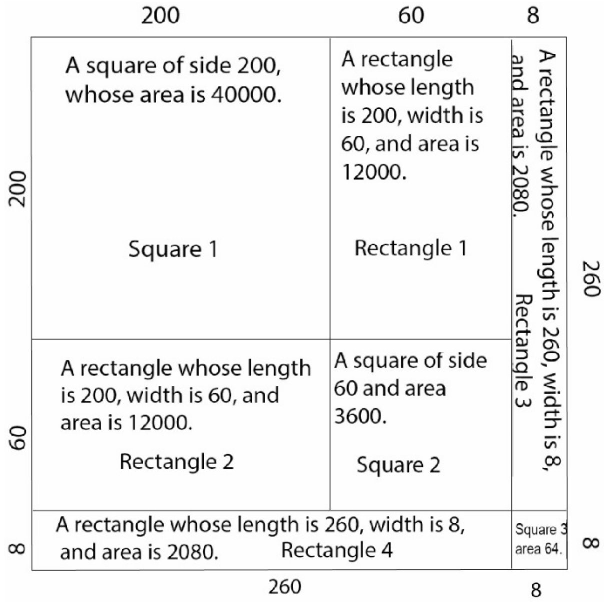


Figure 2. 3 4 A geometric means of calculating the square of 268

Source: Drawn from Yong, 1970, p.94

Hambidge (1953, p. 89) discovered, how to perform a √5 rectangle division within a square and a whirling square rectangle division and subdivisions of a square. When a √5 rectangle is drawn within a square, the square side is divided into 0.5528 and 0.4472 units assuming that the square side length is one unit (Figure 2.35). This division yields a proportion close to 5: 4.

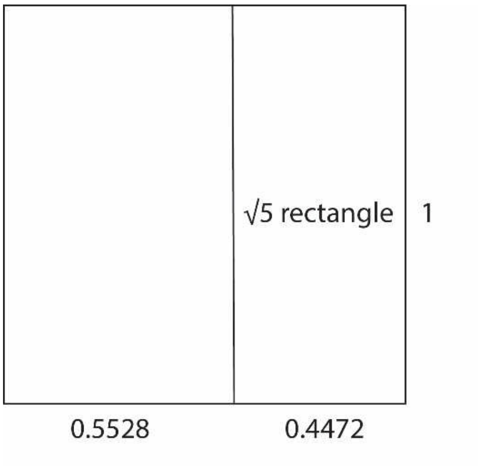


Figure 2. 3 5 A square divided by a root-five rectangle

Source: Drawn from Hambidge, 1953, p. 90

A whirling square rectangle shown in Figure 2.36 is a rectangle (AEFD) derived from the diagonal to half a square (GB). As shown in Figure 2.36, ABCD is a square. BG bisect CD, use the distance of BG as a radius to draw arc BF that intersects DC's extension at F, then draw line EF parallel to AD and extend AB to E, the resultant rectangle AEFD is a whirling square rectangle. If such a rectangle is drawn inside a square, and the square length is one unit, the square side is then divided into 0.382:0.618 (Figure 2.37 a). If a middle line is added to the rectangle, the square edge is then divided into 0.382; 0.309 and 0.309 proportions. Figure 2.37 shows this case.

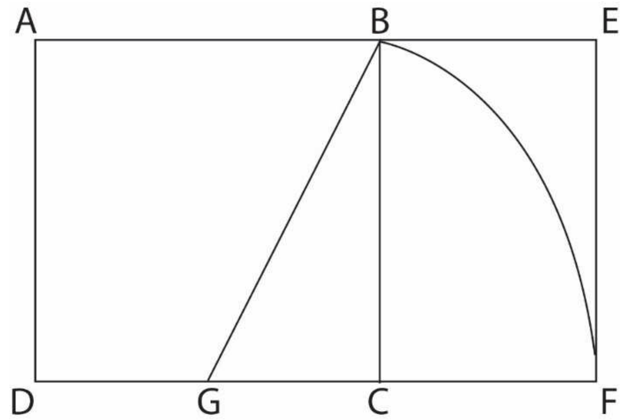


Figure 2. 3 6 The initial stage of a whirling square rectangle construction

Source: Drawn from Hambidge, 1953, p. 25

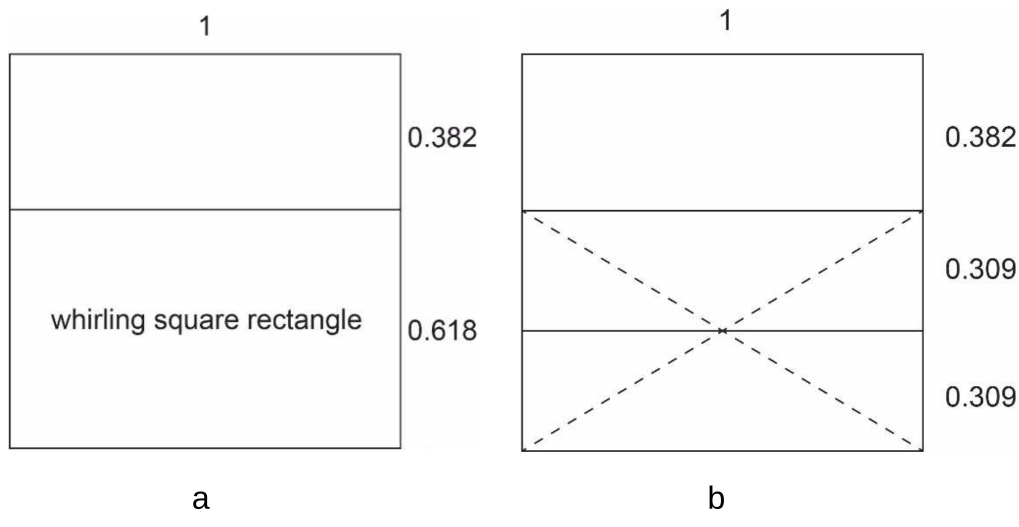


Figure 2. 3 7 A square divided by a whirling square rectangle

Source: Drawn from Hambidge, 1953, p. 94

2.7.2 Square space divided by three lines

In design practice, square spaces are usually divided by an even number of lines. However, on occasions three lines may be used. Hambidge (1953, p.95) discussed the division of squares by three lines when explaining the nature of dynamic geometry. He illustrated a square, with side length of one unit (ABCD), cut first by a whirling square rectangle (EFCD), then the rectangle's diagonal (DF) and its reciprocal diagonal (EK) is drawn and those two lines intersect at a point shown in Figure 2.38. Vertical and horizontal lines (IJ and GH) are drawn as shown. The square edge is cut into 0.1708 (HC), 0.4472 (FH), and 0.382 (BF) by the horizontal divisions, and 0.2764 and 0.7236 by the vertical division (Hambidge 1953, p.95).

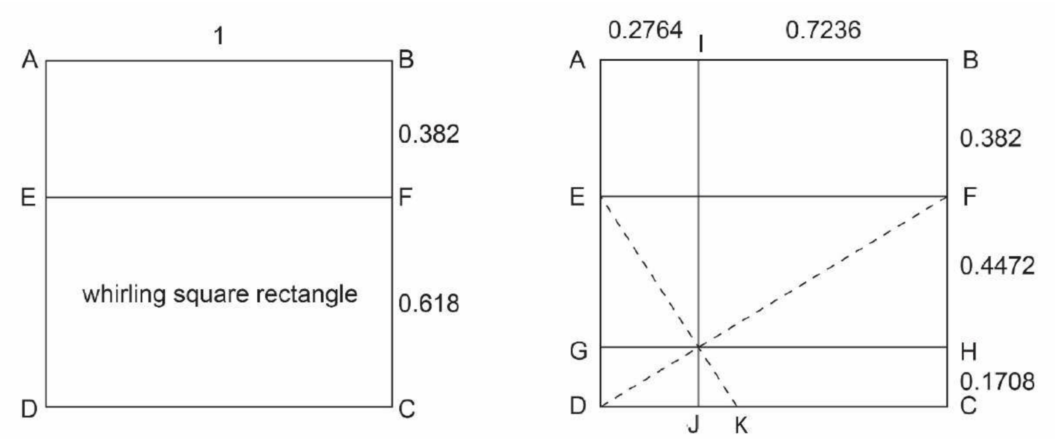


Figure 2.38 A square divided by three lines

Source: Drawn from Hambidge, 1953, p. 95

Another three-line division presented by Hambidge is reproduced in Figure 2.39, in which, the horizontal division includes a whirling square rectangle (EFCD) within a square (ABCD), and the vertical side of the square is divided into 0.382 (BF) and 0.618 (FC) (Hambidge 1953, p.97). Meanwhile, the horizontal sides are divided by two vertical lines, which go through the intersection points of the rectangular diagonals and its reciprocal diagonals. The upper and lower sides of the square are partitioned into measurements of 0.2764 (AG), 0.4472 (GH) and 0.2764 (HB) (Hambidge 1953, p.97).

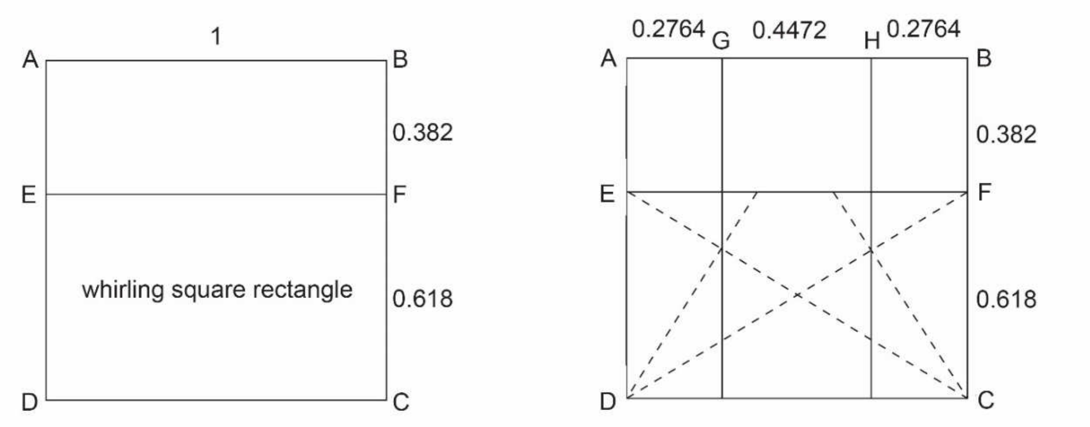


Figure 2. 3 9 A square with three division lines

Source: Drawn from Hambidge, 1953, p. 97

2.7.3 Square space divided by four lines

In design practice, square spaces are commonly divided by four lines (straight or curved). Elam (2004, p.13) considered graphic compositions based on 3x3 grids (where two vertical lines intersect with two horizontal lines). The 3x3 grid is thus a square space divided into thirds horizontally and vertically (Figure 2.40) (Elam 2004, p.13). The four intersecting points are known as 'optimal focus' points and key visual elements are usually arranged on or near those points (Elam 2004, p.13). The same division is also found commonly in ancient Roman architectural design (Jacobson, 1986, p.16). In the analysis of the geometrical structure of six floor plans, modular proportions were found in both rectangular and circular temples. Among these, a 3x3 grid structure was found in the ground plan of the annex of 'the temple of the Venus ' (Figure 2.41) (Jacobson, 1986, p.18) where, the circular constructions are closely packed within 3x3 grids.

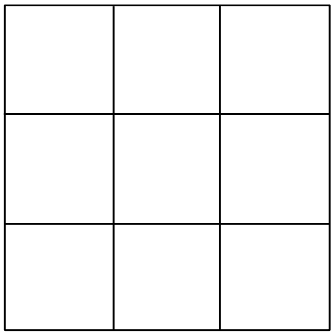


Figure 2. 4 0 The 3x3 grid

Source: Drawn from Elam, 2004, p.13

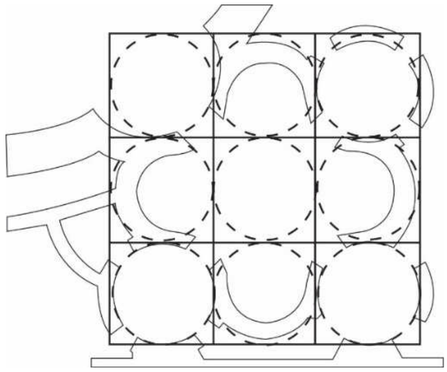
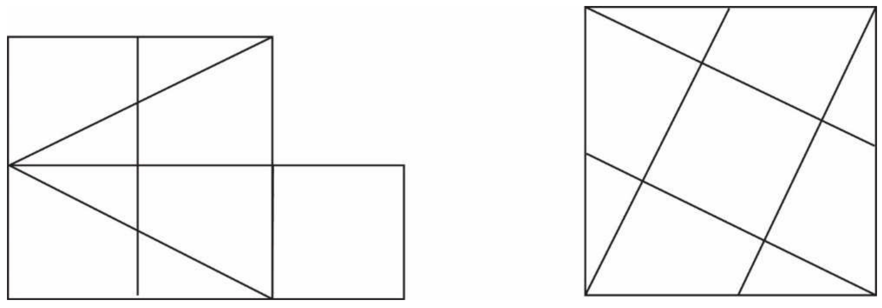


Figure 2. 4 1 The annex of 'the temple of Venus '

Source: Drawn from Jcobson, 1986, p.18

In Islamic pattern design, one method of designing patterns by using square units is to assemble a large figure from five square units (Figure 2.41) (Özdural, 2000, p.175). Figure 2.42a shows a figure constructed from four units and an extra square unit. Then the large square is divided by its half diagonal lines, thus creating four identical right-angled triangles, four identical right-angled trapezoids and one extra square unit (as shown in Figure 2.42a) (Özdural, 2000, p.175). These triangles, trapezoids and the square can be rearranged to create a new structure as shown in Figure 2.42b (square ABCD) (Özdural, 2000, p.175).



a b

Figure 2. 4 2 A larger square is made of 5 square units

Source: Drawn from Özdural, 2000, p.175

In a study of Babylonian geometry, a structure involving 'halving, squaring, addition, subtraction, square roots and multiplying by reciprocals ' was found (Figure 2.43) (Bidwell, 1986, p.23). Geometrically, the construction shown in Figure 2.43 can be considered as a square within a square with four identical rectangles between the two (Bidwell, 1986, p.23). One of the four rectangles (shaded in grey) can be considered to repeat in an anticlockwise (alternatively, a clockwise) direction within the larger square. As illustrated in Figure2.43, the width of the rectangle is one unit, while the length is three units; the side of the inner square is two units and the sides of the whole square are each four units. Thus the proportion of 1:2:3:4 exists in this division.

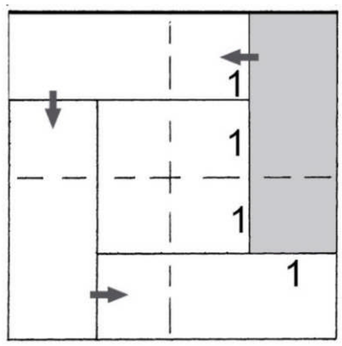
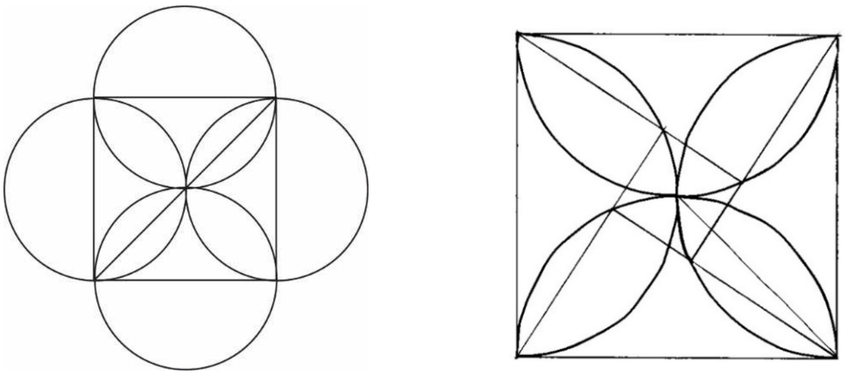


Figure 2. 4 3 Babylonian geometrical division

Source: Drawn from Bidwell, 1986, p23

Instead of division by straight lines, the square spaces can be divided by curved lines (arcs) as well. The most common example of a square space divided by four arcs is known as the 'sacred cut'. This has been explained previously in section 2.3. 'Sacred cut' construction has been used in Christian cathedrals, Buddhist temples and in Islamic designs (Dabbour, 2012, p.38).

In Islamic design, the square is often cut by four circles with diametres equal to the side length of the square (Figure 2.44a) (Dabbour, 2012, p. 383). The square and its inner constructions can be further divided into a small square and four right triangles (Figure 2.44b) (Özdural, 2000, p.184).



a b

Figure 2. 4 4 Square divided by circles

Source: Drawn from Dabbour, 2012,p. 383; Özdural, 2000, p.184

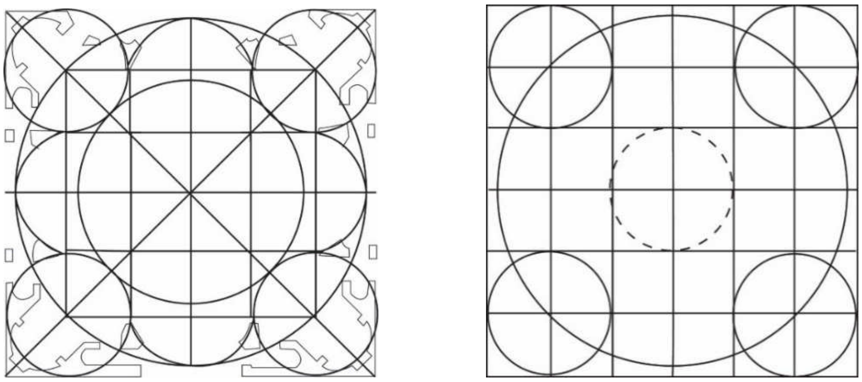
2.7.4 Modular grid division

The modular division of space can be based on grids (as with the 3x3 grids). Also common is the 6x6 grid used frequently in design practice. In graphic design, Elam for example, found that 6x6 grids underpinned various poster constructions including the 'Identification of the AIDS virus' poster (Figure 2.45) (Elam, 2004, p.104).

Figure 2. 4 5 The 6x6 grid used in the 'Identification of the AIDS virus' poster

Source: Elam, 2004, p104

The 6x6 grid structure was found to exist also in the floor plan of 'Hadrian's Villa' (at Tivoli, Italy) (Figure 2.46a), a building plan associated with ancient Rome (Jacobson, 1986, p.77). The geometrical structure identified by Jacobsen is re-produced in Figure 2.46a and the main elements of the structure are given in Figure 2.46b.



a b

Figure 2. 4 6 The 6x6 grid in the floor plan of 'Hadrian's Villa'

Source: Drawn from Jacobson, 1986, p77

In the floor plan of the 'small bath' in Hadrian's villa, a square and two rhombuses are constructed within a 6x6 grid (Figure 2.47) (Jacobson, 1986, p.80).

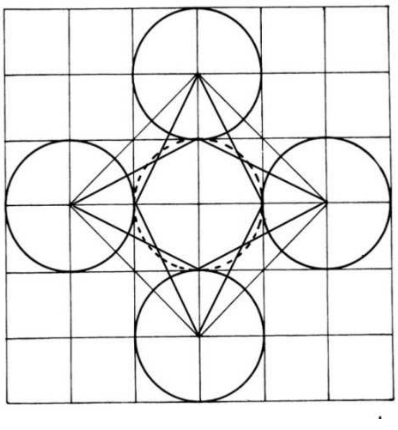


Figure 2. 4 7 The floor plan of Hadrian's villa, small bath

Source: Drawn from Jacobson, 1986, p.80

The length of the square is 2√2 units, while the length of each side of the rhombuses is √5 units. Thus, the proportion 1: √5: 2√2 can be found in this construction.

Moreover, the 6x6 grid can be considered as an elaboration of the 3x3 grid.

2.7.5 Other types of space division

Square space can be divided by square constructions to achieve dynamic (or continuous) division. Examples can be found often in church and cathedral floor plans (Wiemer and Wetzel, 1994, p.460; Dudley, 2010, p.49). Figure 2.48 shows an example of this sort of division. Similar structures exist in window mullions of ancient temples (Shelby, 1972, p. 400). Geometrically, it is a square space divided by a smaller square which is set at 45 degrees inside it, with the smaller square's corners touching the middle points of the edges of the larger square. A √2 proportion exists between the side lengths of the adjacent squares. This division process can be repeated.

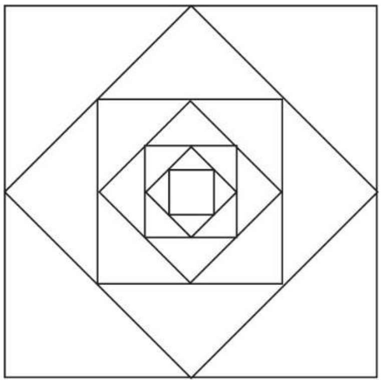


Figure 2. 4 8 The illustration of a square divided by square

Source: Drawn from Dudley, 2010, p.49

In graphic design, two or more types of grids can be put together to provide interesting layouts. Likewise, in the case of space division, more than one type of divisions can be combined as well. In the floor plan of Canterbury Cathedral, two identical squares are each divided into 3x3 grids, and then combined with one at 45 degrees to the other (Dudley, 2010, p.46; Wiemer and Wetzel, 1994, p.452). This construction is illustrated in Figure 2.49.The divided square lines form an octagon (illustrated in bold line in the figure). The inner two squares form an eight-point star (shown shaded).

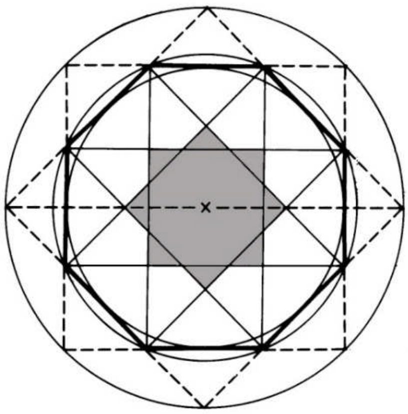
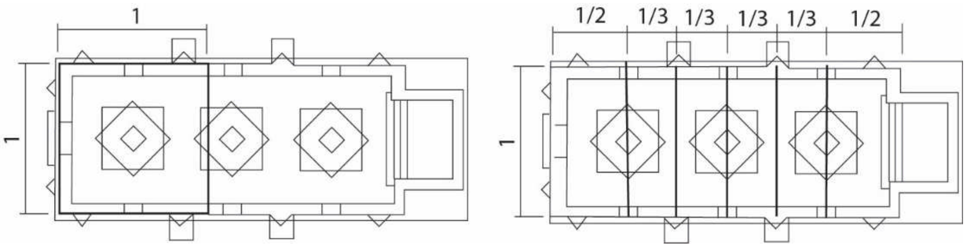


Figure 2. 4 9 Grids on grids square space division

Source: Drawn from Wiemer and Wetzel, 1994, p.452

It is also worth noticing that in the analysis of the plan of Dombauhütte (Köln, Germany), Anderson (2008, p.451) started his analysis process by dewing squares with the same length as the floor plan width (shown in Figure 2.50a), then he found out that the overall length of the Dombauhütte is composed of halves and thirds of the floor plan width (shown in Figure 2.50b).



a b

Figure 2. 5 0 The halves and thirds in the plan of Dombauhütte

Source: Drawn from Anderson, 2008, p.451

In summary, this section reviewed the methodology of geometric division of square space. In particular, 2, 3 and 4 line divisions were discussed, followed by grids division and shape division methods. Proportions such as 1:2; 1:3; 5: 4; 1:√2; 1:√5 and 1: 0.618 are common proportions among different division methods in Islamic patterns, graphic design as well as various architectural designs.

2.8 Summary

This chapter reviewed the fundamental principles of geometry applied in two-dimensional designs. Firstly, the geometry characteristics of a number of regular polygons were introduced. Then symmetry and the operations were reviewed. Attention was paid also to common types of two-dimensional grids. These are all of importance in design composition.

Chapter 3 : Case study group number 1 - Terracotta warriors, Xi'an (China)

3.1 Introduction

The terracotta army was discovered in Xi'an, China in 1974 (Geddes, 1984, p.5). The site can be dated back to 247 B.C.E. (Liu, Pagán and Liu, 2011, p.353) and was constructed to guard the after-life of the first emperor of China.

Two-dimensional grids are used as guidelines to solve layout problems in various spheres of design. Square grids were also found underlying ancient Egyptian paintings (Weingarten, 2000, p.104; Iversen, 1968, p.217), underlying ancient Greek sculptures (Weingarten, 2000, p.106) and underlying Assyrian reliefs (Robins, 1990, p.117) to provide proportional reference points for parts of the human body. This chapter reviews the common types of cannon used (generally square grids of given proportions), as well as how different types of cannon divide the human body differently. A 15-grid system is developed (based on the division of three) in order to study the terracotta warrior standing figure proportions.

Attention is focused firstly on background information and the sampling methods used for the terracotta figures. Then common types of cannons and how they provide proportional division on human figures are reviewed, followed by an explanation of the analytical methods use for the terracotta warrior proportion study with two examples of applying the methods to the case samples.

3.2 Data

This section provides a range of background information relating to the terracotta army and also provides commentary on the source of data used for this case study.

3.2.1 Terracotta army's background information

The so-called terracotta army was discovered in Lintong, a country district in the east of Xi'an, China in 1974 (Geddes, 1984, p.5). The site can be dated back to 247 B.C.E. (Liu, Pagán and Liu, 2011, p.353) and was constructed to guard the after-life of the first emperor of China. Approximately 8000 individual soldier figures invariably refered to as 'warriors' (Geddes, 1984, p.5; Liu Pagán and Liu, 2011, p.352), 130 chariots and 670 horse figures (Liu Pagán and Liu, 2011, p.353) have been excavated so far, and this is believed to be only a small proportion of the total number of the terracotta army; also there are sites yet to be excavated (Liu Pagán and Liu , 2011, p.353).

From 1974 to 1976, three pits were found and numbered pit 1, pit 2 and pit 3. These are located closely and occupy a total area of around 20,000 square metres (Zhao, 1988, p.1).The relative position of each is shown in Figure 3.1.

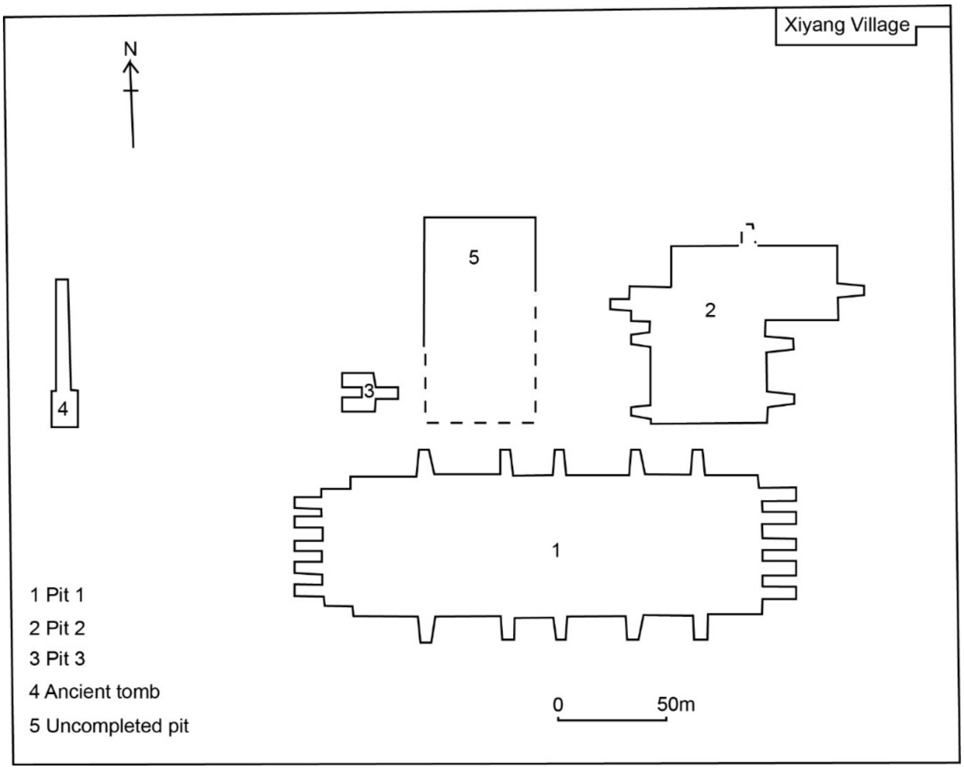


Figure 3. 1 Positions of pit1, pit 2 and pit 3

Source: Drawn from Zhao, 1988, p.5

The excavation of pit 1, (which occupies over 14,000 square metres) started in May 1978 (Zhao, 1988, p.1). The whole pit was divided into 27 squares (Figure 3.2). From 1979 to 1981, five squares against the east end of the pit were excavated. They are marked 1, 2, 10, 19 and 20, and illustrated in shadow in Figure 3.2 (Zhao, 1988, p.9). Within these five sections, 1087 soldier figures (687 with armour and 400 without), 8 chariots and 32 horse figures were excavated (Zhao, 1988, p.10). By the year 1984, 28 terracotta (pottery) horses and 714 warriors in different ranks had been repaired (Zhao, 1988, p.10).

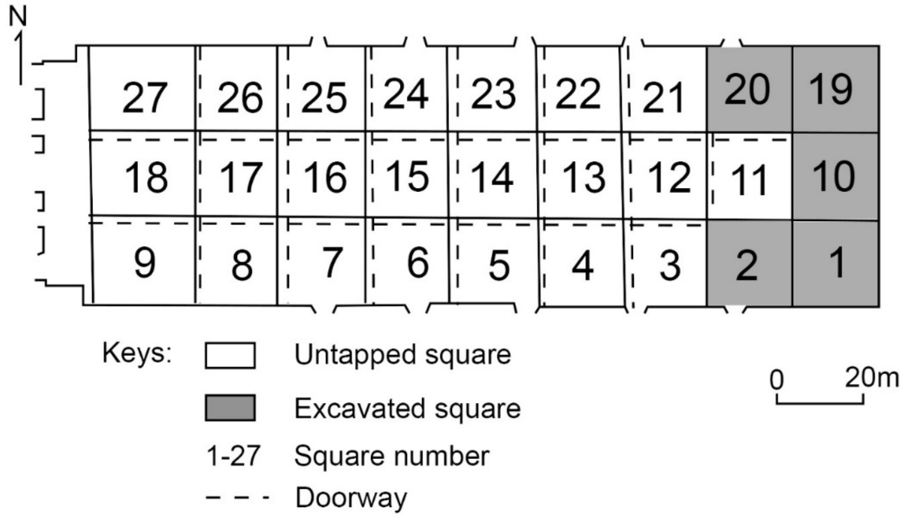


Figure 3. 2 Locations of squares in pit 1 excavation

Source: Drawn from Zhao, 1988, p.10

All illustrations of the figures and the measurements are based on the excavation report of the five squares (1, 2, 10, 19 and 20) in pit 1.

The uniforms of soldiers and officers have no significant difference. The difference between the type of arms and ranks depend on the difference in the types of armour. Figure 3.3 shows the types of armour (Fu, 1985, p.10; Zhao, 1988, p.142).

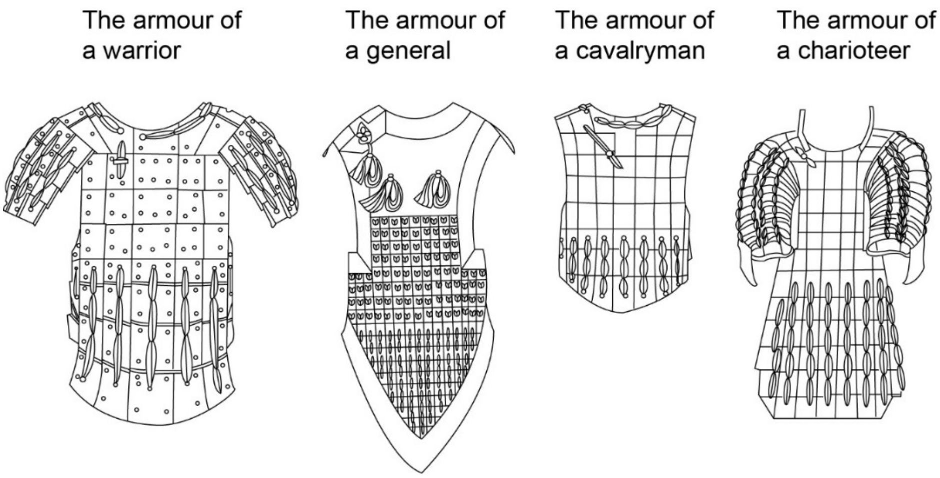


Figure 3. 3 Types of armours

Source: Drawn from Fu, 1985, p.10

Each terracotta warrior may be an individual portrait of an actual soldier (Portal, 2007, p.21) but this is not known for certain. However, archaeological evidence shows that the manufacture of the warriors involved a degree of mass production as a limited repertoire of body parts were found joined together in different combinations (Portal, 2007, p.21), with detailed work added by hand subsequently (Portal, 2007, p.21).

Zhao (1988, p.503) explained the process of making terracotta warriors in two steps: a rough cast was made first, and then detailed engraving was added. The rough figure was made section by section from bottom to top: 'the footboard was made first, then feet, legs, torso and forearms' (Zhao, 1988, p.503). When the rough shape was finished, clay was applied for a second time to sculpt the details of the body, including the clothing details, feet and leg muscles and, in some cases, bone structures (Zhao, 1988, p.504).

The heads and hands of the terracotta warriors were made separately, and then they were added to the torsos (Zhao, 1988, p.503). Similar to the body producing process, the rough shape of heads and hands were made with moulds first, and then individual details were sculptured on the top (Zhao, 1988, p.504). The variety of face shapes and the variety of hand sizes and gestures suggests that there were a few different types of moulds used to produce rough shapes during the manufacturing process (Zhao, 1988, p.499).

3.2.2 The selection of cases to be analysed

This section discusses the criteria, the source, the scope and the data selection methods of this case study.

Robins mentioned that 'the whole figure must be preserved if it is to be used for grid analysis'; photographs have to 'be taken straight on without distortion'(Robins, 1990, p.108).Furthermore, the proportion between the illustration size and its actual size may be of importance when collecting data with measurements.

Based on the above criteria, the 35 standing warrior figures illustrated in 'The Pits of terracotta Warriors and Horses of Qin Shihuang Mausoleum--- An Excavation of No. 1 Pit' (Pit 1 excavation report) were selected. Kneeling figures and figures with other gestures were regarded as out of the scope of this study.

The Pit 1 excavation report includes 37 individual standing warrior figure drawings as well as a large number of photos taken in the excavation site. In terms of the illustrations, all of them are drawn based on a scale to their actual measurements with whole figures presented. Precisely, 17 of them were illustrated of their front, side and back views; 10 figures have their front and side view illustrated; 7 of them only illustrated in front view; 2 figures have both front and back view and 1 only has a side view.

In the respect of photographs, the report presented 40 photos which include the whole body, however, only 8 of them have the photo taken of the front of the figures. The rest of the figures are taken in a perspective view, where distortions of the figures can be detected by the eye. Furthermore, the scale of the photograph and the figures' actual measurements are not found in the report.

Compared to the photographs presented in the report, the illustrations of the warrior figures have less distortion and therefore are more suitable for case analysis. However, two of the illustrations are excluded because one does not have a front view, the other one is in a pose of shooting an arrow.

Thus, the Pit 1 excavation report is the source book of the selection. All of the standing figures presented in the front view are selected as samples for further proportion study.

3.3 Methods

Grid systems play an important role in dividing the human body geometrically since ancient times. Square grid systems (or cannons of proportion) have been found in ancient Egyptian drawings (Robins, 1994, p.73), ancient Greek sculptures (Weingarten, 2000, p.103) as well as Renaissance statues (Zenas, 1976). These grid systems allow for the standardization of proportions, and permit artists to place key points of the human body on particular grid lines in both horizontal and vertical directions. However, considerations relating to ideal human proportions appear to be different from culture to culture. This section reviews six types of modular grid systems (for detailed literature about common types of grids please refer to chapter 2, section 2.6) from ancient times to Italian Renaissance times.

3.3.1 The first Egyptian cannon of proportion

The first Egyptian cannon is a square grid system used before the 25th dynasty (early-7th century BCE) (Carter, Steinberg, 2010, p.104). With this system, male standing figures were divided into 18 equal parts horizontally from the soles of their feet to their hairlines (Figure 3.4) (Robins, 1994, p.73; Weingarten, 2000, p.103). Key points of the body were marked by the horizontal division lines as follows:

Line 18: Hairline.

Line 17: Through or near the bottom of the nose.

Line 16: Through or near the junction of the neck and shoulder.

Line 14: Through or near the nipple.

Line 11: The navel.

Line 9: Through or near the lower border of the buttocks.

Line 6: Through the knees.

Line 0: Below the soles of their feet.

(Robin, 1994, p.73; Weingarten, 2000, p.103)

Other horizontal lines did not go through such obvious parts of the body (Robin, 1994, p.74). The vertical lines were drawn symmetrically parallel to the bisection line of the figure (Robins, 1994, p.74; Weingarten, 2000, p.103). Some key points can be defined also according to the position of the relationship between the lines and the body parts. For example, the shoulder width of the body was always six units wide (Robins, 1994, p.74); the width of the narrowest part of the waist was 2 1/4 to 2 1/2 squares (Robins, 1994, p.74).

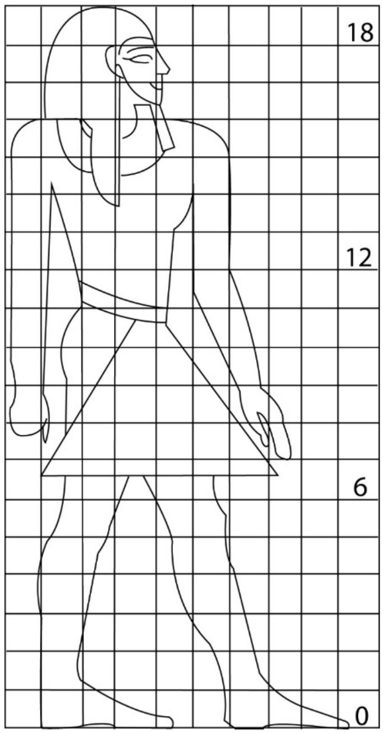


Figure 3. 4 The first Egyptian cannon of proportion: the 18-square division

Source: Drawn from Weingarten, 2000, p.104

3.3.2 The second Egyptian cannon of proportion

In the 26th dynasty (664-525 BCE) (Carter, Steinberg, 2010, p.104), the second Egyptian cannon replaced the first grid system to provide proportional divisions for human figure drawings. In this later system, male standing figures were divided into 21 equal parts from the sole of their feet to their upper eyelids (Figure 3.5) (Robins, 1994, p.160; Iversen, 1968, p.217). Key points of the body were divided by the horizontal lines as follows:

Line 21: Through the upper eyelid.

Line 20: Through the mouth.

Line 19: Through the junction of the neck and shoulder.

Line 16: Through or near the nipple.

Line 13: Through or near the small section of the back.

Line 11: Through or near the lower border of the buttocks.

Line 7: Top of the knees.

Line 6: Below the bulge of the tibial tubercle.

Line 0: Below the soles of their feet.

(Robins, 1994, p.160)

A vertical line goes through the ear bisection of the body, and other vertical lines are displayed symmetrically on both sides of the line (Robins, 1994, p.160). The shoulder width is approximately 7 squares; the armpit width is 5 squares and the width of the narrowest part of the waist is 2 3/4 to 3 squares (Robins, 1994, p.163).The body features were, therefore placed between the grid lines rather than on the grid lines (Robins, 1994, p.160). For example, in Figure 3.5, the outer edges of the shoulder are placed between grid lines instead of placed on the grid lines. Likewise, the edge of upper arm and waist are in the middle of the grid cells.

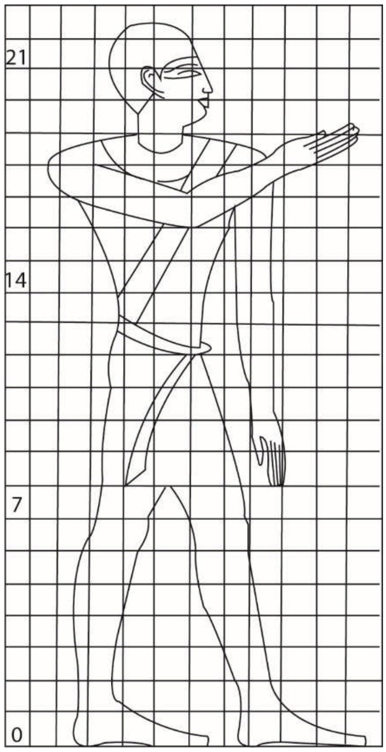


Figure 3. 5 The second Egyptian cannon of proportion: the 21-grid division

Source: Drawn from Iversen, 1968, p.217

3.3.3 The 21-grid proportions in ancient Greek

In the study of Korai (the largest Minoan statue) proportions, Guralink declared that the second Egyptian cannon of proportion was found in both male and female Korai figures, and thus argued that Greek sculptures adopted Egyptian cannon without major modification (Guralink, 1981, p.270). However, in a more recent study, Weingarten (2000, p.106) suggested a 21- grid for the Palaikastro Kouros statue. As can be seen in Figure 3.6, the 21 grid measurement was between the hairline and the sole of the feet. Using this system the key points of the statue were proposed as follows:

Line 21: The hairline.

Line 18: The widest point of the shoulders.

Line 17: The nipples and armpits.

Line 1 1: Top of buttocks.

Line 10: Joins of the legs or lower buttocks.

Line 6: The top of the knees.

Line 1: Ankles.

Line 0: Below the soles of their feet.

(Weingarten, 2000, p.105)

Furthermore, Weingarten drew the vertical lines on both sides of the middle line and discovered that the widest part of the shoulders occupied 3 units on each side, 'exactly as in the Egyptian cannon' (Weingarten, 2000, p.108).

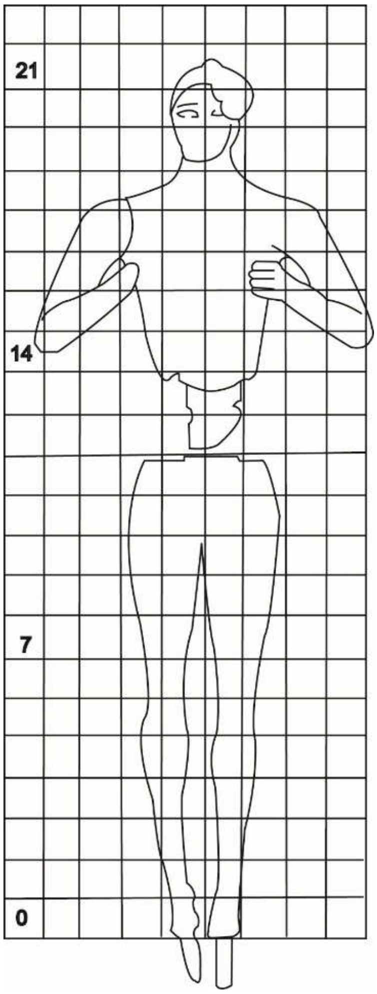


Figure 3. 6 The 21-grid division for the Palaikastro Kouros statue, as proposed by Weingarten

Source: Drawn from Weingarten, 2000, p.106

3.3.4 The 15-grid system in Assyrian sculpture

Robins set out to discover the proportions of Assyrian figures by applying a 15-grid system to the representations of 125 complete standing figures with human or eagle-headed features from North-west palace of Assurnasirpal II at Nimrud (Robins, 1990, p.107). This grid system divides each figure from the middle of their eyes to the bottom of the soles of their feet into 15 equal parts (Robins, 1990, p.108). Accordingly, the key points in the horizontal direction were found to be:

Line 15: The middle of the eye.

Line 13: The forward shoulder (eagle-headed figure only).

Line 9: Top of the buttocks.

Line 5: The bottom of the kilt.

Line 2: 1/2: The calf muscle.

Line 0: Line 0: Below the soles.

(Robins, 1990, p.109)

Vertically, the division spreads from the body axis like the Egyptian cannon. The width of the body at the buttocks is 3 squares (shown in Figure 3.7) (Robins, 1990, p.110). Robins also pointed out that although the heights of those Assyrian figures are not the same, the key points of the body are located in a fairly limited range (Robins, 1990, p.116).However, none of them is identical (Robins, 1990, p.116).

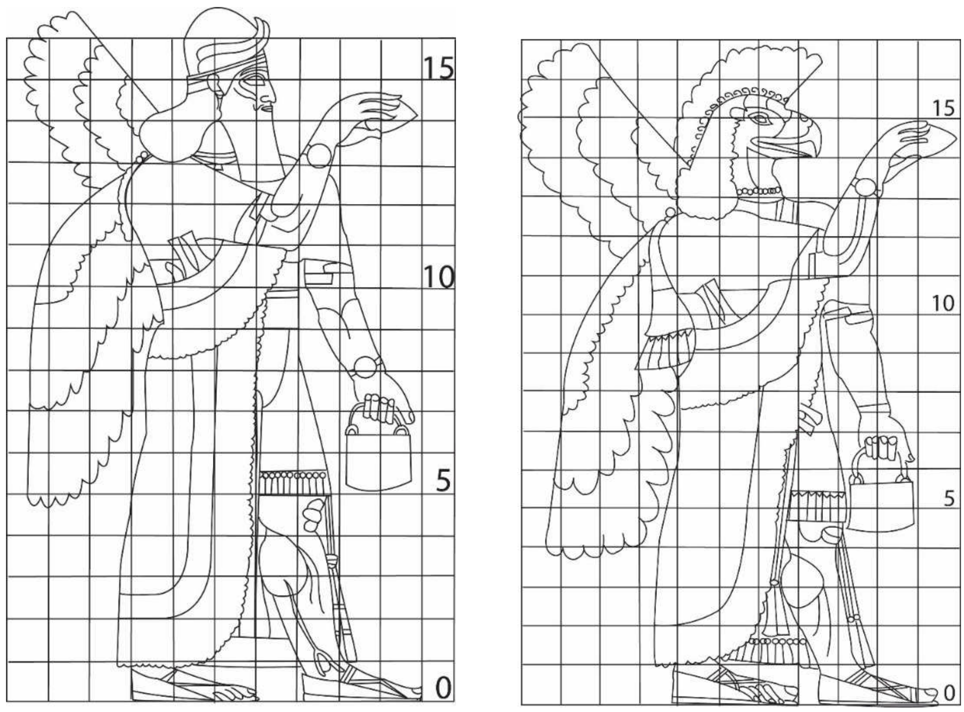


Figure 3. 7 The 15-grid division in Assyrian human and eagle-headed figures

Source: Drawn from Robins, 1990, p.117

3.3.5 Cennini's cannon

Cennini's Cannon is a proportional division in Italian Renaissance large-scale sculptures, which divides the human standing figure into 9 face lengths from the top of the head to the bottom of soles of their feet (Zervas, 1976). Evidence for such division was found in Ghiberti's St. Matthew (Figure 3.8 a). The faces of the sculptures are divided into three equal parts. Cennini's cannon can be further interpreted into a 27-grid cannon (9 faces, each divided by 3) from the top of the head to the base of the soles. Figure 3.8 b shows this case. Accordingly, the key points can be listed as follows:

Line 27: Top of the head.

Line 22: Pit of the throat.

Line 19: Middle of the chest (nipple).

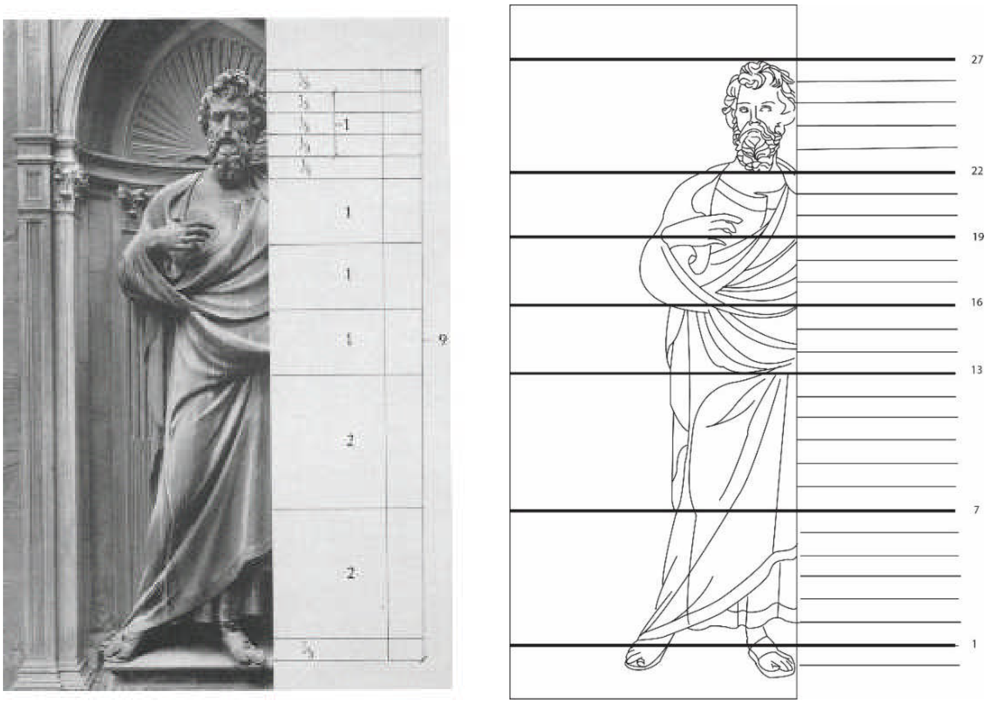
Line 16: Navel.

Line 13: Thigh joint.

Line 7: Knee.

Line 0: Sole of the feet.

(Zervas, 1976, p.37).



a b

Figure 3. 8 The Cennini's cannon division in ;arge-scale Italian Renaissance sculptures

Source: Drawn from Zervas, 1976, p.39; Morselli, 1978, p.236

3.3.6 Alberti's 6-grid division

Alberti, an Italian Renaissance artist, divided the total human height into 6 equal parts (Figure 3.9 a and b) (Morselli, 1978, p.238). This division fits perfectly on the sculpture of St. Stephen (located in Florence, created by Ghiberti during 1427-28). The key points marked by each division line are:

Line 6: The top of the head.

Line 5: The shoulders.

Line 4: At the lower edge of the sternum.

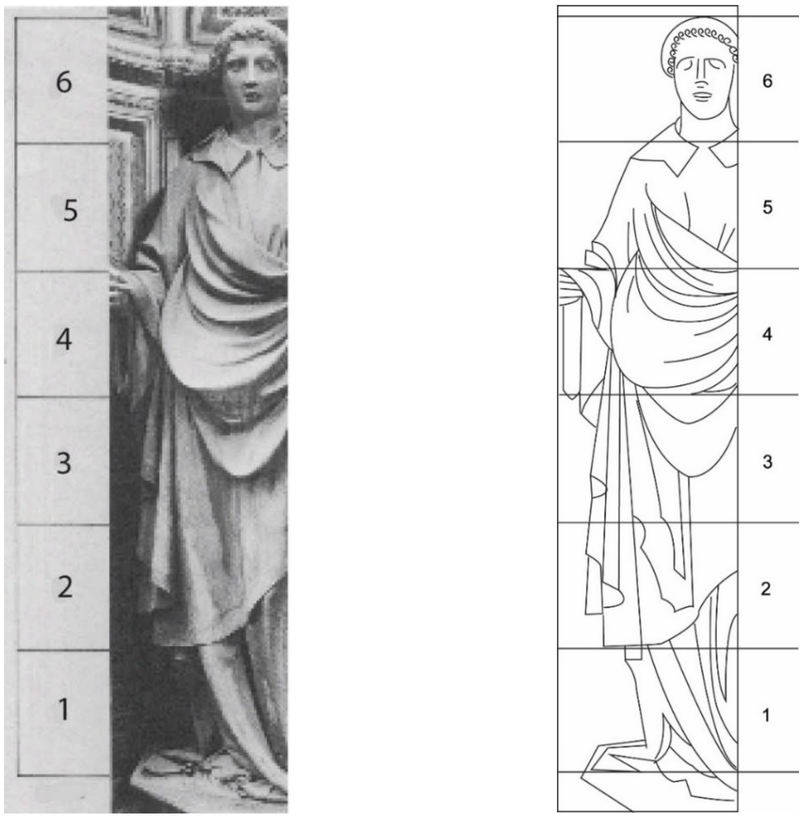
Line 3: At the pubis.

Line 2: Above the knee.

Line 1: On the shin.

Line 0: Sole of the foot.

(Morselli, 1978, p.238)



a b

Figure 3. 9 Alberti's 6 grids division on St. Stephen sculpture

Source: Drawn from Morselli, 1978, p.238

Apart from cannon division, artists also tend to divide the human body by the length of certain body parts. For example, the height of the human body equals to eight head-lengths (Wolf, 1943, p.364); ten face-lengths (Fairbanks, 1988, p.76) or thirty-one nose-lengths (Fairbanks, 1988, p.76). Leonardo da Vinci also studied the proportional relationship between human body parts. He found out that 'four fingers make one palm and four palms make one foot' as well as 'the length of a man's outspread arm is equal to his height' (Creed, 1986, p.1541).

All the cannons mentioned above are based on multiples of 3. (For example, 27, 21, 18, 15 and 6). All the base lines are located at the bottom of soles of the feet. Only the top reference lines vary from the top of the head to the middle of the eyes.

3.4 Analysis

Cannons of proportion (Weingarten, 2000, p.104), divide the human body into equal square grids according to a certain standardization of their natural proportions (Iversen 1968, p.215; Robins, 1994 p.23). This section explains the development of a suitable system of analysis and its application to two sample figures.

3.4.1 The development of a novel 15 square grid

This section explains how a particular grid system for terracotta warriors standing figures’ proportion is developed.

After applying the common types of grid systems (explained previously in section 3.3) to the terracotta warrior figures, none of them showed a convincing relationship between the grid division lines and the key points of the body.

In the study of Assyrian standing figure proportion, Robins took the distance between the top of the knee and the bottom of the sole as a unit of measure, three units from the sole of the feet reached the middle of the eye (Robins, 1990, p.108). Then he sub-divides each unit into five equal grids. Therefore, the Assyrian figures were divided into 15 grid divisions from the middle level of their eyes to the bottom of their soles (Robins, 1990, p.108). Further details of Robin's 15 grid division were given in section 3.3 above.

In the case of terracotta warrior standing figures, most key points of the body are obscured by the armour and robes they wear, especially key points such as nipples, navel, and knees. Thus the method Robin used to define the upper reference point is not suitable in this study. Because most cannons can be divided by three (mentioned in section 3.3), the division of three will also be considered as a starting point of terracotta warrior proportional division.

Similar to all the cannons reviewed previously, the bottom of the soles of the figures feet is considered as a baseline, which is the lower reference point. After applying the division of three and various sub-divisions (5, 6, 7, and 9) between the baseline and various upper points (including the top of the head, hairline, upper eyelid and middle of the eye), it was observed that a 15-grid division between hairline and baseline makes more sense than other types of grids, as most horizontal division lines go through key points of the body. Thus, the bottom of the soles of each figure's feet is the lower reference point, while the hairline is considered as the upper reference point. The distance between the upper and lower reference points are divided into three equal sections, then each section is further divided into five equal parts. In other words, a 15-grid system from hairline to the bottom of the soles is chosen as the grid type most suitable to the study of terracotta warrior proportions study. Measurements are calculated in square units, half squares and a quarter square (Robins, 1990, p.109).

3.4.2 The application of the proposed grid to the sample figures

Figure T1G2: 22 in Zhao, 1988, p.80 is one out of 35 warrior figures. The height from the soles of the feet to the top of the head measured 178 cm (Zhao, 1988, p.355). The distance between the soles and hairline is calculated as 172.25 cm. When a grid model of 11.48 cm square grid system is placed over the figure (Figure 3.10), the underlying structure marked by the horizontal grid lines can be listed as follows:

Line15: The hairline.

Line 13: Through the junction of neck and shoulder.

Line 11: Through or near the nipple.

Line 9: Through or near the small section of the back.

Line 4: Through the top of the knees.

Line 0: Below the soles of the feet.

Although the positions of the nipple and knee are obscured in the figure, Line 11 and line 4 still mark the approximate position of these two key points.

Unlike Egyptian or Assyrian figures, this figure cannot be symmetrically divided in a horizontal direction. The width of the body occupies 5 grid units, the narrowest part of his waist took 3 and a half units.

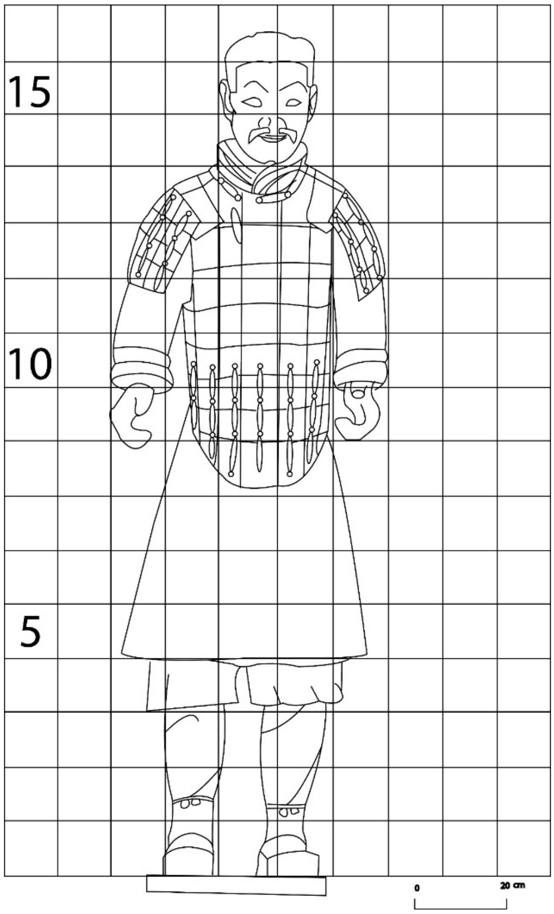


Figure 3. 1 0 The application of the proposed grid to Figure T1G2: 22 from Zhao (1988)

When the same grid is applied to an unarmoured figure T10G7:10 in Zhao, 1988, p.70, the scale of the grid units are slightly smaller than the previous case (T1G2: 22), as the measurement of T10G7:10 from top of his head to the bottom of his sole is 176 cm (Zhao, 1988, p.364). The distance between his sole and hairline is calculated 170 cm; therefore the length of each grid unit is 11.35 cm. Figure 3.11 illustrates this case. The horizontal division lines mark the following key points:

Line15: The hairline.

Line 13: Through the junction of neck and shoulder.

Line 11: Through or near the nipple.

Line 9: Through or near the small section of the back.

Line 4: Through the top of the knees.

Line 0: Below the soles of the feet.

In this case, line 11 and line 4 mark the position of the nipple and knee respectively, where these two points are obscured by the robe.

Horizontally, the figure occupies slightly less than 5 units, almost two and a half units on each side of the bisection line. The narrowest part of the body takes approximately two and a half units.

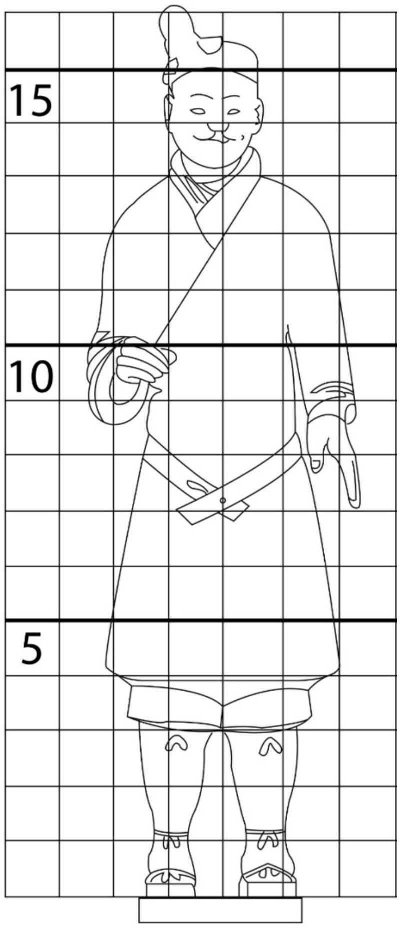


Figure 3. 1 1 The application of the proposed grid to Figure T10G7: 10 from Zhao (1988)

3.5 Results

After applying the same division method and the proposed grids to 35 standing terracotta figures, the key points which are marked by the horizontal division line can be summarised as follows:

Line 15: mark the hairline in all cases.

Line 13: through the junction of neck and shoulder or very close to the junction of neck and shoulder in 28 samples, 4 samples have this line half unit below the junction of neck and shoulder, the other 3 sample figures have this line a quarter unit below the junction.

Line 11: marks or near the position of nipples in 27 cases.

Line 9: goes through the narrowest part of the waist in 33 out of 35 samples.

Line 4: marks the top of knee in all samples.

Line 0: as the baseline, were placed at the bottom of the feet in all cases.

The widths of the sample figures vary from 4 to 6 units, among which three pieces are with a width of 6 units, one piece with 4 units, 16 with 5 or almost 5 units, and the other 15 figures with 5.5 units.

The detailed relationship between the key points and the grid division lines is listed in Table 3.1 (Appendix A)

There is no evidence to show in this study that the grid unit size is based on the length (or width) of the nose, hands or other parts of the body.

Therefore, although there is no evidence that the ancient Chinese applied a particular cannon to provide a guideline for the proportions of human figures, the division of three and the 15-grid system indicate that some key body parts of the sample figures do fall on or are located close to certain grid lines, even though the heights and width of the sample figures are different. In other words, although no two identical proportions are found, the proposed division and grid system suggested that the ancient Chinese crafts people did follow certain proportion systems when producing terracotta warrior figures.

3.6 Summary

Square grids (or cannons) have been used to provide proportions for human figures since ancient times. Different types of cannons were developed in different cultures. This chapter reviewed the common known types of cannons first, and then a 15-grid system based on the division of three was proposed in order to study proportions of terracotta warrior standing figures. In the end, this 15-grid system was applied on 35 individual samples. It is observed that some key points of the sample figures do fall on or are located close to certain grid lines. This suggested that the terracotta warrior figures did follow certain proportion systems when produced by ancient Chinese crafts people.

Chapter 4 : Case study number 2 - Cathedral floor plans

4.1 Introduction

Cathedral designs have long been studied by scholars from different cultural backgrounds. Complicated geometrical and numerical proportions are found in the measurements (Wu, 2002, p.1). On the other hand, evidence shows that the masons in the Middle-Ages (5th - 15th centuries) were not likely to have had a sophisticated understanding of mathematical and geometrical systems (McCague, 2003, p.11). This chapter suggests some simple methods which may have been used in the design of floor plans, based on the use of square derivative constructions, which construct the whole plan from a single square without any measurements.

Prior to this, a brief review of the background information as well as the scope and the source of the case study samples are described (section 4.2). Attention then switches to reviews of the existing analysis methods of various floor plans (section 4.3). Further related geometric principles such as the combinational use of the golden-section rectangle; $\sqrt{2}$ rectangles; modular systems; Sacred cut as well as root rectangles are dealt with in section 4.4. Two examples with illustrations are also given to help explain the analysis process. Section 4.5 overviews the findings of all samples.

4.2 Data

This section provides background information relating to the case study, as well as sources and the scope of the data examined.

4.2.1 Background information

A cathedral may be defined as ‘a very large, usually stone, building for Christian worship. It is the largest and most important church of a diocese’ (http://dictionary.cambridge.org) [accessed 12 May 2016]. Cathedrals are widely spread all over the world. The study of cathedrals covers buildings found in Germany, Italy, England and France (Wu, 2002, p.87) as well as America (Schuetz-Miller, 2003, p.395). Because of the function of a cathedral, the design of the site, the size and layout are all symbolic considerations (Davis and Neagley, 2000, p.161). The world's oldest cathedrals can be dated back to 301AD (Etchmiadzin Cathedral, Vagharshapat, Armavir Province, Armenia) (http://www.armenianchurch-ed.net) [accessed 20 May 2016]. The architecture style of cathedrals vary; characteristic styles are associated with Byzantine cathedrals, Romanesque cathedrals, Gothic cathedrals and Renaissance cathedrals (http://www.english-online.at) [accessed 20 May 2016].

In terms of the British cathedrals, these were built largely from 1100s to relatively modern times (http://www.bbc.co.uk) [accessed 12 May 2016]. Gothic, Renaissance, and modern architectural styles are identified in web-site British cathedrals (http://www.bbc.co.uk) [accessed 12 May 2016].

Cathedral floor plans are considered as the first step prior to construction, and are closely related to other parts of the cathedral's design (Wu, 2002, p.123). Usually a cathedral plan includes a nave, a choir, transepts and maybe also a dome (http://www.bbc.co.uk) [accessed 12 May 2016]. Hiscock (2000, p.6) suggested that both mathematical and geometrical methods are applied in the design of a cathedral, and more than one type of proportional system may be found in one cathedral (Hiscock, 2000, p.6).

Although evidence shows that mathematics has been used in architecture since the Middle Ages (McCague, 2003, p.11), the masons, including the master masons, were believed to be illiterate (McCague, 2003, p.12), and they could only apply basic geometrical operations with simple tools and rules and adopt the simplest techniques when designing the cathedral's layout (McCague, 2003, p.11, (Davis and Neagley, 2000, p.163).

4.2.2 The selection of cases to be analysed

This case study is based on the floor plans of twenty well known British cathedrals selected from 'The cathedrals of Britain' listed on the BBC history archive website (http://www.bbc.co.uk) [accessed 12 May 2016].

The following cathedrals were considered: Bradford Cathedral (location: Bradford, years built: 1400 – 1965); Cardiff Metropolitan Cathedral (location: Cardiff, years built: 1839–1842); Chester Cathedral (location: Chester, years built: 1541); Christ Church Cathedral (location: Oxford, years built 1160–1200); Clifton Cathedral (location: Bristol, years built: 1970-1973); Coventry

Cathedral (location: Coventry, years built: 1956–1962); Durham Cathedral (location: Durham, years built: 1093–1133); Ely Cathedral (location: Ely, years built: 1083–1375); Exeter Cathedral (location: Exeter, years built: 1112-1400); Liverpool's Anglican Cathedral (location: Liverpool, Years built:1904–1978); Lincoln Cathedral (location: Lincoln, years built: 1185–1311); Liverpool's cathedral (location: Liverpool, years built:1904–1978); Norwich Cathedral (location: Norwich, years built: 1096–1145); Peterborough (location: Peterborough, years built: 1118–1237); Ripon Cathedral (location: Ripon, years built:1160–1547); St. Magnus Cathedral (location: Kirkwall, years built:1137-1468); Salisbury Cathedral (location: Salisbury, years built:1220–1320); St. Paul's Cathedral (location: London ,years built: 1675–1720); St. Michael's of Coventry (ruins) (location: Coventry ,years built: the late 14th century and early 15th century, ruined in 1940); St. Albans Cathedral (location: St Albans , years built: 1077–1893); St. Giles' Cathedral (location: Edinburgh, years built: 1883); Southwark Cathedral (location: London , years built: 1106–1897); Westminster Cathedral (location: London , years built: 1895–1903); Winchester Cathedral (location: Winchester , Ground breaking: 1079); Worcester Cathedral (location: Worcester , years built:1084-1504); Wells Cathedral (location: Wells , years built: 1176–1490) and York Minster (location: York , years built: 637) In total 27 cathedrals.

Each cathedral’s official website was visited and the floor plan image was downloaded. However, in the data collection process, the floor plan images of Bradford Cathedral; Cardiff Metropolitan Cathedral; Clifton Cathedral; Liverpool's Anglican Cathedral; Liverpool's cathedral and St Magnus Cathedral could not be found, and Coventry Cathedral was build next to the ruins. Due to the lack of images (sources) as well as the ambiguities of reconstructions after the ruins, these seven cathedrals were excluded from the case study selections.

A total number of twenty cathedrals were thus selected for further study. Their floor plan images were reproduced in Illustrator with each original image taken from the official website, to provide the maximum clarity and the minimum distortion of each image.

4.3 Methods

Geometry has been applied widely in architectural designs, and evidence can be found in church or cathedral plans in the Roman, Medieval and Renaissance periods (Williams, 1997, p.9) across much of Europe. Although no one declares that geometry was rigidly applied (Wu, 2002, p.7), arithmetical as well as geometrical considerations were found in most cathedrals between parts and whole (Wu, 2002, p.8; Duvernoy, 2015, p.23). The broad use of geometry in cathedral designs is due to a range of reasons. Gothic designs always have symbolic meanings (Davis and Neagley 2000, p.18), which are associated with elementary shapes. Simple geometric manipulation can generate great complexity (Neagley, 1992, p.2). The geometric solution is the simplest method (Yeomans, 2011, p.3) as only simple tools such as compasses and straight edges are needed (Jacobson, 1986, p.5). It is also an efficient, economic and practical way (Neagley 1992, p.13) to set up an overall building plan using a logical process (Cohen, 2008, p.22). Furthermore, the harmony proportion system generated by geometry constructions is easy to repeat (McCague, 2003, p.6). For example, proportions governing the cathedral plan are also found often to govern the facade as well (Wu, 2002, p.28).

This section reviews basic types of geometric shapes, their symbolic meanings, proportions as well as the relationship between them in the design of cathedral floor plans.

4.3.1 Triangular structures in cathedral floor plan design

Triangular shapes, along with squares and pentagons are found commonly in cathedral plans (Wu, 2002, p.86, Hiscock, 2007, p17).This section considers triangles in architecture and the relationship between triangles and other shapes.

A triangle is believed to have a symbolic meaning due to its close link to the number three (Schuetz-Miller, 2006, p336). Equilateral triangles form the surface of tetrahedrons, octagons and icosahedrons which represents fire, air and water respectively according to Plato’s cosmology (Hiscock, 2007, p151).

A golden-section triangle is an isosceles triangle in which the ratio between the sides and the base is in the golden ratio (Calter, 2008, p.71). It also has base angles of 72 degree and an apex angle of 36 degrees (Hiscock, 2007, p220). The golden-section triangle exists in pentagons and decagons (Figure 4.1) (Hiscock, 2007, p218).

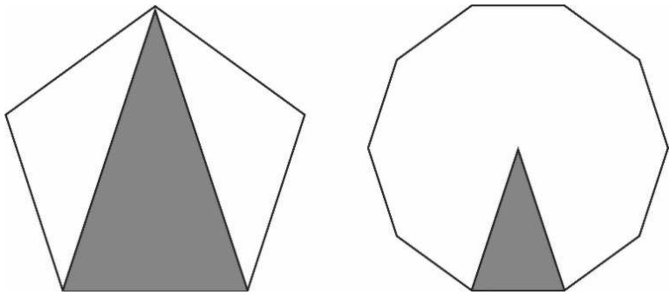


Figure 4. 1 Golden-section triangle in pentagon and decagon

Source: Drawn from Hiscock, 2007, p.218

The right triangle is 'a triangle in which one interior angle is at a right angle (90 degrees)' (Calter, 2008, p.75). Two types of right angle triangles are commonly seen in design practice. The first type is derived from a construction known as the 'ad quadratum' which usually exists in square or rectangle division (Hiscock, 2007, p.187). Example of a square divided by diagonals or by another square is shown in Figure 4.2.

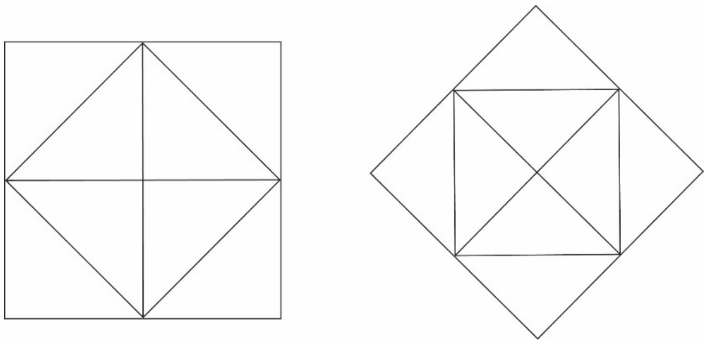


Figure 4. 2 Square divided by diagonals or other square

Source: Drawn from Hiscock, 2007, p.187

This type of division creates isosceles right angle triangles with their inner angles of 45, 45 and 90 degrees, and a proportion of 1: $\sqrt{2}$ between the lengths of the triangle sides (Hiscock, 2007, p.187).

The other type of right angle triangle is called the 3-4-5 triangle or the Pythagorean triangle (also, sometimes, referred to as the Egyptian triangle). It can be found in a few cathedral / church constructions. For example, the east end of the floor plan of Notre-Dame (location: Paris, France, years built: 1163-1250) was constructed based on octagons (Figure 4.3) (Liefferinge, 2010, p.498), which can be divided into squares and 3-4-5 triangles (Figure 4.4) (Liefferinge, 2010, p.498).

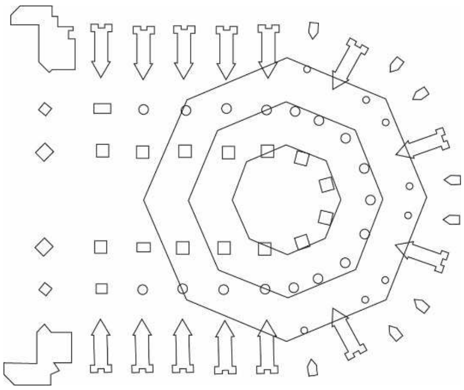


Figure 4. 3 The east end of the floor plan of Notre-Dame (location: Paris, France, years built: 1163-1250)

Source: Drawn from Liefferinge, 2010, p.498

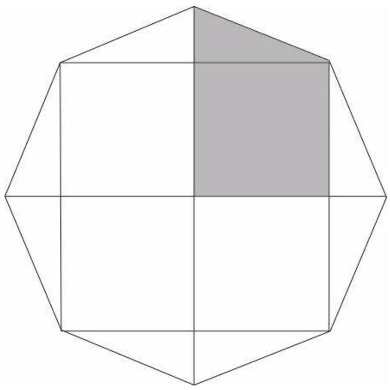


Figure 4. 4 Octagon divided into square and 3-4-5 triangles

Source: Drawn from Liefferinge, 2010, p.498

Furthermore, the 3-4-5 triangle is also found in the floor plan of Temple A of the Asklepieion at Kos (location: Kos, Greece, year built: 350 B.C.E.) (Senseney, 2007, p.556). After inscribing the main constructions in a circle, a 3-4-5 triangle marks the width of the plan (Figure 4.5).

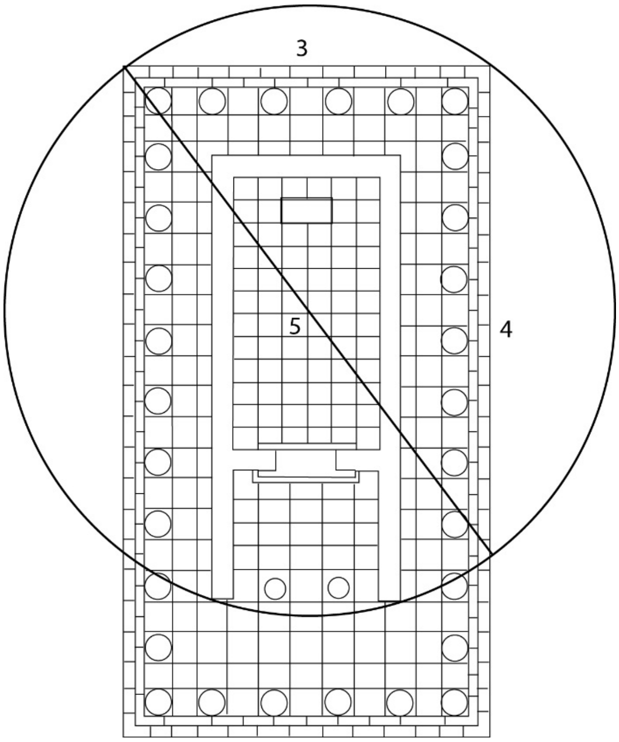


Figure 4. 5 A 3-4-5 triangle in the floor plan of Temple of the Asklepieion (location: Kos, Greece, year built: 350 B.C.E.)

Source: Drawn from Senseney, 2007, p.577

An equilateral triangle has three equal length sides and three equal interior angles each of 60 degrees. It is the most commonly seen in cathedral designs as it has a close relationship with right-angle triangles, circles, hexagons and 12- point stars.

The equilateral triangle can be divided into two right angle triangles, which provide a proportion of 1: 2: $\sqrt{3}$ (Figure 4.6) (Hiscock, 2007, p.150). This can be found in the arrangement of columns in the nave of church of San Lorenzo (location: Florence, Italy, year built: 1470) (Figure 4.7) (Antonino, Pistone and Zorgniotti, 2007, p.147).

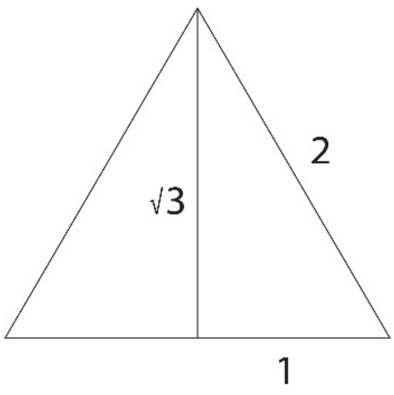


Figure 4. 6 The equilateral triangle can be divided into two right angle triangles

Source: Drawn from Hiscock, 2007, p.150

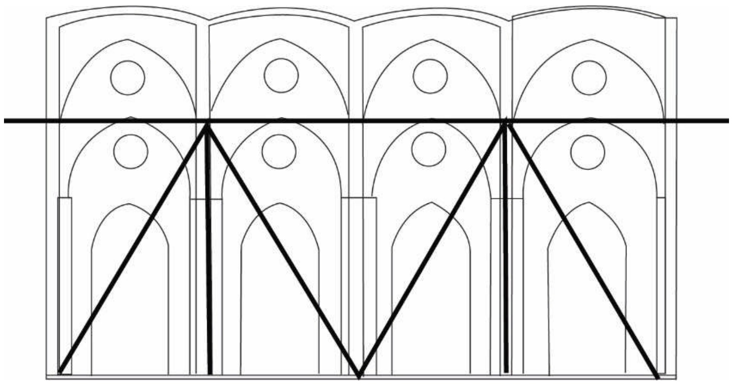


Figure 4. 7 The equilateral triangles in the church of San Lorenzo (location: Florence, Italy, year built: 1470)

Source: Drawn from Antonino, Pistone and Pistone, 2007, p.147

The equilateral triangle was usually inscribed inside a circle to define cathedral floor plans. Examples can be found in the ground plan of St. Michaels' (location: Germany, Kloster Ebrach, years built: 1583-1597), in which the bottom of the equilateral triangle marks the bottom edge of the transept (Figure 4.8) (Wiemer and Wetzel, 1994, p.456). Similar construction can be found in the floor plan of Santo Angel de la Guarda de Satevo (location: Madrid, Spain, year built: 1702) (Figure 4.9) (Schuetz-Miller, 2006, p.515).

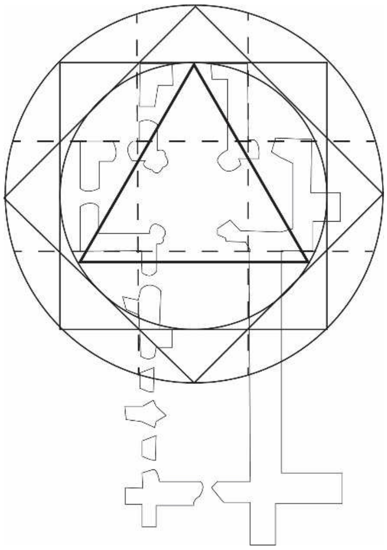


Figure 4. 8 Equilateral triangle in St. michaels' ground plan (location: Germany, Kloster Ebrach, years built: 1583-1597)

Source: Drawn from Wiemer and Wetzel, 1994, p.456

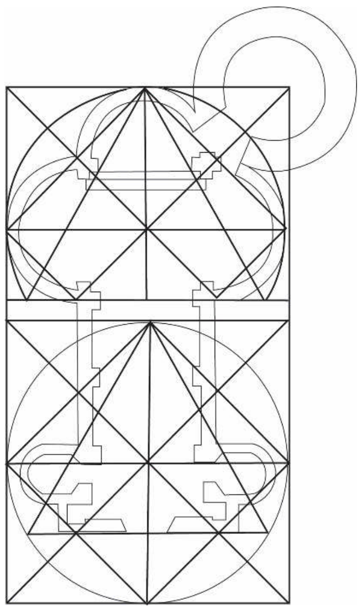


Figure 4. 9 The equilateral triangle and circle in Santo Angle de la Guarada de Satevo floor plan (location: Madrid, Spain, year built: 1702)

Source: Drawn from Schuetz-Miller, 2006, p.515

Part of the plan of Sant'lvo (location: Rome, Italy, year built:1660) shows an hexagon inscribed in an equilateral triangle and a circle (Figure 4.10). According to Smyth-Pinney (2000, p.315), the centre of the hexagon and the circle were constructed first.

Then the lobes were added, which are indicated as three small equilateral triangles attached to the hexagon sides in Figure 4.10.

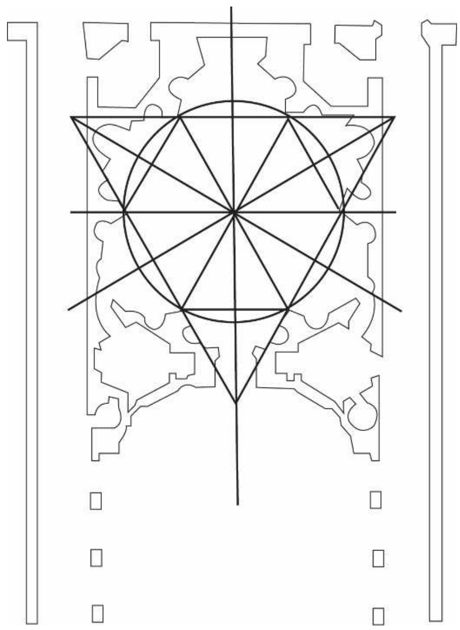


Figure 4.1 0 Basic geometries of San'Ivo plan (location: Rome, Italy, year built:1660)

Source: Drawn from Smyth-Pinney 2000, p.315

A hexagon or a six-point star can be constructed by two interlocking equilateral triangles with one pointing up and the other pointing down (Figure 4.11) (Hiscock, 2007, p153; Bucher, 1972, p.44).

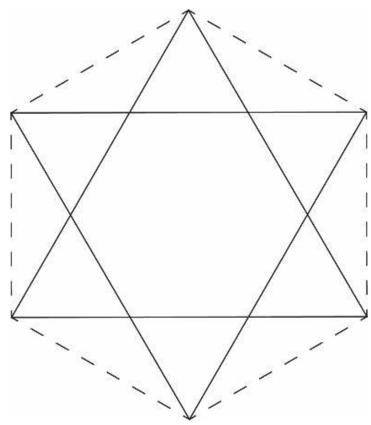


Figure 4.1 1 A six-point star derived from two equilateral triangles

Source: Drawn from Hiscock, 2007, p.150

A twelve point star formed by four inter-locking triangles governs the plan of the Latin theatre (Figure 4.12) (Senseney, 2007, p.562; Yeomans, 2011, p.28).

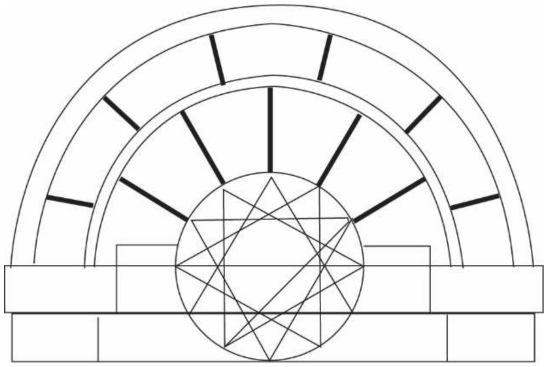


Figure 4.1 2 A twelve-point star derived from equilateral triangles (according to Vitruvius's description)

Source: Drawn from Senseney, 2007, p.562

Equilateral triangles also exist in the *vesica piscis*. The *vesica piscis* is a symbol of Christianity. It is a geometric composition formed by the intersection of two circles with the same radius. These circles intersect in such a way that the centre of one circle lays on the circumference of the other (Barrallo, González-Quintial, Sánchez-Beitia, 2015, p. 671). Two equilateral triangles facing in opposite directions can be constructed inside the intersection area (Figure 4.13) (Barrallo, González-Quintial, Sánchez-Beitia, 2015, p. 672). The *vesica piscis* is occasionally found in the cathedral/church floor plan construction, Figure 4.14 shows an example.

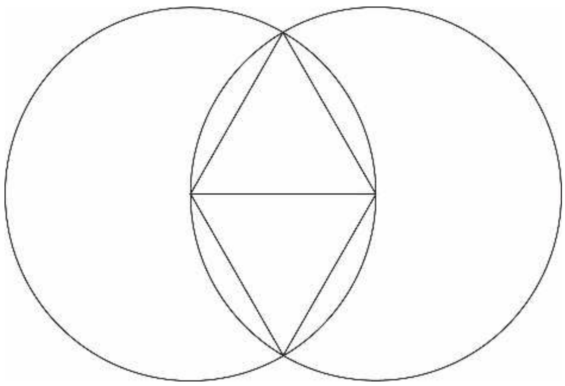


Figure 4.1 3 Equilateral triangles in the *Vesica Piscis*

Source: Drawn from Hiscock, 2007, p.150

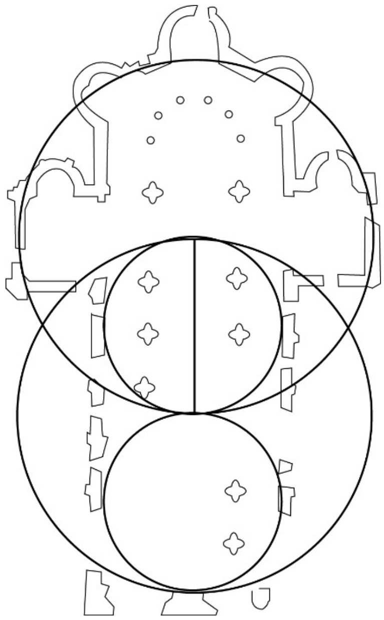


Figure 4.1 4 ***Vesica Piscis*** **in St. Etienne plan (location: Nevers, France, years built: 1063-1097)**

Source: Drawn from Wu, 2002, p.50

The Reuleaux triangle is a construction related to the *vesica piscis*, which involves three intersecting circles and the centre of each circle lays on the circumference of another (Barrallo, González-Quintial, Sánchez-Beitia, 2015, p. 680). Only one equilateral triangle can be constructed inside the intersection of the circles (Figure 4.15 coloured in grey).

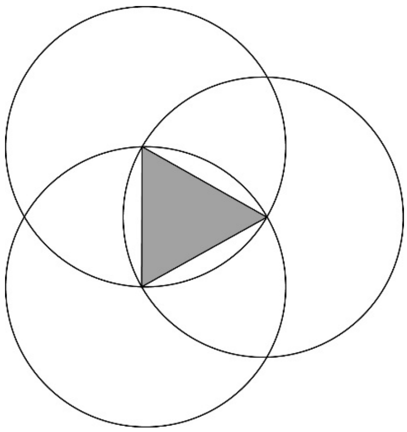


Figure 4.1 5 The equilateral triangle (coloured in grey) in a Reuleaux triangle

Source: Drawn from Barrallo, González-Quintial, Sánchez-Beitia, 2015, p. 682

4.3.2 Square structures in cathedral floor plan design

The square and its derivatives govern the geometry of medieval designs (Bucher, 1972, p.37), as it is standardised, easy to repeat and has no irrational numbers (Bucher, 1972, p.37). The geometric construction of a single square; square grids; square rotations and square inscribed by square is known as 'quadrature' (Hiscock, 2007, p.181). When a small square inscribed in a large square, while the diagonal length of the small square equal to the side length of the large square, the figure is known as an *ad quadratum* figure (Calter, 2008, p. 96), which will be discussed later in this section.

Vitruvius stated that the first step to set up a building is to fix the north-south axis (Yeomans, 2011, p.26). The same procedure exists in cathedral plan designs as most cathedrals/ churches were designed based on longitudinal axis and a perpendicular axis (Wu, 2002, p.38). All the other structures are centred on these axes (Wu, 2002, p.38). Similarly, the architecture in Roman design is found to be highly axial and centred (Watts and Watts, 1986, p.138).

The square is 'the first and the most central design shape' (Bucher, 1972, p.37) in Gothic plan design, as most cathedral plans use the crossing square as a centre and all the other plan parts were generated from it (Wu, 2002, p.129). Examples can be found in various cathedral/church plans. The transept is the centre of the plan in Pierre Robin (Neagley, 1992, p.401). The Saint-Urbain and Saint-Ouen plans were also generated from the centre of their transepts (Davis and Neagley, 2000, p.177). Furthermore, Norwich Cathedral (location: Norwich, Britain, years built: 1096-1145) is believed to be set up from the single square over the crossing (Wu, 2002, p.92), then by applying the diagonals, the equatorial triangle, the square and the pentagon were then generated to develop the plan design (Figure 4.16) (Wu, 2002, p.92). This cathedral is also included in the selection of the 20 in this case study.

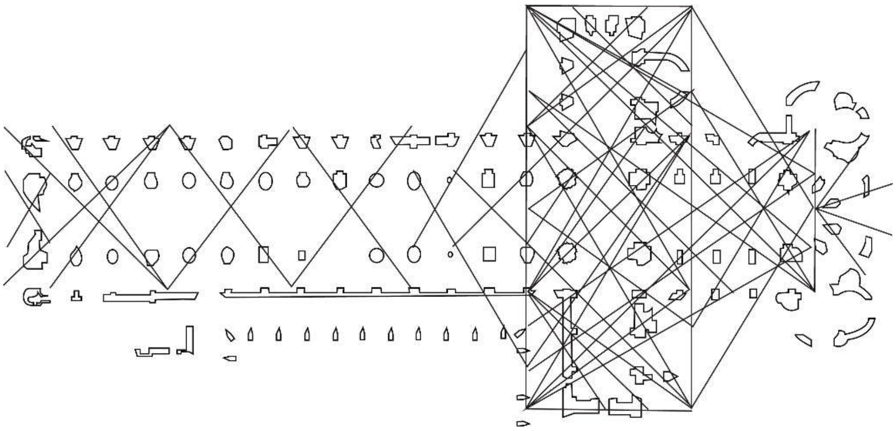


Figure 4. 1 6 The plan of Norwich Cathedral (location: Norwich, Britain, years built: 1096-1145)

Source: Drawn from Wu, 2002, p.92

4.3.2.1 Square and its diagonals

According to Bork (2014, p.4), the design of Gothic buildings is based on simple sequences of dynamic geometry. This section reviews the use of square diagonals as well as their derivatives in cathedral design. A square and one of its diagonal can generate a 1: √2 proportion (Figure 4.17) (Wu, 2002, p.83; Hiscock, 2007, p.201). This was suggested also by Vitruvius and has been applied in architecture (McCague, 2003, p.14).

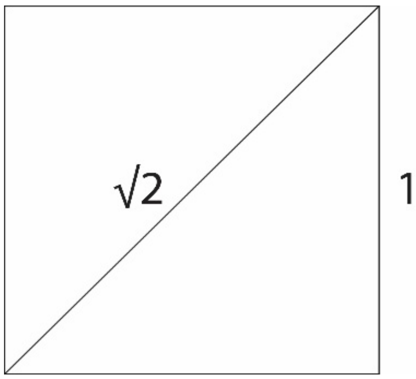


Figure 4. 1 7 The square and one of its diagonal

Source: Drawn from Figure 2.2

The gnomon is a way to add to or subtract from a square to make it larger or smaller (Watts and Watts, 1992, p.309). It is a construction created by drawing arcs which are centred at the corners of the square and the arc radius equals to the length of the square diagonals (Watts and Watts, 1992, p.309). This is illustrated in Figure 4.18. This progression has been applied in the plan of Muckross Friary (location: Killarney, Ireland, year built: 1448) (Figure 4.19) (Yeomans, 2011, p.37).

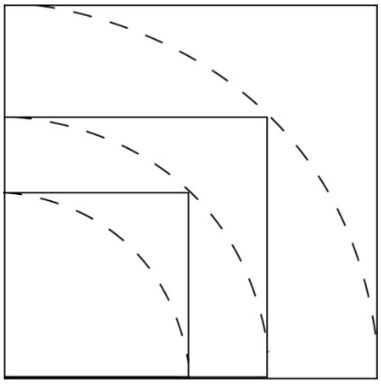


Figure 4.1 8 The gnomonic progression of a square

Source: Drawn from Figure 2.5

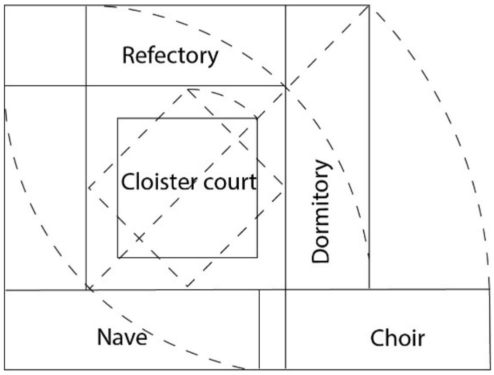


Figure 4.1 9 The geometry of Mukross Friary (location: Killarney, Ireland, year built: 1448)

Source: Drawn from Yeomans, 2011, p.37

A √2 rectangle is also commonly seen in cathedral floor plan construction. A √2 rectangle can be constructed based simply on a square and its diagonal. As shown in Figure 4. 20, ABCD is a square with the edge length of 1 unit, so that the length of DB is √2. Connect DB and make DF=DB, the resulted rectangle AEFD is a root-two rectangle (Hambidge, 1953, p.18; Hann, 2012, p.39; Elam, 2001, p.34), which provides a 1: √2 proportion between its length and width.

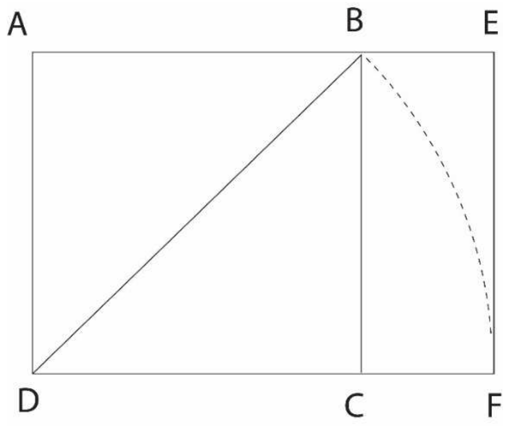


Figure 4. 2 0 The construction of a root-two rectangle

Source: Drawn from Hann, 2012, p.39

A √2 rectangle existed in the plan of Notre-Dame de Remis (east end of Notre-Dame Cathedral) (location: Paris, France, years built: 1163-1250) (Figure 4.21 a)(Wu, 2002, p.152).The plan of the Basilica of San Lorenzo (location: Florence, Italy, year built: 1470) (Figure 4.21 b) (Cohen, 2008, p.37); the floor plans of Rouen, Saint-Ouen Cathedral (location: Rouen, France, years built: 1318-1537) (Figure 4.21 c) (Davis and Neagley,. 2000, p.167); the plan of the Pantheon (location: Roman, Italy, years built: 118-128) (Figure 4.21 d) (Williams, 1997, p.108) as well as the ground plan of Medici Chapel (location: Florence, Italy, years built: 16^{th}-17^{th} century), all included √2 rectangles (Figure 4.21 e) (Williams, 1997, p.108).

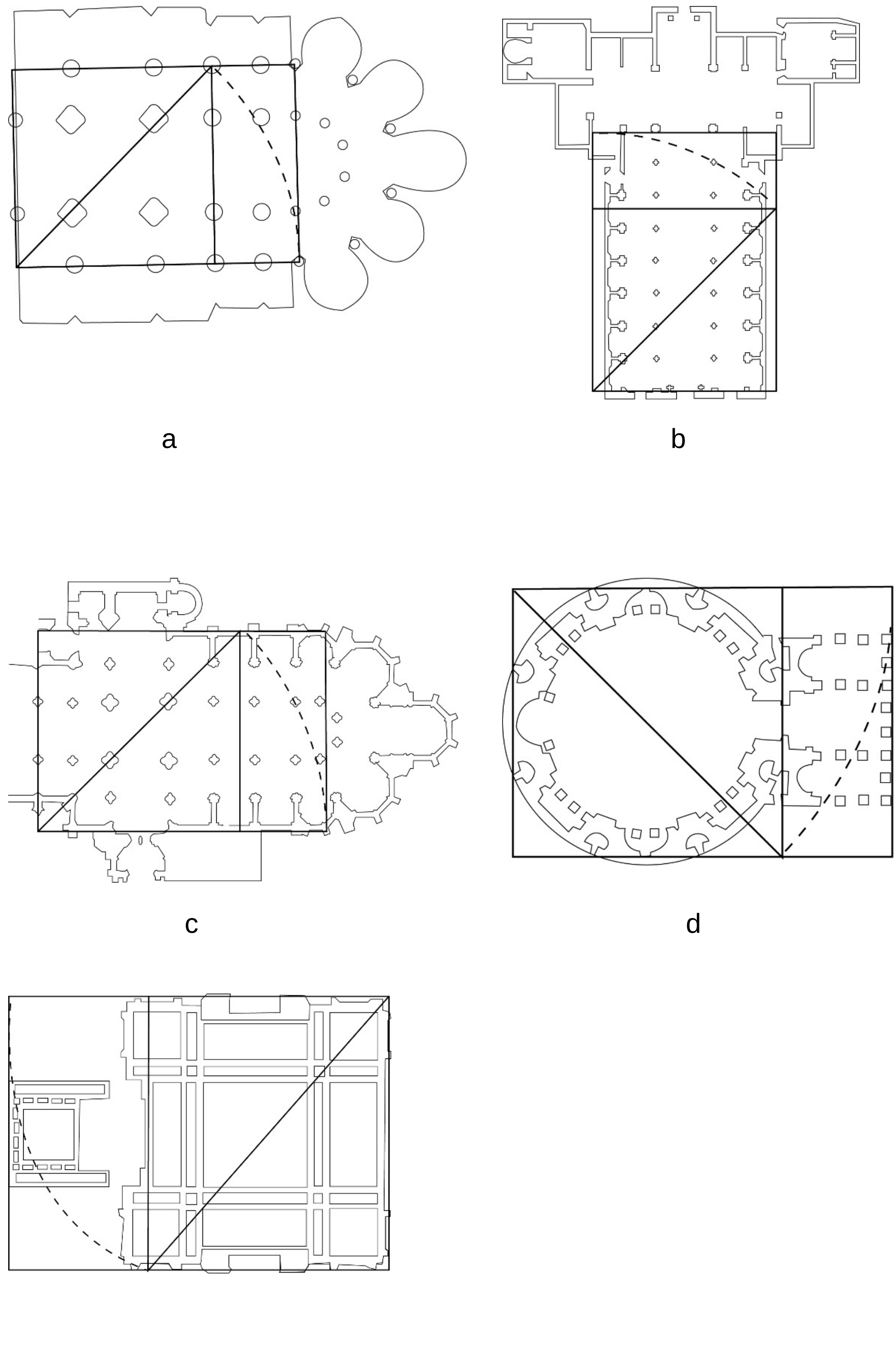


Figure 4. 2 1 Root rectangles in floor plans

Source: Drawn from Wu, 2002, p.152; Cohen, 2008, p.37; Davis and Neagley,2000, p.167; Williams, 1997, p.108

Furthermore, √2 rectangles can be subdivided into two smaller √2 rectangles (Hambidge, 1953, p.18; Hann, 2012, p.39; Elam, 2001, p.34) and the dividing process can be continued endlessly (Figure 4.22) (Elam, 2001, p.34).

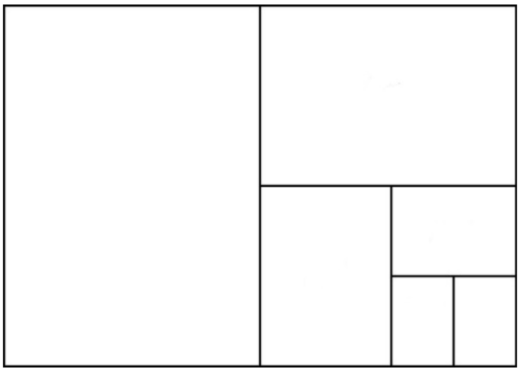


Figure 4. 2 2 The division of a root-two rectangle

Source: Drawn from Elam, 2001, p.36

A square and its diagonal can produce a √2 rectangle (shown in Figure 4.20). A √2 rectangle and its diagonal can produce a √3 rectangle etc. Figure 4.23 shows the relationship between square and the root rectangles√2 (AEFD), √3 (AGHD), √4 (AIJD) and√5 (AKLD) rectangles.

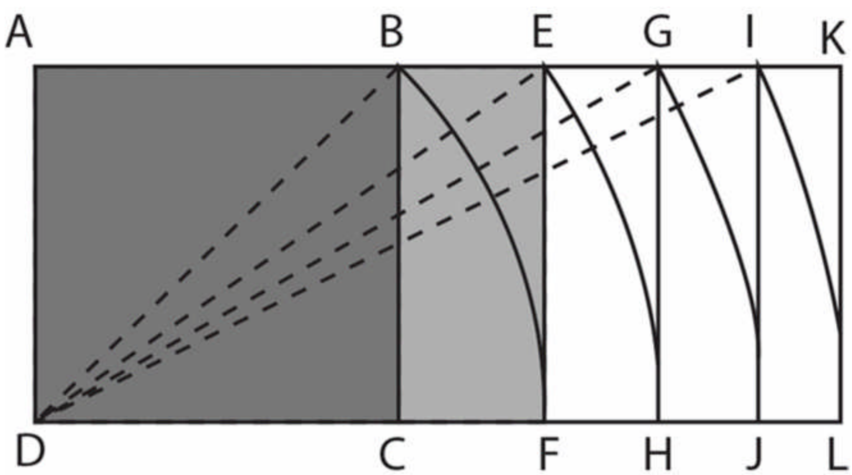


Figure 4. 2 3 The relationship between square and root rectangles

Source: Drawn from Figure 2.20

Root rectangles can be found in some of the cathedral floor plans. The floor plan of Xavier de Vigge Biaundo in San Francisco (built in 1697) is one of the examples (Figure 4.24). The construction of the nave is based on the root proportions generated by the square, the side width of which equals the transept width.

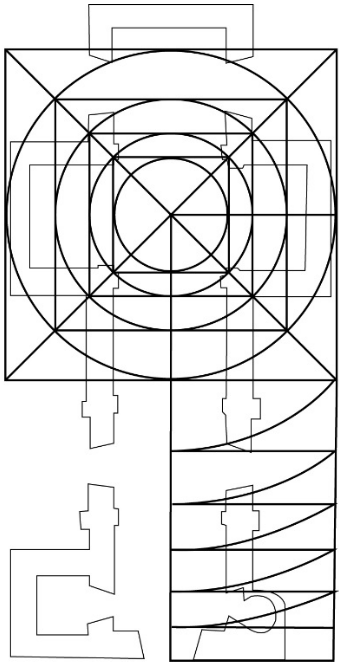


Figure 4. 2 4   Root rectangles in floor plan of Xavier de Vigge Biaundo (location: San Francisco, USA, year built: 1697)

Source: Drawn from Schuetz-Miller, 2006, p.368

A golden-section rectangle can be drawn from the diagonal line of half a square. As shown in Figure 4.25, ABCD is a square. Bisect CD, connect the middle point of DC and B, use the distance as a radius, and draw an arch between BF that inserts DC's extension at F, then draw a line EF parallel to AD and continue AB to E, the resulting rectangle AEFD is a golden-section rectangle. The small rectangle BEFC is a golden-section rectangle also since it has the same angles and proportions as rectangle AEFD. These two rectangles are called similar polygons (Rich, 1963, p.92). Also rectangle BEFC is known as the reciprocal of rectangle AEFD (Hambidge, 1953, p.30; Hann, 2012, p.111).

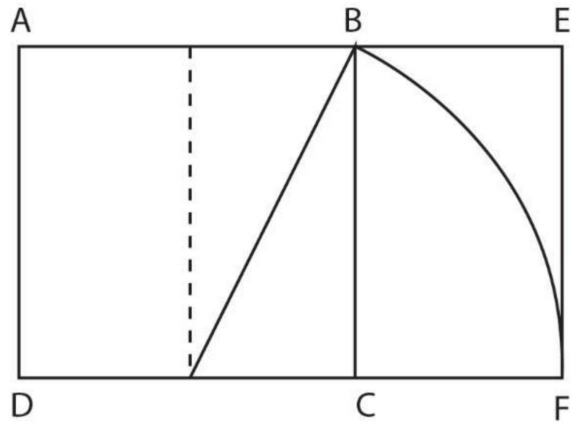


Figure 4. 2 5 The construction of a golden-section rectangle

Source: Drawn from Figure 2.15

If two golden-section rectangles are interlocking together, a √5 rectangle is then generated (show in Figure 4.26). As shown in the figure, ABCD is a square, the side length of which is 1 unit. Rectangle EBCH and rectangle AFGD are two interlocking golden-section rectangles. EFGH is a √5 rectangle.

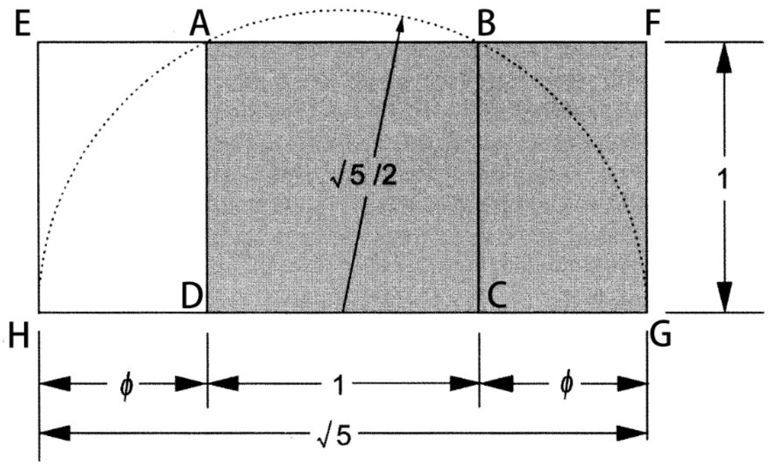


Figure 4. 2 6 The construction of a root-five rectangle

Source: Drawn from Figure 2.25

Similar to the√2 rectangle, a golden-section rectangle can be divided this way endlessly, and then a golden-section spiral can be drawn inside the rectangle. This case is shown in Figure 4.27 (Hann, 2012, p.111).

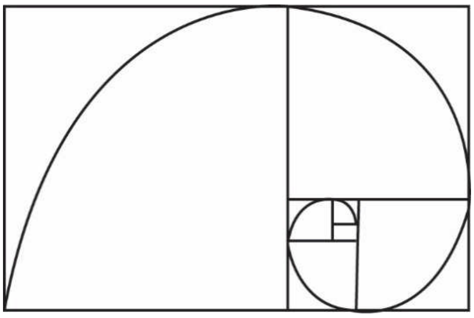


Figure 4. 2 7 Golden-section rectangle division and a golden-section spiral

Source: Drawn from Figure 2.16

The golden-section proportion has been found in the plan of Salisbury and Reims (Hiscock, 2000, p.180). Also, in the Saint-Urbain (located: Troyes Aube France, years built: 1262-1905) floor plan, the golden-section rectangle constructed is based on the square of the cross, which defines the position of the outer wall of the cathedral (Figure 4.28) (Davis and Neagley, 2000, p.167). In the case of Saint-Ouen (located: Rouen France, years built: 1318-1537), the golden-section rectangles generated from the square over the crossing define the width of the aisle in the north, south and west directions (Figure 4.29) (Davis and Neagley, 2000, p.170).

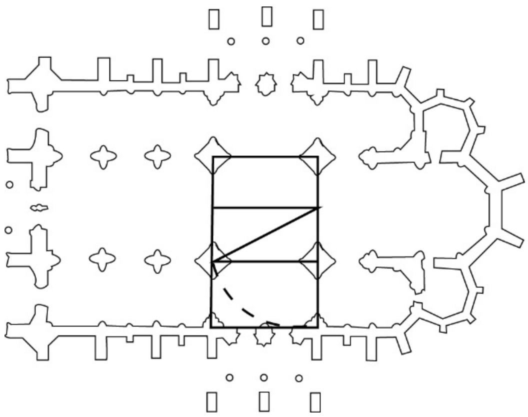


Figure 4. 2 8 The golden-section rectangle in Saint-Urbain floor plan (located: Troyes Aube France, years built: 1262-1905)

Source: Drawn from Davis and Neagley, 2000, p.167

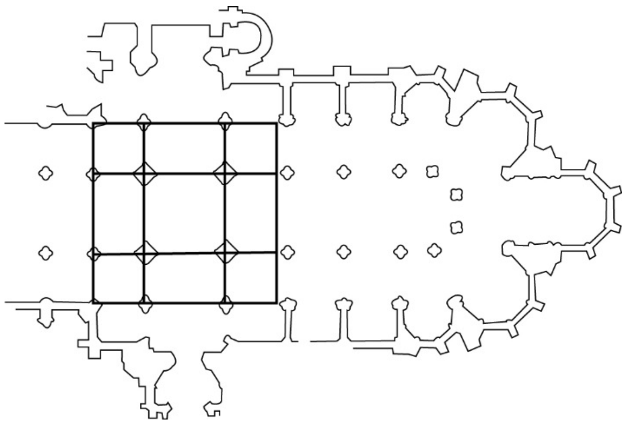


Figure 4. 2 9 The golden-section rectangle in Saint-Ouen floor plan (located: Rouen France, years built: 1318-1537)

Source: Drawn from Davis and Neagley, 2000, p.170

The Brunes star (Figure 4.30) is shown when a square is divided into four equal parts with the addition of half and full diagonals (Hann, 2012, p.42). The intersecting points which are illustrated as black dots in Figure 4.30 are highly symmetrical and the parallel lines passing through those points divide the square into various equal sections (Figure 4.30) (Hann, 2012, p.43).For example, as shown in Figure 4.31, the intersection points of square diagonal lines and the half square diagonal lines divide the lower side into three (Hiscock, 2007, p.201).

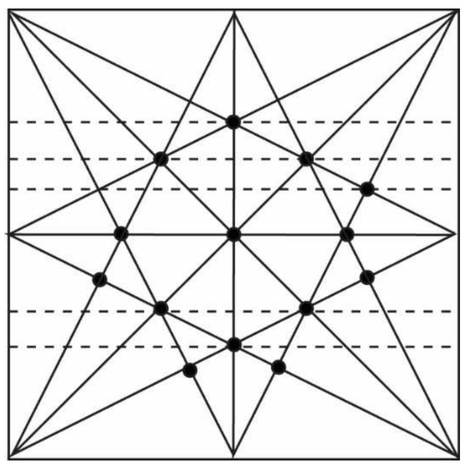


Figure 4. 3 0 The Brunes star

Source: Drawn from Figure 2.26

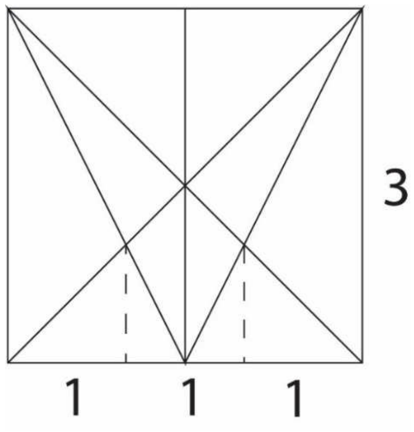
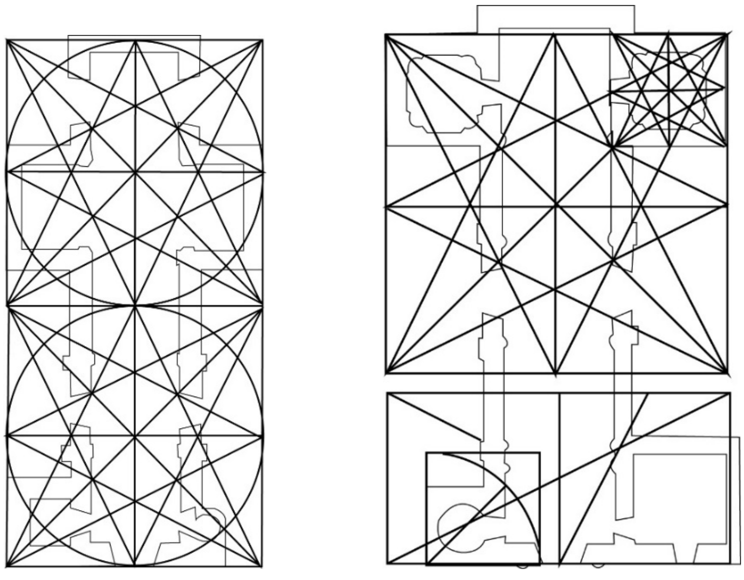


Figure 4. 3 1 Brunes star points divide the rectangle edges into equal sections

Source: Drawn from Hiscock, 2007, p.201

The Brunes star is commonly seen in cathedral floor design. For example, Schuetz-Miller found that the Brunes star existed in Xavier de Vigge Biaundo Biaundo (located: San Francisco, USA, year built: 1697) (Schuetz-Miller, 2006, p.367) and the floor plan of Borja (location: San Francisco, USA, years built: 1762-1807) (Schuetz-Miller, 2006, p.395), which are shown in Figure 4.32 a and Figure 4.32 b respectively.



a b

Figure 4. 3 2 a:Brunes star in Xavier de Vigge Biaundo (located: San Francisco, USA, year built: 1697); b: Borja (location: San Francisco, USA, years built: 1762-1807) floor plans

Source: Drawn from Schuetz-Miller, 2006, p.367 and p.395

The 'sacred cut' refers to a construction of four arcs that are centred on the four corners of a square, with the half diagonal length of the square as the radius in each case, and those arcs intersecting each other in the centre of the square (Figure 4.33) (Watts and Watts, 1992, p.309).When four lines are drawn which touch the arcs while parallel to the square edges, a nine-unit-grid is yielded (Figure 4.34) (Wightman, 1997, p.68). The inner square can be sacred cut again and this process can be continued.

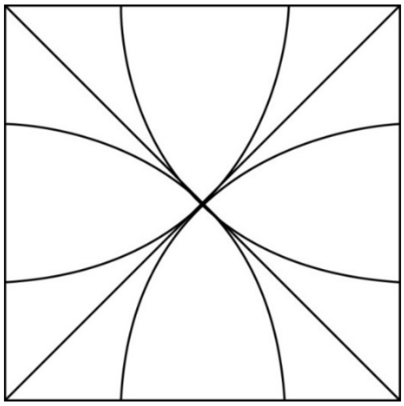


Figure 4. 3 3 'Sacred cut' construction

Source: Drawn from Figure 2.6

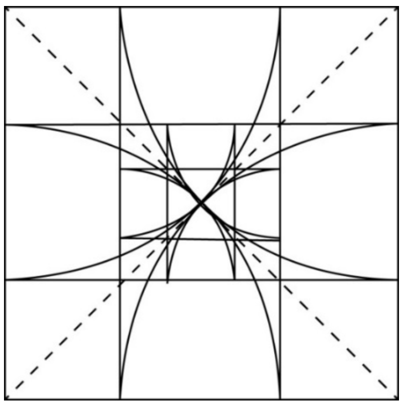


Figure 4. 3 4 The endless 'sacred cut'

Source: Drawn from Figure 2.7

The sacred-cut process can be reversed, with the inner square defining the next largest square (Watts and Watts, 1987, p.271). As shown in Figure 4.35, the inner square can be drawn first, and then it can be cut by four arcs centred at its four corners with its radius equal to its side length. Then when the four circles from the arcs are completed, followed by the extension of the square diagonals the next largest square can be constructed. The intersecting points of diagonals and circles define the four corners of this next largest square (Watts and Watts, 1987, p.271).

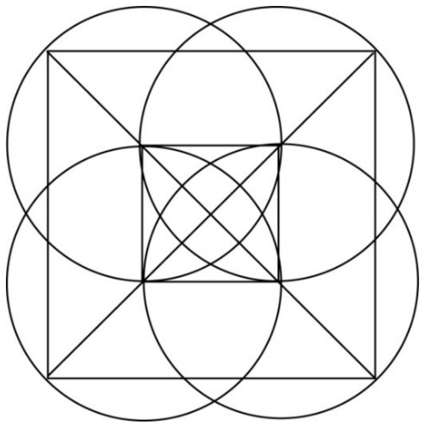
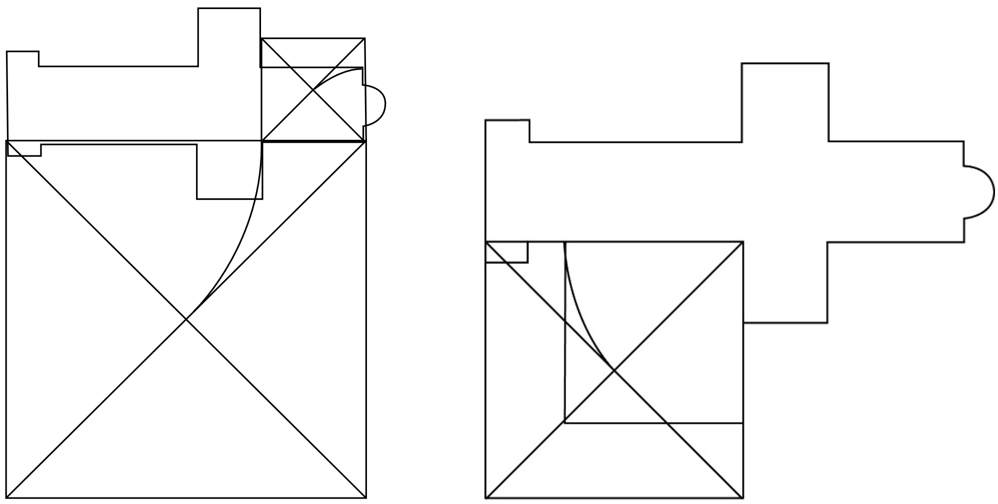


Figure 4. 3 5 The reversed sacred cut process

Source: Drawn from Figure 2.8

This type of division has been found in ancient Roman Gardens (Watts and Watts, 1986, p.137), paintings (Watts and Watts, 1987, p.274) and cathedral floor-plan constructions. For example, the sacred-cut division exists in Durham cathedral (location: Durham, UK, years built: 1093-1133) (part and whole) plans (McCague, 2003, p.13) as shown in Figure 4.36 a and b.



a b

Figure 4. 3 6 The sacred cut division in Durham Cathedral (location: Durham, UK, years built: 1093-1133) plan

Source: Drawn from McCague, 2003, p13-14

4.3.2.2 Square and square rotation

Bucher pointed out that the rotation of squares is the ‘practical and aesthetic key for Gothic architecture’ (Bucher, 1972, p.43). This section reviews the geometric constructions in cathedral plans which are generated by square and square rotation. Two equal side squares, with one tipped 45 degrees while over laid on the other one, generate an 8-point star (Figure 4.37). The overlapping area of the two squares creates a regular octagon (coloured in grey in Figure 4.37).

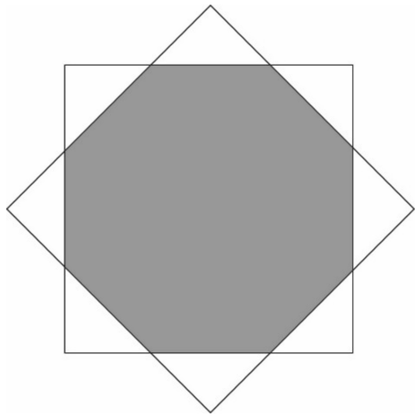


Figure 4. 3 7 An eight-point star generated by square rotation

Source: Drawn from Figure 2.4

This pattern exists in the upper stage plan of Baiae (location: Hadrian's Villa, Tivoli, Italy, year built: 128), annex of ‘Temple of Venus’ (Figure 4.38) (Jacobson, 1986, p.81). In the floor plan of St.-Maclou (location: Rouen, France, years built: 1436-1521), the inner octagon generated by square rotation marks the edges of the east end of the plan (Figure 4.39) (Neagley, 1992, p.405). The combination of overlaid squares as well as the octagons generated inside, together with overlapping circles is used to define the whole plan structure of Strasbourg Cathedral (location: Strasbourg, France, years built: 1015-1439) (Figure 4.40) (Bork, 2005, p.460).

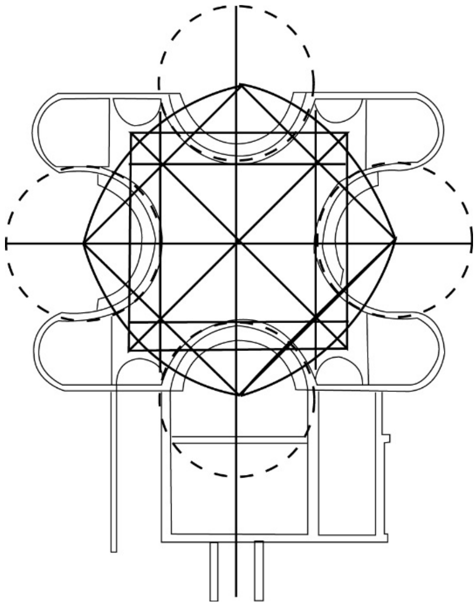


Figure 4. 3 8 Square rotations in plan of Baiae annex of 'Temple of Venus' (location: Hadrian's Villa, Tivoli, Italy, year built: 128)

Source: Drawn from Jacobson, 1986, p.81

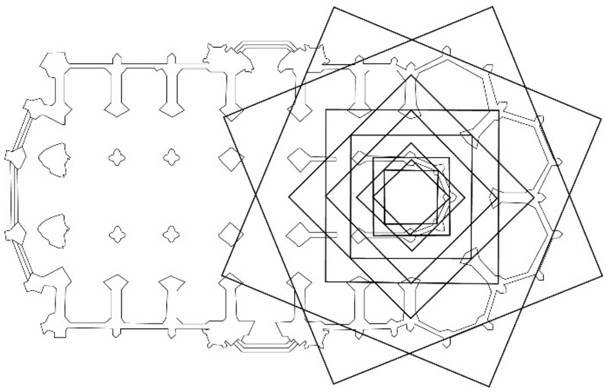


Figure 4. 3 9 Square rotations in the floor plan of St. Maclou (location: Rouen, France, years built: 1436-1521)

Source: Drawn from Neagley, 1992, p.405

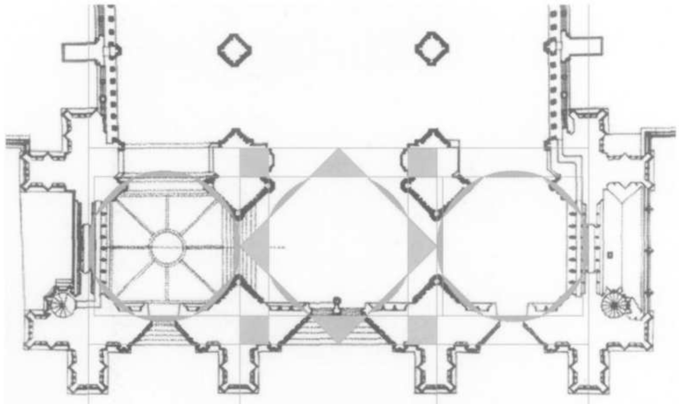


Figure 4. 4 0 The geometric construction of Strasbourg cathedral ground plan (location: Strasbourg, France, years built: 1015-1439)

Source: Drawn from Bork, 2005, p.460

Three squares tipped and overlapping each other can form a 12-point star, which can be found in the plan of a Gothic theatre (Figure 4.41) (Senseney, 2007, p.563). In this case, the vertex of the squares defines the line of circle circumference (Senseney, 2007, p.563).

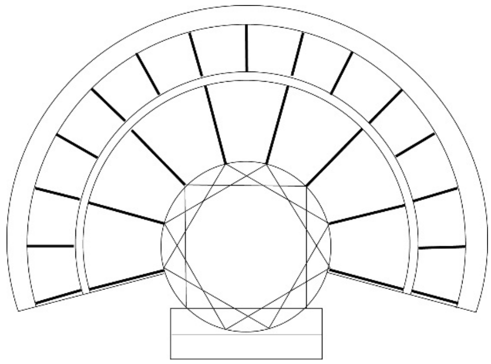


Figure 4. 4 1 The squares create a twelve-point star (according to Vitruvius's description)

Source: Drawn from Senseney, 2007, p.563

Another square rotation structure in cathedral architecture plans is a square divided by a smaller square, which is set to 45 degrees inside it, and the corners of the small square touch the middle points of the large square (Calter, 2008, p.96). This is known as the *ad quadratum* figure which was shown previously in Figure 4.2.This process can be continued endlessly and a $\sqrt{2}/2$ proportion exists between the side lengths of the adjacent squares (Figure 4.42). The $\sqrt{2}/2$ proportion between a square side's lengths can also be achieved by constructing squares inscribed in circles, which is shown in Figure 4.43.

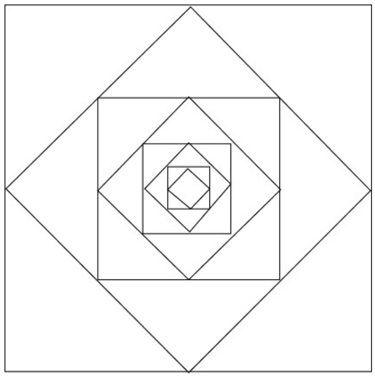


Figure 4. 4 2 Square divided by square

Source: Drawn from Birkett and Jurgenson, 2001, p.256

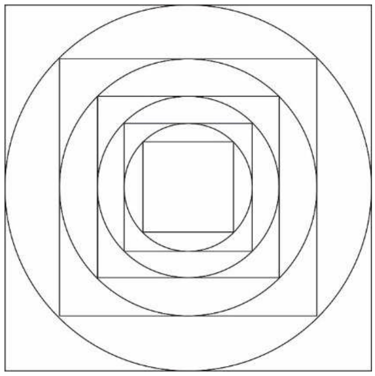


Figure 4. 4 3 Square divided by circles

Source: Drawn from Birkett and Jurgenson, 2001, p.256

In practice, two interlocking ‘ad quadratum’ figures were drawn in the plan of Saint-Urbain (location: Troyes, Aube France, years built: 1262-1905) (Figure 4.44), one of the inner squares marks the edge of the east end of the plan (Davis and Neagley, 2000, p.165).

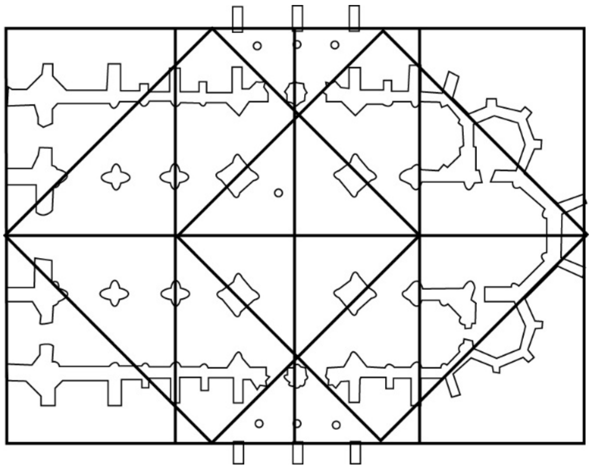


Figure 4. 4 4 Interlocking *ad quadratum* figures in Saint-Urbain's floor plan (location: Troyes, Aube France, years built: 1262-1905)

Source: Drawn from Davis and Neagley, 2000, p.165

More complicated square rotation combinations also exist in design practice. Inside the plan of Dombauhütte (location: Köln, Germany, years built: 1248-1473) (shown in Figure 4.45), there are three square on square patterns (Anderson, 2008, p.448). If three tipped squares are drawn to circumscribe the patterns (Figure 4.46), the corner of these new drawn squares mark the gaps of the exterior wall and define the width of the plan (Anderson, 2008, p.454).Two interlocking rotated squares (Figure 4.47) mark the excess construction of the plan. When an *ad quadratum* figure is drawn to inscribe all the three patterns while touching the excess constructions (Figure 4.48), the *ad quadratum* figure defines the whole length of the plan (Anderson, 2008, p.454).

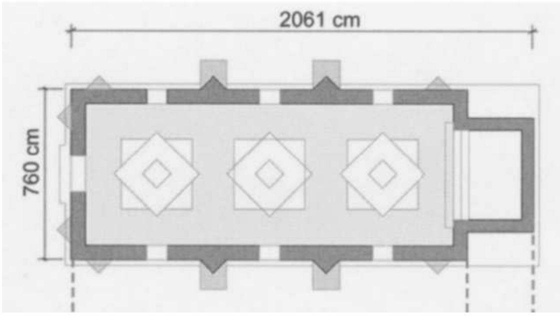


Figure 4. 4 5 The plan of Dombauhütte (location: Köln, Germany, years built: 1248-1473)

Source: Anderson, 2008, p.454

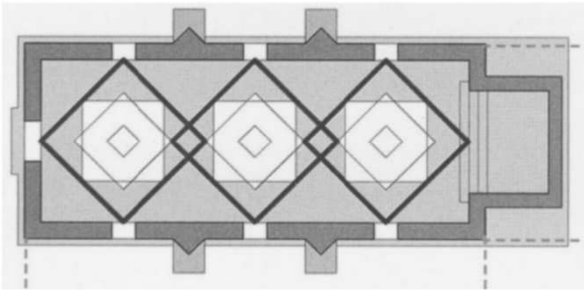


Figure 4. 4 6 The *ad quadratum*

Source: Anderson, 2008, p.454

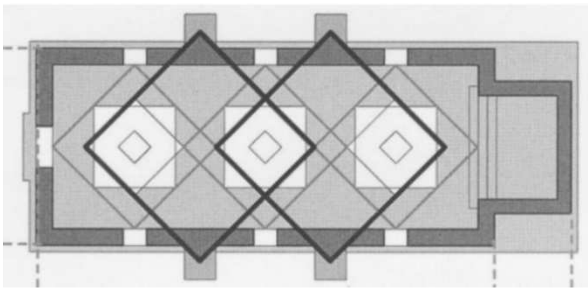


Figure 4. 4 7 The *ad quadratum*

Source: Anderson, 2008, p.454

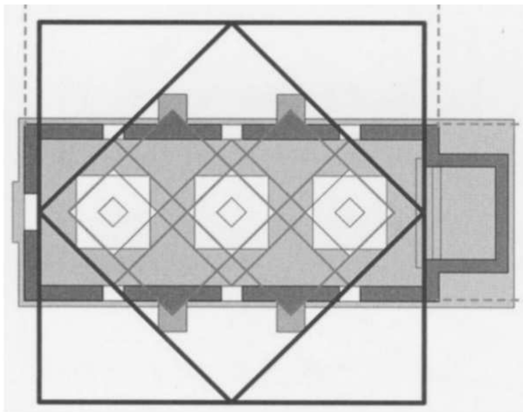


Figure 4. 4 8 The *ad quadratum*

Source: Anderson, 2008, p.454

4.3.2.3 Modular

A modular system was found in several cathedral plan designs. A modular system is ‘using multiples (or divisions) of a standard length…to establish its dimension’ (Wu, 2002, p.58). Le Corbusier defined modular as ‘a tool of linear or optical measurements, similar to music script’ (Cohen, 2014, p.1). The square is the most common shape used as a module to define grids in building structures (Bucher, 1972, p.37). There are various ways to define the module in the practice. For example, the wall thickness of Ely Cathedral (Ely, Britain) has been taken as one unit in the analysis (Hiscock, 2000, p.194). While in the plan of St. Gall (location: Switzerland, years built: the 8th century), the square generated by the crossing of the church are considered as a unit (Figure 4.49) (Bucher, 1972, p.37).

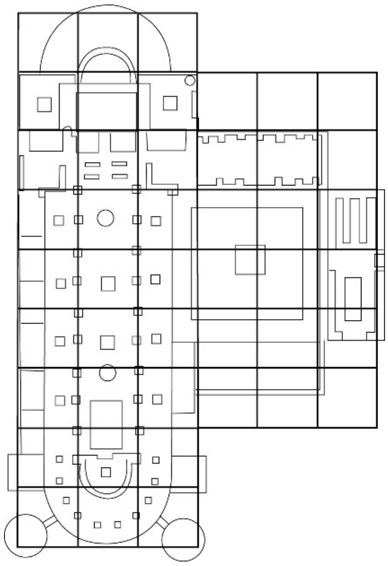


Figure 4.４９ The modular construction of St. Gall (location: Switzerland, years built: the 8th century)

Source: Drawn from Bucher, 1972, p.37

In the plan of Dombauhütte (location: Köln, Germany, years built: 1248-1473), a grid takes the smallest square in the floor plan as a unit and the whole grid is rotated by 45 degrees and taken to define the modular structure (Figure 4.50)(Anderson, 2008, p.448).

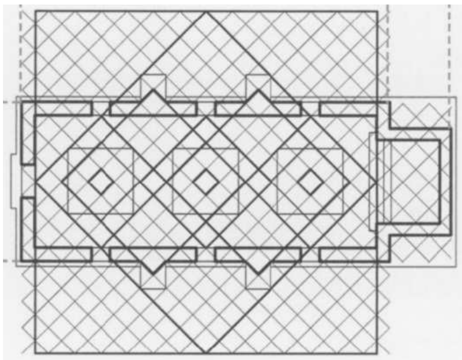


Figure 4.５０ The modular of Dombauhütte plan (location: Köln, Germany, years built: 1248-1473)

Source: Anderson, 2008, p.454

The plan design of the Basilica of San Lorenzo (location: Florence Italy, year built: 1470) is hypothesised to be based on the division and sub-divisions of two 65 x 65 squares to define the ‘chapels, crossing square transept arms and nave‘(Figure 4.51) (Cohen, 2008, p.32).

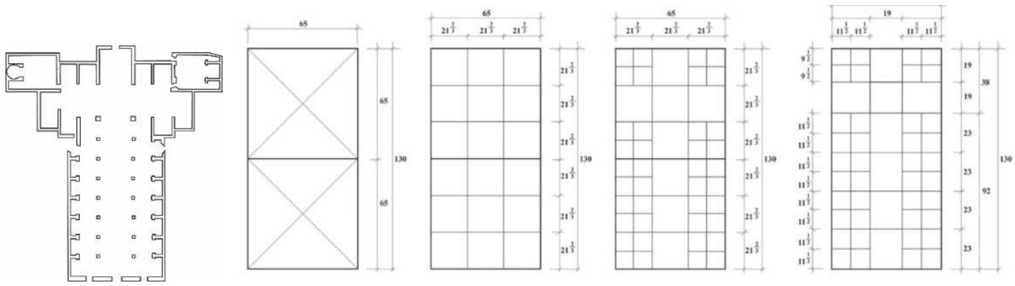


Figure 4. 5 1 The hypothesised plan design of the Basilica of San Lorenzo (location: Florence Italy, year built: 1470) division

Source: Drawn from Cohen, 2008, p.32

Apart from cathedral / church constructions, a square modular unit is also used in Islamic art (Sarhangi,and Jablan, 2006, p.10). The Hellenistic architecture (Senseney, 2007, p.555), the India stone temples (Meister, 1983, p.266), as well as the city plans (Bafna, 2000, p.26) are further examples.

4.3.2.4 Other polygons

Pentagons are sometimes seen in cathedral plan structure. A regular pentagon is a polygon which has five equal sides and five equal interior angles (Calter, 2008, p.136). Pentagons are closely associated with number five and contains golden-section triangle (for a further explanation please refer to chapter 2, section 2.5). Rotational pentagons can be found in the semi-circle constructions of several cathedrals. For example, in the plan of Saint-Quentin (location: France, years built: the 12th-the 16th century), two rotated pentagons mark the position of chancel (Figure 4.52) and the chapels (Figure 4.53) (Wu, 2002, p.132). Similar constructions are found in the east end of Notre-Dame (location: Paris, France, years built: 1163-1250) floor plan (Figure 4.54) (Wu, 2002, p.151). Moreover, some plans are constructed based on circles (as shown in Figure 4.38).

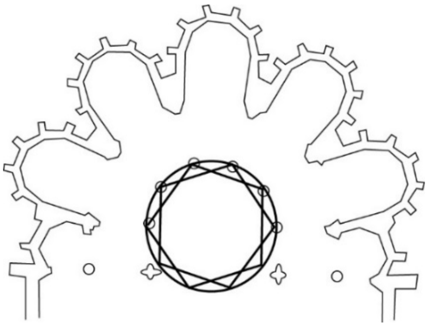


Figure 4. 5 2 Pentagons in the plan of Saint-Quentin (location: France, years built: the 12th-the 16th century)

Source: Drawn from Wu, 2002, p.144

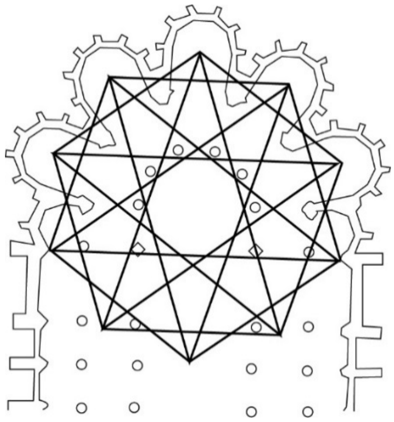


Figure 4. 5 3 Pentagons in the chapel's plan of Saint-Quentin (location: France, years built: the 12th-the 16th century)

Source: Drawn from Wu, 2002, p.144

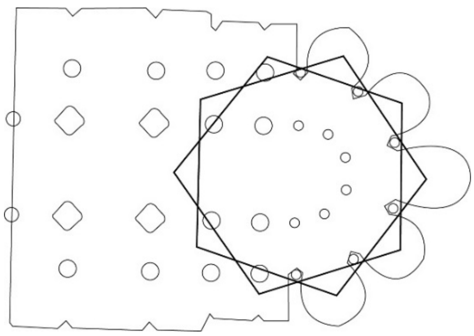


Figure 4. 5 4 Pentagons in the east end of Notre-Dame floor plan (location: Paris, France, years built: 1163-1250)

Source: Drawn from Wu, 2002, p.165

Therefore, basic shapes such as triangles, squares, pentagons as well as circles can be found in the floor plan of many cathedrals. In most cases, the combination of different shapes as well as their derived geometrical constructions may exist in the same floor plan (Schuetz-Miller, 2006, p.350).

Hiscock illustrated cathedral plans constructing by using the sides of equatorial triangles, diagonal lines of squares, rectangles as well as diagonal lines of pentagons (Bork, Clark, McGehee, 2011, p.130).

Figure 4.55 illustrates the plan of Winchester Cathedral (location: Winchester UK, year built: 1079) by using polygon diagonal lines (Hiscock, 2000, p.225), which starts from the diagonal lines of the square generated from the cross.

Figure 4.56 illustrates square and rectangle constructions in the Winchester Cathedral floor plan. Figure 6.57 shows the pentagons as well as diagonal lines marking the key stones in the cross section of the plan.

This methodology is also applied in the ground plans of Peterborough Cathedral, Norwich Cathedral, Ely Cathedral and Durham Cathedral (Hiscock, 2000, p.207-252).

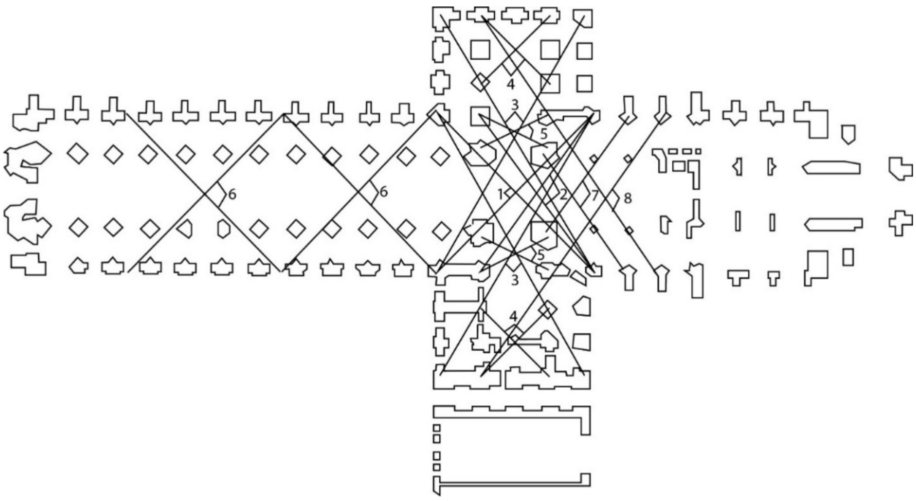


Figure 4. 5 5 The Winchester Cathedral plan (location: Winchester UK, year built: 1079)

Source: Drawn from Hiscock, 2000, Plate 60

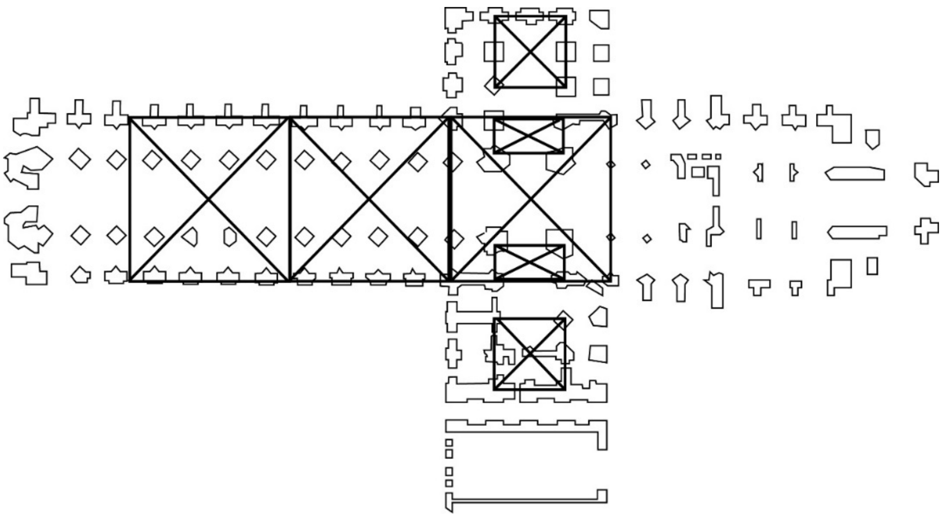


Figure 4. 5 6 The Winchester Cathedral floor plan

Source: Drawn from Hiscock, 2000, Plate 60

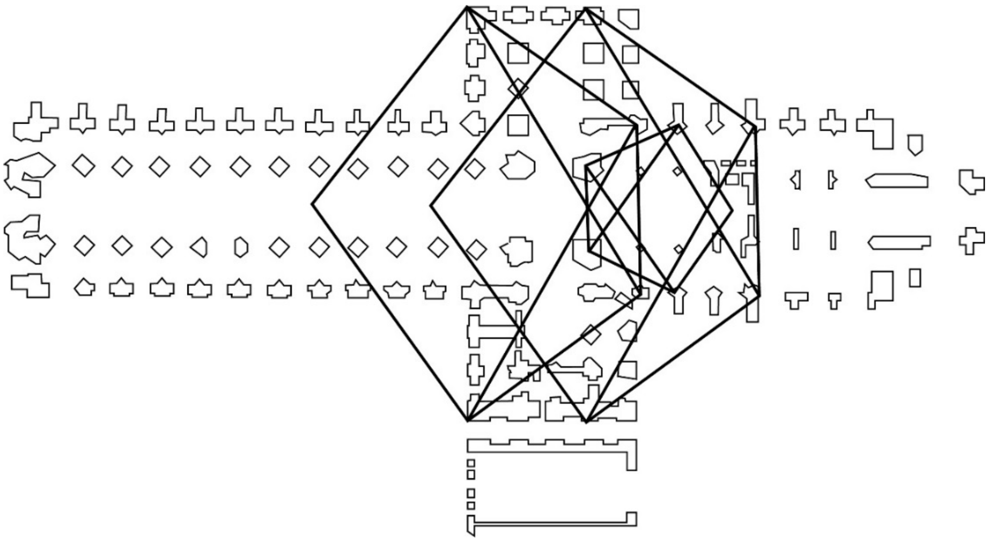


Figure 4. 5 7 The pentagon constructions in the Winchester Cathedral floor plan

Source: Drawn from Hiscock, 2000, Plate 60

4.4 Analysis

Cathedrals are believed to be designed according to geometrical methods and proportions. This section develops the analytical methods for cathedral floor plan and illustrates the application of the proposed methods in the floor plan of Chester Cathedral and St. Paul's Cathedral.

4.4.1 The development of analysing methods for cathedral floor plan

From the above literature, various shapes (equilateral triangles, squares, regular pentagons), shape combinations (*ad quadratum*, triangle on triangle, pentagon on pentagon), geometry structures and proportions derived from regular shapes (the 3-4-5 triangle, golden-section triangle; golden-section rectangle, root rectangles), and space division methods such as proportional division of root two and golden-section rectangles, the Brunes star, the sacred-cut and the modular (grids) system have been found in previous floor plan analysis.

Furthermore, the golden-section proportion has been found in the plan of Salisbury (Hiscock, 2000, p.180), Reims (Hiscock, 2000, p.180), Saint-Urbain (Davis and Neagley, 2000, p.167) and Saint-Ouen floor plans (Davis and Neagley, 2000, p.170). In most cases, the golden-section rectangle is constructed based on the square of the cross, and usually the golden-section rectangles generated from the square over the crossing define the width of the aisle.

Therefore, the hypothesis of the following research is that in many cases the whole cathedral floor plan can be constructed based on a single square (the central square of the cross), while combining various basic shapes and simple geometric constructions without any further measurement. Furthermore, the common proportions provided by the geometric operations should exist between the parts and whole of a floor plan.

4.4.2 The application of the proposed analytical methods in two cathedral floor plans

Chester Cathedral (location: Chester UK, year built: 1541) measures 348 feet in length and 73 feet in width (Guilt, 1842, p.213), which is 180m and 23m respectively (www.emporis.com) [Accessed 15 May 2016]. The names of important parts of the cathedral are shown in Figure 4.58 (www.chestercathedral.com) [Accessed 18 May 2016].

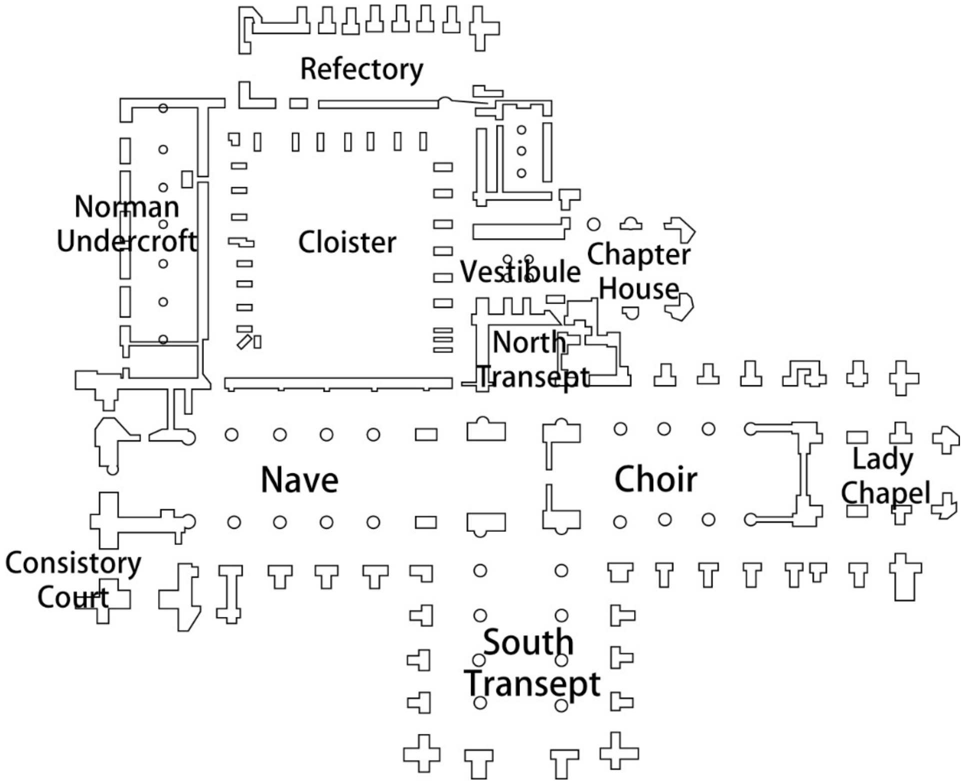


Figure 4. 5 8 The floor plan of Chester Cathedral (location: Chester UK, year built: 1541)

Source: Drawn from chestercathedral.com [Accessed 18 May 2016]

The first step is to identify the central square which has the same width as the Nave and Choir. Golden-section rectangles can be drawn based on the square in four directions (shown in Figure 4.59). These golden-section rectangles mark the key stones which defines the south transept, the north transept, the Nave and the Choir. When the edges of the four overlapping golden-section rectangles are extended, a square which marks the centre area of the cross is generated (which is coloured in grey in Figure 4.60). This square can be considered as a unit and be duplicated. As shown in Figure 4.60, the distance between the south transect and the refectory is four units. One unit on both east and west side of the central unit marks the edge of the

Lady Chapel and the Nave. The golden-section rectangles can be constructed on the east and west units to define the east and west ends of the cathedral (shown in Figure 4.60). Furthermore, a root two rectangle can be constructed based on the square unit which covers the area of the North transept and the Vestibule (Figure 4.60). The edge of this root-two rectangle defines the Chapter House.

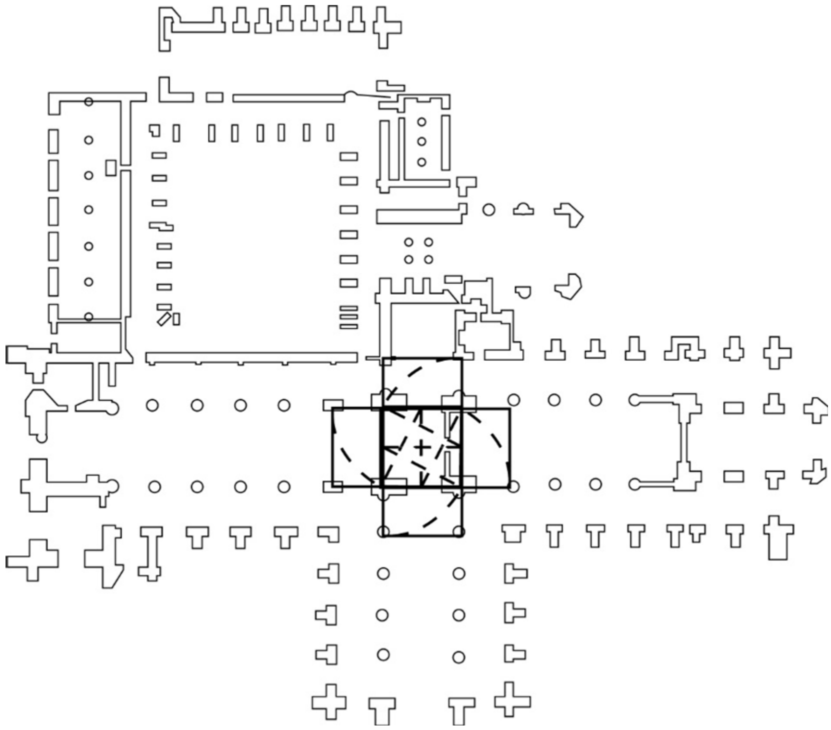


Figure 4. 5 9 The golden-section rectangles in Chester Cathedral plan

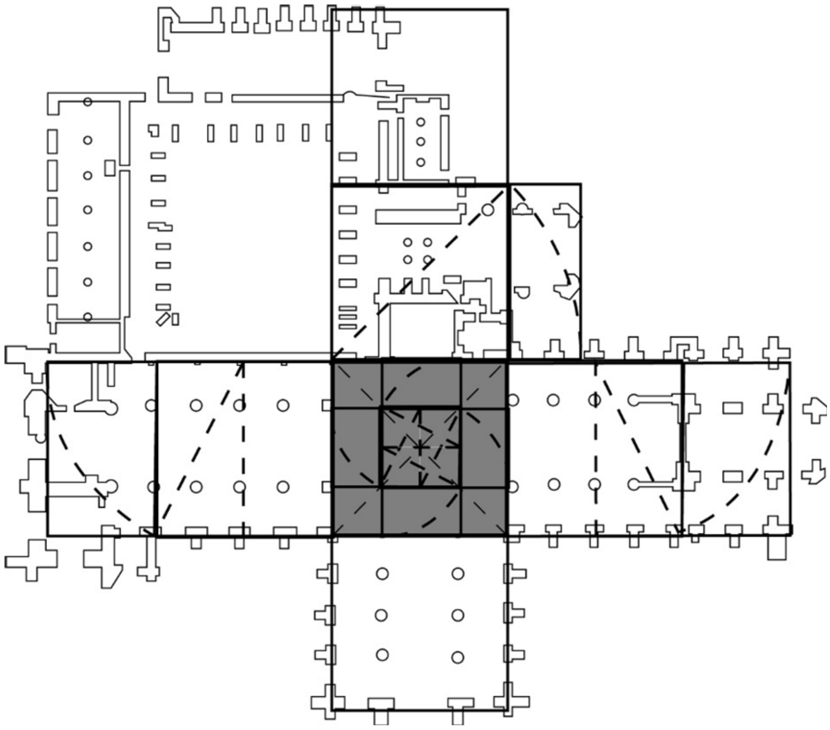


Figure 4. 6 0 The modular nature of Chester Cathedral plan

A sacred-cut square can be drawn to cover the area of the Cloister and the Norman Undercroft (Figure 4.61). The wall between the Cloister and the Norman Undercroft is against a sacred-cut division line. When the sacred cut is conducted again in the middle square, the inner Cloister garden is defined by a division line. Furthermore, the inner garden and the refectory are all designed based on the sacred cut of the corner square (Figure 4.61).

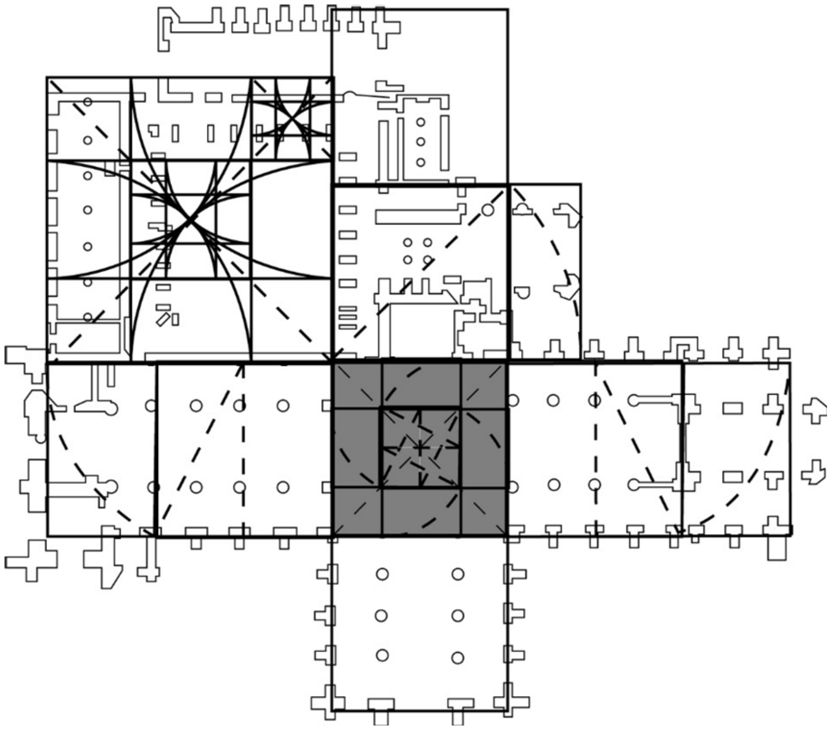


Figure 4. 6 1 The sacred cut in the Chester Cathedral plan

Root rectangles (square to root-five rectangles) can be drawn based on the length of the cathedral plan (Figure 4.62). The square marks the aisle of the south transept; the root-two rectangle defines the boundary of the south transept; the root-four rectangle marks the west end of the nave and the root-five rectangle defines the west end of the whole plan. Similarly, root rectangles also mark the key points vertically. When root rectangles are drawn based on the distance between the south transept and the refectory (shown in Figure 4.63), the square marks the north edge of the nave; the root-two rectangle marks the north edge of the Vestibule. The root-three and the root-four rectangle define the boundary of the refectory.

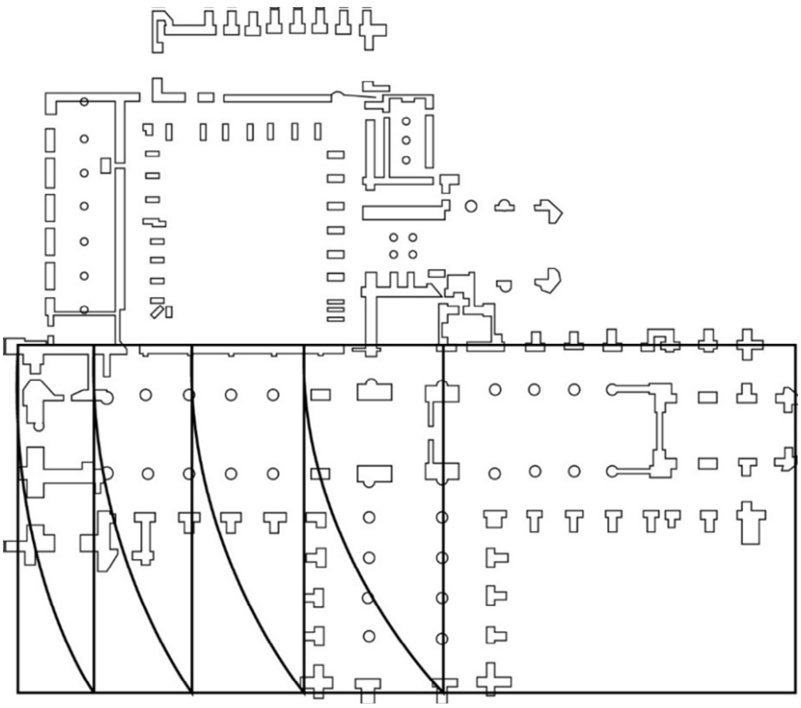


Figure 4. 6 2   The root rectangles in Chester Cathedral plan (no. 1)

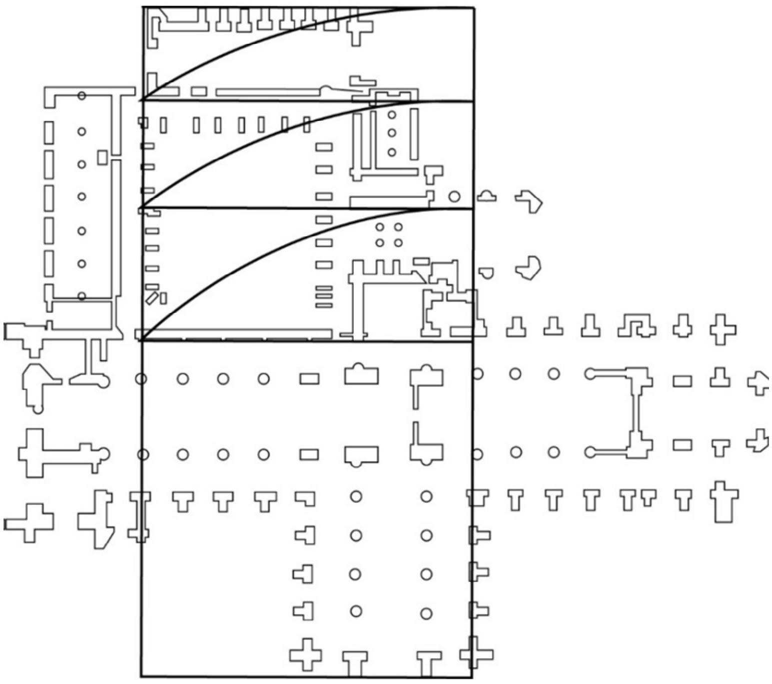


Figure 4. 6 3   The root rectangles in Chester Cathedral plan (no. 2)

When *ad quadratum* figures are drawn based on the basic central square (S1 in Figure 4.64), the third square (S3 in Figure 4.64) marks the overlap of the cross. Square 4 (S4) goes through the key stones in east, west and south directions. Square 5 (S5) marks the north edge of the North Transept; Square 6 goes through the south end of the South Transept.

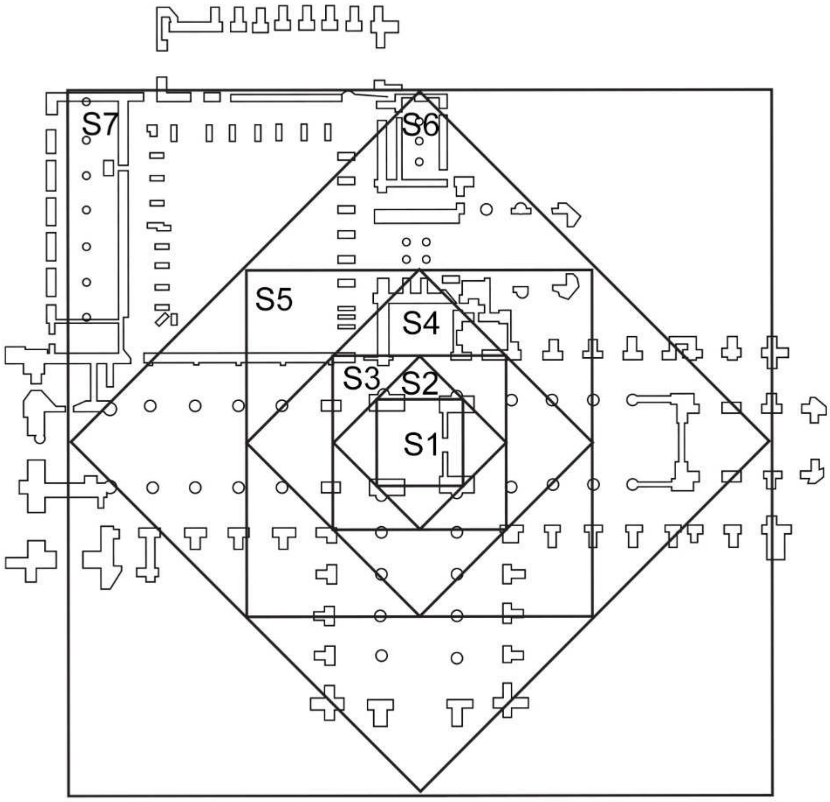


Figure 4. 6 4 The *ad quadratum* in Chester Cathedral plan

A square grid system based on the width of the pillars in the nave can be applied to the floor plan, and then an 18 x 16 grid can cover the floor plan (Figure 4.65). Most key stones can be found in the grid lines.

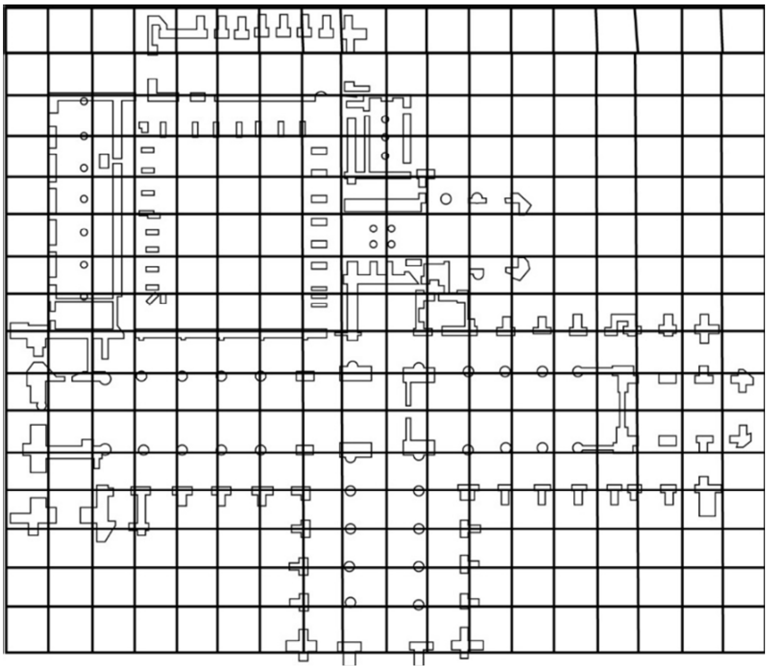


Figure 4. 6 5 The square grids in Chester Cathedral plan

The St. Paul's Cathedral (location: London UK, years built: 1675-1720) plan, measures 157m length and 73.8m width (www.emporis.com) [Accessed 15 May 2016]. The plan of St. Paul's Cathedral is shown in Figure 4.66 (www.stpauls.co.uk) [Accessed 15 May 2016].

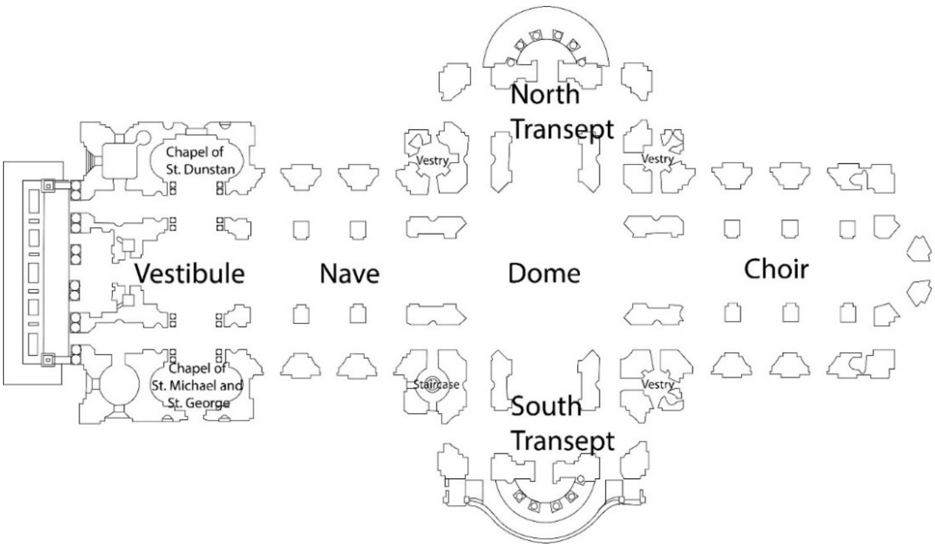


Figure 4. 6 6 The floor plan of St. Paul's Cathedral (location: London UK, years built: 1675-1720)

Source: Drawn from stpauls.co.uk/ [Accessed 15 May 2016].

The whole plan can be included in a root-five rectangle (shown in Figure 4.67). If a square is drawn in the rectangle, it divides the floor plan into φ: 1: φ proportion. In other words, the proportion between the length of the Nave and Dome as well as the east and west sections are 1: φ: φ, the centre of the cross is a dome, which is surrounded by eight key stones. Two squares overlapping each other in 45 degrees can mark the dome (Figure 4.68). One square's vertex marks the centre of the Vestries. The other square's vertex marks the North Transept, the South Transept, the Nave and the Choir.

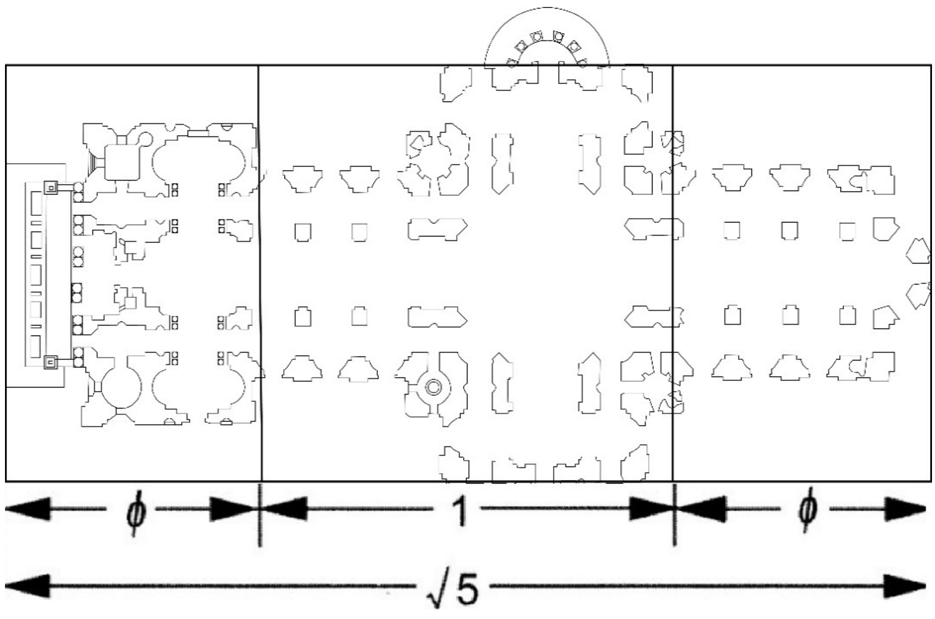


Figure 4. 6 7 A root-five rectangle on the St. Paul's Cathedral

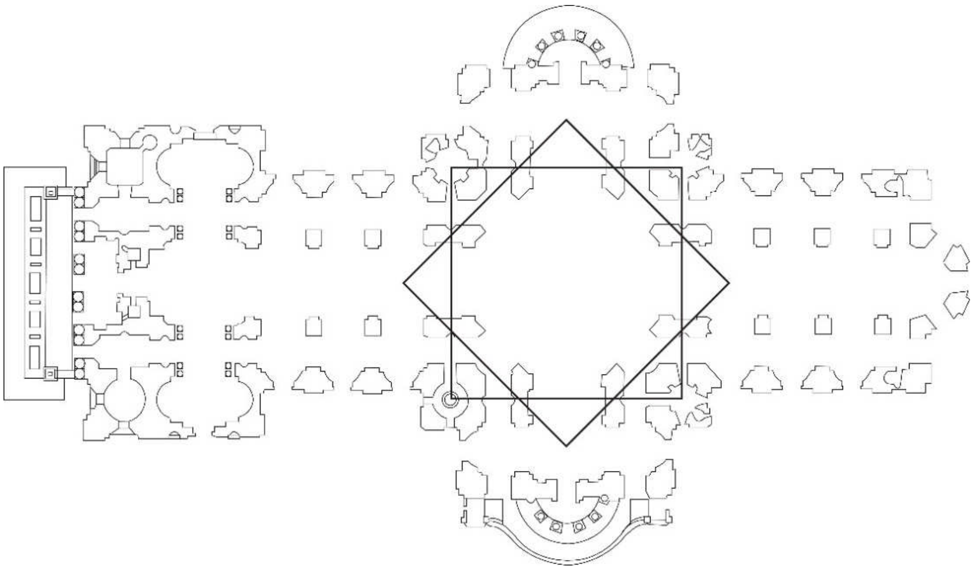


Figure 4. 6 8 The overlap of squares in the St. Paul's Cathedral plan

The square which marks the centre of the Vestries can be considered as a modular to provide proportion for the whole plan. The length of the plan (except the east end) is roughly four units (shown in Figure 4.69). Two overlapping root-two rectangles drawn from the central square mark the width of the south and north transepts (Figure 4.70). The rectangles cover the Chapel of St. Dunstan, the Vestibule and the Chapel of St. Michael and St. George are all constructed based on a golden-section rectangle (Figure 4.70).

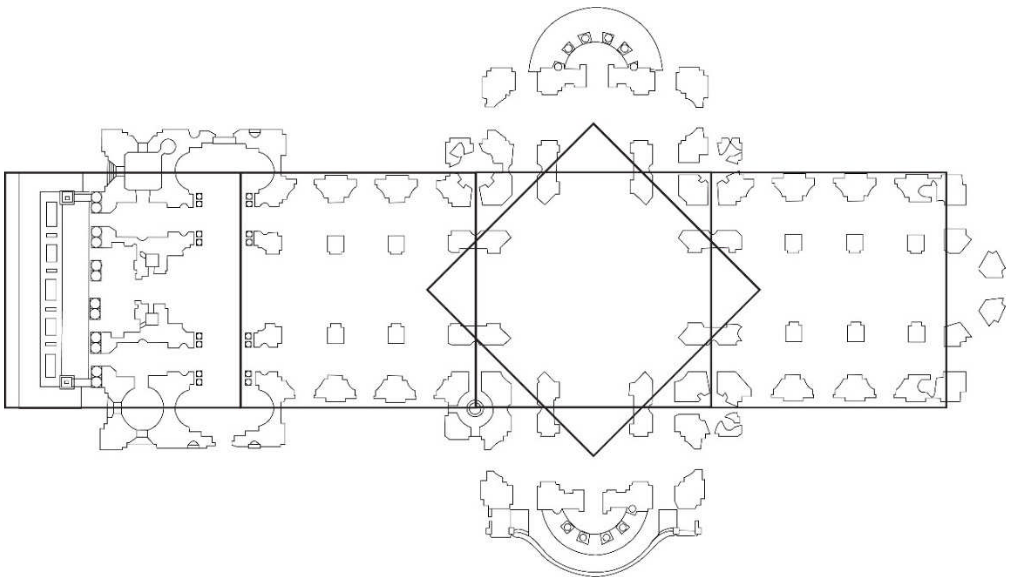


Figure 4. 6 9 The modular constructions in the St. Paul's Cathedral plan

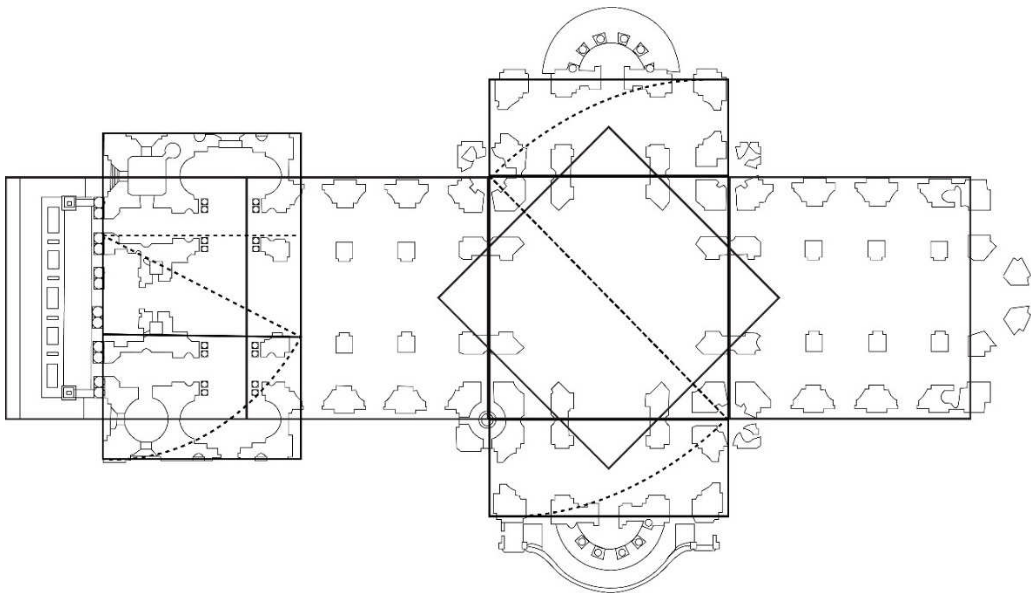


Figure 4. 7 0 The golden-section and the root-two rectangle constructions in the St. Paul's Cathedral plan

When the width of a square Brunes star equals to the distance between the North and the South Transepts (Figure 4.71), the eight key stones of the dome are marked by the intersection points of the square half diagonals.

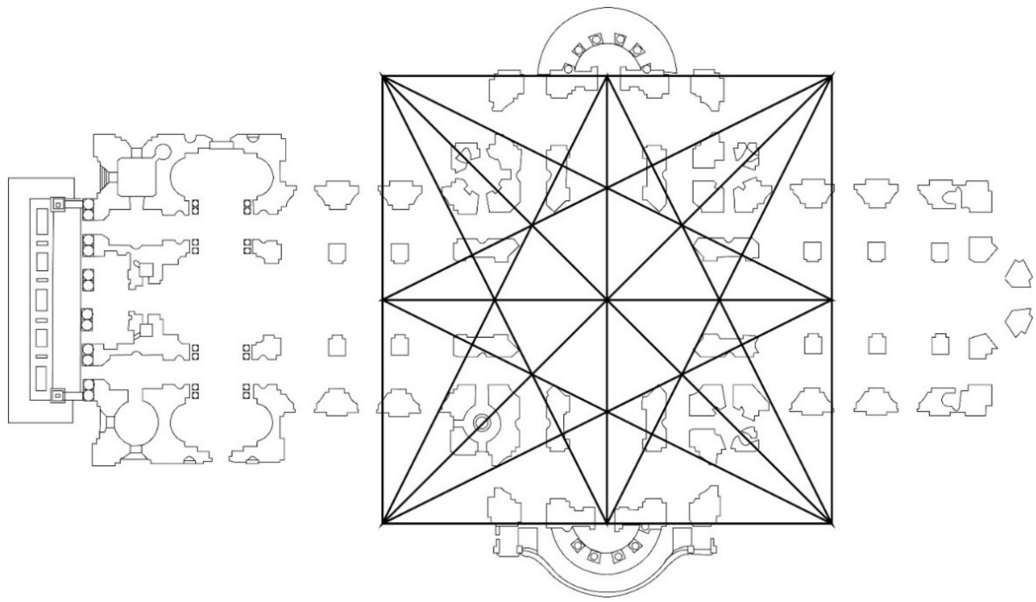


Figure 4. 7 1 The Brunes star in the St. Paul's Cathedral plan

If the width of a scared-cut square equals to the distance between the North and the South Transepts (Figure 4.72), the walls of the cathedral nave, the choir, the North Transept and the South Transept will be defined by the division lines. The five squares (the central and the four squares on the corners) can be scared cut again. The Nave and Choir and the Vestry key stones are all against the scared-cut lines (Figure 4.72).

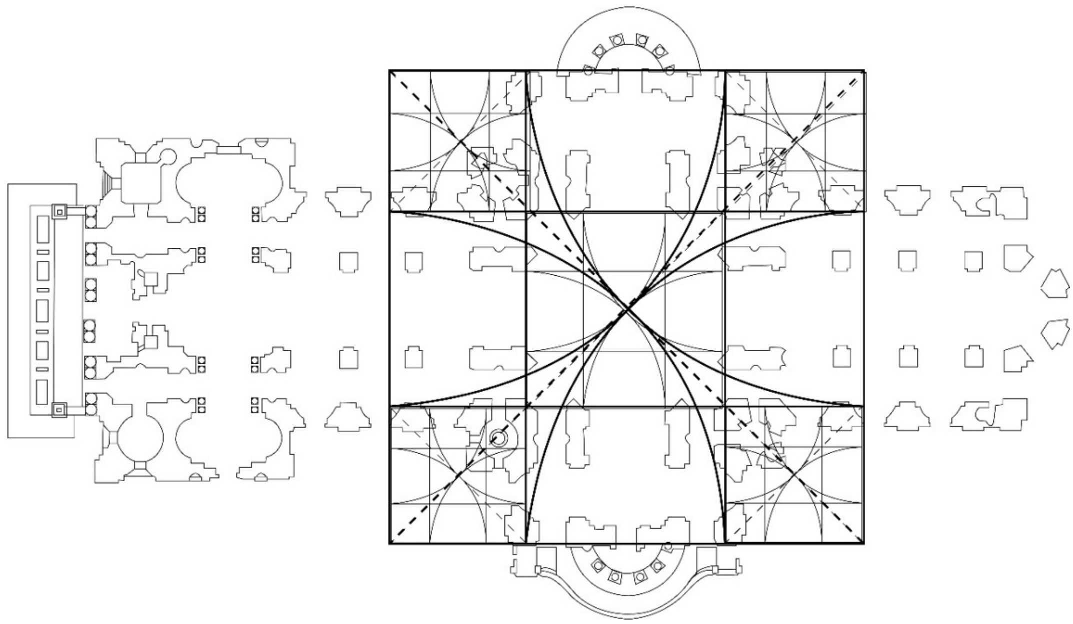


Figure 4. 7 2 The scared cut in the St. Paul's Cathedral plan

Furthermore, the south and the north ends of the cathedral can be defined by two rotated pentagons (Figure 4.73); the east end can be defined by two rotated squares (the intersection points), the same proportional square can also be found in the Vestibule and the two chapels.

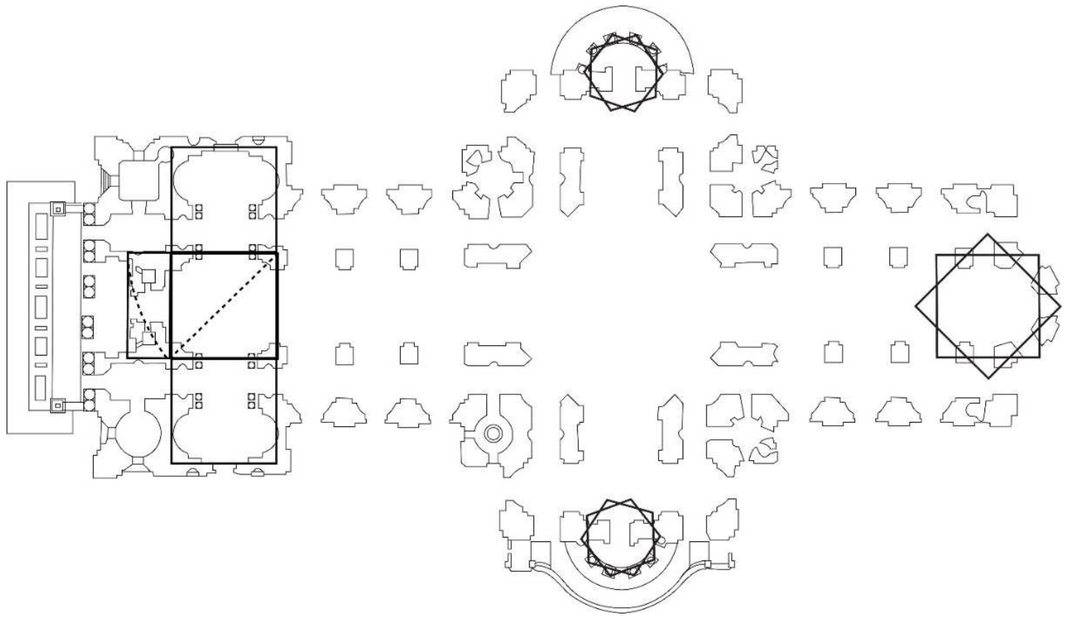


Figure 4.73 The rotated pentagons and squares in the St. Paul's Cathedral plan

4.5 Results

After applying the same methods to the 20 selected cathedral plans, it is interesting to notice that although the appearances and results are different from cathedral to cathedral, all the plans can be constructed based on a single square by applying simple geometric operations. The constructions of golden-section rectangles; modular systems; sacred cut as well as root rectangles (√2 to √5 rectangles) are found most frequently used. The summary of analysis methods in each case are listed in Table 4.1 and Table 4.2 (Appendix B).

4.6 Summary

Cathedrals as religious architecture, have been studied by scholars worldwide. Their constructions, especially the floor plans, reveal various geometric features. This chapter reviewed the possible geometrical methods which may have been applied in cathedral design. It was found that often cathedral floor plans were based on square-related constructions. Furthermore, the combinational use of the golden-section rectangle; modular systems; sacred cut as well as root rectangles ($\sqrt{2}$ to $\sqrt{5}$ rectangles) were found in most of the selected cases.

Chapter 5 : Case study number 3 - Scottish clan tartans

5.1 Introduction

It is common knowledge that a conventionally woven textile consists of two assemblies of parallel threads (warp and weft), one interlaced with the other at ninety degrees. Where each of the two assemblies is arranged in a particular colour sequence, a check design, known as a 'tartan', may be created. Although similar check-type cloths have been produced worldwide, it is the tartans of Scotland which have received most attention and it is here that a complex set of rules evolved and tartans of different types became associated traditionally with different regions, family groups or 'clans'.

This chapter explains the nature of tartans, identifies typical surface structures, ratios and proportions, and suggests possible avenues of analysis. The principal sources of data were a collection of tartans held at ULITA – An Archive of International Textiles (University of Leeds, UK) and Stewart's 1974 publication *The Setts of Scottish Tartans*. Attention is focused also on square constructions and their divisions.

5.2 Data

This section is concerned with providing background information relating to the case study, and to giving a brief discussion of the nature and function of tartans, as well as their geometrical features. Attention is focused also on sources and scope of the data examined.

5.2.1 Background information

Although tartan-type textiles have attained popularity the world over, as noted above it is in Scotland where this category of woven textiles underwent an evolution in design up to modern times and various design types (or setts) became associated with particular families, clans or geographical regions. There is an impressive array of publications focused on the identification of tartans and their clan associations. Probably the best known early works are those by Logan (1831), Stuart and Stuart (1842 and 1845), Smith and Smith

(1850), Simbert (1850), Grant (1886), Whyte (1891), Stewart (1893), Whyte (1906), Adam (1908), MacKay (1924) and Innes (1945); most of these are available for reference only at relevant specialist libraries. An interesting series of monographs, each focused on a particular clan, its tartan, armorial crest and related matters, was published in the 1950s and early 1960s, under the general title of *Johnston's Clan Histories*; examples included Grant (1952), Moncrief (1954), Stewart (1954), Dunlop (1957), Fraser (1954) and Dunlop (1960). Readily available publications, focused specifically on tartans, include: Bain (1938), McClintock (1943), Innes (1945), Hesketh (1961), Dunbar (1962) and Scarlett (1972 and 1973). Stewart (1974, p.113-117) provided a useful explanatory bibliography of these and other important publications. Subsequently, notable treatese were produced by Dunbar (1984), Teall and Smith (1992), Way and Squire (2000), Urquhart (2000 and 2005), Martine (2008), and Zaczek and Phillips (2009). More recently, Hann (2015, p.78-81) provided an explanatory section on tartans, including thirty-two colour plates of rarer tartan types, in the publication *Stripes, Grids and Checks*.

In the popular imagination, tartans are believed to be of very ancient lineage. This may well be the case with checked wool textiles in general, and it may be the case also that thread colours used in a particular region, in ancient times, were derived from dyestuffs available locally; so there may have been a tendency for certain colour palettes to dominate in different regions, depending on local dye-stuff availability. Detailed classification of Scottish clan tartans, and the specific use of a particular tartan design and colour palette by a particular family group, however, is of relatively recent origin (within the past two-hundred years). Often commentary on tartan origins will make reference to various historical documents, paintings or illustrations. Famously, a woodcut image, dated to 1631, showing checked textiles being worn by figures reputed to be Scottish highland soldiers (and volunteers to the army of Gustav Adolphus of Sweden), is cited as early evidence for tartan use (Hampshire and Stephenson, 2007,p.39). Meanwhile it is pointed out often that Bonnie Prince Charlie’s armies were organized into tartan-clad regiments (Hann, 2015, p. 79) and, after the defeat of the Jacobites at the Battle of Culloden, in 1746, a range of repressive legislation was enacted by the English authorities banning the wearing of highland dress (Hampshire and Stephenson, 2007,p. 39; MacInnes, 2000, p.18). This was under the Act of Proscriptions which came into force on 1st August 1746 and made the wearing of 'highland dress' , including tartan or a kilt, illegal in Scotland (Moxon, 2016). The law was repealed in July 1782, presumably because the Jacobites were no longer regarded as a threat (Moxon, 2016). During the nineteenth century the use of tartans gained in popularity in the wake of various visits to Scotland by English royalty, initially George IV in 1822 and Queen Victoria with her husband Prince Albert in the 1840s (Moxon 2016). In the twentieth century, tartans were famed worldwide, new designs were commissioned by major multi-national companies and eminent fashion designers launched tartan collections at key international fashion shows (Hann, 2015, p. 80). By the early-twenty-first century tartans had retained their popularity and were a well recognised textile category worldwide.

Tartan cloth famously displays a checked feature, comprised of squares and other rectangles created by interlacing two series of threads (warp and weft), with each series arranged in a particular colour sequence and to a particular thread count and density (e.g. threads per centimetre or per inch); this sequence or order of different coloured threads is known as the ‘cloth sett’ or simply ‘sett’.

There are many publications (some listed in section 5.2 to this chapter) which identify different tartan types and provide interesting historical backgrounds to Scottish regional clans. By comparison, only a few publications have focused on actual production issues, including the identification and enumeration of setts and the precise orders of differently coloured yarns in given tartans. Stewart’s (1974) publication is one of these few and gave sett details for over two-hundred-and-fifty designs, though it was remarked that this list was not exhaustive and by no means accounted for all tartans produced (Stewart, 1974, p. 31). Issues such as weaving tension, yarn crimp and post-weaving relaxation shrinkage in warp and weft directions, as well as orders of shrinkage which may occur during finishing, are of great importance in manufacture, but seem to have been ignored largely in published work.

As indicated above, the ‘cloth sett’ (or simply ‘sett’) of a tartan gives the planned colour order and numbers of warp threads and weft threads. Full production details would include also a precise statement of yarn (or thread) count and the number of threads per unit length (inch or centimetre) in both warp and weft directions. It seems that all traditional tartan fabrics are of square (or balanced) sett, when in the finished state, which means that they have identical numbers and orders of yarn types, counts and colours (per unit of measurement) in both warp and weft directions. Further to this, setts may be classed as either ‘symmetrical’ or ‘asymmetrical’. The importance of symmetry in crafted and industrially manufactured objects has been recognized by numerous observers. A detailed explanation with relevant illustrations was, for example, provided relatively recently by Hann (2012, p. 72-96). The concept may be used in the description of various figures, objects and images, all of which are either symmetrical or asymmetrical. Where symmetry does exist, two or more identically sized and shaped versions of each identical component of the figure, object or image, can be identified within the whole, and the placing of each identical component can be visualized most easily in terms of 'symmetry operations' of which reflection is probably the most common. Symmetrical setts have a series of pivots (in both warp and weft directions), with each pivot (denoted in notation form as an oblique stroke) acting like a two-sided mirror (or reflection axis) reflecting the order of threads in a warp or weft direction. So a pivot is where the colour and number of threads is reversed or reflected. With different pivots operating at similiar points in warp and weft directions, an identical order of colours and yarn counts will occur in both directions; reflection symmetry is thus a dominant characteristic of the majority of traditional tartans. For example, a MacKeane tartan has warp threads ordered as follows: 4/yellow, 2 black, 24 red, 16 black, 8 red, 16 black and 8/red (considered at the 'sett' or, occasionally, with symmetrical tartans, as the 'half sett') which is reversed or reflected to continue in reverse order as 16 black, 8 red, 16 black, 24 red and 2 black; reflection occurs therefore at each of the two pivots (4/yellow and 8/red), and the yarns at each pivot are not themselves reflected (Stewart, 1974, p.78). In shortened form this order of threads (in both warp and weft directions) can be represented as 4/Y, 2 Bk, 24 R, 16 Bk, 8R, 16Bk, 8/R which is reversed at either of the two pivots (each shown as an oblique stroke) to produce a 'symmetrical' arrangement of twelve bundles of yarn which repeat in the same colour sequence in both warp and weft directions. Meanwhile an 'asymmetrical' arrangement has no pivots, and the sett or order of threads will simply repeat across and down the cloth; so although the colour, order and types of threads in warp and weft directions are identical, groups of threads are not reversed through the use of pivots. Examples of asymmetrical arrangements include the Buchanan and MacAlpine tartans (Stewart, 1974, p. 41 and 66), though it appears that the vast majority of tartans are organised on a symmetrical basis. Thus symmetrical tartans appear largely identical when viewed along the cloth (from top to bottom or bottom to top) or across the cloth (from right to left or left to right). Figure 5.1 illustrates this case.

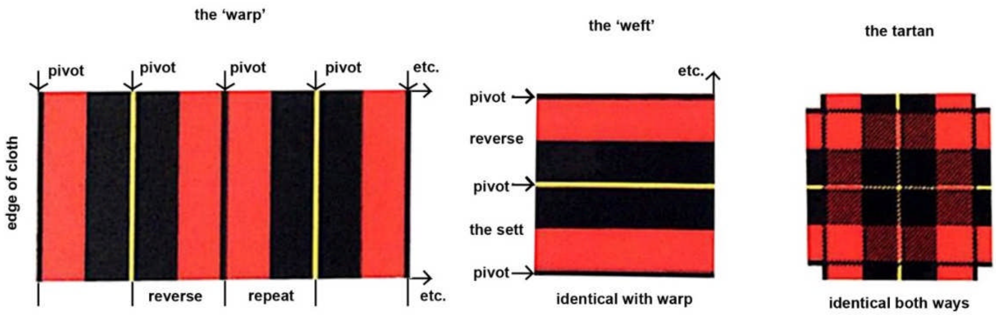


Figure 5. 1 Example of Scottish tartan construction showing pivot points

Source: Shin, 2011, p.128

It is worth noting that traditionally tartans were woven using a 2/2 twill (in a 'Z', or 'right-hand', direction); a minor consideration is the direction of the twill lines, which will differ when viewed in either a warp or a weft direction, though in the vast majority of cases this is only detectable at a close range of less than twenty centimetres (Hann, 2015, p. 79). As a general rule, when in use, the 'Z' twill orientates vertically (with the upper and lower bars of the 'Z' oriented horizontally). Weaving is perceived often as a restrictive means of production, with patterning in the conventional process dependent on the manipulation of setts of threads interlaced at ninety degrees. Despite this, tartan checks (which are, after all, only a sub-category of woven textiles) show immense variation, through the numbering and ordering of yarn colours in warp and weft directions. Importantly, the repeating unit for all symmetrical tartans is in a square format, with equal numbers of warp and weft threads, to the same count and woven to equal density (threads per centimetre or inch). Within this square, further squares and other types of rectangles are created, as threads of the same or differing colours interlace. The 2/2 twill weave and the reflection of the yarns is shown in Figure 5.2.

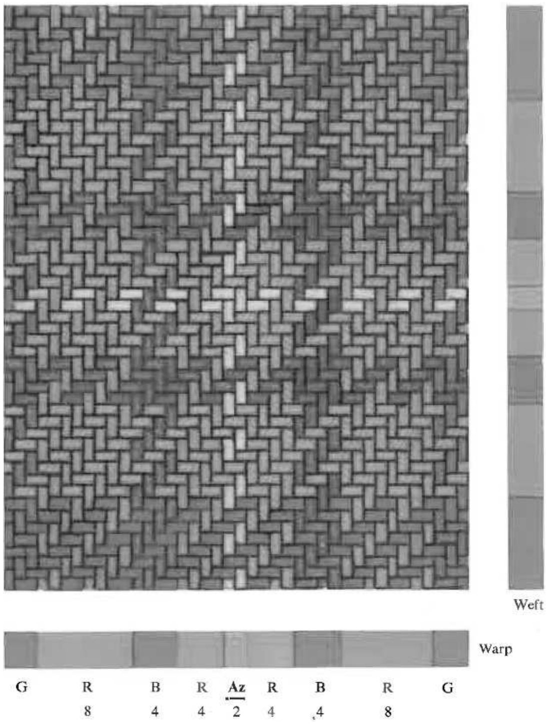


Figure 5. 2 The 2/2 twill weave and the reflection of the yarns in tartan

Source: Stewart, 1974, p.130

It is the contention here that the modern designer has much to learn from considering the design of textiles such as these and, with this in mind, consideration is given below to aspects of space division associated with a selection of tartans as well as common geometric ratios and proportions associated with the finished textile.

5.2.2 The selection of cases to be analysed

All data were collected from the analysis of samples of finished tartans, selected from a collection held at ULITA – An Archive of International Textiles (University of Leeds) and cross referenced with the various publications listed earlier in this chapter. Numerical details of setts were taken from Stewart (1974). Further comparisons were made with web-site based material (provided, for example, by the Scottish Tartans Authortity at http://www.tartansauthority.com/). Occasionally, where contradictions were apparent, samples were not included for analysis. Twenty-five symmetrical tartan designs (in their finished cloth state) were selected, with this sample size determined by the number of examples for which dependable cross referencing was available; the selected tartan types are listed with their half setts (not allowing for reversing of numbers at pivots) and colours in Table 5.1.

However, three of them Macrae (Hunting); Stewart of Appin and Stewart of Galloway did not lend themselves to reproduction with Illustrator. So a total number of twenty-two pieces of tartan were selected from the original twenty-five, and each was reproduced for further study.

It is readily apparent that all except one of the sett numbers in the sample are even numbers; this is apparently because working practice among traditional hand weavers was to work from left to right and the insertion of an even number of weft threads in each given colour allowed the shuttle to return to its original box at the left-hand side of the loom, in readiness for further use. The one exception is the Robertson tartan sett which contains three red threads within its half sett (Stewart, 1974, p. 97); the author has been unable to find a reason for this apparent annomoly.

It should be noted that warp- and weft-ways measurements were carried out on finished historical textiles and that it was not possible to assess the degree of post-weaving shrinkage, though it should be noted that where the known setts suggested square ratios (as with all symmetrical tartans in the sample) this indeed was always evident. It may be the case that warp- and weft-ways shrinkage were largely similiar and, as a result, did not affect ratios and proportions to any visually detectable degree. It should however be stated further that the assessment of warp and weft-ways shrinkage, in the absence of knowledge of production conditions, is not readily attainable, and this is an obvious weakness of examining historical collections.

Table 5.1 The (half) setts and colours of a selection of twenty-five tartans

Sample number	Name	Sett																
1	Balmoral	4	2	16	4	4	2	2	2	8	4	2	2	2				
		Cy	R	Cy	Lv	Bk	Cy	Lv	Cy	Lv	Cy	Bk	Cy	R				
2	Brodie	4	32	16	2	16	4											
		Bk	R	Bk	Y	Bk	R											
3	Campbell of Breadalbane	2	2	16	16	2	28	2	16	2	2	2	2	16				
		B	BK	B	BK	Y	G	Y	BK	B	BK	B	BK	B				
4	Davidson	2	12	6	12	2												
		W	G	Bk	B	R												
5	Drummond of Perth	72	2	6	2	32	16	6	4	2								
		R	W	B	Y	G	R	B	Az	W								
6	Fraser of Lovat	32	2	2	2	24	32	4	32	24	24	2	2					
		B	R	B	R	G	R	G	R	G	B	R	B					
7	Huntly	16	4	16	24	4	6	4	24	2	6	2	24	6	24	2	6	2
		G	R	G	R	G	R	G	R	W	R	Y	B	R	B	Y	R	W
8	Kennedy	4	48	8	6	6	6	6	6	8	24	2	4	2	6	2	4	4
		R	G	B	Bk	B	Bk	B	Bk	B	G	Cr	G	Cr	G	Y	G	Bk
9	MacCallum	2	12	12	8	2	4	16										
		BK	B	BK	G	Az	BK	G										
10	Lord of the Isles (hunting)	48	2	4	4	4	2	24	2	4	4	4	2	24				
		C	W	C	W	B	W	B	W	B	W	B	W	B				
11	MacKeane	4	2	24	16	8	16	8										
		Y	Bk	R	Bk	R	Bk	R										
12	MacLachlan	6	4	32	32	6	4	48										
		Y	W	Bk	G	Y	W	R										
13	MacLeod	6	4	30	20	40	4	4										
		R	Bk	C	Bk	B	Bk	Y										
14	MacNeill	2	6	30	28	32	4	2										
		Y	Bk	G	Bk	B	R	W										
15	MacPherson	2	2	16	2	2	2	16	2	2								
		B	R	Gy	R	B	R	Bk	R	B								
16	Montgomerie	8	10	8	56	8	10	8										
		Bk	Res	Bk	P	Bk	R	Bk										
17	Ogilvie	4	10	4	4	12	4	12	4	12	4	10	20	6	20			
		W	Az	Y	P	R	W	R	W	R	Bk	Y	Az	R	Az			
18	Ogilvie (hunting)	8	6	2	6	2	32	16	4	48								
		R	G	Bk	G	Bk	G	Bk	Y	B								
19	Robertson	2	4	36	4	4	36	3	36	4	4	36	4	2				
		W	G	R	B	R	G	R	B	R	B	R	G	W				
20	Stewart	24	2	4	2	24	4	24	2	24	4	24	2	4	2	4	2	24
		G	Bk	B	Bk	G	R	Bk	R	Bk	R	Bk	Bk	G	Bk	G	Bk	B
21	The Prince's Own, as worn in 1745-46	4	4	14	14	2	6	2	14	18	4	10	6	6				
		Bk	R	Gy	R	Bk	R	Bk	R	B	R	Bk	R	Y				
22	From a coat worn at Culloden	6	4	26	26	4	28	4	10									
		Y	Bk	Dy	Bk	W	Helio	Az	R									
23	Macrae (Hunting)	6	2	30	28	8	4	8	4	28								
		W	Bk	P	Bk	Res	Cr	Res	Bk	Res								
24	Stewart of Appin	4	4	2	4	48	4	4	16	4	4	8	48	4	2	4	6	
		G	R	Az	B	R	G	R	B	R	G	R	G	R	Az	B	R	
25	Stewart of Galloway	6	48	8	2	4	2	8	12	6	2	4	2					
		Bk	R	Bk	Y	Bk	W	B	G	R	Bk	R	W					

Key: Y= yellow; R= red; B= blue; Bk= black; Gy= grey; G= green; W= white; Lv= lavender; Az=azure; Helio= heliotrope (or light purple); Cr= crimson; Res= reseda (or pale green); Dy=dull yellow; P= purple

Source: Stewart, D. C. (1974). *The Setts of the Scottish Tartans*, London: Shepheard-Walwyn.

5.2.3 Ratios and proportions

In all symmetrical tartans there will always be a strong preponderance of squares in either solid colour or 'blended' colour (the latter involving one colour from the sett interlacing with another colour from the sett). Squares will result when equal numbers of warp and weft threads are interlaced. Interlacements involving unequal numbers of warp- and weft-direction threads will produce rectangular forms in differing length and breadth ratios depending on the number of threads used. The most common ratios found in the sample of twenty-five tartans were identified and are listed in Table 5.2. Considering the prepondance of squares of various sizes in all symmetrical tartans, it is not surprising that the most common length to breadth ratio (found in 100 per cent of the tartans examined) was 1:1. The next most common ratio, found in 80 per cent of the sample, was 1:2, followed by 2:3 (48 per cent), 1: 3 (36 per cent), 1:4 (28 percent) and 3:4 (24 per cent).

Table 5.2 Common ratios found in Scottish clan tartan setts

Ratio	% of sample
1:1	100%
1:2	80%
2:3	48%
1:3	36%
1:4	28%
3:4	24%

Sample size: 25 finished tartans

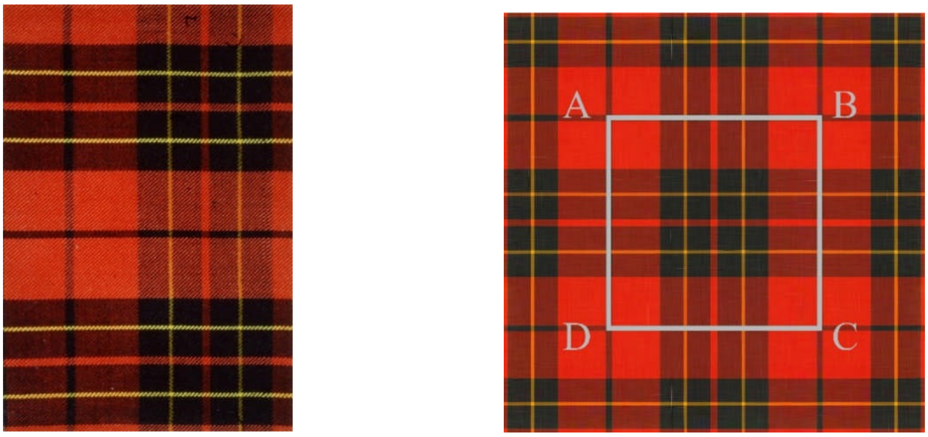
Source: ULITA – An Archive of International Textiles (University of Leeds, UK)

5.3 Developing and applying the analysis methods for the case group

As noted in the introduction and elsewhere in this chapter, the dominant aesthetic characteristic of tartans is their checked appearance, based on warp threads in a given order of colours interlacing at right angles with weft threads in the same order. Each colour in a sett can be visualised conveniently as a layer or grid, formed from two series (one warp and the other weft) of parallel threads of the same colour intersecting at ninety degrees. So, in order to understand more fully the dominant aesthetic features of tartans, it was decided to consider each tartan sample in terms of a series of layers or grids, and to ascertain the dominant features of this layering in each case.

5.3.1 Unit check identification in tartans

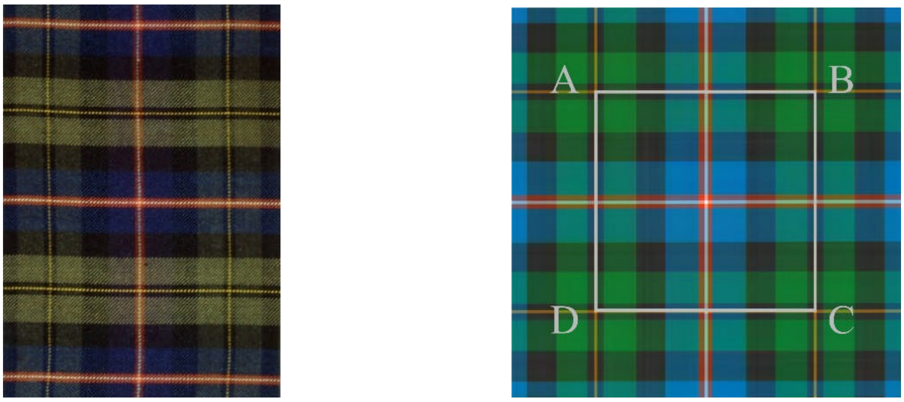
Each tartan in the sample was reproduced making reference to the samples held at ULITA – An Archive of International Textiles and supported by the sett data provided in Stewart (1974). The repeat unit within each tartan was identified. By way of example, black-and-white reproductions for Brodie and MacNeill tartans are presented in Figures 5.3b and 5.4b respectively. The repeat unit of each tartan (comprised of the full sett, which takes into account reflections at pivots) is held within a box labelled ABCD (Figures 5.3b and 5.4b).



a b

Figure 5. 3 The original picture and the reproduced image of tartan Brodie

Source: Photograph taken by M. A. Hann



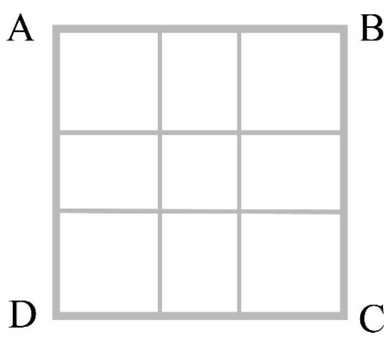
a b

Figure 5. 4 The original picture and the reproduced image of tartan MacNeill

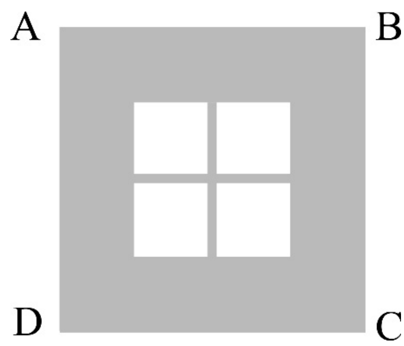
Source: Photograph taken by M. A. Hann

5.3.2 Identifying layers in the check unit

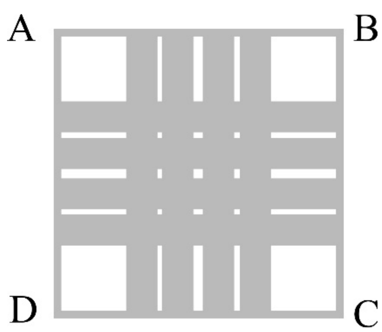
Within this repeat unit, the design in each case can be considered, in three-dimensional space, divided into a series of layers with each layer formed from a grid of warp and weft threads of a given single colour. So the number of layers for each tartan will be equal to the numbers of colours used in the sett (e.g. three for the Brodie tartan Figure 5.5 and six for the MacNeill tartan Figure 5.6).



a: The yellow threads

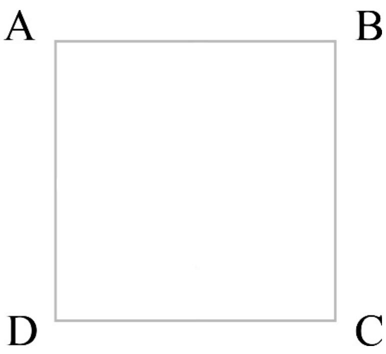


b: The red threads

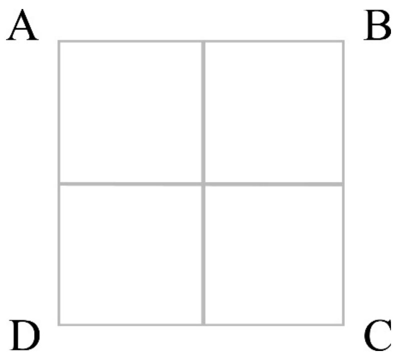


c: The black threads

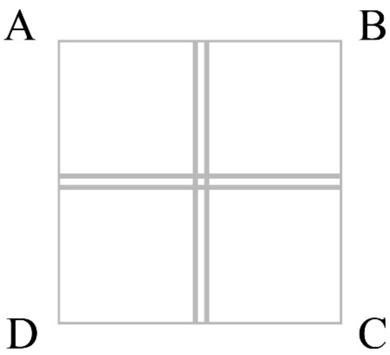
Figure 5. 5 The layers of one check unit in Brodie tartan



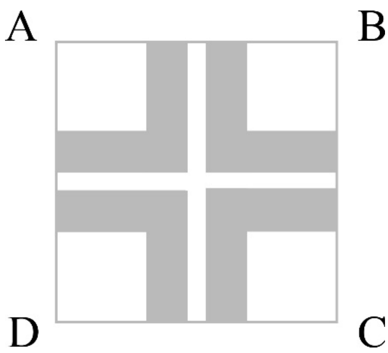
a: The yellow threads



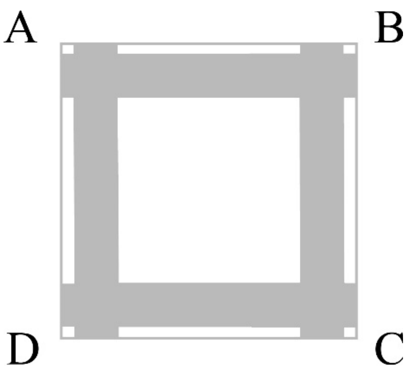
b: The grey threads



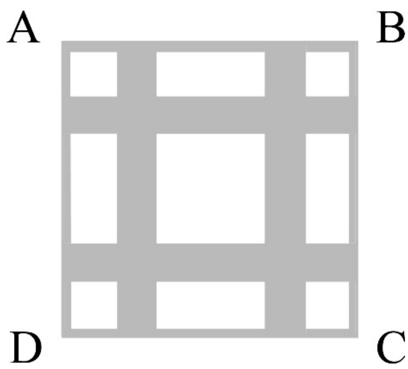
c: The red threads



d: The blue threads



e: The green threads



f: The black threads

Figure 5. 6   The layers of one check unit in MacNeill tartan

5.3.3 The development of tartan analytical methods

With both the Brodie and MacNeill tartans it was found that warp- and weft-direction stripes (which together give the checked appearance) coincided clearly with vertical and horizontal dividing lines within the square repeat. These dividing lines were positioned at half-way and third way points, and bundles of yarn colours were distributed equally on either side of these dividing lines. Similar results were obtained across the full sample of twenty-five tartans. This is also indicated in the most common ratios found in the sample of twenty-five tartans were identified and are listed in Table 5.2 given previously. The most common length to breadth ratio (found in 100 percent of the tartans examined) was 1:1. The next most common ratio, found in 80 percent of the sample, was 1:2, followed by 2:3 (48 percent), 1: 3 (36 percent), 1:4 (28 percent) and 3:4 (24 percent).

5.3.4 The application of the proposed divisions to the Brodie and MacNeill tartans

Again making reference to the Brodie tartan, the check unit can be divided successively as shown in Figure 5.7 (a-c). A first division (shown in continuous line in Figure 5.7a, 5.7b and 5.7c) divides the square unit into four equal sections. A second division (shown as broken line 2 in Figure 5.7a, Figure 5.7b and 5.7c) divides one square section, of the first division, into four equal smaller squares. A third division (shown in broken line 3 in Figure 5.7a and 5.7c) further divides the second-division squares.

It is obvious that the stripes are marked by the third time division lines in Figure 5.7a. In Figure 5.7b, the stripes are positioned at the second time division lines. In Figure 5.7c the stripes coincide with the second time and the third time division lines.

The check unit of Brodie tartan can also be divided successively as shown in Figure 5.8 (a-c). A first division (shown in solid line in Figure 5.8) divides the square unit into nine equal sections. A second division (shown as broken line 2 in Figure 5.8) divides one square section, of the first division, into nine equal smaller squares. A third division (shown in broken line 3 in Figure 5.8) further divides the second-division squares.

Then the same methods were applied to MacNeill tartan layers. Figure 5.9 (a-e) illustrates the division and sub-division of halves, while Figure 5.10 (a-d) shows the detailed division and sub-division of thirds.

The stripes are marked by the first time division lines in Figure 5.9a and Figure 5.9b. In Figure 5.9c and Figure 5.9d the stripes coincide with the fourth time division lines. While in Figure 5.9e, the strips are marked by the fourth and the fifth time division lines.

It is worth noticing that only four layers can be divided into thirds. In the case of Figure 5.10a, Figure 5.10c and Figure 5.10d, the third time division lines define the edges of the stripe patterns, while in Figure 5.10b, the stripes are defined by the fourth time division lines.

Therefore, the division of halves and thirds as well as their sub-division lines define the position of stripes in Brodie and MacNeill tartan layers.

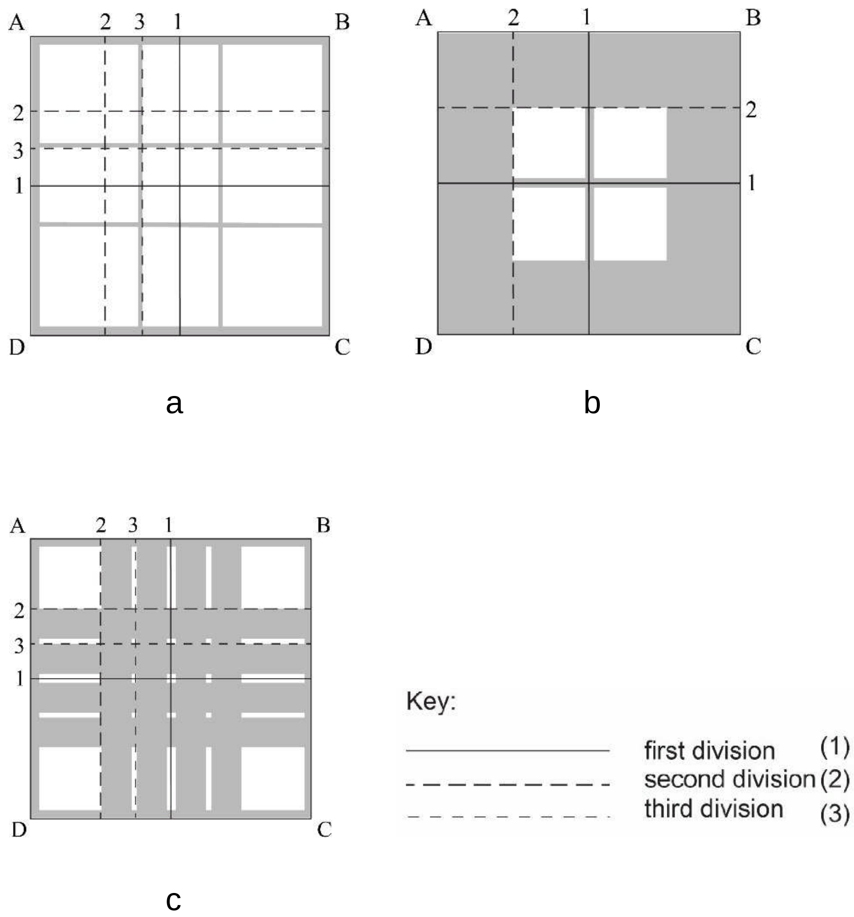


Figure 5. 7 The division into halves of Brodie tartan layers

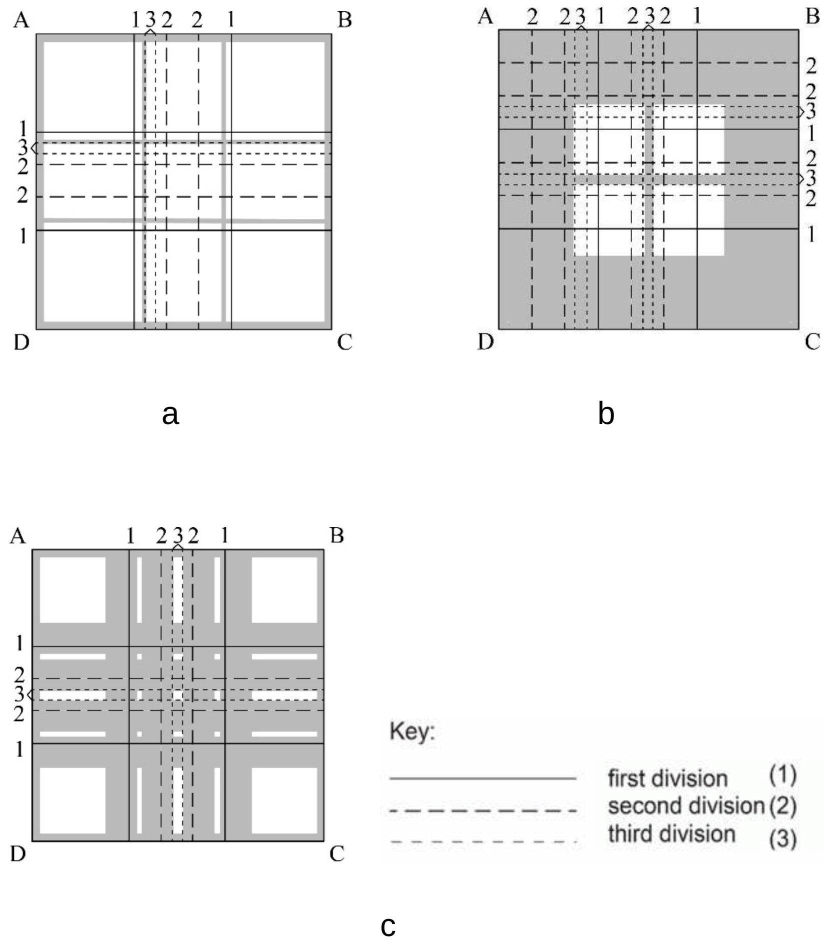


Figure 5. 8 The division into thirds of Brodie tartan layers

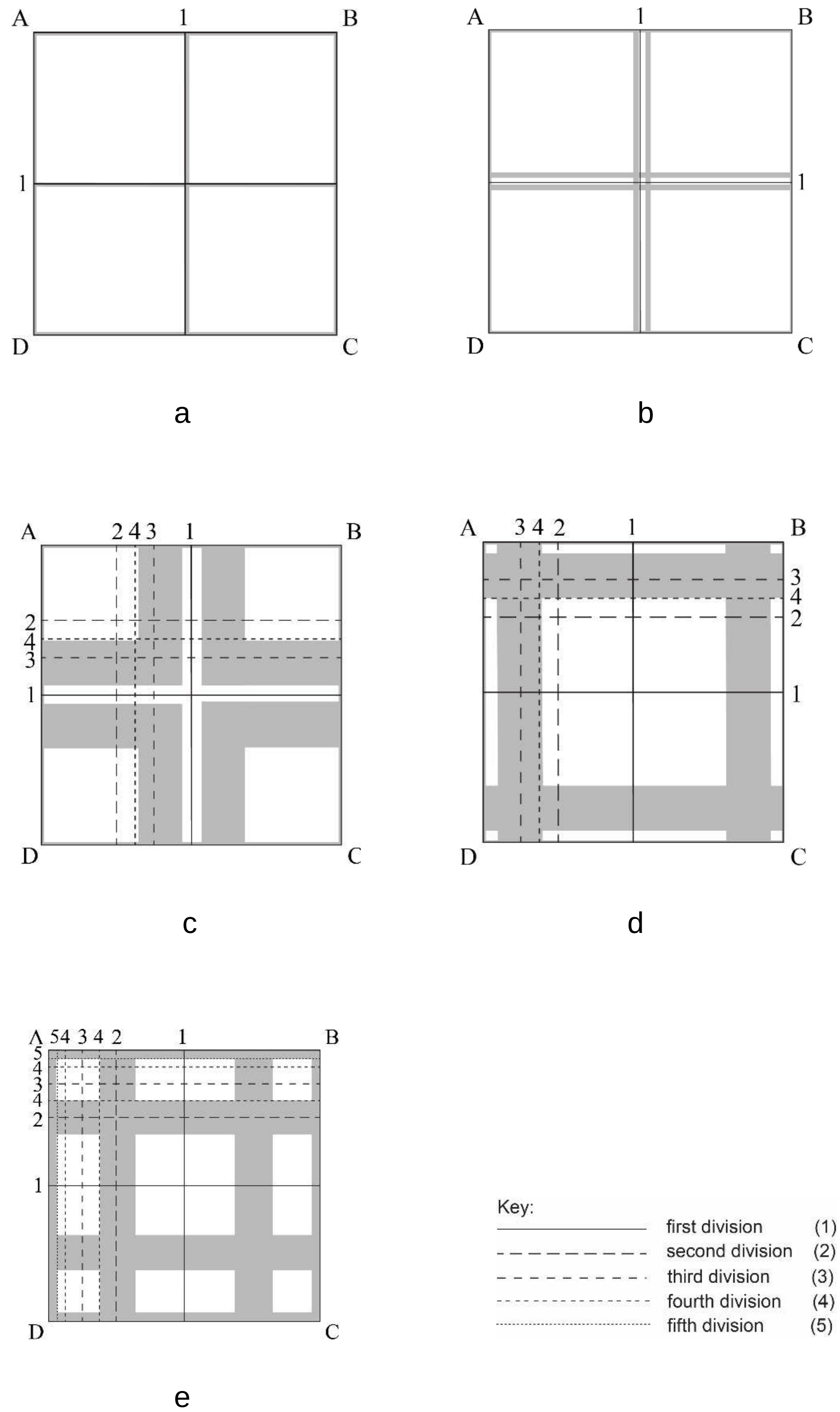


Figure 5. 9   The division into halves of MacNeill tartan layers

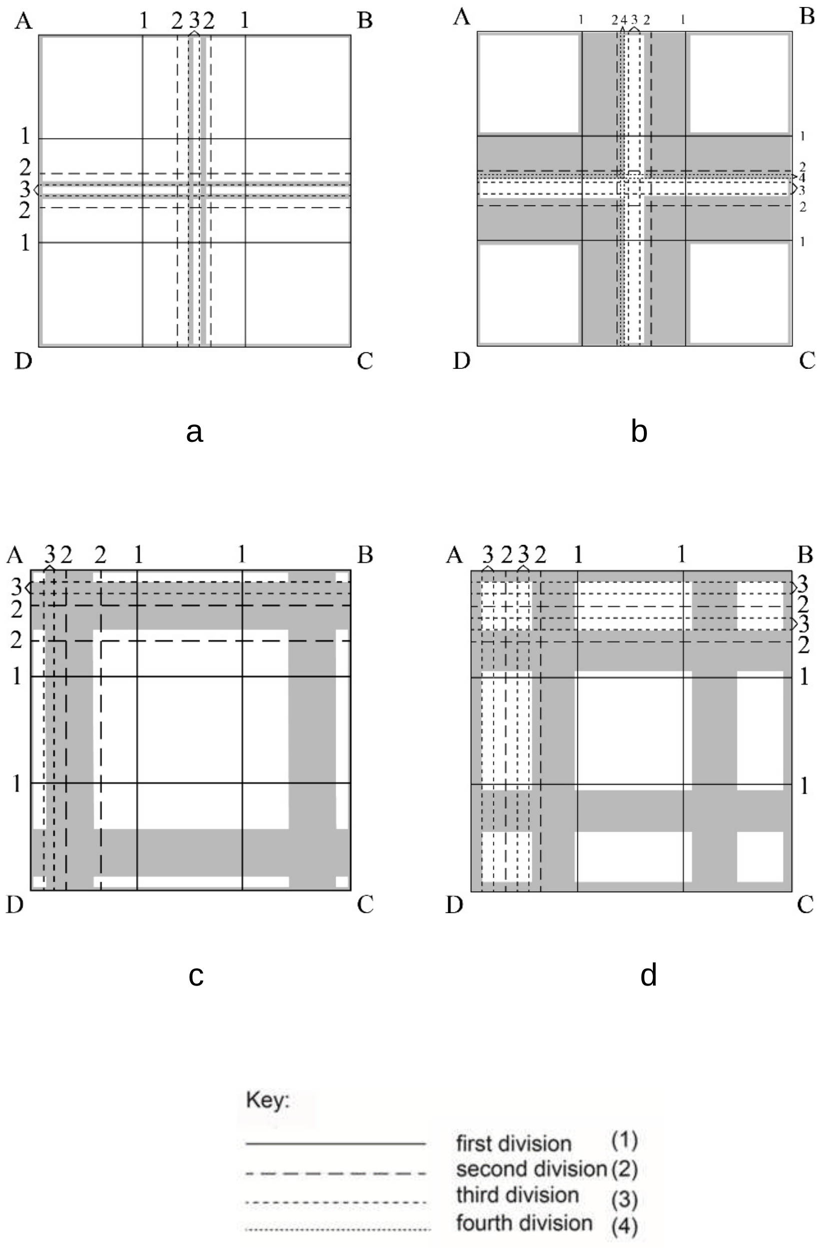


Figure 5.1 0 The division into thirds of MacNeill tartan layers

5.4 Results

After applying the same two division methods to the samples of 22 tartans, 77 separate layers resulted. It should be noted that different tartans display different number of layers and therefore show different numbers of overlapping checks. In each case relevant number of divisions will differ.

Each repeat unit across the whole sample was considered and it was found in 100 percent of cases that the constituent groups of threads in a given colour were arranged at half way and/or quarter way and/or eighth way line divisions, both vertically and horizontally, within the repeat unit. Half-way division is not surprising as all the tartans in the sample are symmetrical, but further half divisions (or sub-divisions) where bundles of threads are positioned at quarter way or eighth way points within the repeat unit seem worthy of note. Third-way divisions and sub-divisions (at one sixth or one twelfth) of the repeat unit were less common, at 76 per cent of the sample, but still worth noting as this has a great influence on the proportions evident in the relevant check designs.

Therefore, although there is no evidence that tartan stripes are arranged geometrically during the weaving process, the division of halves and thirds as well as their sub-divisions indicate that most coloured stripes do follow same systematic division rules when dividing a check unit space, with a resultant variety of final results.

5.5 Summary

Tartan, a national emblem of Scotland, is a cloth often made from wool displaying a checked feature created by weaving different colours of yarns arranged in a pre-determined sequence. This chapter reviewed the nature of tartans and especially the geometrical features of tartan checks. This brief examination of Scottish clan tartans has highlighted that beneath conventional check designs various ratios and proportions are present. Common geometric space division methods were reviewed, and two types of square division methods were explained and used to study the layout of samples of tartans. A set of samples of twenty-two tartans yielded seventy-seven individual layers. The results suggested that tartan patterns are not made randomly; rather they follow certain rules (probably unconsciously during the weaving process). The proportions found in the analysed tartan samples were also found previously by other researchers in the study of pattern design (Özdural, 2000; Thompson, 1977); religious paintings (Popovitch, 1924); graphic design (Behrens, 1998; Elam, 2004); church or domestic floor plans (Wiemer and Wetzel, 1994; Betts, 1993) as well as in mathematics or geometry studies (Bidwell, 1986; Yong, 1970).

Chapter 6 : Case study group number 4 – Posters

6.1 Introduction

Geometry is a compositional principle as geometric structures can bring order and harmony through proportions (Popovitch, 1924, p.223), which will establish a rigorous relationship between parts and the whole in a piece of design work (Ogden, 1937, p.201). The application of geometry, can be found in the composition of paintings (Bouleau, 1980, p.39) and various design works.

This chapter suggests some simple methods which have been used in poster design based mainly on the use of square derivative constructions, which can form the construction basis of the whole design without any further measurements.

In addition to presenting various background information, including a discussion of data considerations and the review of geometric construction methods which have been used in painting, graphic design and architecture, a range of case study material is selected, analyzed and discussed also.

6.2 Data

This section provides a range of background information relating to poster designs and also provides commentary on the source of data used for this case study.

6.2.1 Background information

A poster is usually considered to be a large sized announcement, printed on paper and displayed on walls to show certain messages to passers-by, and usually includes pictorial elements along with verbal messages to emphasize the selected theme (Hutchison, 1968, p.9).

Poster appearances are highly influenced by time, region, theme, art style and design techniques. This subsection discusses poster characteristics based on the above aspects.

Early posters were found to appear in the mid-19th century due to the developments of printing techniques dating back to 1798 and the awareness of Japanese wood colour printing art style (Hutchison, 1968, p.10; Weill, 1985, p.55).

From 1860 to 1900, the Industrial Revolution largely enhanced the commercial market in Europe and North America (Hutchison, 1968, p.14). Mass sales and the expansion of markets were needed, which led to a development in poster design (Hutchison, 1968, p.14). Between 1880-1890, a large number of painters in Paris were influenced by impressionist and post-impressionist paintings and this contributed to a boom in poster production (Weill, 1985, p.47, Ades, 1984, p.25). As a result, the production of posters was spread internationally by the end of the 19th century (Timmers, 1998, p.48).

The posters in the early-20th century were mainly commercial posters (Timmers, 1998, p.48 Hutchison, 1968, p.48). However, during World War One, posters switched their functions from commercial promotion to political propaganda (Weill, 1985, p.129; Timmers, 1998, p.109). As there was no wide spread use of radio or TV, posters became the most powerful communication tool between the government and the public (Hutchison, 1968, p.70). Therefore, posters at that time were designed mainly to stimulate emotions, and to enhance hopes and ambitions (Hutchison, 1968, p.70).

After the World War One, the selling of products was more widely spread (Ades, 1984, p.6). Some painters then only focused on the creation of posters and became graphic designers (Ades, 1984, p.6).

Furthermore, the coloured lithographic poster was invented in 1920s, which then became the most powerful advertising method (Wrede, 1988, p.20). It is also worth noticing that Russian film posters from the period 1925-1929 are considered to be among the most innovative and expressive in the world (Ades, 1984, p.71; Weill, 1985, p.144).

Posters in the World War Two are different from those in the World War One. One of the reasons is that governments were able to reach the public by radio which, compared to posters, was a more direct and faster way (Hutchison, 1968, p.129; Timmers, 1998, p.123). Posters in the World War Two were persuasive (Timmers, 1998, p.124) though graphics were simple (Weill, 1985, p.287). The poster themes were more related to public safety to persuade women to work in industry (Timmers, 1998, p.123), or to encourage people to grow food (Hutchison, 1968, p.129).

After World War Two, industrial production was rapidly recovered and exceeded the pre-war level, while new types of mass media were developed (Hutchison, 1968, p.135).

The 1960s' counter-culture posters which mainly focused on civil rights activism (Timmers, 1998, p.136) were psychedelic posters which had their own visual style (Wrede, 1988, p.36). Posters in 1970-80, however, emphasized typography, abstraction and composition (Wrede, 1988, p.37).

According to Timmers (1998, p.12), posters can fulfill three purposes: 'pleasure and leisure'; 'protest and propaganda' as well as 'commerce and communication'.

Pleasure and leisure posters have highly decorative features as they are closely related to the art movement of the day and display their status as art (Ades, 1984, p.27). Exhibition posters are such examples (Timmers, 1998, p.76).

Protest and propaganda posters influence the viewers' action by promoting attitudes, ideas and ethics (Timmers, 1998, p.146), and have a concern with moral, ethical and social issues (Timmers, 1998, p.143). War posters (Timmers, 1998, p.103) and Olympic Games posters belong to this category (Timmers, 1998, p.50).

Commerce and communication posters aim to sell products or services (Weill, 1985, p47). The most famous commercial posters are those posters designed for certain clients. For example, London Regional Transport was a client of graphic design in 1930s (Wrede, 1988, p.32). Similar big clients such as British Railway companies and the Shell Company also contributed to commercial poster design (Timmers, 1998, p.201). Furthermore, film posters (Ades, 1984, p.54), theater posters (Ades, 1984, p.45), music business posters (Timmers, 1998, p.68) and tourist posters (Hutchison, 1968, p.67) are all of this kind.

Posters can be classified by regions as well. In Europe, posters were first developed in Paris (Weill, 1985, p.47, Ades, 1984, p.25) and quickly spread to the other European countries. Posters became commercially essential in

Britain in the 19th century (Timmers, 1998, p.177), and were designed as advertisements for clients (Weill, 1985, p.223).

In Germany posters did not take the French poster style (Weill, 1985, p.95). The World Wars, especially World War Two made German artists design for political purposes (Hutchison, 1968, p.115). The Belgian and Italian posters were mainly commercial advertising (Timmers, 1998, p.175, Weill, 1985, p.84). Danish artists were the first to add humorous elements in poster design (Weill, 1985, p.94).

Although America did not have its own art tradition (Hutchison, 1968, p.39), the demand of the market still made America develop the poster the fastest (Weill, 1985, p72). Furthermore, the Americans started to design posters for leisure and for educated and wealthy classes which are distinctive from those for mass population in 1890s' (Timmers, 1998, p.185).

Japan had their wood-cut print technique and the full colour lithographic technique in the early-20th century (Timmers, 1998, p.202; Wrede, 1988, p.37). Advertising posters were the main focus (Wrede, 1988, p.37).

Furthermore, posters in Cuba and China were known as the collectivist posters (Weill, 1985, p341), and they were mainly propaganda posters for the revolution (Weill, 1985, p341).

As poster designs are inspired by art and posters have the forms of painting (Timmers, 1998, p.72), some art style had profound influences on poster design.

The impressionist and the post-impressionist paintings in 1860s Paris provided the condition for poster design (Ades, 1984, p.25). Cubism, which started in Paris in 1907 (Hutchison, 1968, p.88), had a great influence on painting and sculpture, and it influenced poster design until the middle of World War One (Ades, 1984, p.30). Expressionism adopted and synthesized its style from gothic forms and cubism (Wrede, 1988, p.20) to develop an art style which only used shapes and colours to attract attention from passers-by (Ades, 1984, p.71). This art style had a profound influence on Russian film posters during 1925 -1929 (Ades, 1984, p.71).It also greatly influenced the design style of the Bauhaus in the 1920s (Wrede, 1988, p.22).

Russian constructivism was a response to the Russian revolution in 1917 (Lodder, 1983, p.2). When constructivism was applied to posters, it usually used exclusive typography and abstract geometric forms (Ades, 1984, p.64) to deliver the message clearly, legibly and forcefully (Ades, 1984, p.65). Furthermore, dada and pop art also influenced commercial art (Wrede, 1988, p.37).

Poster design also largely depends on technologies. Printing techniques (Ades, 1984, p.15) and the computer technology influenced the appearance of posters significantly (Wrede, 1988, p.37).

6.2.2 The selection of cases to be analysed

The appearance of poster is highly influenced by time, region, theme, art style and design techniques (please refer to the last subsection for more discussion). Therefore, there is a wide range of choices to be considered in the selection of posters for this case study.

In the beginning of the data selection process, the top twenty museums around the world ranked by CNN (http://edition.cnn.com) [Accessed: 13 October 2016] were found by web search, including the Louvre (Paris); the National Museum of Natural History (Washington); the National Museum of China (Beijing); the National Air and Space Museum (Washington); the British Museum (London); the Metropolitan Museum of Art (New York); the National Gallery (London); the Vatican Museums (Vatican); the Natural History Museum (London); the American Museum of Natural History (New York); the National Museum of American History (Washington); the TATE Modern (London); the National Palace Museum (Taiwan); the National Gallery of Art (Washington); the Centre Pompidou (Paris); the Shanghai Science and Technology Museum (Shanghai); the Musee d'Orsay (Paris); the National Museum of Natural Science (Taiwan); the Science Museum (London) and the Victoria and Albert Museum (London).

The museums from non-English speaking counties were first excluded from the list, as the posters' background information may have been in different language too. Thus, only the Museum of Natural History (Washington); the National Air and Space Museum (Washington);

the British Museum (London); the Metropolitan Museum of Art (New York); the National Gallery (London); the Natural History Museum (London); the American Museum of Natural History (New York); the National Museum of American History (Washington); the TATE Modern (London); the National Gallery of Art (Washington); the Science Museum (London) and the Victoria and Albert Museum (London) remained on the list for further consideration.

Among those museums, only six are art and design related, including: the British Museum (London); the National Gallery (London); the TATE Modern (London); the Victoria and Albert Museum (London); the Metropolitan Museum of Art (New York) and the National Gallery of Art (Washington). Poster collections as well as poster themes, years, designers, country and dimensions were then checked for collection in all six museums. It was found that, the National Gallery in London and the National Gallery of Art in Washington provided mainly artwork collections, while the Victoria and Albert Museum did not have web-based measurements on their poster collections. Therefore, these three museums were excluded from the list.

Apart from the online sources, books related to poster collections at University of Leeds libraries were checked as well. 'The modern posters' by Stuart Wrede (1988) was published to accompany one poster exhibition held during June 6, 1988 to September 6, 1988 in the Museum of Modern Art in New York. Thus the web-site of the Museum of Modern Art in New York was visited and their poster collections were checked. Finally, as a result of the stages of elimination the Museum of Modern Art, along with the TATE Modern, the British Museum and the Metropolitan Museum of Art were the sources of poster collections selected for this case study.

The posters for this case study are thus only based on online collections. Due to confidential and copy right issues, all the above museums have a limited number of posters displayed in their online collections. In other words, not every one of the collected posters has a digital version online. So availability of digital version posters was a further limiting factor of this case study.

The data were selected from the most up-dated time period to the least up-dated time period. For example, the search for on line poster collections from each museum is firstly refined by time period from 2000 to 2016, in order to make sure that the most up-dated data were selected. Then the time period between 1990 and 1999 is searched, followed by 1980-1989. Thus the time range of the selected posters for this study is 1980-2016.

The aim of this case study is to discover the underlying geometric constructions and proportions which governed the layout of each poster. Therefore, extreme cases such as posters that only have images and only contain text were excluded from this study.

Based on the above criteria, 23 posters from the Museum of Modern Art (New York); 17 from TATE Modern (London); 4 from the Metropolitan Museum of Art (New York) and 2 from the British Museum (London) were selected. Thus a total of 46 posters were selected from relevant museums' online collections in New York and London, which also fitted in the time period between1980-2016.

6.3 Methods

The application of geometry to art or art-related production is universal (Mayeux, 1889, p.28). Complex design is usually made from the combination of simple forms (Mayeux, 1889, p.28). Multiple evidence of using geometry can be found in the composition of paintings (Bouleau, 1980, p.39) and architecture (Coyne, Snodgrass and Martin, 1994, p.125). These structures all convey deliberate intentions and serve particular functions (Erickson, 1986, p.214). By bringing order and harmony through proportions (Popovitch, 1924, p.223), geometry as a compositional tool, establishes a rigorous relationship between the parts and the whole in almost every piece of design work (Ogden, 1937, p.201).

This section reviews the common geometric structures, their proportions as well as their combination, which may benefit the poster analysis in the later section.

The diagonal of the square sometimes governs painting composition, as shown previously in Figure 2.2 (chapter 2, section 2.3), which is re-drawn here as Figure 6.1, where two identical squares overlapping each other are illustrated. Square on square construction can also be constructed as a large square and a small square inside it. The small square is rotated 45 degrees and its corners touch the middle points of the sides of the large one. This case is shown in Figure 6.2. A $\sqrt{2}/2$ proportion exists between the side lengths of the adjacent squares (Birkett and Jurgenson, 2001, p.256).

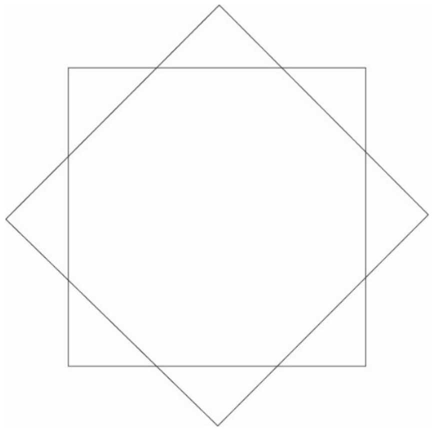


Figure 6. 1 Two identical squares overlapping each other

Source: Drawn from Figure 2.4

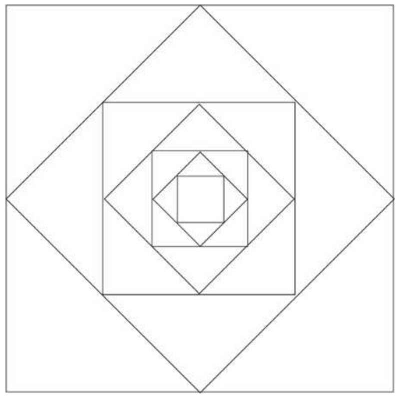


Figure 6. 2 Square divided by square

Source: Drawn from Birkett and Jurgenson, 2001, p.256

When these two types of overlapping square constructions are combined and repeated endlessly, while enclosed in a circle with square diagonal lines added, a compositional framework is then formed (Figure 6.3) (Bouleau, 1980, p.39). This framework was found governing the composition of the painting called ‘Adoration of the Magi’ (artist: Botticelli, painted: 1475), which is shown in Figure 6.4.

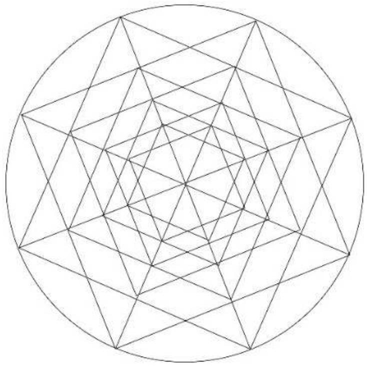


Figure 6. 3   A compositional framework

Source: Drawn from Bouleau, 1980, p.39

Figure 6. 4   Adoration of the Magi (artist: Botticelli, painted: 1475)

Source: Bouleau, 1980, p.39

As shown in Figure 6.1, two identical overlapping squares at 45 degrees create an eight-point star. When the vertexes are connected, a regular octagon is created (Figure 6.5 in bold lines). When the diagonal lines of the octagon as well as the two squares are added, a framework is then created (Figure 6.5).This frame work was found in the painting ‘Noah’s Ark’ (artist: French Romanesque Painter, painted: 1100), shown in Figure 6.6 and the vertexes of the octagon mark the key points on the edge of the circular frame (Bouleau, 1980, p.58).

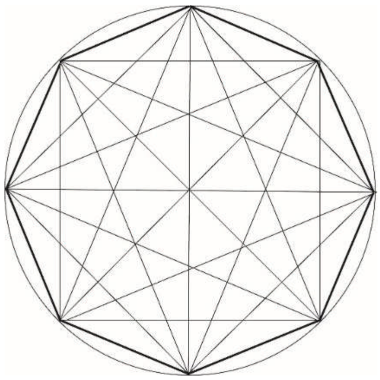


Figure 6. 5   An octagon framework

Source: Drawn from Bouleau, 1980, p.57

Figure 6. 6   Noah's Ark (artist: French Romanesque Painter, painted: 1100)

Source: Bouleau, 1980, p.58

Instead of overlapping rotationally, the squares can be overlapping translationally, which is shown in Figure 6.7. The diagonal lines of both squares (solid lines) as well as the diagonals of the rectangle (dash lines) can be identified. Parallel or vertical lines may be drawn at the intersecting points, which may mark some key elements in painting composition. This type of framework is applied in Giotto's painting 'St Francis before the Sultan' (artist: Giotto, painted: 1320) (Figure 6.8).

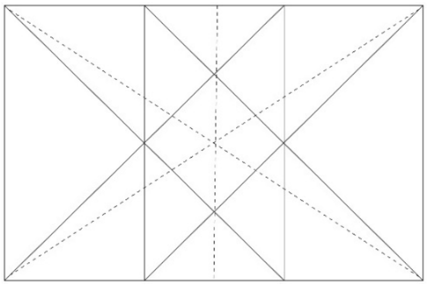


Figure 6. 7 An overlapping square framework

Source: Drawn from Bouleau, 1980, p.45

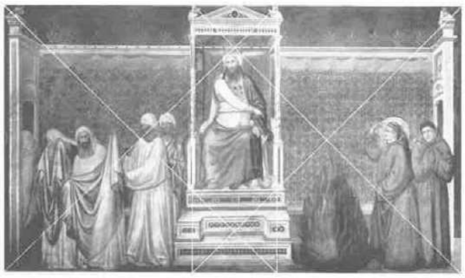


Figure 6. 8 St. Francis before the Sultan (artist: Giotto, painted: 1320)

Source: Bouleau, 1980, p.45

The golden-section proportion is a ratio of 1: 1:1.618, which can be illustrated in line segments if a line is divided into two parts. As shown in Figure 6.9, 'a' is to 'b' as 'b' is to 'a'+'b', and when 'a' equals 1, 'b' will equal 1.618 (Hann, 2012, p.110). (Further explanation given in chapter 2, section 2.5)

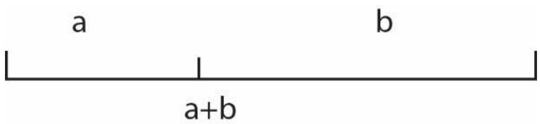


Figure 6. 9 Golden ratio in line segments

Source: Drawn from Figure 2.13

It is believed that the golden-section ratio has long been applied in painting layout to bring harmonic proportion (Bartlett, 2007, p.102). A rectangular framework based on the golden-section division is also commonly used in design construction. As shown in Figure 6.10, the golden- section division points of each side of the rectangle are identified and marked as φ.

Then, from each point (including vertex), lines are drawn to link other points so that a rectangular framework based on the golden-section proportion is developed. The intersecting points may mark the key elements in a painting. Figure 6.11 is the painting named ‘July interior’ (artist: Porter, painted: 1963) (Bartlett, 2007, p.103), where this guideline is seemingly applied.

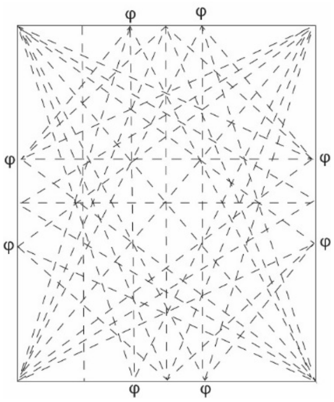


Figure 6.10 The golden-section framework

Source: Drawn from Bouleau, 1980, p.137

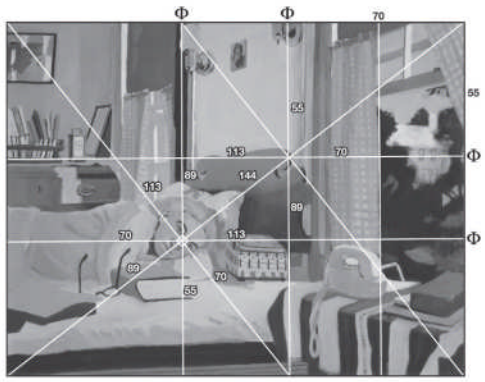


Figure 6.11 July interior (artist: Porter, painted: 1963)

Source: Bartlett, 2007, p.103

A rectangular shape has been considered as the most convenient frame in art and design (Bouleau, 1980, p.46). It governs most structures in architecture too (Bartlett, 2007, p.102). Renaissance artist and architects added whole number of ratios, such as 1:2; 2:3 and 3:4 to the length and width of rectangles (Erickson, 1986, p.213) to express cosmic order (Patricios, 1973, p.316). Figure 6.12 shows all the rectangles with different proportions within the range of 1 to 5.

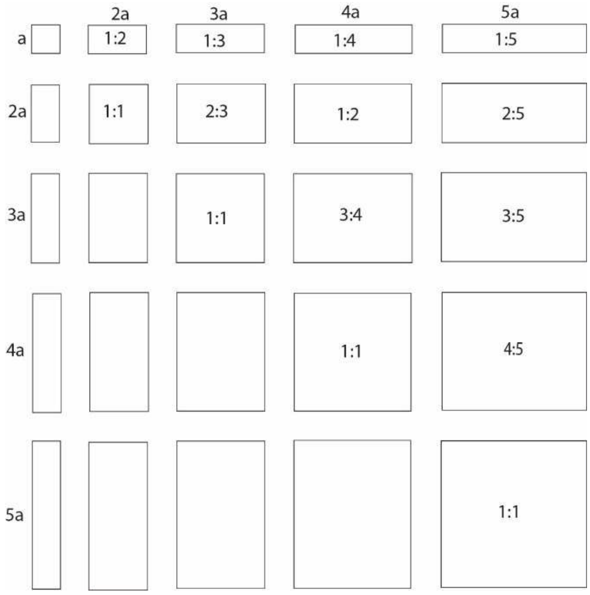


Figure 6.12 Rectangles with different proportions within the range of 1 to 5

Source: Drawn from March and Steadman, 1974, p.223

Apart from this, rectangles with proportions such as 4/6/9, 9/12/16, 3/6/9 and 3/6/8, as illustrated in Figure 6.13 a-d are common ones that often govern the paintings (Bouleau, 1980, p.84). The lines of the dividing points can be connected. Figure 6.14 illustrates a framework constructed based on 4/6/9 rectangle division. Similar guidelines are found in the painting of 'Entombment' (artist: Caravaggio, painted: 1602-1603) as shown in Figure 6.15.

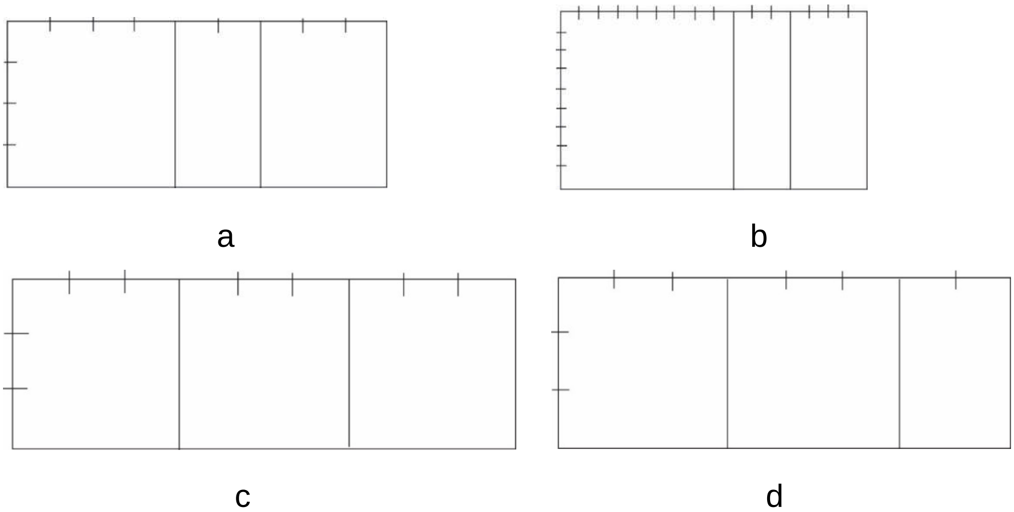


Figure 6.13 The 4/6/9 (a), 9/12/16 (b), 3/6/9 (c) and 3/6/8 (d)

Source: Drawn from Bouleau, 1980, p.84

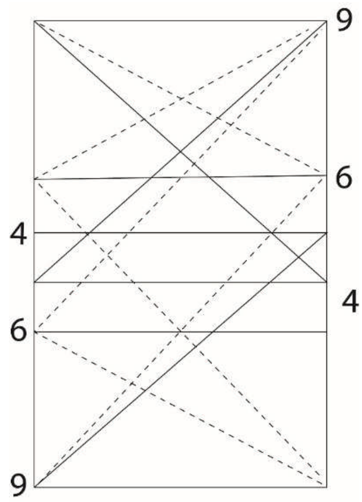


Figure 6. 1 4 The 4/6/9 rectangle framework

Source: Drawn from Bouleau, 1980, p.157

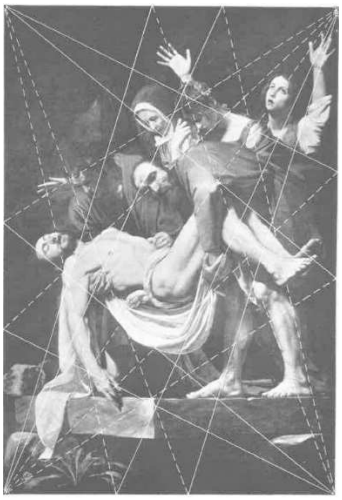


Figure 6. 1 5 Entombment (artist: Caravaggio, painted: 1602-1603)

Source: Bouleau, 1980, p.183

Grids as rational objective and regulative systems, have long been applied in art, architecture and design composition to provide invisible guidelines to element arrangement and to provide the unity of layout (Bartlett, 2007, p.102).

Some grids are designed according to certain proportions. For example, as mentioned before, Figure 6.13 a is a 4/6/9 framework. Figure 6.16 is a grid system constructed based on the 4/6/9 proportion (Bouleau, 1980, p.105). Similarly, Le Corbusier discovered an architectural proportion that based on proportions of 2:1:2:1:2, and 0.5:1.5:1.5:1.5:0.5 (Hildner, 1999, p.144), which is illustrated in Figure 6.17. This proportion has then been further interpreted into a 1:2:3:4 proportion by Hildner as illustrated in Figure 6.18. The 1:2:3:4 proportion is also found in Le Corbusier's painting 'Composition with Guitar and Lantern' in 1920 (Figure 6.19).

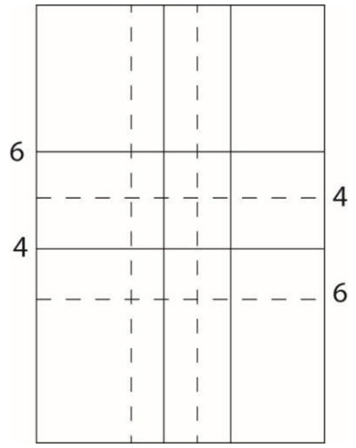


Figure 6.1 6 A grid system constructed based on the 4/6/9 proportion

Source: Drawn from Bouleau, 1980, p.105

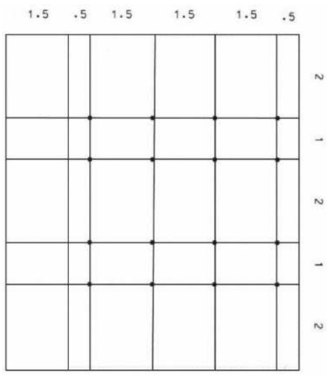


Figure 6.1 7 Le Corbusier's architecture proportion

Source: Drawn from Hildner, 1999, p.144

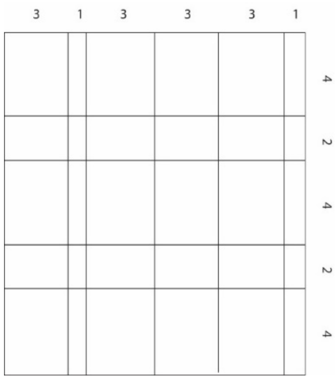


Figure 6.18 Le Corbusier's 1:2:3:4 proportion

Source: Drawn from Hildner, 1999, p.145

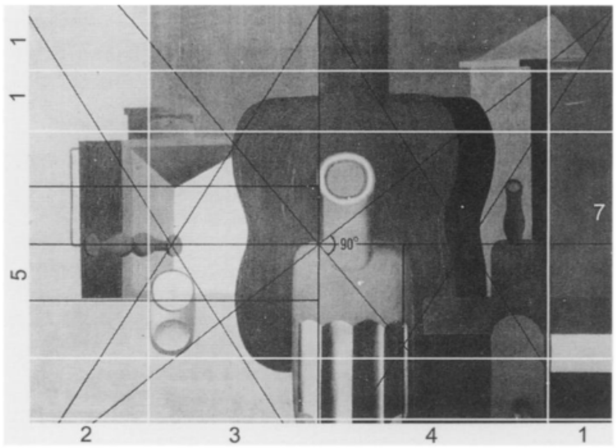


Figure 6.19 The 1:2:3:4 proportion in painting (artist: Le Corbusier, painted 1920)

Source: Hildner, 1999, p.145

Another grid division is to divide a rectangular frame into two and three in both sides (Bouleau, 1980, p.125). In other words, this grid is designed by identifying the 1/2, 1/3, and 1/5 (bold lines) division points as illustrated in Figure 6.20.

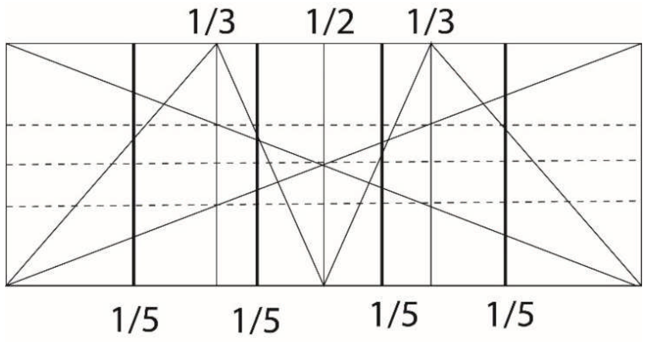


Figure 6. 2 0 The 1/2, 1/3, and 1/5 division grids

Source: Drawn from Bouleau, 1980, p.125

Modular grids may be the most widely applied grids, which have been used in painting (Frank, 2008, p.81); architecture (Dwyer, 2001, p.331); computer art (Clauser, 1988, p.118) and carpet design (Guilmain, 1985, p.537). Although the square is the most common shape for grid units, the superimposed grid (Figure 6.21) and the diagonal grid (Figure 6.22) are found in design practice too.

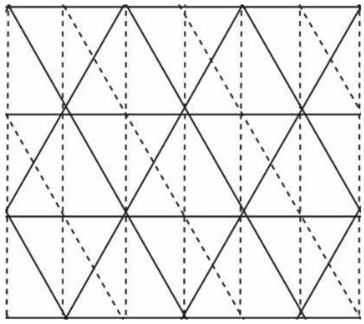


Figure 6. 2 1 The superimposed grid

Source: Drawn from Frank, 2008, p.81

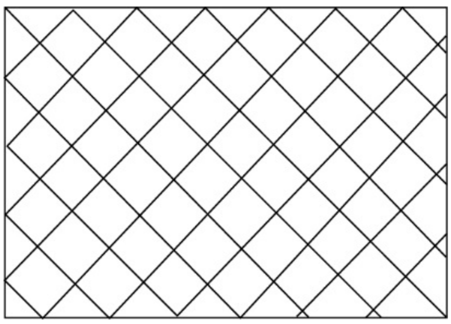


Figure 6. 2 2 The diagonal grid

Source: Drawn from Guilmain, 1985, p.539

In carpet design practice, due to the nature of the technique of weaving, the thickness of the band may be sub-divided to suit certain pattern designs. Therefore, the original guide grids need to be sub-divided accordingly. Figure 6.23 shows an example, which illustrates the sub-division of grid units to suit pattern design (Guilmain, 1987, p.36).

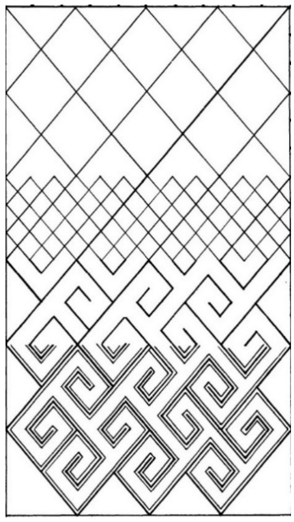


Figure 6. 2 3 The sub-division of grid units

Source: Drawn from Guilmain, 1987, p.36

Grid frameworks can be distorted to become guide lines for visual arts creation (Peden, 2004, p.377). Figure 6.24 shows the wave pattern effect made of square modular grids (Peden, 2004, p.377).

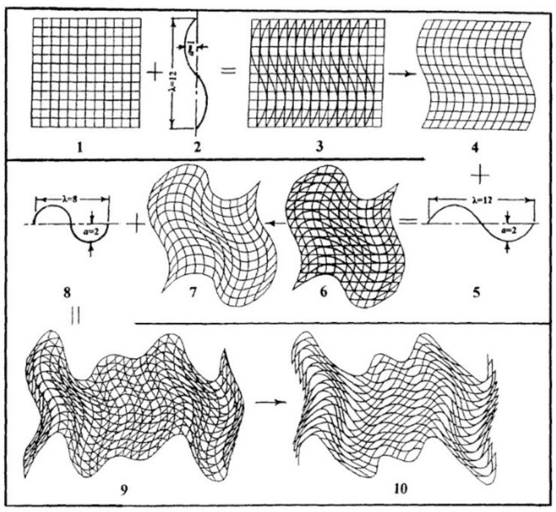


Figure 6. 2 4 Wave pattern effect made of square modular grid

Source: Peden, 2004, p.377

Furthermore, the modules in design practice do not have to be square. Ogden (1937, p.214) illustrates the modules in painting Rembrandt's 'Lesson in Anatomy' (1632) by using circles instead of squares (Figure 6.25).

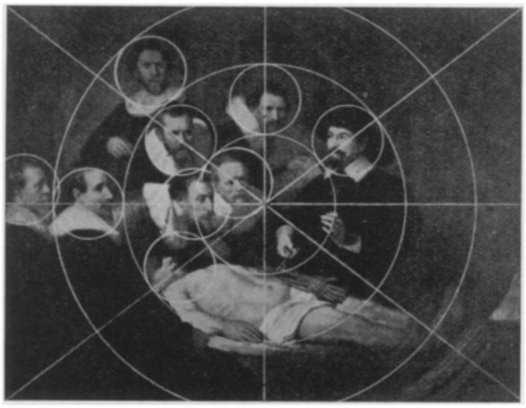


Figure 6. 2 5 Lesson in Anatomy (artist: Rembrandt, painted 1632)

Source: Ogden, 1937, p.214

The Brunes star (Figure 6.26) is a construction made of the half and full diagonals of a square (Hann, 2012, p.42) (See a more detailed explanation in chapter 2, section 2.5). When the middle points of the sides of the Brunes-star-type construction are linked and vertical and horizontal lines are drawn through the intersecting points (Figure 6.27), the space can be divided into regular sections (Bouleau, 1980, p.42). As shown in Figure 6.27, the intersecting points of the half diagonals divide each half side into three (Bouleau, 1980, p.4), therefore the whole figure can be divided into six. Figure 6.27 illustrates the division of 3,4,6, on the frame sides. Based on this grid, various diagonal type constructions can be developed. Figure 6.28 a-c shows three diagonal designs (Bouleau, 1980, p.43).

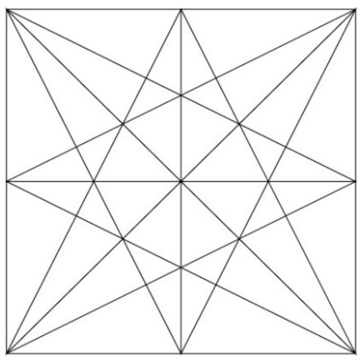


Figure 6. 2 6 The Brunes star

Source: Drawn from Figure 2.26

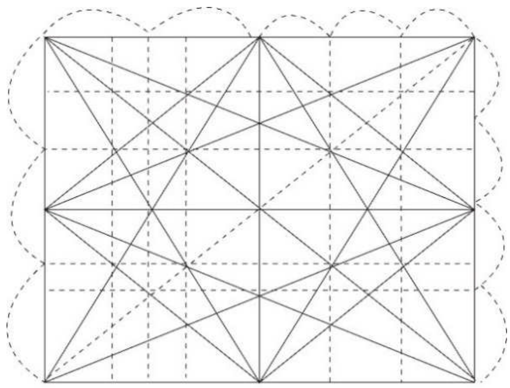


Figure 6.２７ Brunes-star-type grids construction

Source: Drawn from Bouleau, 1980, p.42

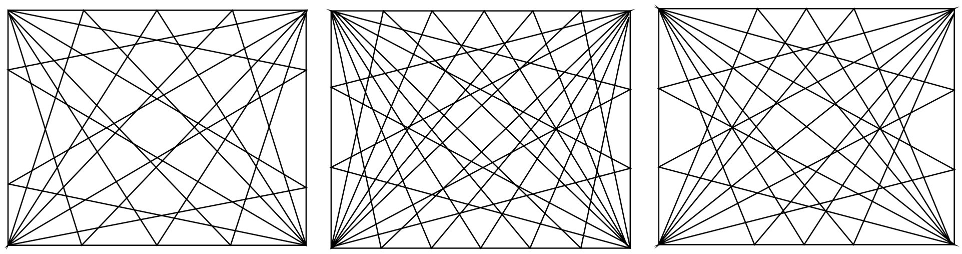


Figure 6.２８ a-c three diagonal designs

Source: Drawn from Bouleau, 1980, p.43

More complicated construction grids are also found in underlying design works (Figure 6.29). This type of compositional grid is named 'tartan compositional grids' by Behrens (1998, p.302), which is widely used in page layout design (Behrens 1998, p.302).

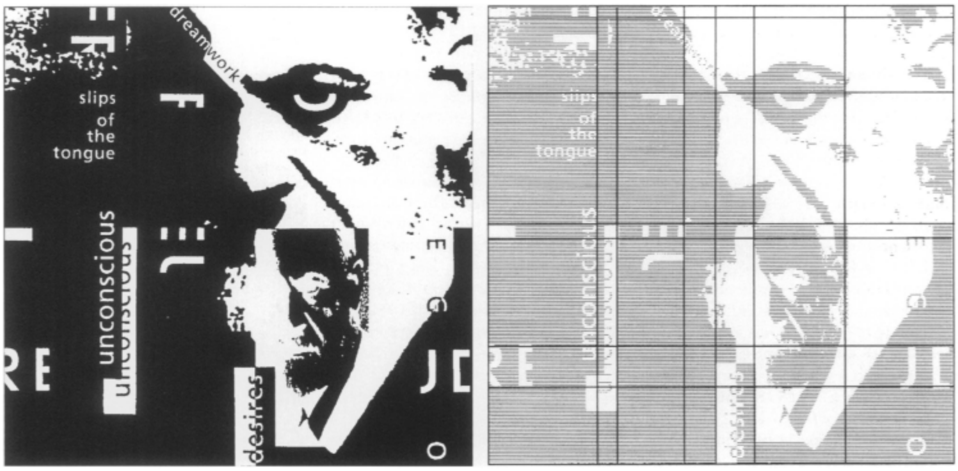


Figure 6. 2 9 Tartan compositional grids in page layout design (artist: James, created: 1996)

Source: Behrens 1998, p.301

A regular pentagon inside a circle (more detailed explanation given in chapter 2, Section 2.5) has been identified as a common framework, which sometimes is seen in composition (Bouleau, 1980, p.64; Elam, 2001, p.45). Figure 6.30 shows a framework made of a circle, a regular pentagon and a golden-section triangle.

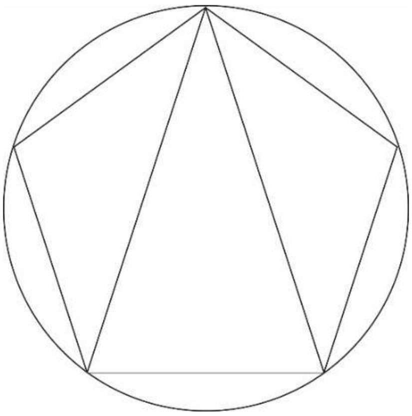


Figure 6. 3 0 A framework made of a circle, a regular pentagon and a golden-section triangle

Source: Drawn from Bouleau, 1980, p.64

Similarly, two rotated overlapping pentagons can be placed in a circle as well (Figure 6.31). By connecting some of the pentagon's diagonal lines in Figure 6.31, a square can be created in the centre of the framework, and a Brunes-star-type construction can be drawn inside the square. This is shown in Figure 6.32.

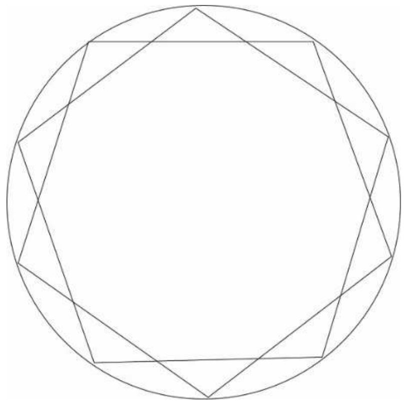


Figure 6. 3 1 Two rotated overlapping pentagons placed in a circle

Source: Drawn from Bouleau, 1980, p.65

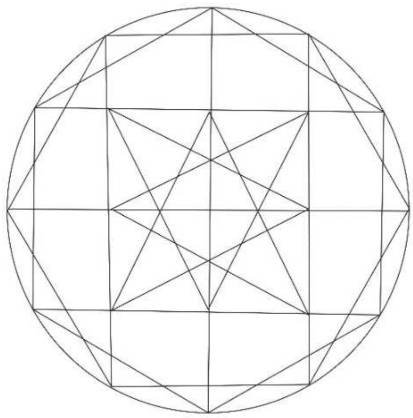


Figure 6. 3 2 Pentagons, a square and a Brunes-star-type framework

Source: Drawn from Bouleau, 1980, p.95

In summary, this section reviews various geometric shapes, construction divisions as well as the proportions they generated. Although construction guidelines are hardly seen in most of the completed art / design works, it seems that almost all designs are somehow governed by geometric rules. Furthermore, in most art / design works, more than one type of geometrical construction is often applied to achieve the hierarchy of order.

6.4 Analysis

Geometric methods are evident often in posters' layout composition although the final appearance may hide this. Some simple forms, division methods and proportion methods are commonly seen in poster design. This section analyses the geometric rules in two posters: 'Heraus - Forderung Tier. Städtische Galerie, Karlsruhe' and 'Morisawa 10 Poster' to illustrate the possible geometric constructions in poster design.

6.4.1 The development of the analysis methods for poster design

The above literature review identifies various frameworks based on the combination and division of squares, including square overlapping square, square divided by square, squares made up by octagons; the Brunes star. The rectangular framework includes the golden-section division; proportional rectangles; the 4/6/9, 9/12/16 and 3/6/9 divisions; the 1/2, 1/3, and 1/5 division. Grid systems were developed based on those divisions also, as well as various types of modular grids (eg. the square grid; the superimposed grid and the diagonal grid). The applications of those frameworks and the proportions they generated has been found in paintings, architecture and graphic designs, which may be of benefit to poster analysis.

Therefore, the hypothesis of the following research is that although the appearance and the themes of the selected posters are all different, some basic geometric constructions and proportions may be found underlying most compositions, which can provide harmony between the parts and whole of a poster, and which may in turn attract the most attention from viewers.

6.4.2 The application of the proposed analytical methods in two posters

As shown in Figure 6.33 'Heraus - Forderung Tier. Städtische Galerie, Karlsruhe' is a poster designed by Joseph Beuys. The piece is held in a collection at the Tate / National Galleries of Scotland in the year 2000 (www.tate.org.uk) [Accessed 23 October 2016]. The dimension of this poster is 837 x 591 mm (www.tate.org.uk) [Accessed 23 October 2016].

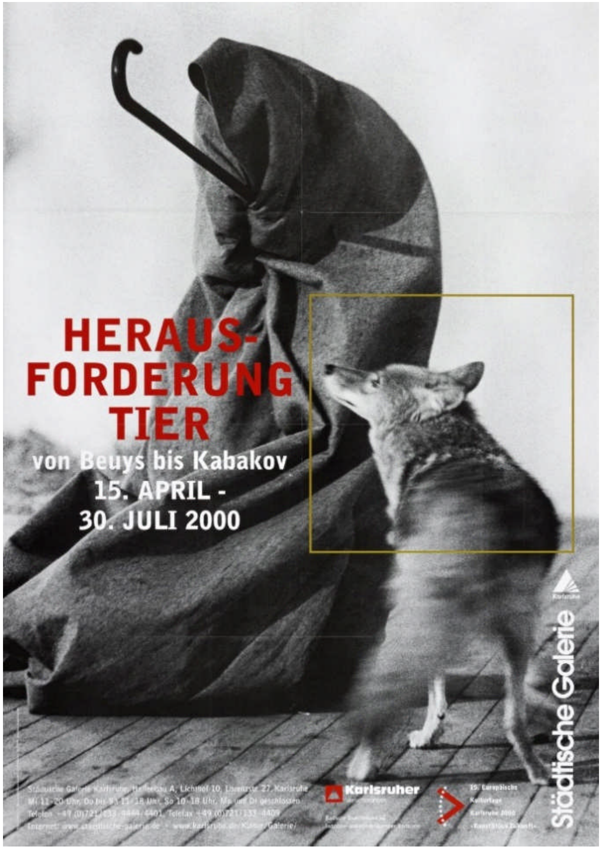


Figure 6. 3 3 Heraus-Forderung Tier. Städtische Galerie, Karlsruhe

Source: www.tate.org.uk [Accessed 23 October 2016]

It is obvious that there is a square frame in the right side of the poster. The square is likely to be part of the construction guideline (units), and has been left in the final design deliberately. Therefore, a square of the same size is constructed in the left side of the original square, which happened to embrace the text next to the dog and the text is in the middle of the square frame (Figure 6.34). Six squares of the same size with the same distances between them are constructed, then the main area of the poster can be covered. Especially the two bottom square units define the left, right as well as the bottom boundary of the text area, which is in the bottom of the poster layout (Figure 6.34).

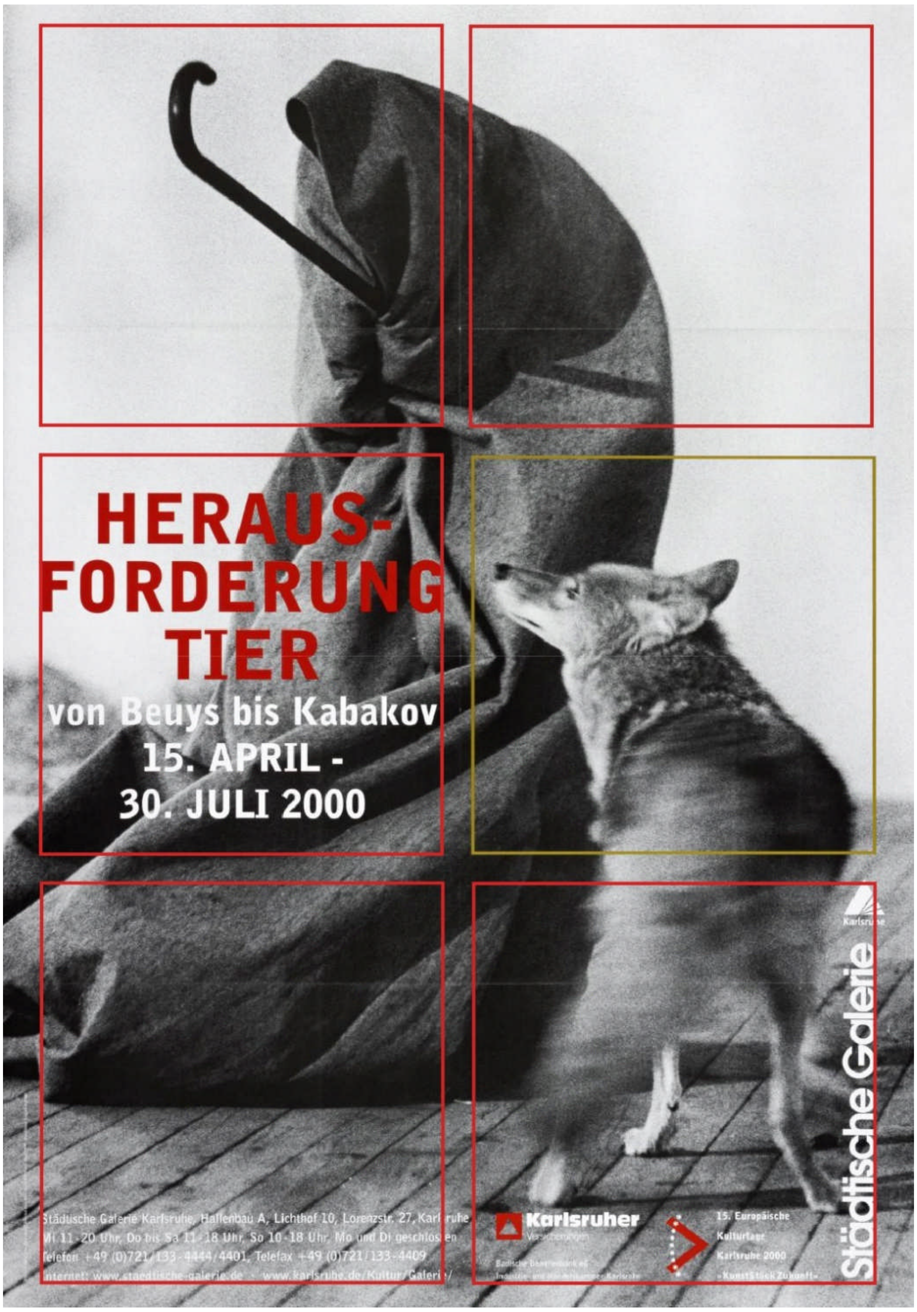


Figure 6. 3 4 Square grids in the poster construction

In order to explain the geometric relationship between the square units and the arrangements of the design elements, the square units are marked 1-6 as is shown in Figure 6.35.

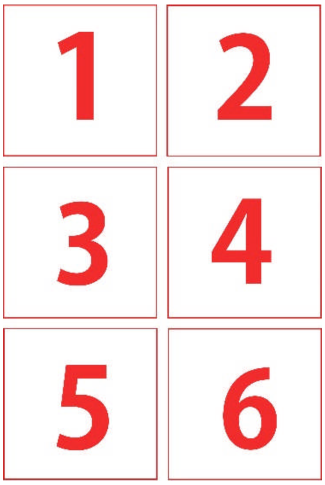


Figure 6. 3 5 The labels of the units in the poster construction

A golden-section grid is a grid system constructed based on linking the φ points of the opposite sides of a square / rectangular frame (see more detailed explanation in section 6.3, illustrated in Figure 6.10 and Figure 6.11). The guide lines in unit 1 and unit 3 of Figure 6.36 are formed in this way. In unit 1, the edge of the human figure is placed against one of the division lines. Furthermore, the curve of the stick is marked by one of the intersecting points. In unit 3, the white text is separated from the red text by one such division lines.

The method 'division into halves' plays an important role in grid 2 and grid 4 (Figure 6.36). In grid 2, the space is first divided into halves, and the back of the human figure is marked by the vertical division line. Then the top left section is divided again to make the horizontal division line close to the edge of the human figure. Furthermore, the third division line also marks the edge of the human figure. Similarly, in grid 4, the eye of the dog, as well as the top of its head are marked by the same type of division lines.

A combination of 'division into halves' and 'division into thirds' is found in grid 5 and grid 6. After placing a 3x3 grid in unit 5, and then dividing the bottom three grids into halves (illustrated in dash lines in Figure 6.36), the top edge of the text is identified. The same division can be found in unit 6. Furthermore, the placement of the logo in the bottom right corner is also governed by the sub-division lines of halves.

Figure 6. 3 6 The geometric divisions in each square unit

Figure 6.37 shows the ‘Morisawa 10 Poster’. It was designed by John Maeda and has been collected by the Museum of Modern art, New York in 1996 (www.moma.org) [Accessed 23 October 2016]. The dimension of this poster is 73 x 103 cm (www.moma.org) [Accessed 23 October 2016].

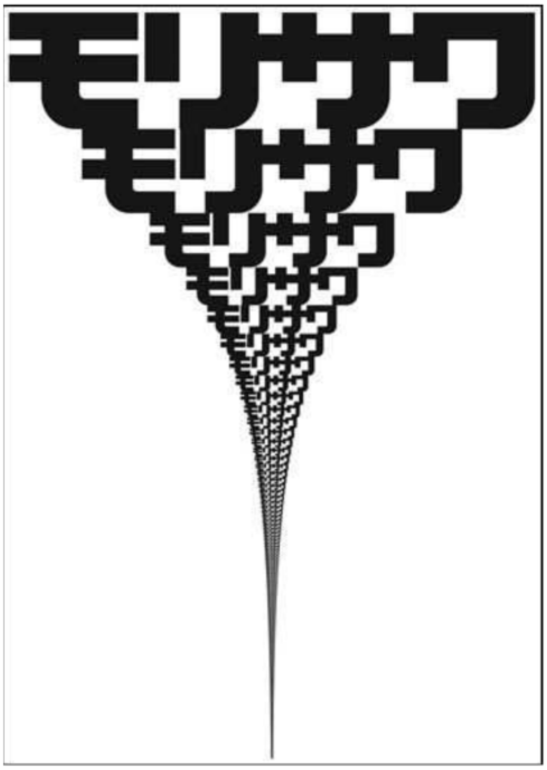


Figure 6. 3 7 Morisawa10 Poster

Source: www.moma.org [Accessed 23 October 2016]

Although this poster is constructed by repeating Japanese characters, the black area is highly symmetrical, in other words, reflection symmetry exists in the design (Figure 6.38).

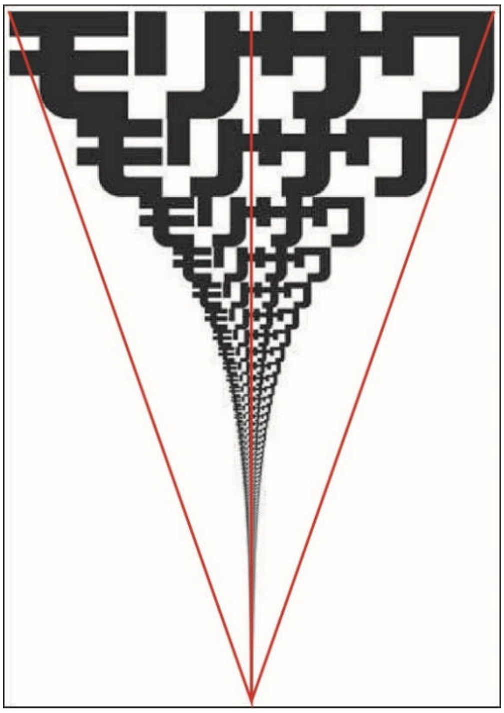


Figure 6.３８ Reflection symmetry in the poster

Furthermore, a root-two proportion exists in the height of the text. Figure 6.39 shows this by adding a root-two progression square framework on the top of the poster. It is clear that the top edges of the progression squares mark the bottom of each line of the text, thus there is a clear increase of root-two between the adjacent text heights. When the root-two progression squares were constructed based on the length instead of the height of the text, a progression very close to root-two proportion was found as well (Figure 6.40).

It is likely that the root-two proportion progression and the reflection symmetry are the main aspects of this poster design and construction.

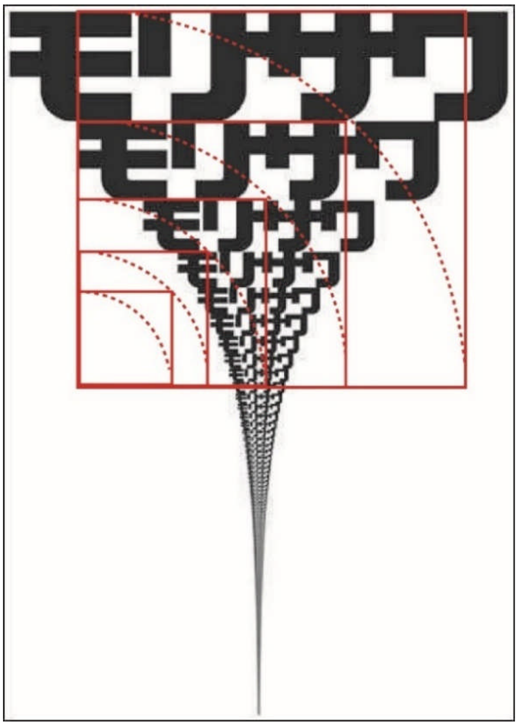


Figure 6. 3 9 A root-two progression square framework in the poster

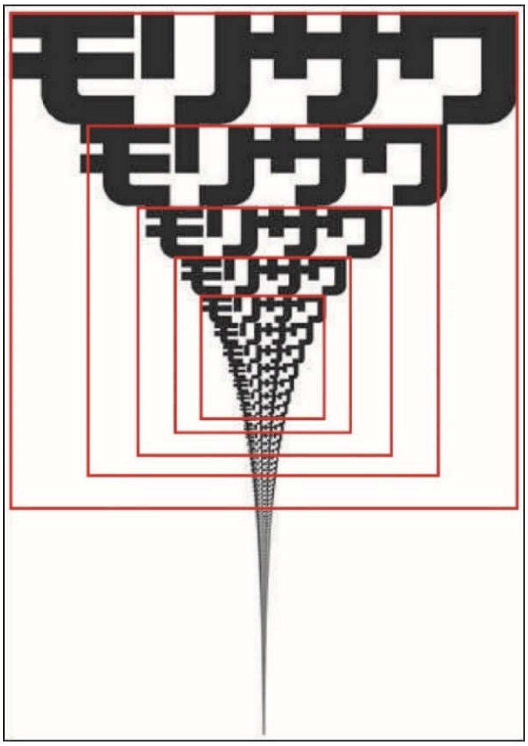


Figure 6. 4 0 A root-two progression square framework in the poster

6.5 Results

After analysing 46 posters, the findings can be summarized as follows: geometry frameworks which guide the composition of the posters' layouts are found in all the selected posters. The majority of posters are governed by more than one type of framework (30 out of 46 posters). Furthermore, modular grids are found most commonly used in poster design (21 out of 46 posters), among which, 12 posters have square modules; grids constructed based on Brunes-star proportion were found in 11 posters; grids designed based on the golden-section division were found in 6 posters; the Brunes-star and the overlapping square construction exist in 5 posters. This is summarized in Table 6.1 (Appendix C).

6.6 Summary

This chapter considered the possible geometrical methods which may be applied in poster design, including various square, rectangular frameworks and grid systems. After analysing the selected posters, it was found that almost all the selected posters contain geometrical guidelines, in which modular grids are found in the majority of cases. The combined use of the golden-section rectangle; $\sqrt{2}$ rectangles; progression and square rotation was also commonly seen in the design of the selected posters.

Chapter 7 : Case study group number 5 - Web-pages

7.1 Introduction

Grids have long been used as an effective method to solve design problems. Grids can provide order, balance and proportion to a visual layout. Grid systems can be seen in different design disciplines, such as newspaper layouts, magazine layouts, book pages, interior design and architectural structure.

This case study considers space division methods using grids, detectable by analyzing the home page layouts of the top 100 companies in the London stock exchange (listed as the FTSE 100). Section 7.2 reviews the background information and considers sampling methods, section 7.3 reviews common methods of grids division and section 7.4 develops the analysis methods for the FTSE 100 home page layout study.

7.2 Data

This section provides basic information about web-sites and web-pages, including the definition, the functions, and how to perceive a web-site or web-page from the web user and web designer's perspectives.

7.2.1 Background information

The web, as a 'highly public, visual and interactive medium' (Baron, 2002, p.36) has dramatically changed our lives. Web-sites refer to pages or files linked together via the internet and authorized by organizations, companies and individuals (Landa, 2014, p.331). These websites provide all kinds of information such as news, business and knowledge on specific areas.

Web-pages are usually arranged in a hierarchy structure. Hierarchy here refers to the arrangements of information from general to specific (Baron, 2002, p.86). Hierarchy structure is a natural structure (e.g. tree structure), and it is familiar to users from different backgrounds (Ahmad, Basir, Hassanein, 2003, p.35). The individual web-pages are linked to each other by hyper-text, thus allowing web users to go through a web-site in multiple paths base on their own interest (Nakayama, Kato, Yamane, 2000, p.811). The web-page hierarchy structure as well as the hyper-text links in the web-pages are illustrated in Figure 7.1 a and Figure 7.1 b.

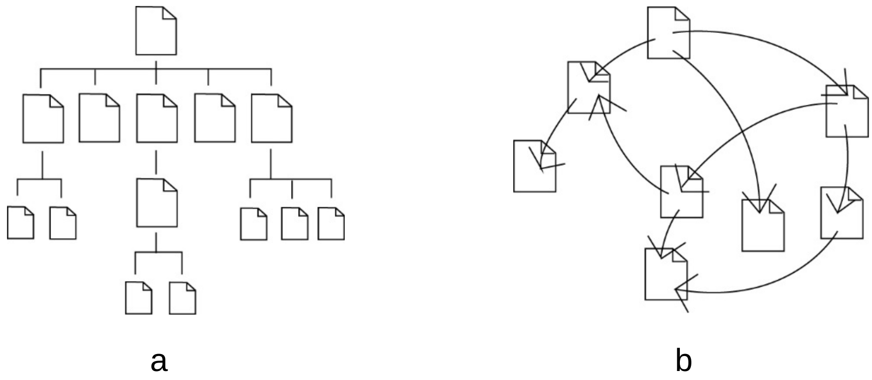


Figure 7. 1 Web-page hierarchy structure (a) and hyper-text linking the web-pages (b)

Source: Drawn from Baron, 2002, p.86

Commercial web-sites are the most complicated web-sites compared with other types (Baron, 2002, p.4), as they are market driven (Ahmad, Basir, Hassanein, 2003, p.33) and aim to sell products or services (Baron, 2002, p.8) by providing business information to customers who have different backgrounds, goals and interests (Nakayama, Kato, Yamane, 2000, p.811). The success of commercial web-sites depends largely on the satisfaction of the web users (Baron, 2002, p.9), so that the site has to guide customers through different levels of information and to make the business transaction occur (Baron, 2002, p.9). Furthermore, commercial web-sites are designed to attract customers and to turn non-customers to customers (Schaik, Ling, 2000, p.2). The function of commercial web-sites is to inform, to communicate and to make the business transaction occur (Baron, 2002, p.9). The main components of a business web-site includes the home page (Baron, 2002, p.48); the category page (Baron, 2002, p.153); the product page (Baron, 2002, p.156) and the checkout page (Baron, 2002, p.165).

The home page of a web-site functions as an entrance or a gateway (Singh and Dalal, 1999, p.96; Landa, 2014, p.334). The home page displays the most important information of the entire site and should get the visitors to accomplish their tasks immediately (Baron, 2002, p.148). Furthermore, most website home pages are designed to serve a large number of audiences (Singh and Dalal, 1999, p.92), to set up an impression of the entire site (Landa, 2014, p.334), and the home page template may be found usable for other pages as well (Landa, 2014, p.334).

There is no standard for what should be included and how it should look in web home page design (Baron, 2002, p.148). Most website home pages include content (the body information of a site); a navigation system (a schema of breadth and depth of search paths); web header and page footer (Landa, 2014, p.334, King, 1998, p.458; Lynch and Horton, 2008, p.89). This case is illustrated in Figure 7.2.

Figure 7. 2 Web-page structure

Source: Drawn from Lynch and Horton, 2008, p.89

The page layout is defined as the visual presentation (Becker, Mottay, 2001, p.55) or page segmentation (Pnueli, Bergman, Schein, Barkol, 2009, p.3) of a web-page. Although there is no standard for web-page layout design (Nakayama, Kato, Yamane, 2000, p.816), certain information is often arranged in a certain position (He, Cai, Wen, Ma, Zhang, 2007, p.6). For example, the most important information is usually located in the centre of a page, the navigation bar may appear at the top, left or right side of the page and the copyright information always appears on the footer (Song, Liu, Wen, Ma, 2004, p.17).

Four types of common web layout were provided by Baron, (2002, p.133) and these are illustrated in Figure 7.3 a-d.

Figure 7. 3 Common types of web layout

Source: Drawn from Baron, 2002, p.133

The length of a web-page can vary from one screen to ten screens (King, 1998, p.462). Figure 7.4 shows a web-page whose length is four screens. In this case, the most important information is usually displayed on the first screen (Song, Liu, Wen, Ma, 2004, p.17).

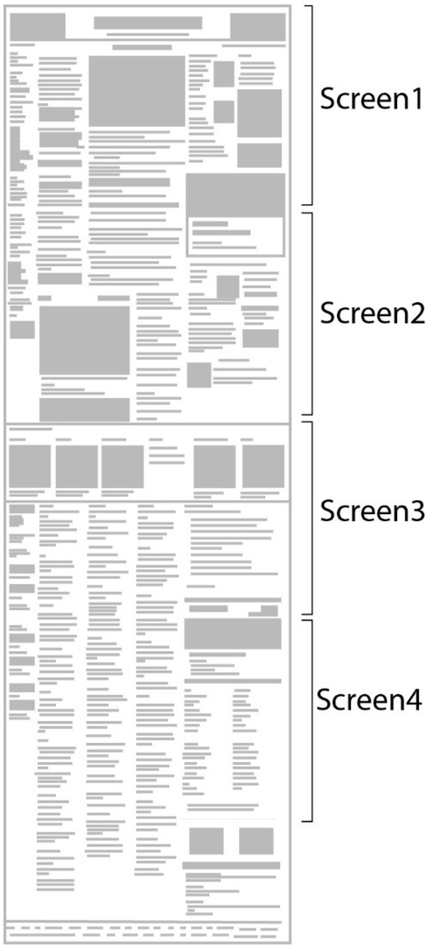


Figure 7. 4 The relationship between the web-page and the computer screens

Source: Drawn from Lynch and Horton, 2008, p.104

A web-site visitor is 'a user by making choice: visit a site, move through a site; enter information, reviews or comments; and generally interact with content at various points.'(Landa, 2014, p.327). Usually, viewers get a two-dimensional web-page (Song, Liu, Wen, Ma, 2002, p.3). The top left corner of the page is always shown (Dabner, 2003, p.118), a scroll bar on the right or bottom of the screen maybe shown when the page size exceeds the monitor size (Kalbach, Bosenick, 2003; Dabner, 2003, p.118). In this case, the viewers have to scroll to view the whole page (Dabner, 2003, p.118). No matter how big the size is, viewers can only view one page at a time (Lynch and Horton, 2008, p.104).

Web users usually expect an interactive experience (Landa, 2014, p.327), and expect certain objects to be located in certain areas on the web-page (Kovaevi, Diligenti, Gori, Maggini, Milutinovic, 2002, p.251). Users have different viewing and searching behaviours when they access a site (Dabner, 2003, p.118).

The viewing behaviour of a web user follows his or her reading behaviour when viewing a web-page, usually from top left to bottom right (Schaik, Ling, 2000, p.2). The viewers' attention may be first caught by large tags on the page such as news headings and advertisements (Song, Liu, Wen, Ma, 2004, p.14). No difference was found between new web users and old web users in their viewing behaviour (Schaik, Ling, 2000, p.2).

In terms of searching behaviours, the views tend to be attracted by the most informative segments of a web-page (Pan, Hembrooke, Gay, Granka, Feusner, Newman, 2004, 2004, p.147), or by the titles or headings similar to the searching subject (Blackmon, Polson, Kitajima, Lewis, 2002, p.464).

Web design is a complicated process which includes 'strategy, collaboration, creativity, planning, design, development and implementation' (Landa, 2014, p.331). A good web-site has design consistency and feels like it was designed by a single designer (Baron, 2002, p.7). However, most web-sites are the outcome of the corporation of several teams (Baron, 2002, p.7).

Most websites are designed to help their visitors achieve certain goals (Nakayama, Kato, Yamane, 2000, p.811). Designers would first construct a site with an easy or effective navigation system (Becker, Mottay, 2001, p.55; Nakayama, Kato, Yamane, 2000, p.1). Then the page layout will be designed to accommodate the monitor size as web-pages may appear differently on different computer screens (Krause, 2001, p.102), due to the different resolutions (Sklar, 2009, p.18). After that, the web-site will be planned from the overall site architecture to individual page details (Lin, Newman, Hong, Landay, 2000, p.511).

In the refining process, technique and aesthetic knowledge are involved. The technique aspect includes writing code for tables, columns and images in the web-page (Sklar, 2009, p.133); the use of HTML (Hypertext Makeup Language), the responding time, mapping and metaphors, the use of multimedia and audio and visual content (Palmer, 2002, p.152).

Web-aesthetics refers to the arrangements of elements such as background colour, typography and font size (Deng and Poole, 2012, p.421 Song and Liu, wen, Ma, 2004, p.15;), according to geometric principles such as balance, symmetry, proportion and grids structure (Deng and Poole, 2012, p.422), to provide order out of complexity.

Therefore, this section provides background information of web-sites and the web-pages, as well as the perspectives of web-sites / pages from web designers and web users.

7.2.2 The selection of cases to be analysed

Commercial websites are websites that want to sell (Baron, 2002, p.2). They are designed to satisfy their users across different cultural backgrounds, different education levels and different occupations (Ahmad, Basir, Hassanein, 2003, p.35). The home page of a commercial site displays the most important information of the products or services that a company provides, and it is supposed to attract and guide the visitors to have further action (Baron, 2002, p.148). Due to the similar goals, the web-site homepage of commercial sites may have similar components and similar layouts (Baron, 2002, p.119).

This research aims to find common division methods, especially grids division of the web homepage by analyzing a selection of FTSE 100 companies (the 100 largest companies listed in the London stock exchange) homepage layouts.

The names of the FTSE 100 companies are obtained from google search (http://shareprices.com/ftse100) [Accessed 14 October 2014]. They are: 3i group; Aberdeen Asset Management; Admiral Group; Aggreko; Anglo American; Antofagasta ; ARM Holdings; Ashtead Group; Associated British Foods; AstraZeneca; Aviva; Babcock International Group; BAE Systems; Barclays; BG Group; BHP Billiton; BP; British American Tobacco; British Land Co; British Sky Broadcasting Group; BT Group; Bunzl; Burberry Group; Capita; Carnival;Centrica; Coca-Cola HBC AG (CDI); Compass Group; CRH; Direct Line Insurance Group; Diageo; Dixons Carphone; EasyJet; Experian; Fresnillo; Friends Life Group; G4s; GKN; GlaxoSmithKline; Glencore; Hammerson; Hargreaves Lansdown; HSBC Holdings; IMI; Imperial Tobacco Group; InterContinental Hotels Group; International Consolidated Airlines Group; Intertek Group; Intu Properties; ITV; Johnson Matthey; Kingfisher;

Land Securities Group; Legal & General Group; Lloyds Banking Group; London Stock Exchange Group; Marks & Spencer Group; Meggitt; Mondi; Morrison (Wm) Supermarkets; National Grid; Next; Old Mutual; Pearson; Persimmon; Petrofac Ltd.; Prudential; Randgold Resources Ltd.; Reckitt Benckiser; Reed Elsevier; Rio Tinto; Rolls-Royce Holdings; Royal Bank of Scotland Group; Royal Dutch Shell; Royal Mail; RSA Insurance Group; SABMiller; Sage Group; Sainsbury (J); Schroders; Severn Trent: http; Shire Plc; Smith & Nephew; Smiths Group; Sports Direct International; SSE; St James's Place; Standard Chartered; Standard Life; Tesco; Travis Perkins; TUI Travel; Tullow Oil; Unilever; United Utilities Group; Vodafone Group; Weir Group; Whitbread; Wolseley; WPP. Then each site's home page is accessed and downloaded. In order to view the whole page, sizes of the pages are compressed in certain percentage.

In the compression process, the homepage of Barclays occupies eight screens in length, it cannot be compressed into the size of one screen and keep the same details. The layout of the homepage of Centrica, ITV; London Stock Exchange Group; Persimmon; and Shire Plc changed dramatically when compressed. The home pages of Glencore and SAB Miller only contains baseline grids. Thus, the sample homepages mentioned above were excluded.

The remaining web home pages were compressed in different percentages as the lengths and widths varied among the remaining 92 sample web-sites. In particular, 16 samples were compressed into 90% of the original page size; 37 samples were compressed into 75%; 22 samples were compressed into 67% of their original size; 9 of them were composed into half of the original size, and 8 samples did not need to be compressed at all.

There should be no distortions as the proportion between the length and the width of each web-page remains the same.

All of the web-pages were selected and compressed into a 17 inch Sony monitor with a resolution of 1280x1024 pixels. The layout of the webpages may appear differently when displayed on other devices, such as iPads and smartphones, so the web-page layouts on iPads and smart phones (or smart watches) are not included in this research.

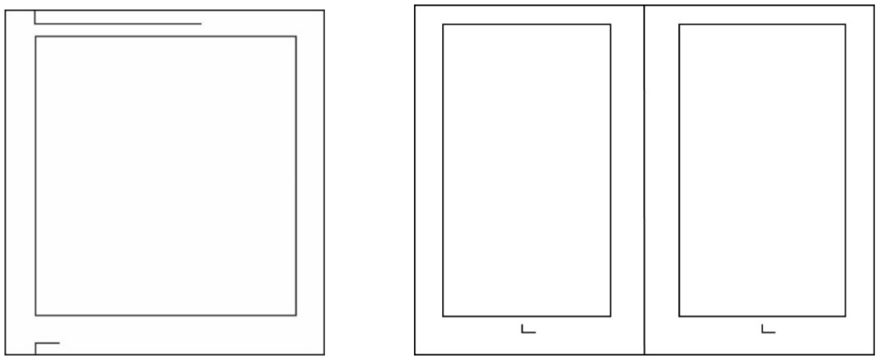
7.3 Methods

This section reviews the common types of grid in two-dimensional design as well as how grids or grid combinations divide a space, in order to ascertain which methods may be best suited to the study of web home pages' compositional division.

7.3.1 Column grids

Column grids are widely applied to newspaper, magazine and book page design. 'Columns are vertical alignment or arrangements used to accommodate text and images' (Landa, 2014, p.179). The space between columns is known as column intervals (Landa, 2014, p.179). The number of columns chosen in design practice largely depends on the presentation of the content. Thus, columns may have the same width or different widths in one page (Landa, 2014, p.179). In other words, columns can work separately or be combined to fulfill the requirements of different contents. The following section reviews common types of column grids as well as column combinations.

A single column grid, also known as a manuscript grid, is the simplest page structure (Figure 7.5 a) (Samara, 2003, p.26; Landa, 2014, p.175). It refers to a block of text defined by margins (Samara, 2003, p.26) and the margins function as a proportional frame (Landa, 2014, p.175). This type of grid usually creates a mirror image in a book spread (Figure 7.5 b) (Hurlburt, 1978, p. 69).

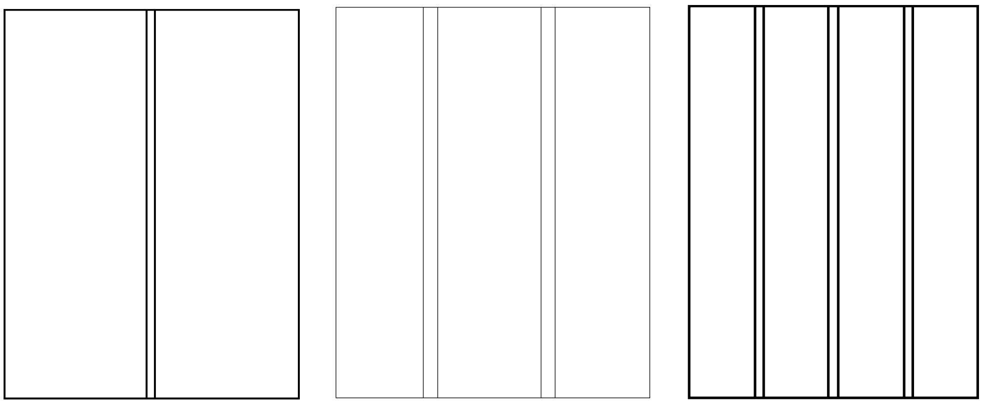


a b

Figure 7. 5 Single-column grid

Source: Drawn from Samara, 2003, p.26

Although single-column grids are often seen in book-page spreads, multiple-column grids have wider applications. 2,3 and 4-column grids are common in magazines (Hurlburt, 1978, p. 69), newspapers (Hurlburt, 1978, p. 69) and web-page design (Landa, 2014, p.177).These column grids are illustrated in Figure 7.6.



a b c

Figure 7. 6 The 2, 3 and 4-column grids

Source: Drawn from Samara, 2003, p.27; Landa, 2014, p.177

Mixed grids can achieve flexibility without complexity (Jute, 1996, p.71). In this case, 12-column grid and 14-column grid provide great flexibility as their narrow column units can be grouped in various ways (Hurlburt, 1978, p. 55; Jute, 1996, p.71). The 12-column grid (Figure 7.7), have a flexibility to create 6-column, 4-column, 3-column and 2-column page layouts by combining the columns (Hurlburt, 1978, p. 55), while 14-column grid (Figure 7.8 a) can be divided in width from two units to eight units (Jute, 1996, p.71). This is illustrated in Figure 7.8 b.

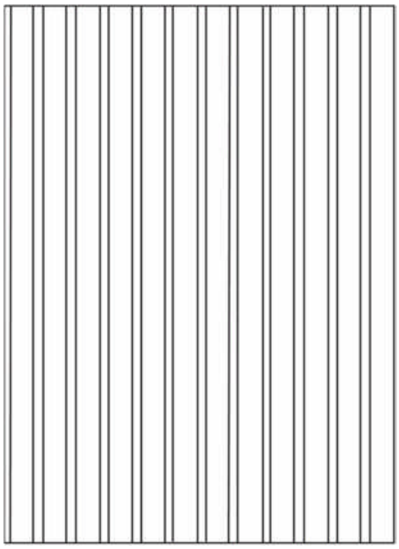
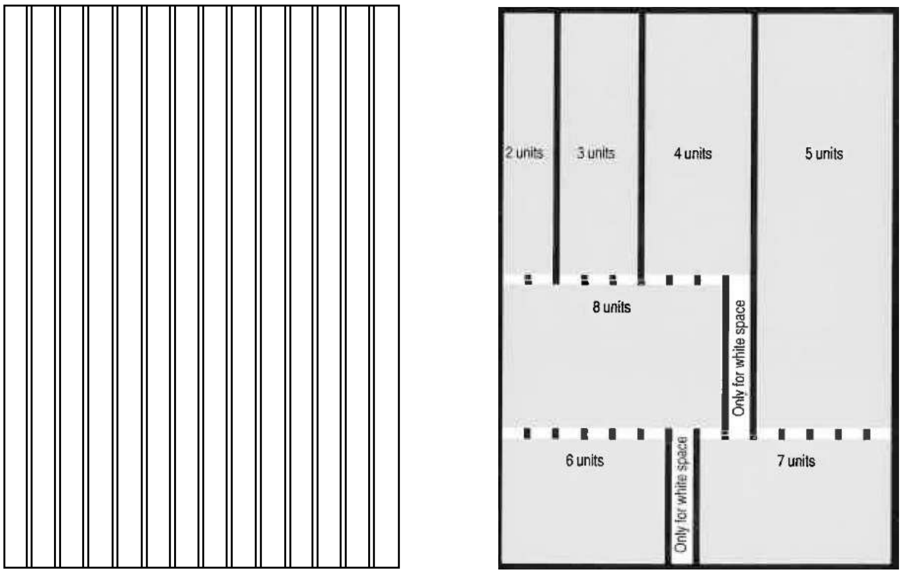


Figure 7. 7 The 12-column grid

Source: Drawn from Hurlburt, 1978, p.55



a b

Figure 7. 8 A 14-column grid which enables 2, 3, 4, 5, 6, 7 and 8 columns layouts

Source: Drawn from Jute, 1996, p.71

The 960-grid system is a column grid system designed for a web-site whose width is 960 pixels (Landa, 2014, p.179; http://960.gs) [Accessed 30 October 2014]. This grid system often produces a 12-column grid, a 16-column grid or a 24-column grid in web-page design (http://960.gs) [Accessed 30 October 2014]. When a 12-column grid is generated, based on the 960 grid system, each column is 60 pixels wide. The column and the column intervals can be combined to create a column width of 60, 140, 220, 300, 380, 460, 540, 620, 700, 780, 860 and 940 pixels' (Landa, 2014, p.179; http://960.gs) [Accessed 30 October 2014]. This is illustrated in Figure 7.9.

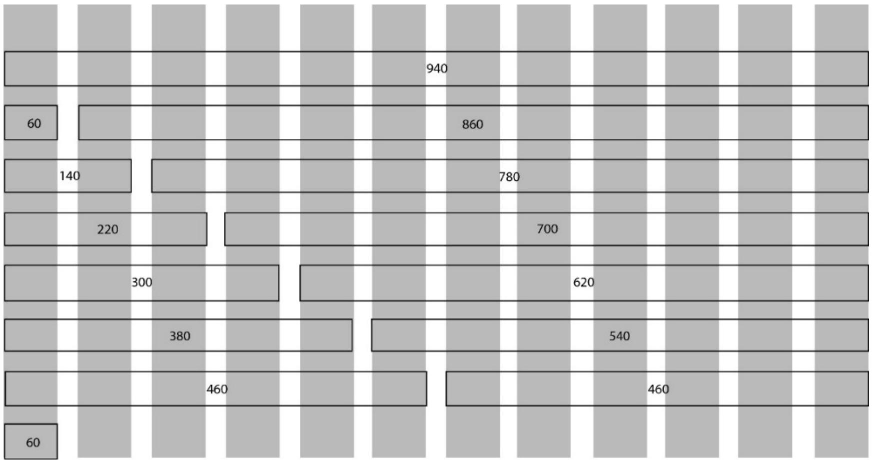


Figure 7. 9 A 12-column grid based on a 960-grid system

Source: Drawn from http://960.gs [Accessed 30 October 2014]

In terms of 16-column grids, the column width is 40 pixels, combined column widths are '40, 100, 160, 220, 280, 340, 400, 460, 520, 580, 640, 700, 760, 820, 880 and 960 pixels' (Landa, 2014, p.179; http://960.gs) [Accessed 30 October 2014]. Figure 7.10 illustrates this case.

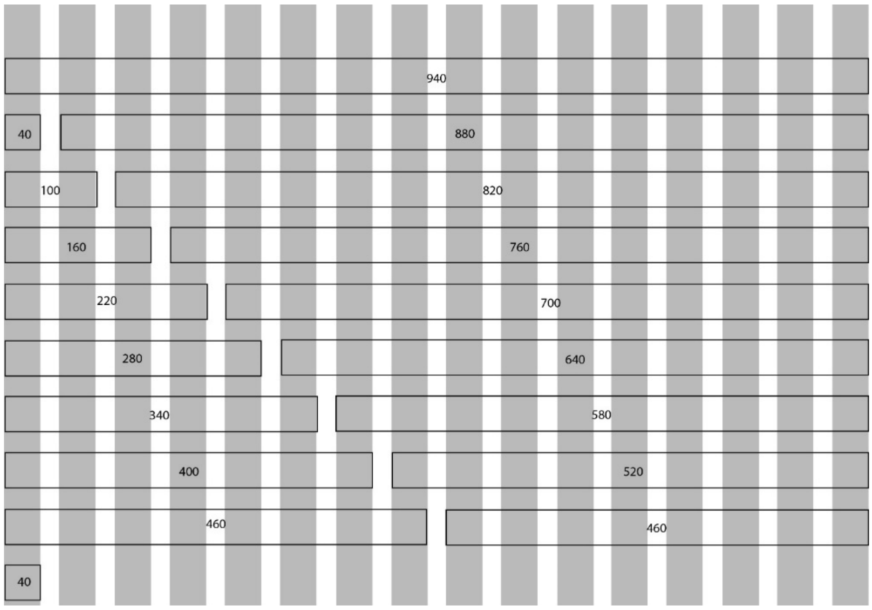


Figure 7.1 0 A 16-column grid based on a 960-grid system

Source: Drawn from http://960.gs [Accessed 30 October 2014]

When a 24-column grid is generated, the grid unit width is 30 pixels. The possible column widths are ’30, 70, 110, 150, 190, 230, 270, 310, 350, 390, 430, 470, 510, 550, 590, 630, 670, 710, 750, 790, 830, 870, 910, and 950 pixels’ (http://960.gs) [Accessed 30 October 2014]. This is shown in Figure 7.11.

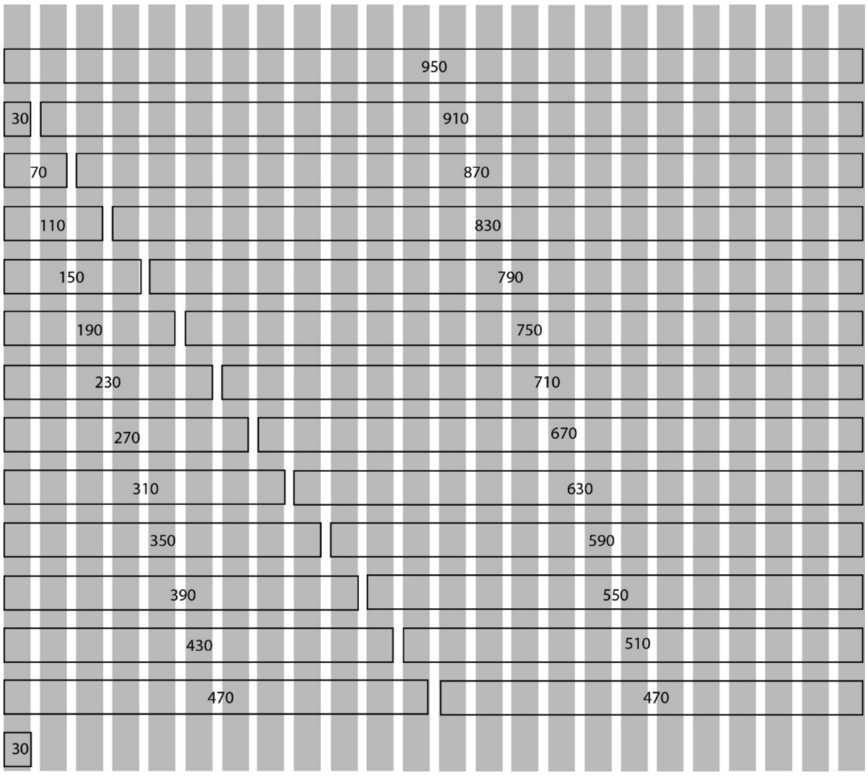


Figure 7. 1 1 A 24-column grid based on a 960-grid system

Source: Drawn from http://960.gs [Accessed 30 October 2014]

The 1200-grid system is another web-site grid based on the 960 grids and designed for wide-screen monitors to support at least 1280x 1024 pixel resolutions (1200px.com) [Accessed 30 October 2014].This grid system also provides flexible width divisions as 1200 can be divided by' 2, 3, 4, 5, 6, 8,10, 12, 15, 16, 20, 24, 30, 40, 48, 60, 80, 120, 150, 220, 240, and 400' (1200px.com) [Accessed 30 October 2014].

It is also possible that different types of column grids may appear in the same page with the same margins and printing areas (Jute, 1996, p.70). Figure 7.12 shows 2, 3 and 4-column grids arranged in the same page.

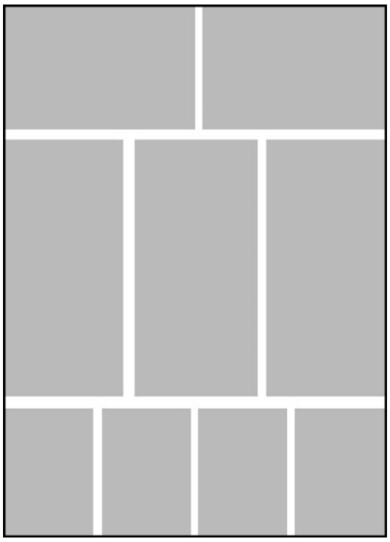


Figure 7. 1 2 A mixed-column grid in the same page

Source: Drawn from Jute, 1996, p.70

7.3.2 Modular grids

A modular-grid system 'has consistent horizontal divisions from top to bottom in addition to vertical divisions (column grids) from left to right' (Landa, 2014, p.341). The modular grid divides a page into small regular units (Landa, 2014, p.341). The space separating the grid units is called 'intermediate space' (Brockmann, 2008, p.11). Each unit is a small information space (Samara, 2003, p.28). Usually, the smallest illustration defines the smallest grid unit (Brockmann, 2008, p.11). Similar to a column grid, modules can either work individually or combine together to form a larger grid field to provide flexibility for page layouts (Samara, 2003, p.28). The control degree of grid systems, however, depends on the size of the modules. The smaller the grid unit, the more flexibility it can provide and the harder it is to control (Samara, 2003, p.28).

The following section reviews common types as well as common combinations of modular grids.

The 3x3 grid is a square space divided into thirds horizontally and vertically (Figure 7.13) (Elam 2004, p.13; Landa, 2014, p.73). The four intersecting points are known as 'optimal focus' points and the key visual elements are usually arranged on or near those points (Elam 2004, p.13).

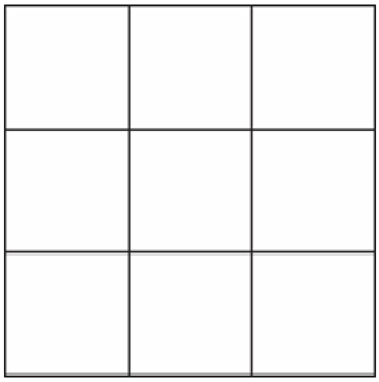
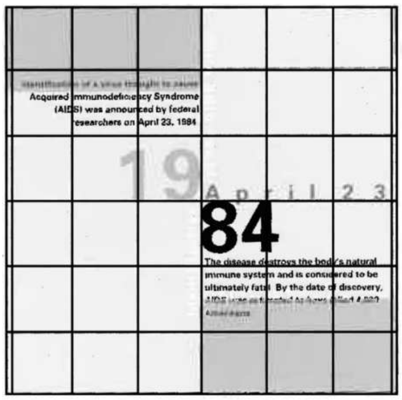


Figure 7. 1 3 The 3x3 grid

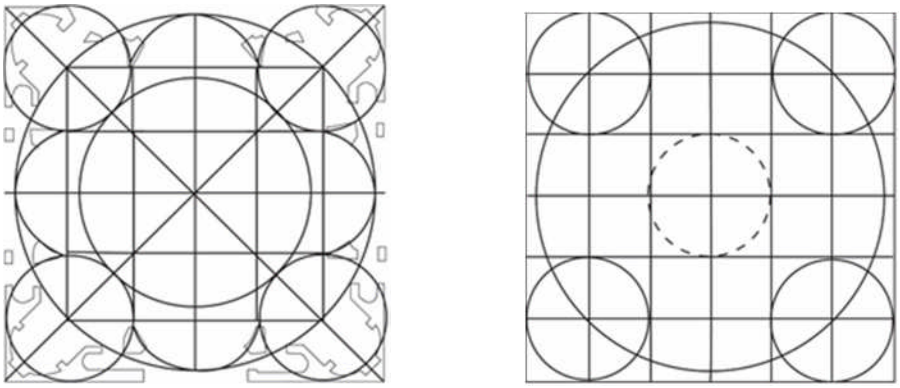
Source: Drawn from mathforum.org. [Accessed 12 October 2014]

Other modular divisions of square space based on the 3x3 grid are also commonly seen in design practice. For example the 6x6 grids (Figure 7.14 a) are found in poster design (Elam, 2004, p.104) and floor plans (Figure 7.14 b and c).



a

Source: Drawn from Figure 2.45



b c

Figure 7. 1 4 The 6x6 grid used in graphic design and floor plans

Source: Drawn from Figure 2.46

The 9x9 grid is the standard puzzle grid for Sudoku (Hayes, 2006, p.1), which is based on the 3x3 grid (marked in thick lines in Figure 7.15) and its sub-divisions. An example is given in Figure 7.15.

					6			1
9						3	7	6
7	1			4				
1	7		8					3
	3						1	
6					3		5	8
				3			6	5
3	5	1						2
8			1					

Figure 7. 1 5 The game of Sudoku

Source: Drawn from daily-sudoku.com [Accessed 12 October 2014]

Crossword puzzles are designed on a 15 x 15 grid. The grid units are coloured either black or white (Ferland, 2014, p. 1). An example is given in Figure 7.16.

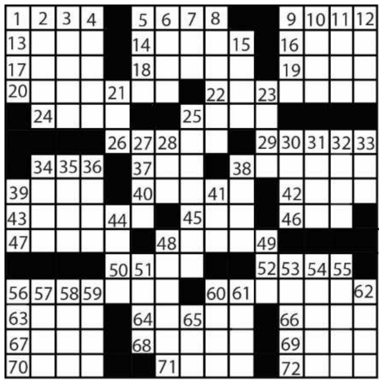
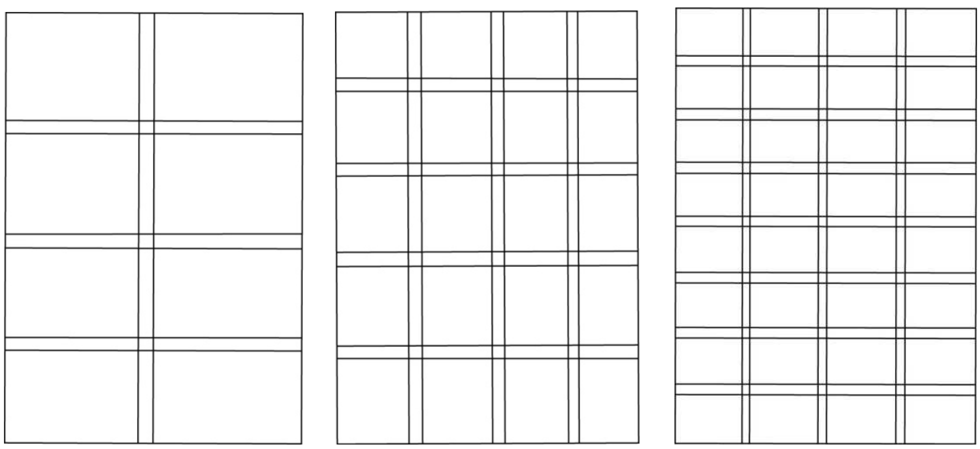


Figure 7. 1 6 The game of crossword puzzles in a 15 x 15 grid

Source: Drawn from Ferland, 2014, p. 1

The importance of 8-unit, 20-unit and 32-unit grids was emphasized by Brockmann. The 8-unit grids, are efficient enough to accommodate pictures in different sizes with or without text (Brockmann, 2008, p.60). Meanwhile 20-unit grids can provide more solutions on format design since they have four fields horizontally and five fields vertically. In design practice, only a small number of grid fields are needed to provide a solution (Brockmann, 2008, p.76). The 32-unit grid is divided into four columns with eight subdivisions in each column (Brockmann, 2008, p.90). It is suitable for displaying a large number of illustrations (Brockmann, 2008, p.87). These 3 types of modular grids are illustrated in Figure 7.17 a-c.

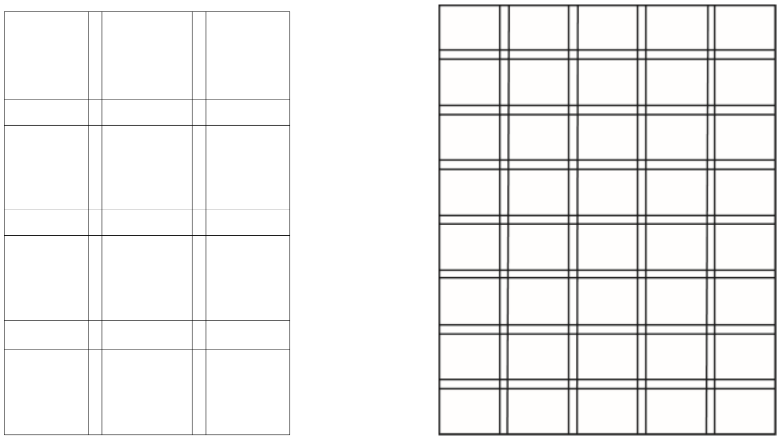


a b c

Figure 7. 1 7 The 8-unit, 20-unit and 32-unit grids

Source: Drawn from Figure 2.28

Jute also stated that the 12-unit grids and the 40-unit grids are of importance in design practice (Jute, 1996, p.69). Since the 12-unit grids can be combined in different ways (e.g. 2x6, 3x4) and the 40-unit grids is created from combining 20- unit grids. These 2 grids are shown in Figure 7.18 a-b.



a b

Figure 7. 1 8 The 12-unit and 40-unit grids

Source: Drawn from Jute, 1996, p.69

It is worth noting that Karl Gerstner's 58-unit grid (Figure 7.19) provides further effectiveness to design systems (Hurlburt, 1978, p.59). It is complex but can provide solutions to two, three, four, five and six column (Figure 7.20 a-e) structures (Roberts and Thrift, 2002, p.29). This system, however, is based on a square, and the square is divided into 58 units in both vertical and horizontal direction. When a two-column structure is constructed in this system, two columns occupy 28 units each and with a two units intersection. Three columns, however, take 18 units each and two inter column spaces take two units each. Four columns, on the other hand, have a column width of 13 units and three columns inter space of two units each. Five columns are structured with a column width of 10 units and inter column spaces of two units each. Six columns have five inter column spaces that occupy two units each and six columns of eight units (Roberts and Thrift, 2002, p.29). Moreover, because the 58-unit grid is based on square paper, the division can be applied both horizontally and vertically.

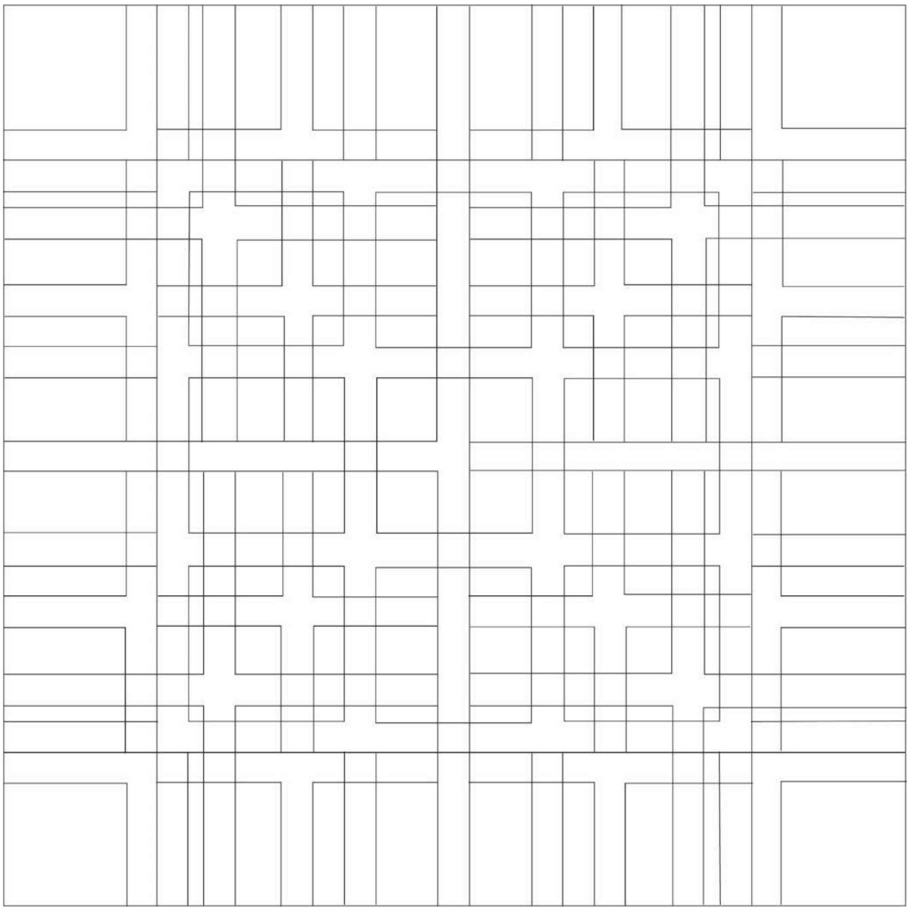
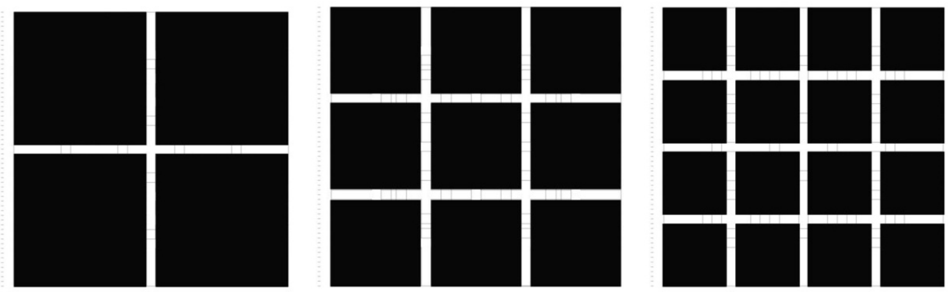
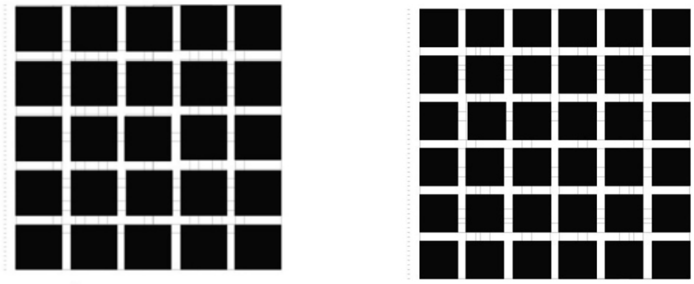


Figure 7.19 Karl Gerstner's 58-unit grid

Source: Drawn from Hurlburt, 1978, p.59



a b c



d e

Figure 7. 2 0 a-e: 58-unit grid column structure

Source: Drawn from Roberts and Thrift, 2002, p.29

7.3.3 Proportional grids

Brockmann stated that the grid fields can be the same or different in size (Brockmann, 2008, p.11). Certain division ways can divide an area into proportional grids.

The DIN system of paper size is based on root-two rectangle sub-divisions (Elam, 2001, p.36). The size of one grid field is always half size of the previous one (Brockmann, 2008, p.15). As shown in Figure 7.21, A2 is half size of A1, A3 is half size of A2…

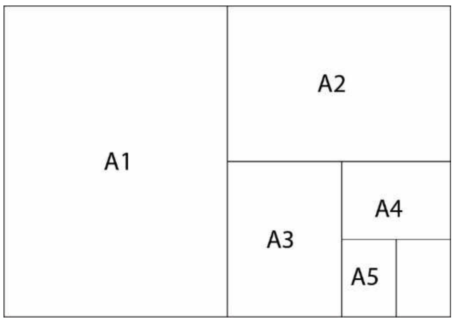


Figure 7. 2 1 The DIN system

Source: Drawn from Figure 2.21

Fibonacci squares divide a space into squares the side lengths of which are correspond to the Fibonacci series (Figure 7.22) (Landa, 2014, p.172). The characteristics of the Fibonacci series is that each number is the sum of the previous two, so that the ratio between adjacent numbers is a golden-section ratio (Elam, 2001, p.11; p.8; Hann, 2012, p.109).Thus, this division is based on a golden-section proportion.

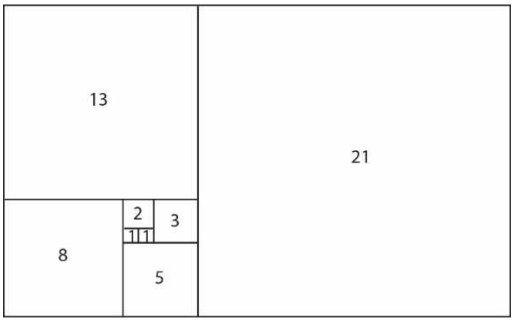


Figure 7. 2 2 The Fibonacci squares

Source: Drawn from Figure 2.17

7.3.4 The vision-based page segmentation (VIPS)

Grids are often applied in web-page design as a framework to create standard layout from page to page (Landa, 2014, p.339). Almost all web-pages are designed on linear grids (Baron, 2002, p.132). However, the grid is not a visible component (Weinman, 2003, p.58). The underneath structure (grids) can still be identified by analyzing the arrangements of the images and text in the page.

A segment on the web-page is a region that a user would identify as distinct from the rest of the page in some way ' (Puneil, Bergman, Schein, Barkol, 2009, p.2). A web-page can be divided into segmentations (or blocks) by different methods.

The vision-based page segmentation (VIPS) is a method based on the algorithms to divide a web-page into blocks by detecting visual cues such as, image size, colour, font etc. (Song, Liu, Wen, Ma, 2004, p.2). Figure 7.23 shows a CNN web-page divided into blocks by VIPS.

Figure 7. 2 3   A web-page divided by VIPS

Source: Song, Liu, Wen, Ma, 2004, p.2

Based on the VIPS method, Puneil, Bergman, Schein and Barkol segmented a web-page according to its visual hierarchy; their algorithm detects the long edges in both horizontal and vertical directions (Puneil, Bergman, Schein, Barkol, 2009, p.4). The approach can be used again for a single-block segmentation, as shown in Figure 7.24. The black frame marks the first time segmentation, and the grey frames are the segmentation within blocks.

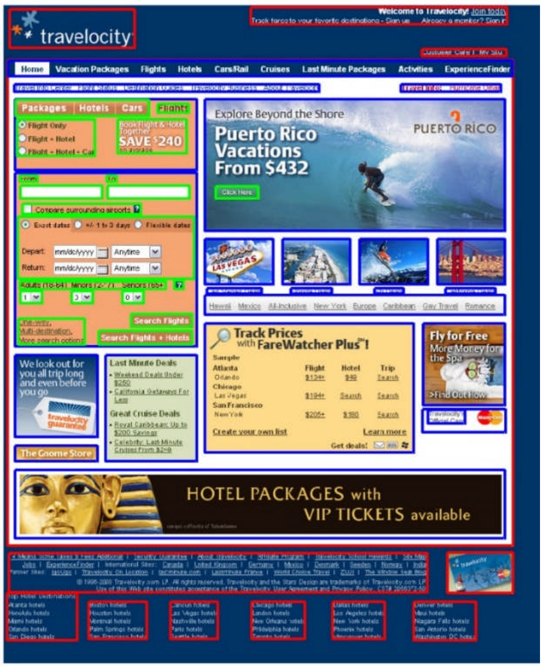


Figure 7. 2 4 A web-page segmentation based on visual hierarchy

Source: Puneil, Bergman, Schein, Barkol, 2009, p.4

In summary, this section reviewed common types and combinations of column grids and modular grids. Attention was paid also to proportional grids and the vision-based page segmentation method.

7.4 Analysis

This section provides an explanation of the methods to be used in the analysis of the case studies on web home page. Examples will be given to aid the explanation.

7.4.1 The development of the analysis methods for web homepage

Grid systems are widely applied in two – dimensional design practice. Column grids are of special importance in terms of web-page layout design. Among these, the 12 - column, 16 – column and 24 - column grids, are common guide lines in web-page layout division. (http://960.gs) [Accessed 30 October 2014]. This research aims to find common grid division methods in both vertical (column grids) and horizontal directions (modular grids) for commercial web-site design by analysing FTSE 100 (the 100 largest companies listed in the

London stock exchange) homepage layouts. Common proportions between the main elements in each web-page are calculated in order to develop space division frameworks based on grid division.

The first step of the analysis is the process is to define the boundaries of each web-page. The boundaries of each web-page are defined according to the VIPS method. Thus, the boundaries of each sample web-page are defined according to the long outer edges of the visual blocks (segmentations). Then the common web grids including 12-column, 16–column and 24-column grids are applied to each case within the boundaries. The fitness of the grid column lines and the block edges are checked as the grid should accommodate the content and not be broke from its regularly (Landa, 2014, p.340).

The following two sections (section 7.4.2 and section 7.4.3) provide a detailed explanation of the methods to be used in the analysis of case studies on the web home page. Examples will be given to aid the explanation.

7.4.2 The division of column grids

The home page of BP is one of the samples selected from the FTSE 100 (Figure 7.25), which has been scaled by 67% of its original size. The grids left boundary was set by marking the company logo, as well as marking the left edges of most of the content, including all the left edges of the text. The edge of the right grid marks the right edge of the search box; the right edges of three vision blocks and right edge of the ‘back to top’ button. The top of the page is defined by the top line and the bottom of the edge is the edge of the green block. This is illustrated in Figure 7.26.

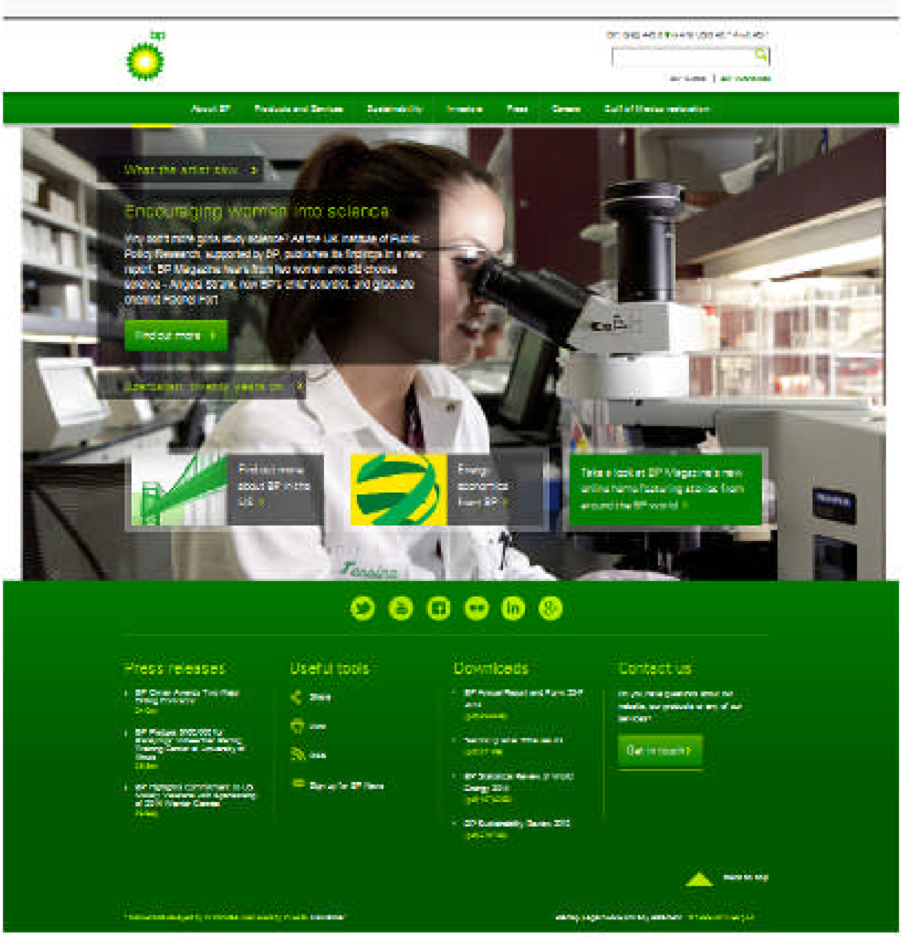


Figure 7. 2 5 The home page of BP Company

Source: [http://www.bp.com/ [Accessed 28 November 2014]](http://www.bp.com/)

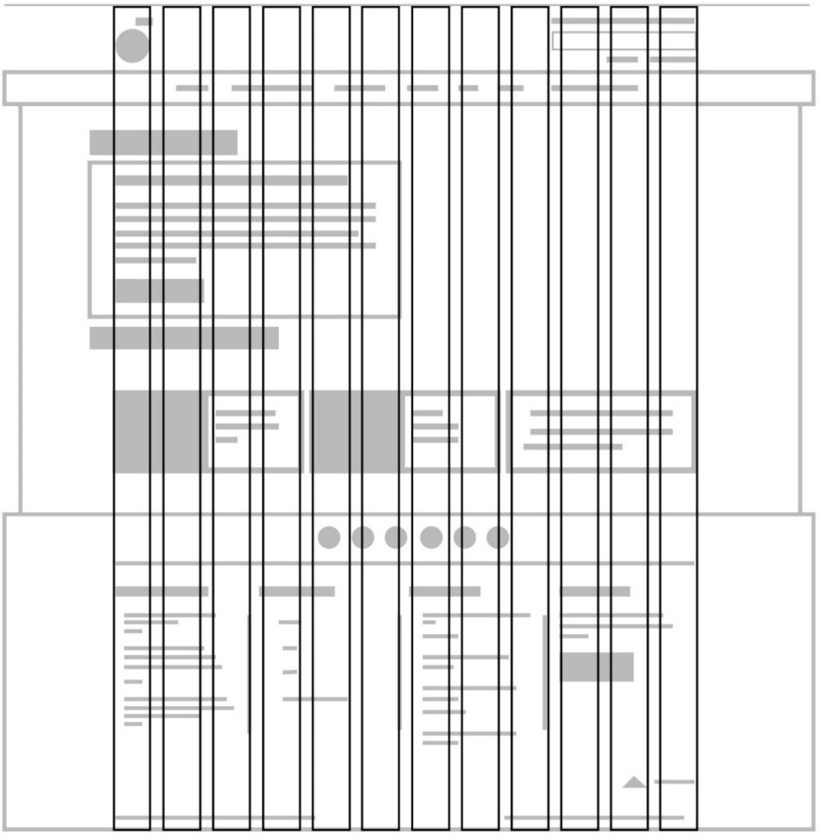


Figure 7. 2 6 The 12-column grid on the BP home page

The total width of the page marked by the boundaries measured 99mm. When a 12-column grid is applied to the page, each column width is 6.4mm, and the gaps between the columns are 2mm each. As shown in Figure 7.26, almost all of the elements in the page fit between the grid division lines. In the page header section, the logo occupies one grid unit; the searching box takes slightly more than 3 units, and the gap between them is eight units. The navigation links occupy 6 grids with the space of one unit on both the left and right sides. The main content section is divided into two parts: the top half mainly contains one text block ‘Encouraging women into science’ and three smaller rectangular chunks below the text block. The text block is six grids wide and takes up half of the page width. The three smaller rectangles occupy four columns each and divide the 12-columngrids into three columns. In the bottom half of the content, the area mainly consists of four columns of text, including ‘press release’ ‘useful tools’ ‘downloads’ and ‘contact us’. The left edge of each text column is marked by a grid line and the text columns’ widths are two or slightly more than two grids. In the page footer section, the copyright and the contact details take roughly four units each in both left and right sides. Table 7.1 summaries the grid numbers occupied by the main elements as well as the numbers of columns generated by them.

Table 7.1 The relationship between the main elements and grid units in BP Company's homepage

Sample number	Page name	Grids number	page sections	number of grids occupied	columns generated	proportions
16	BP	12	page header	1 8 3	3	1:3
			page content	6 6	2	1:1
				4 4 4	3	1:1
				3 3 3 3	4	1:1
			page footer	4 4 4	3	1:1

Therefore, the BP Company homepage is likely to be generated based on a 12-column grids structure, and the grids columns are grouped to generate two, three and four columns layout in the content area.

The home page of the Friends Life Group (Figure 7.27) is one of the eight samples which fits 16-column grids. It has been scaled to 75 per cent of its original size. The grid left boundary makes the left edge of the company logo and the left edges of the main content blocks and defines the left edge of the page footer. The grids right boundary goes through the right edges of the content blocks. While the top and the bottom grid boundaries coincide with the page top and bottom edges. The width of the page marked by the grid boundaries measured 186mm, and 16-column grid were found, the grid unit width of which measured 7.8mm, while the gap width 4mm. It is obvious that almost all of the elements boundaries are defined by the grid lines. This case is illustrated in Figure 7.28

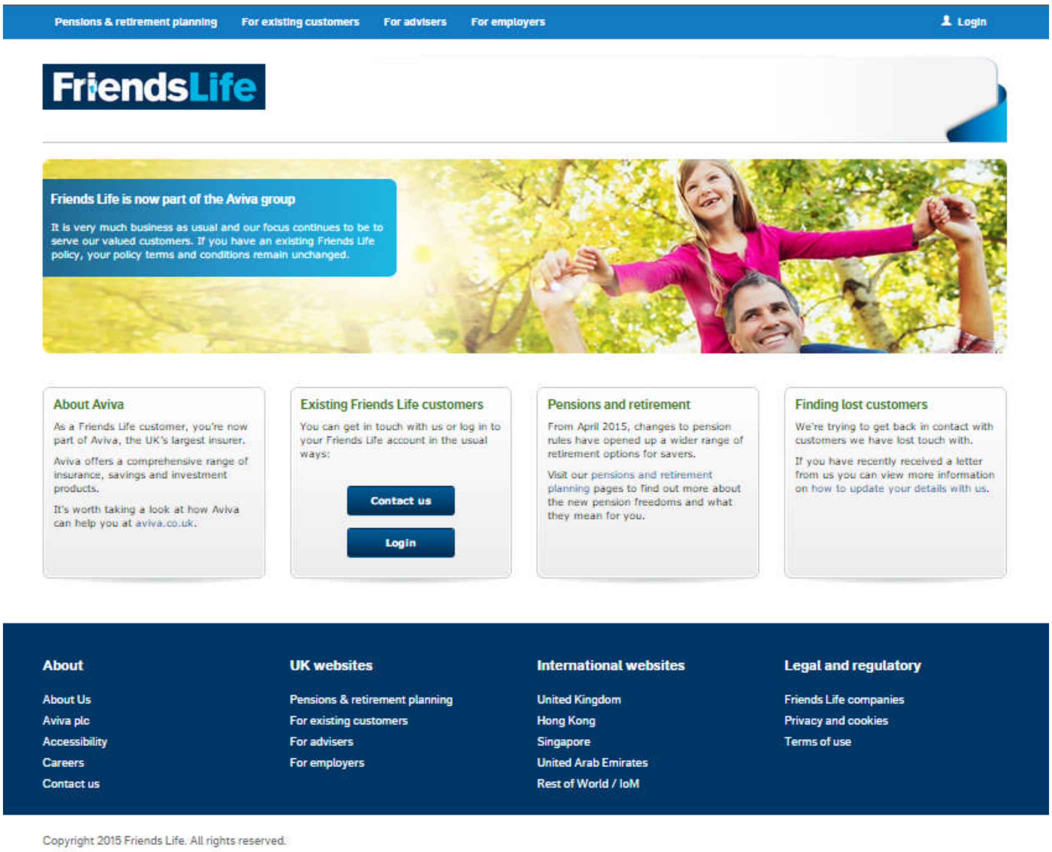


Figure 7. 2 7 The home page of Friends Life Group

Source: http://www.friendslife.com/ [Accessed 28 November 2014]

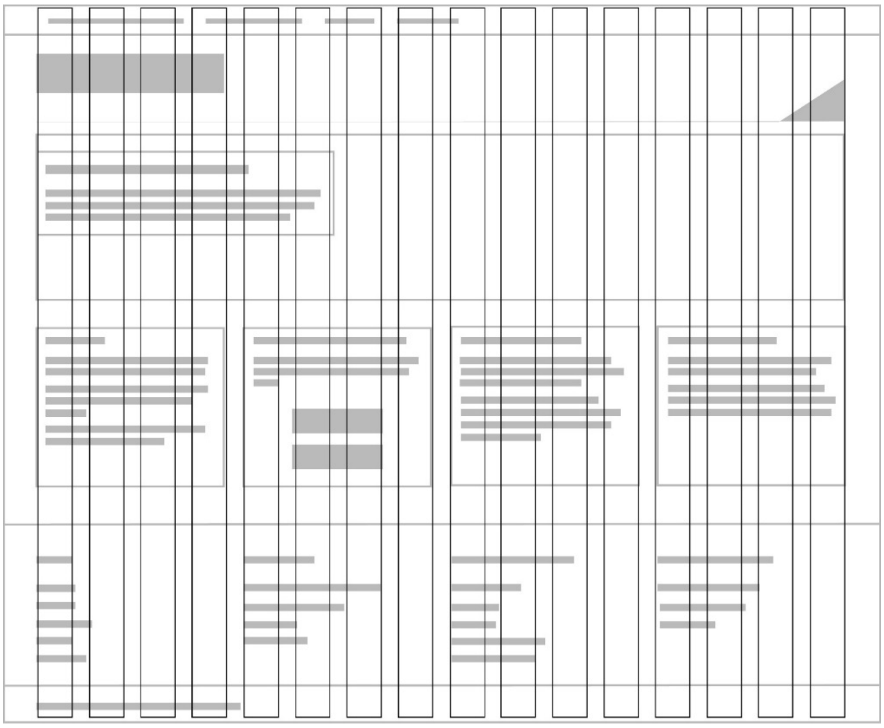


Figure 7. 2 8 The 16-column grid on the Friends Life Group home page

In the page header area, the company logo occupies four units. The main content area is divided into three sections horizontally. In the top section, a blue rectangle occupies six grid units, while the middle section consists of four square blocks, each of which takes four units' width. The bottoms of all the text columns are arranged against the grid lines, and separated from each other by at least one grid unit. The width of the copyright in the page footer section slightly exceeds four grid units. These can be seen in Figure 7.28. The relationship between the grid structure and the main elements is listed in Table 7.2.

Table 7.2 The relationship between main elements and grid units in Friends Life Group homepage

Sample number	Page name	Grids number	page sections	number of grids occupied	columns generated	proportions
34	Friends Life Group	16	page header	4 12	2	1:3
			page content	6 10	2	3:5
				4 4 4 4	4	1:1
				4 4 4 4	4	1:1
			page footer	4 12	2	1:3

Thus, the home page of the Friends Life Group fits a 16-column grid division. two-columns and four-columns are found in the layout. Furthermore, proportions such as 1:1, 1:3 and 3:5 exist among the elements widths.

It is found that more than one third of the samples have 24-column grids as their underlying structures. The home page of International Consolidated Airlines Group is one such case (Figure 7.29). The home page is scaled into 90% of its original size, as shown in Figure 7.30. The left grid boundary marks the company logo, the content left edges and the copyright. The right grid boundary marks the language bar, and the right boundary of the content. The width of the left and right boundaries measures 132mm. After adding a 24-column grid to the page, the grid unit measures 36mm, while the gap measures 2mm.

In the page header area, the company logo counts eleven grids units. The gap between the logo and the language bar occupies nine units, while the language bar width four units. The main content section consists of three parts. The top and middle section are divided by white gaps. The middle section and bottom navigation section are separated by six dash lines. In the top content section, the area is divided into three blocks, which occupy nine units, five units and ten units respectively. The middle section is divided into six units, eight units, six units and four units. The bottom navigation section contains six columns and each column occupies four units. Thus proportions such as 1:2, 2:3, 3:4 and 1:1 exist in the divisions. There is no obvious page footer section in this case. Table 7.3 summarise the above discussion.

Figure 7. 2 9 The home page of International Consolidated Airlines Group

Source: www.iairgroup.com [Accessed 28 November 2014]

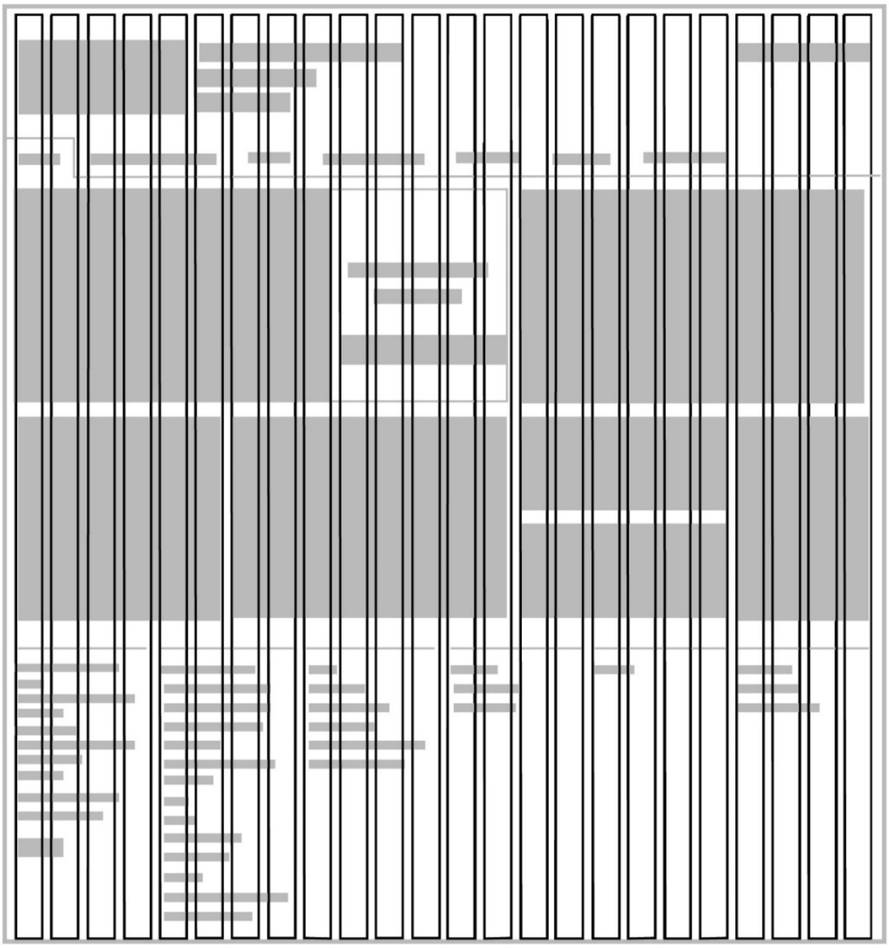


Figure 7. 3 0 The 24-column grid on the International Consolidated Airlines Group home page

Table 7.3 The relationship between main elements and grid units in the homepage of International Consolidated Airlines Group

Sample number	Page name	Grids number	page sections	number of grids occupied	columns generated	proportions
44	International Consolidated Airlines Group	24	page header	11 9 4	3	
			page content	9 5 10	3	1:2
				6 8 6 4	4	2:3 3:4 1:2
				4 4 4 4 4 4	6	1:01

Some of the pages contain more than one type of grid in their underlined structure. It is called 'mixed grids' in this research. The homepage of GKN is one of these cases (Figure 7.31). This page was scaled by 75%. The left boundary of the grid marks the company logo and the left edge of pictures and contents. The right boundary marks the searching box and the right edge of the content area. The width of the web-page measures116 mm and the gap between the top half of the page measures 2mm. Thus a 16- column grid with column width of 5.3 mm and 2 mm gaps divide the top two thirds of the page area perfectly (See Figure 7.32). In the page header, the company logo takes three units. There is a nine grid gap between the logo and the search bar. The search bar occupies four grid units. The content area is divided into three parts by the white gaps. In the top section of the content, the picture as well as the text divides the page into eight grids, four grids and four grids respectively. While in the middle section, the content division is four grids, eight grids and four grids respectively. This 16-column grid, however, cannot divide the bottom one third of the sections. The gaps measure 1mm between the pictures. However, a 24-column grid with unit width 3.7mm and gap 1mm fits this area visual layout. In the bottom part of the content, the area has been divided into four columns, each of which occupies six grids. While in the page footer area, the elements (logo and text) divide the content into ten units, one unit, six units and seven units. The proportions in this page are 1:1, 1:2, 1:5 and 3:5 respectively, which are listed in Table 7.4.

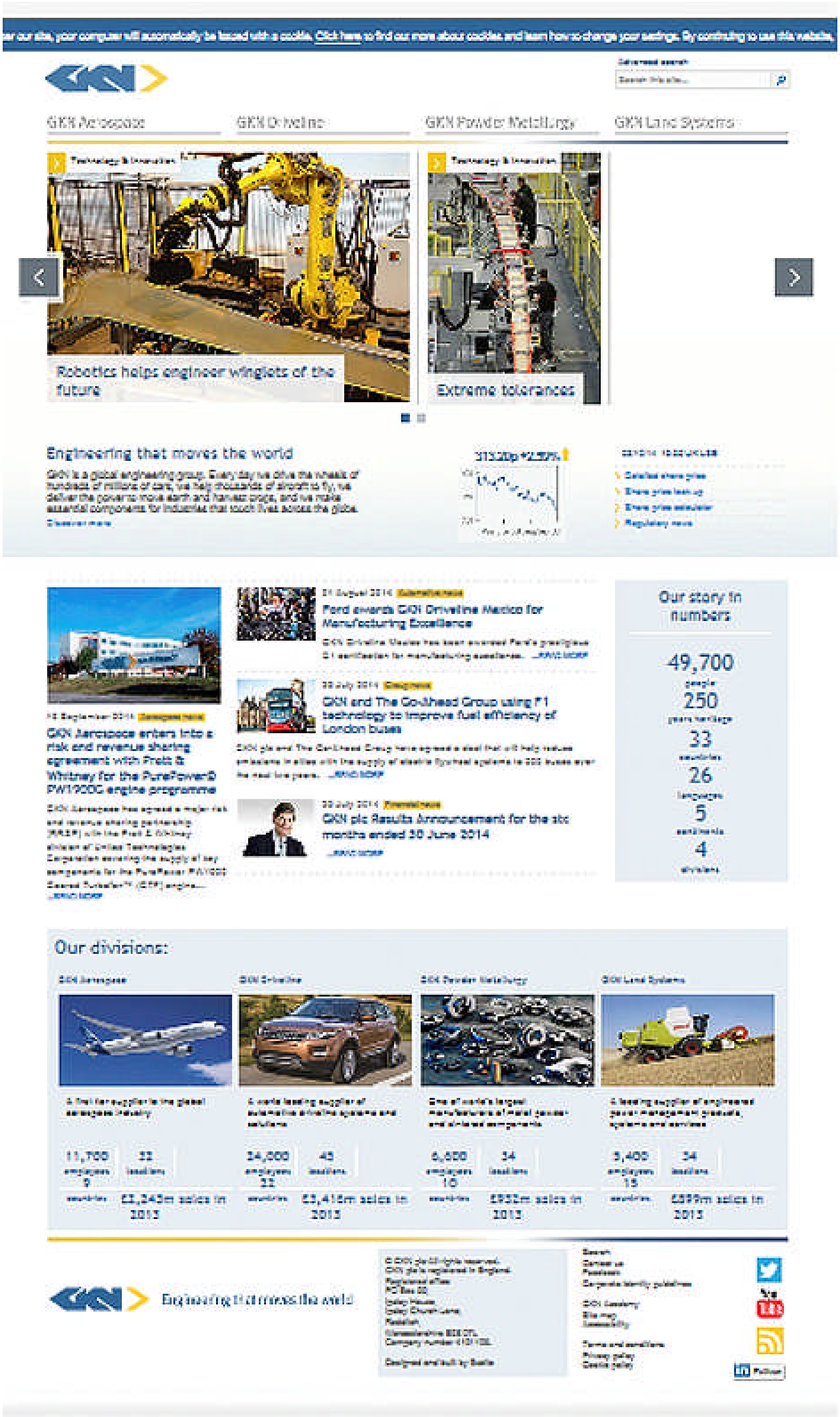


Figure 7. 3 1 The home page of GKN Group

Source: http://www.gkn.com [Accessed 28 November 2014]

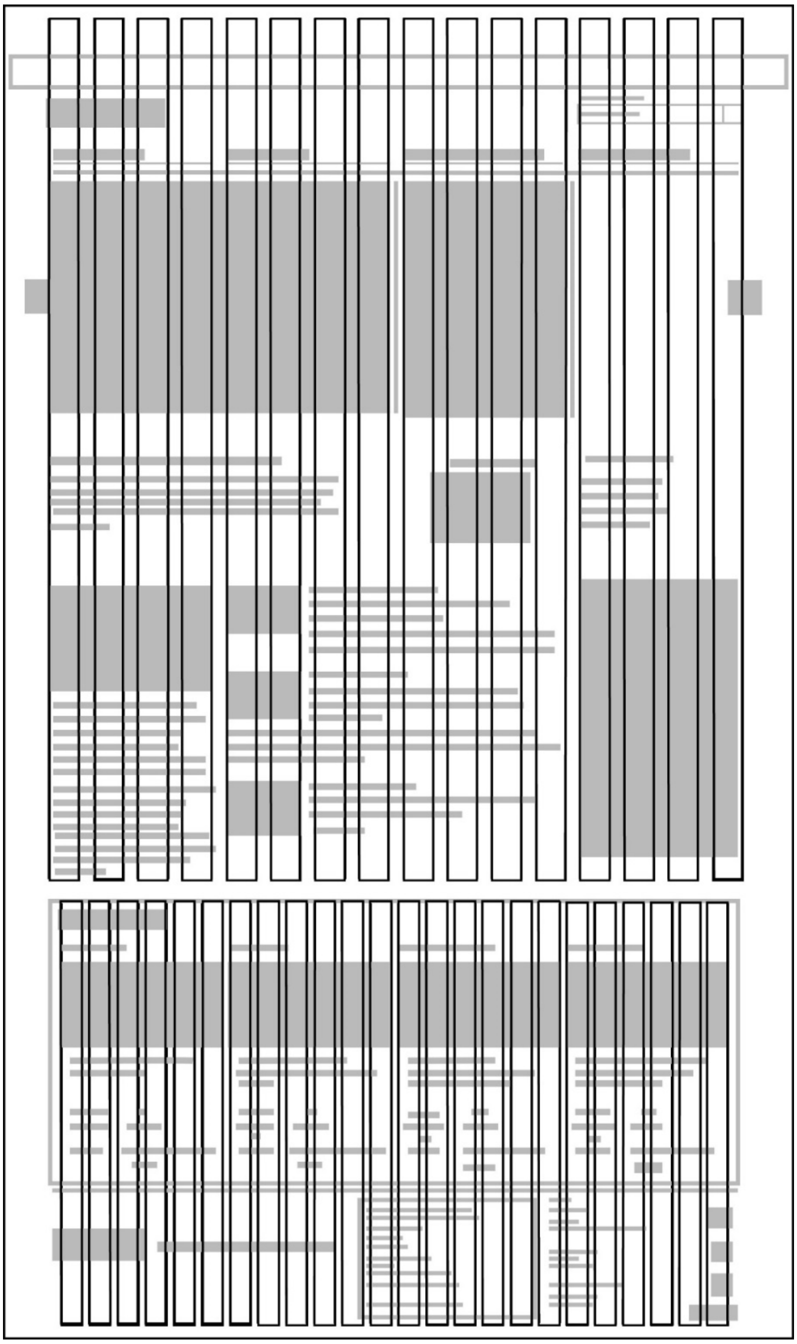


Figure 7. 3 2   The 16 and 24-column grid on the GKN Group home page

Table 7.4 The relationship between main elements and grid units in the GKN homepage

Sample number	Page name	Grids number	page sections	number of grids occupied	columns generated	proportions
36	GKN	16&24				
		16	page header	3 9 4	3	1:03
			page content	8 4 4	3	1:1 1:2
				4 8 4	3	1:1 1:2
		24		4 20	2	1:05
				6 6 6 6	4	1:01
			page footer	10 1 6 7	3	3:05

It is observed that twenty sample pages have the division grids not belong to any category discussed previously. These pages have odd numbers of narrow grid columns. Take the webpage of Admiral Group as an example (Figure 7.33). This page has the left and right boundaries limited by the length of two blue bars. Its top and bottom boundaries are defined by two lines. The width of this page measures 154mm. The smallest elements in the page are the twitter and the RSS icons and the smallest illustrations usually define the smallest grid unit (Brockmann, 2008 p.11). Thus their width is taken as the grid unit. The total width of the page is 154 mm and the unit width is 3.5mm. Then a 44-coloumn grid can divide the page with no gap (Figure 7.34).

The logo divided the page header section into eight and 36 units respectively, which generate a proportion of 2:9.The company name takes 24 grids in content area, the search bar counts nine grids and the gap between them is eight units. The share price takes ten units and the 'latest news' together with the icon takes one grid unit. There is a 1:1, 1:2, and 3:7 proportion in this section. The bottom section of this page is divided into three columns by the text, which take thirteen units, twelve units and ten units respectively. The proportion of 1:1 and 5:6 exist in the division. Detailed division and the proportion between the elements are recorded in Table 7.5.

Figure 7. 3 3 The home page of the Admiral Group

Source: www.admiralgroup.co.uk [Accessed 28 November 2014]

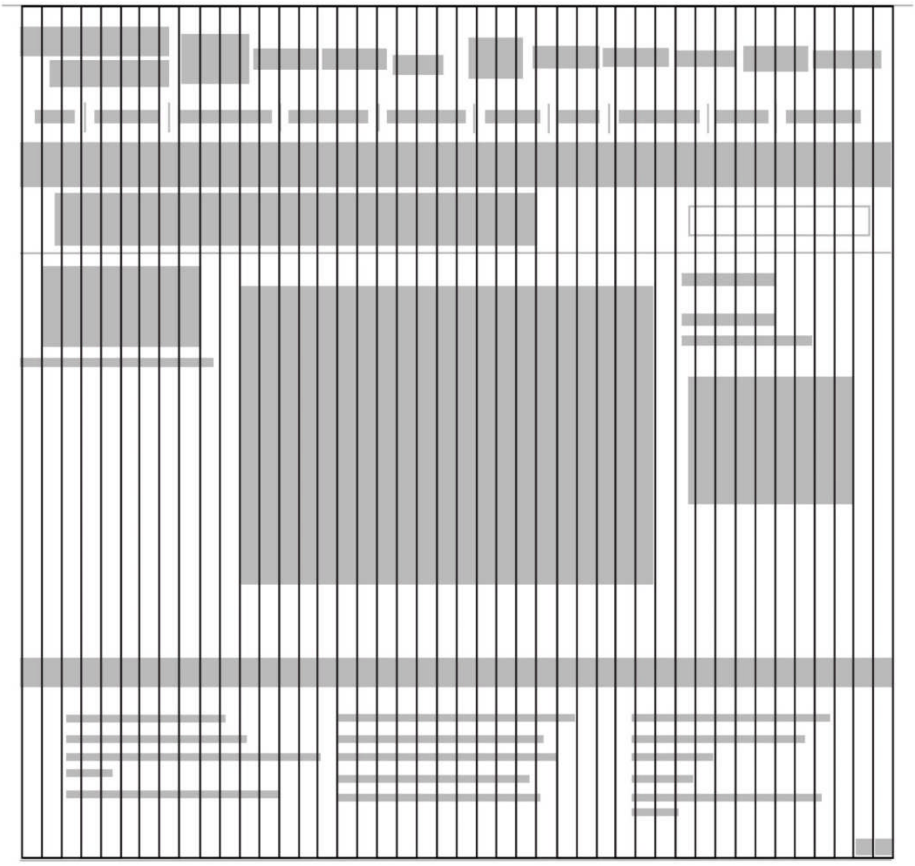


Figure 7. 3 4 The 44-column grid on the Admiral Group home page

Table 7.5 The relationship between main elements and grid units in the Admiral Group homepage

Sample number	Page name	Grids number	page sections	number of grids occupied	columns generated	proportions
3	Admiral Group	44	page header	8 36	2	2:09
			page content	9 8 10	3	1:2 1:1 3:7
				13 12 10	3	1:1 5:6

As mentioned previously, four sample pages can be divided by more than one grid system. For example, the home page of Bunzl and the Severn Trent can be divided by both 12 and 24 grids; that of Imperial Tobacco Group (Figure 7.35) and that of Smith & nephew can fit in both 12 and 16 grids, as does the Severn Trent home page. For example, Figure 7.36a illustrates Imperial Tobacco Group home page in a twelve grids division, while Figure 7.36b shows the same page in 16 grids.

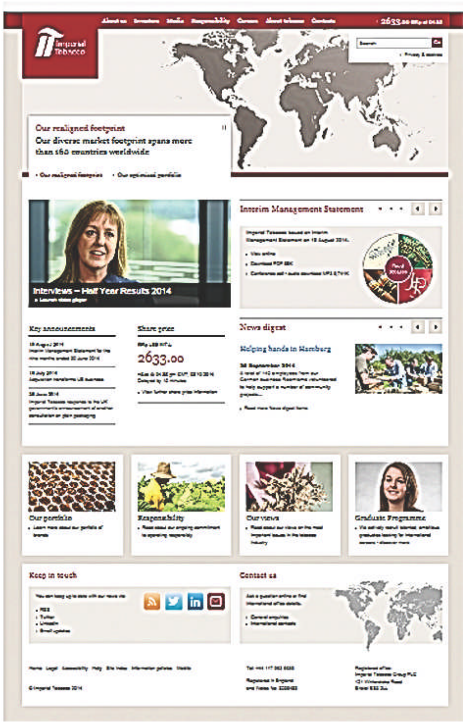
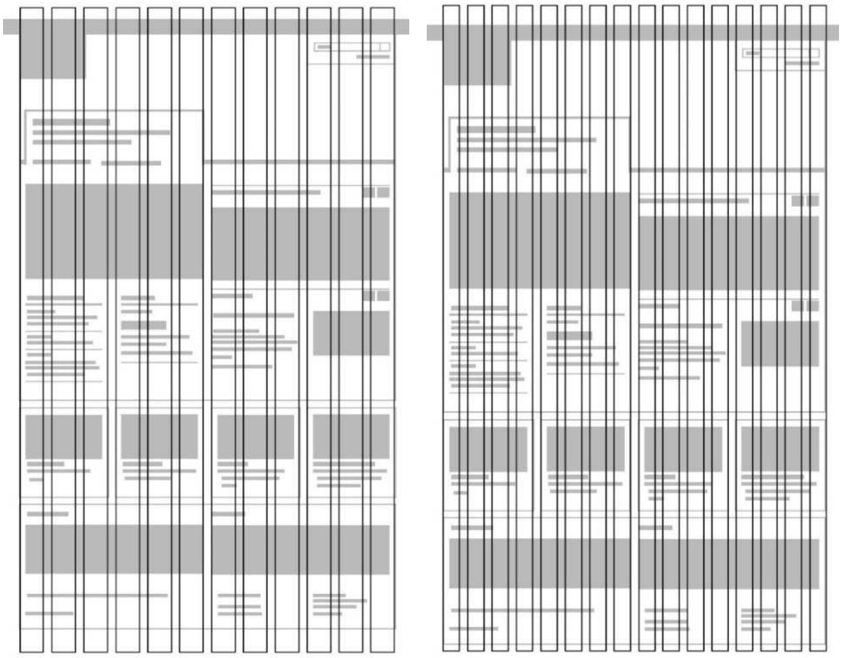


Figure 7. 3 5 The home page of Imperial Tobacco Group

Source: www.imperial-tobacco.com [Accessed 28 November 2014]



a b

Figure 7. 3 6 The 12 and 16 grid divisions of the Imperial Tobacco Group home page

7.4.3 The division of the modular grids

Modular grids are horizontal divisions from top to bottom in addition to the vertical divisions from left to right (Landa, 2014, p.341). The previous section (section 7.4.2) identified the vertical division (column grids) in each case. This section adds the horizontal division on top of the vertical ones (modular grids).

Most of the selected web home pages have obvious top edges. The bottom of the pages is usually defined by the bottom of copyright. In the beginning of the analysing process, square grids (same grid width and gap width as the vertical grids) are generated vertically in each case. The fitness of the element edges and the grid division lines is checked since the grid lines should largely fit the content arrangement (Landa, 2014, p.340).

A total of 71 samples out of 92 fit the square modular grid division. A total of twelve have mixed grids in their vertical divisions. Therefore, when a horizontal division is added, they still show a mixed grid structure. Three cases fit the rectangle modular grids with the length/width proportion of 2:3. Two have 3:5 rectangular modules. Other grid cells with proportions of 1:2; 1:5; 3:4 and 5:7 respectively are found in one case each. Furthermore, the home page of Bunzl, Severn Trent and Smith & Nephew Company can fit more than one modular grids (1:2 grids and 1:1 grids).

The homepage of the Friends Life Group (given above in Figure 7.27) is one of the samples which has 16-column grid in the vertical division (Figure 7.28). The total length of the page measures 161mm. When a grid system with grid unit width of 7.8 mm and a gap width of 4mm (same as vertical grids) is applied in the horizontal direction, a 14 x 16 modular grid system can cover the whole page (Figure 7.37).

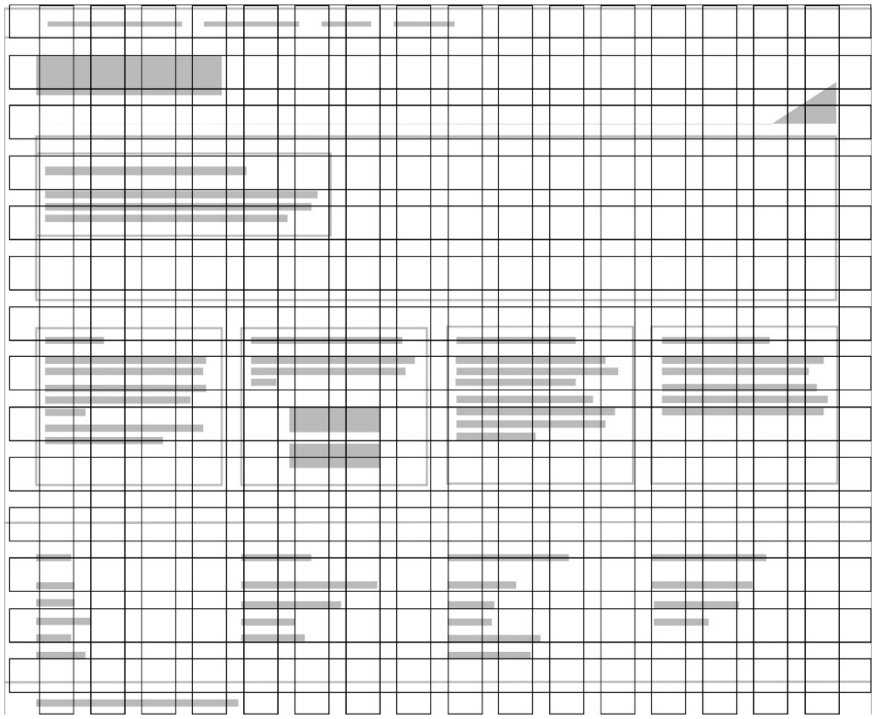


Figure 7. 3 7 Modular grids on Friends Life Group homepage

Horizontally, the page header area takes almost three grid units, while the picture area below the company logo occupies slightly more than three grids. The content below the picture takes four grids, the bottom navigation section takes three grids and the copyright information takes one grid. So there are proportions of 3:3:4:1 between the sections, which is shown in Table 7.6.

Table 7.6 The horizontal relationship between main elements and grid units of the Friends Life Group homepage

Sample number	Page name	Grids number	Page sections	Number of grids occupied	Sections generated	Proportions
34	Friends Life Group	14	page header	3	5	1:1
			page content	3		3:4
				4		1:4
				3		
			page footer	1		

In terms of a mixed grid group, each case has two types of column grids. Figure 7.32 illustrates the case of GKN. When the horizontal division lines are added, two types of modular grids are generated. Figure 7.38 illustrates this.

The total length of the page measures 210mm. When a grid system with column width of 5.3mm and gap width of 2mm is added horizontally (same grid as its vertical grid), 29 grids can divide the whole page length and divide the page length into three grids, nine grids, seven grids and three grids respectively. This is also shown in Figure 7.38.

A few samples have the single type of rectangular grid cells. They are generated based on measurements and calculation of the vertical divisions. Furthermore, three samples including Bunzl, Severn Trent and Smith & nephew's home pages can fit in both square grids and the 1:2 modular grids.

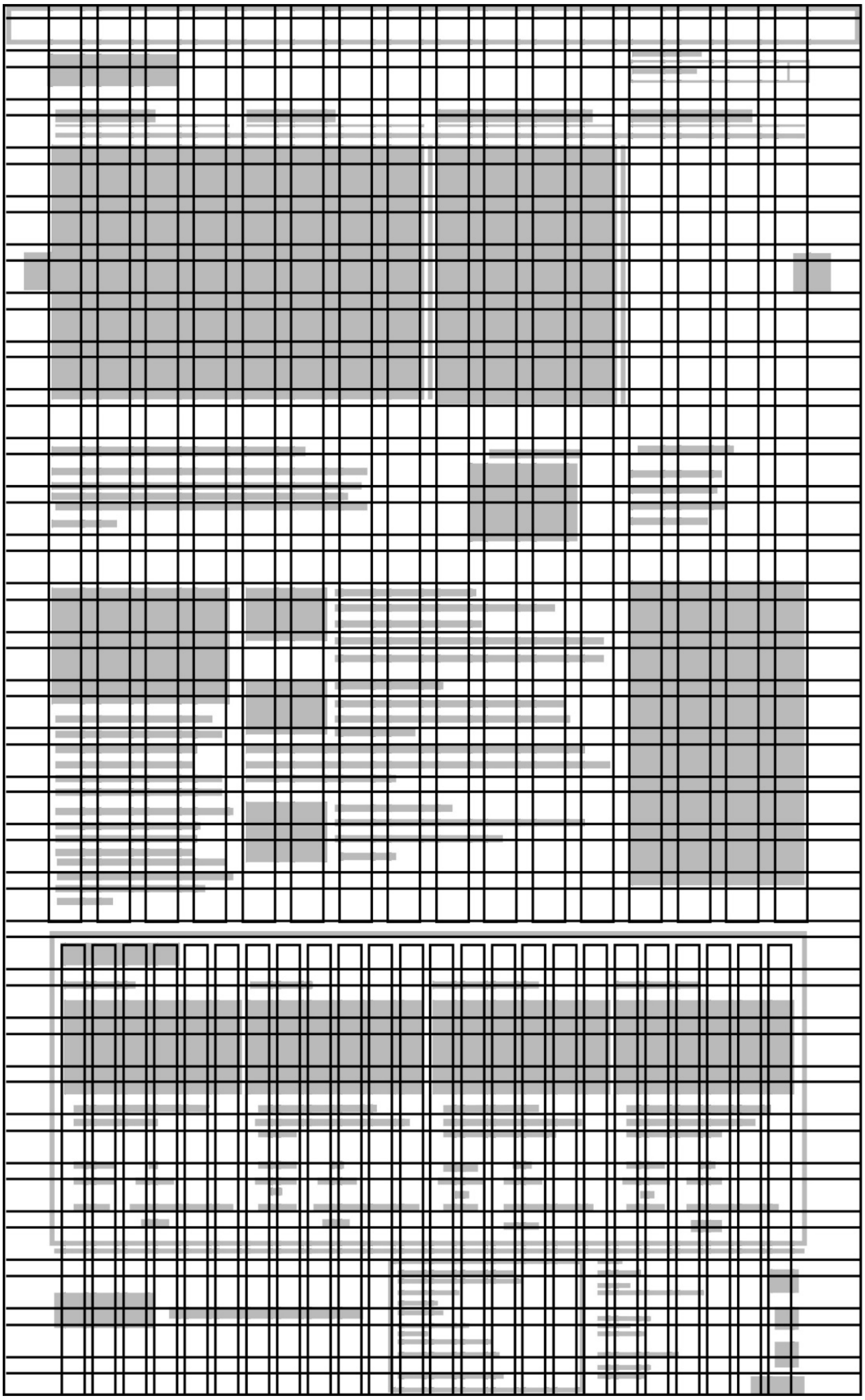


Figure 7. 3 8 Modular grids on GKN homepage

7.5 Results

After considering the vertical (column grid) and horizontal (modular grids) division of 92 sample web home pages, the results can be summarised as follows. In the vertical division, although the measurements and the layout appearances vary from page to page, the division of two, three, and four sections are the most common divisions in page headers, page content as well as page footer areas. In particular, twenty of them fit the 12-column grid, eight fit the 16 –column grid and 36 samples accommodate the 24-column grid. Apart from that, twelve items contain mixed grids and twenty have columns in odd numbers. In addition, four pages can fit in more than one categories.

Horizontally, those samples are most likely to be divided into three, four and five sections (14, 36 and 27 samples respectively are found in each division). The top five proportions between the divisions in both horizontal and vertical directions are 1:1, 1:2, 2:3, 1:3 and 1:4. These divisions and proportions can be permutated and combined to generate multiple frameworks for web-site design. Detailed relationship between main elements and grid units in both vertical and horizontal directions of each layer is summarised in Table 7.7 and Table 7.8 (Appendix D).

7.6 Summary

Web home pages of commercial sites usually display the most important information of a product or service and aim to sell (Baron, 2002, p.148). This research analysed 92 web home pages selected from the FTSE100 (the top 100 companies in the London stock exchange) and found two types of unusual division methods: mixed-grid structure (12 cases) and narrow-grid columns (20 cases) in addition to the 12-column (20 cases), 16 column (8 cases) as well as 24-column methods (36 cases). Horizontally web-pages are most likely to be divided into three, four and five sections (14, 36 and 27 cases respectively) and the most common proportions between the divisions in both horizontal and vertical directions are 1:1, 1:2, 2:3, 1:3 and 1:4. The results suggest that although the appearance of the sample pages are quite different, some of them do have similar components and proportions in their layouts.

Chapter 8 : Design frameworks for analysts

8.1 Introduction

Geometrical constructions have long been applied in design practice and have functioned as guidelines underpinning design. Past examples have focused on architecture, paintings, book-page design and pattern design etc. The concerns of this study have focused on human figure proportions (chapter 3); architecture (chapter 4); textiles (chapter 5); poster design (chapter 6) and web-page design (chapter 7). Although the underpinning geometrical structure may or may not show in the finished design, often the geometrical guidelines can be detected by analyzing the arrangement of the design elements as well as the proportional relationship between them.

It has been observed that, although the appearance of the designs across different disciplines are quite different, very simple geometric structures and basic proportions appear to dominate underpinnings. Furthermore, it is evident that by combining simple geometric structures, often a complicated design appearance can be achieved.

This chapter presents summaries of the space division methods associated with each case study group and, based on these, a range of frameworks of value to design analysts is proposed. Each case study can be considered to yield a unique framework of value to analysts considering similar case study material.

8.2 Frameworks for analysts

An analytical framework is generated for each case study, and these are explained below.

8.2.1 Analytical framework for case study group number 1 - Terracotta Warriors, Xi'an (China)

Human body proportion has long been a study in the disciplines of fine art and medicine, especially human body proportions based on grids of various kinds.

Key literature of human body proportion study in grids includes: ancient Egyptian with Weingarten (2000) and Iversen (1968); ancient Greek, with Weingarten (2000); the Assyrian fifteen grid division as well as grid division of Renaissance statues Zenas (1976). These grid systems allow for the standardization of proportions, and permit artists to place key points of the human body on particular grid lines in both horizontal and vertical directions.

Cannons of proportion (Weingarten, 2000, p.104), divide the human body into equal square grids according to a certain standardization of their natural proportions (Iversen 1968, p.215; Robins, 1994 p.23). A grid system may govern the proportions of the terracotta warrior standing figures. If so, some key points of the sample figures should fall on certain grid lines. Furthermore, no research relating to terracotta warrior standing figures' proportions was found.

'The Pits of Terracotta Warriors and Horses of Qin Shihuang Mausoleum---an Excavation of No. 1 Pit' (Pit 1 excavation report) is the source book of case selection. All of the standing figures presented in the front view were selected as samples for further proportion study, in particular, 35 standing warrior figures illustrated in the 'Pit 1 excavation report' were selected. Kneeling figures and figures with other gestures were out of the scope of this study.

The analytical framework for the Terracotta Warrior standing figures is based on the division of the distance between the upper and lower reference points into three equal sections, and then each section is further divided into five equal parts. Then square grids are constructed according to the division and subdivision lines. This process is shown in Figure 8.1a-c, where, a 15-grid system from the hairline to the bottom of the feet is chosen as the grid type most suitable to the study of Terracotta Warrior proportions as some of the horizontal division lines mark the key points (the detailed rationale of developing the analytical methods was presented in chapter 3).

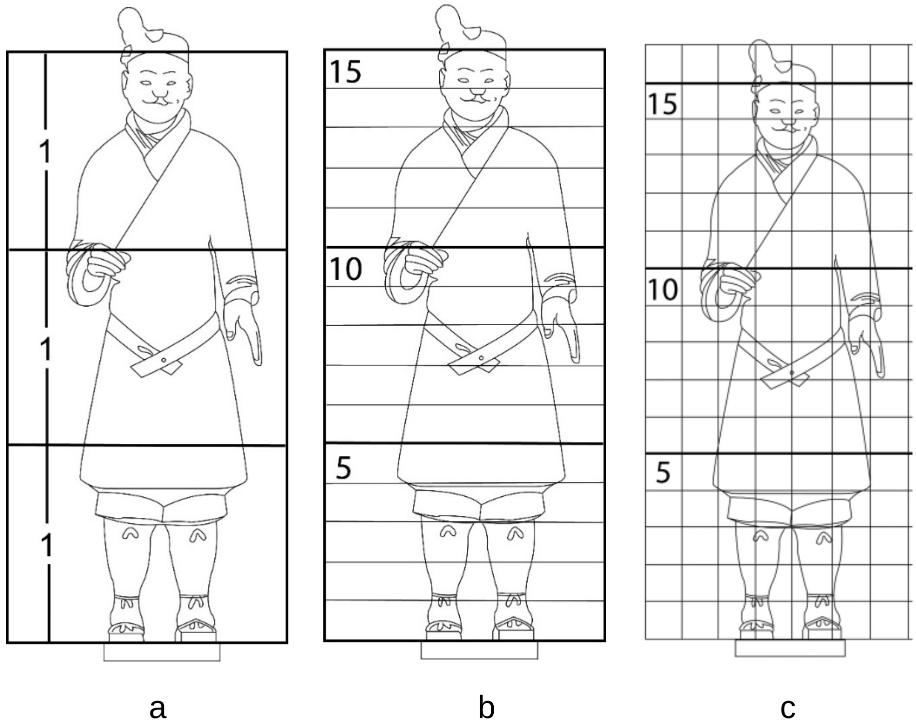


Figure 8. 1 The development of analytical framework for Terracotta warriors standing figures

Therefore, square grid frameworks constructed based on the division of thirds and subdivisions can be used in human figure proportion analysis (Figure 8.2).

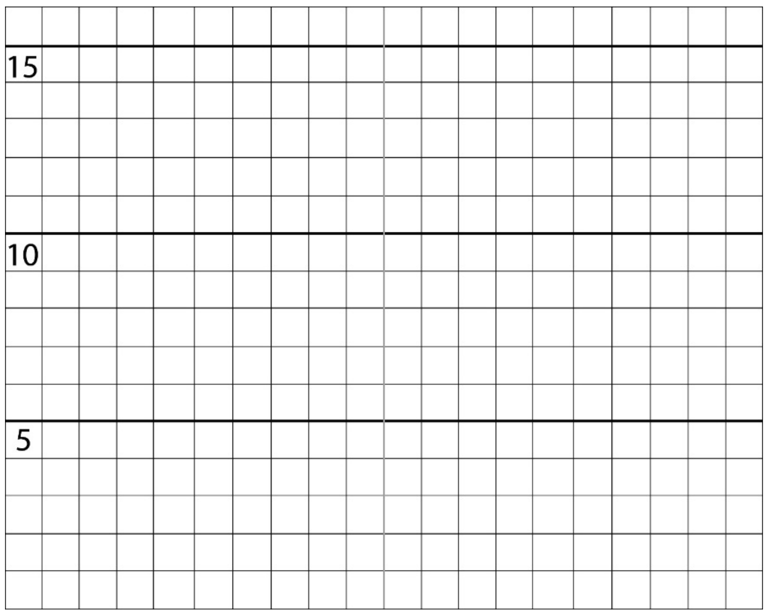


Figure 8. 2 Square grids framework, constructed based on the division of thirds and subdivisions

This framework may be of benefit to analytical work related to human body proportions. Of importance in the idea of division into three equal sections between the upper and lower reference points of a standing human figure and their sub-divisions, which may induce proportional grids in which certain grid lines mark the key points of the body.

8.2.2 Analytical framework for case study group number 2 - Cathedral floor plans

Cathedral designs have long been studied by scholars from different cultural backgrounds. Complicated geometrical and numerical proportions are found often in the measurements (Wu, 2002, p.1).

Key literature relates to geometrical methods for cathedral floor plans with studies including: Wu (2002); Duvernoy (2015); Davis and Neagley (2000); Neagley (1992); Yeomans (2011); Jacobson (1986); Cohen (2008); McCague (2003); Liefferinge (2010); Senseney (2007); Antonino, Pistone and Pistone (2007); Wiemer and Wetzel (1994); Schuetz-Miller (2006); Smyth-Pinney (2000); Hiscock (2000 and 2007); Williams (1997); Watts and Watts (1987and 1992); Bork (2005); Anderson (2008) and Bucher (1972).

Although complicated geometrical and numerical proportions exist in cathedral floor plan measurements (Wu, 2002, p.1), evidence shows that the masons in the Middle-ages (5th - 15th centuries) were not likely to have had a sophisticated understanding of mathematical and geometrical systems (McCague, 2003, p.11). Thus, some simple methods which only involve basic geometric constructions while without any measurements may have been used in the design of cathedral floor plans.

In order to test the hypnosis listed above, a total of twenty cathedrals were selected based on 'The cathedrals of Britain' listed on the BBC history archive website (http://www.bbc.co.uk) [Accessed 12 May 2016] for further study. The floor plan images of each selected cathedral were then reproduced in Illustrator according to the floor plan images provided on official websites.

The analytical framework for cathedral floor plans were, it seems, constructed based on a square (the overlapping square of nave, choir and transepts), including translation of square units, golden-section rectangles; √2 rectangles; Sacred cut (Figure 8.3) as well as root rectangles (Figure 8.4 a-b). The combination use of these geometric principles as well as other related constructions (summarized in chapter 4, Table 4.1 and Table 4.2 in Appendix B) form the underlying structures of all cathedral floor plans.

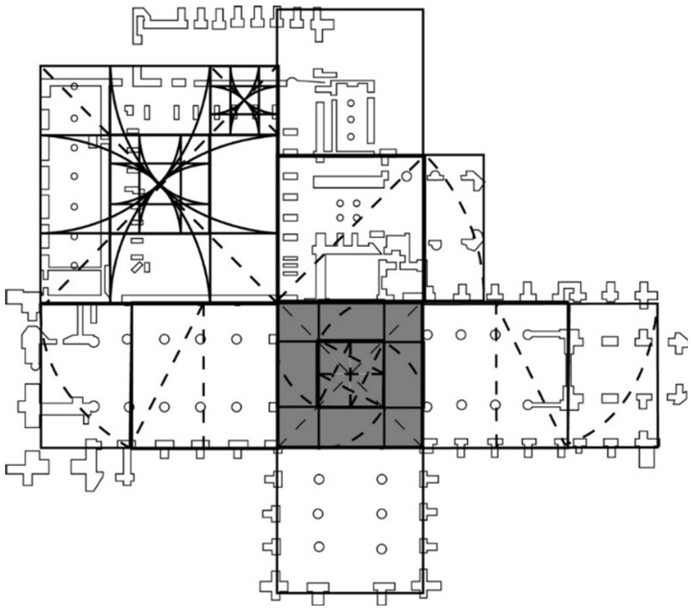
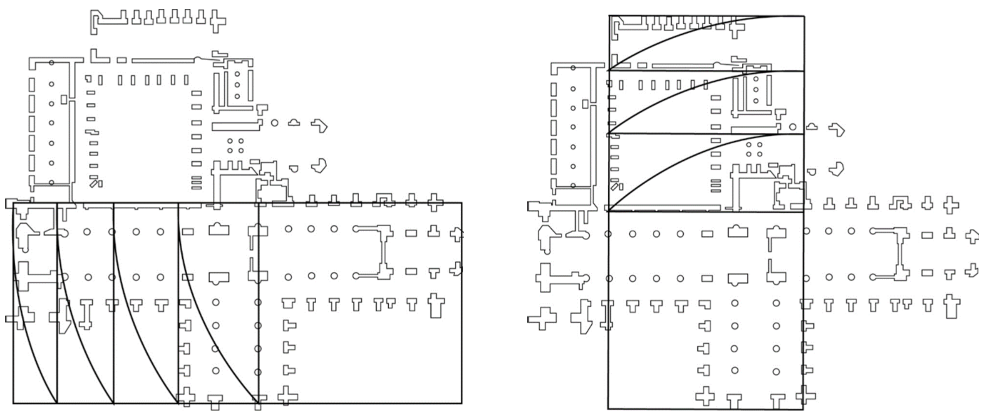


Figure 8. 3 The square units, golden-section rectangle; root -two rectangle and sacred cut in Chester cathedral plan



a b

Figure 8. 4 Root rectangles in Chester cathedral plan

Figures 8.5- 8.9 illustrate the common analytical frameworks for cathedral floor plans found on examine the study group.

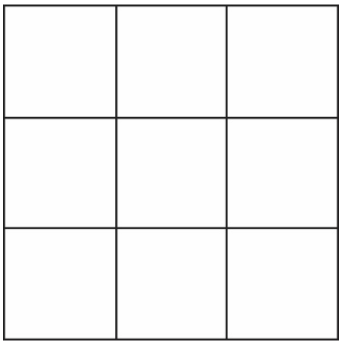


Figure 8. 5 The square modular

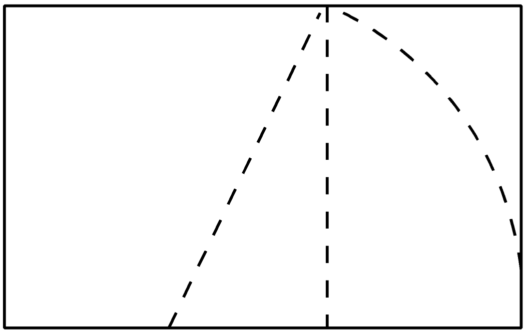


Figure 8. 6 The golden-section rectangle

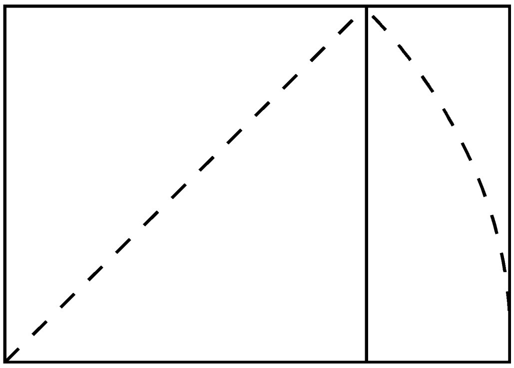


Figure 8. 7 The root-two rectangle

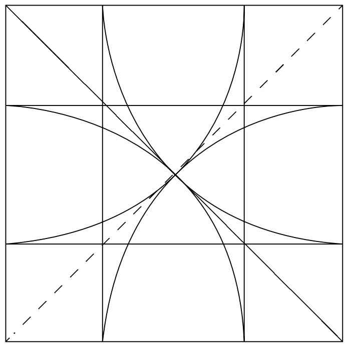


Figure 8. 8 The 'sacred cut'

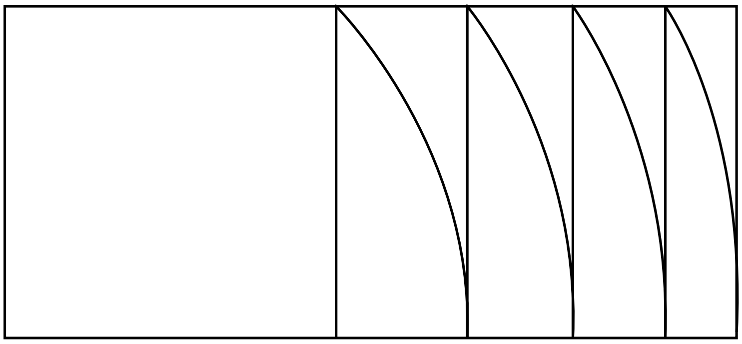


Figure 8. 9 The root rectangles

A few simple geometrical frameworks are found in this case study. Especially the idea of combining simple frameworks to achieve complicated appearances. This may be of benefit to architectural analysis and design in more modern times.

8.2.3 Analytical framework for case study group number 3 - Scottish clan tartans

Tartan-type textiles have attained popularity the world over, but it is in Scotland where this category of woven textiles underwent an evolution in design up to modern times and various design types (or setts) became associated with particular families, clans or geographical regions.

There is an impressive array of publications focused on the identification of tartans and their clan associations. Probably the best known early works are those by Logan (1831), Stuart and Stuart (1842 and 1845), Smith and Smith (1850), Simbert (1850), Grant (1886), Whyte (1891), Stewart (1893), Whyte (1906), Adam (1908), MacKay (1924) and Innes (1945); most of these are available for reference only at relevant specialist libraries. An interesting series of monographs, each focused on a particular clan, its tartan, armorial crest and related matters, was published in the 1950s and early 1960s, under the general title of *Johnston's Clan Histories*; examples included Grant (1952), Moncrief (1954), Stewart (1954), Dunlop (1957), Fraser (1954) and Dunlop (1960). Readily available publications, focused specifically on tartans, include: Bain (1938), McClintock (1943), Innes (1945), Hesketh (1961), Dunbar (1962) and Scarlett (1972 and 1973). Stewart (1974:113-117) provided a useful explanatory bibliography of these and other important publications. Subsequently, notable treatese were produced by Dunbar (1984), Teall and Smith (1992), Way and Squire (2000), Urquhart (2000 and 2005), Martine (2008), and Zaczek and Phillips (2009). More recently, Hann (2015: 78-81) provided an explanatory section on tartans, including thirty-two colour plates of rarer tartan types, in the publication *Stripes, Grids and Checks*.

The most common length to breadth ratio (found in 100 per cent of the tartans examined) was 1:1. The next most common ratio, found in 80 per cent of the sample, was 1:2, followed by 2:3 (48 per cent), 1: 3 (36 per cent), 1:4 (28 percent) and 3:4 (24 per cent). Furthermore, it was found that warp- and weft-direction stripes (which together give the checked appearance) coincided clearly with vertical and horizontal dividing lines within the square repeat. These dividing lines were positioned at half-way and third way points, and bundles of yarn colours were distributed equally on either side of these dividing lines. Similar results were obtained across the full sample of twenty-five tartans. So the hypothesis that the division of halves and thirds as well as their sub-division lines define the position of stripes in tartan layers,

In order to test the hypothesis twenty-two tartans selected from a collection held at ULITA – An Archive of International Textiles (University of Leeds) and cross referenced with the various publications listed in previous paragraph. Numerical details of setts were taken from Stewart (1974).

Figure 8.10 (a-c) illustrates the division and sub-division of Brodie tartan layers into halves, while Figure 8.11 (a-c) shows their division and sub-division of thirds.

It is obvious that the stripes are marked by the third time division lines in Figure 8.10 a. In Figure 8.10 b, the stripes are positioned at the second time division lines. In Figure 8.10 c the stripes coincide with the second time and the third time division lines.

The check unit of Brodie tartan can also be divided successively as shown in Figure 8.11 (a-c). A first division (shown in solid line in Figure 8.11) divides the square unit into nine equal sections. A second division (shown as broken line 2 in Figure 8.11) divides one square section, of the first division, into nine equal smaller squares. A third division (shown in broken line 3 in Figure 8.11) further divides the second-division squares.

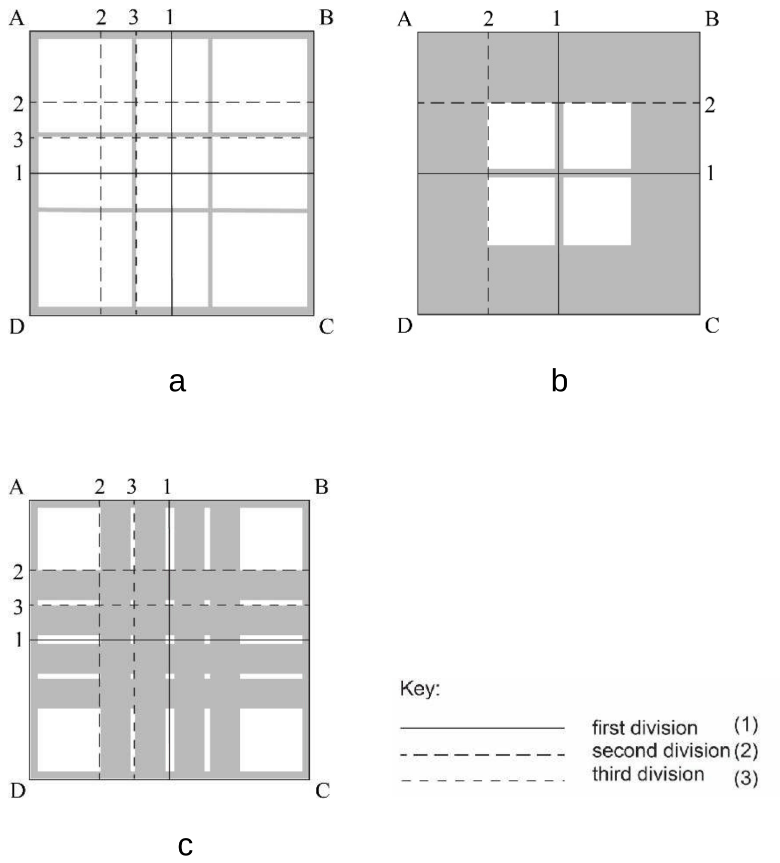


Figure 8.1 0 The division into halves of Brodie tartan layers

Source: Drawn from Figure 5.7

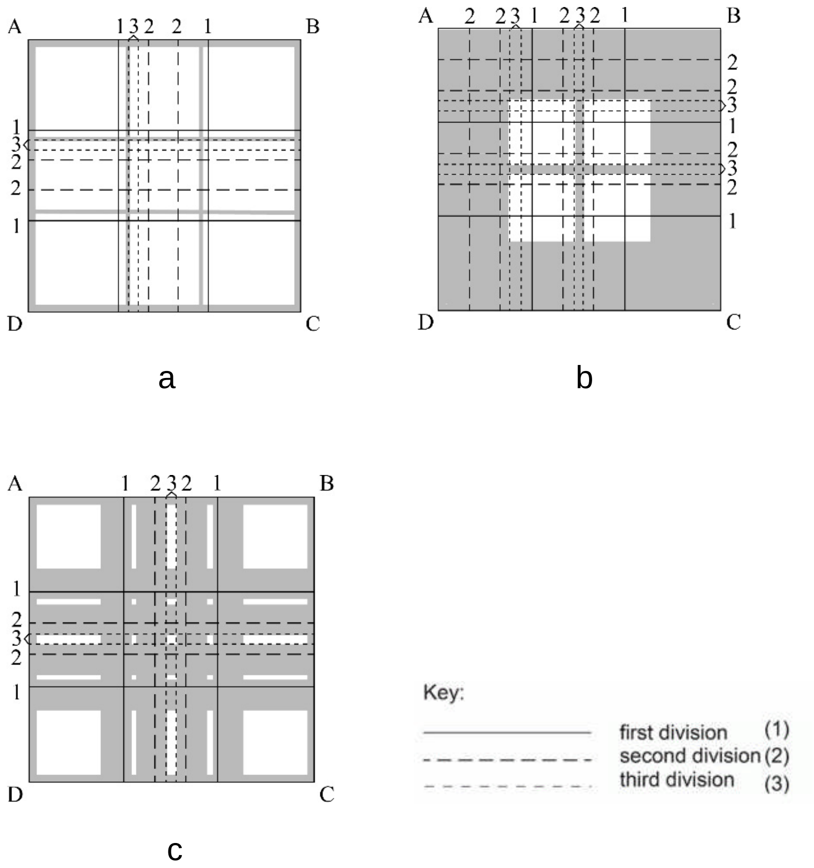


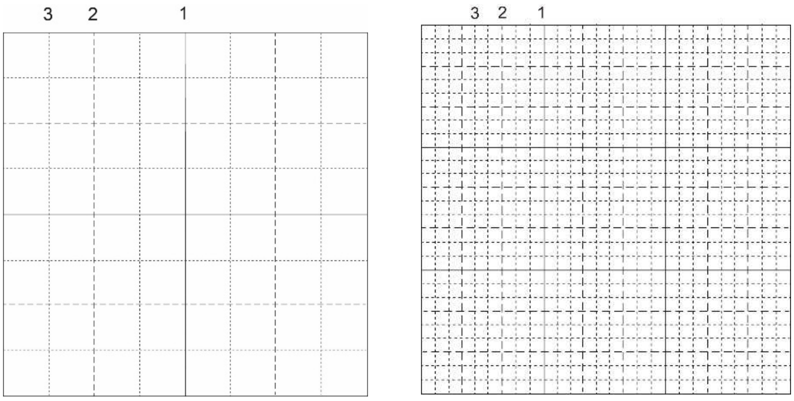
Figure 8. 1 1 The division into thirds of Brodie tartan layers

Source: Drawn from Figure 5.8

Figure 8.12 a illustrates the framework of the division into halves, in which, a square space has been divided into halves in both vertical and horizontal directions. A first time division (shown in a continuous line and marked ‘1’ in Figure 8.12 a) divides the square unit into four equal sections. A second time division (shown as broken line 2 in Figure 8.12 a) divides one square section, of the first division, into four equal smaller squares. A third time division (shown in broken line 3 in Figure 8.12 a) further divides the second-division squares.

Figure 8.12 b illustrates the framework which is divided successively into thirds as shown in Figure 8.12 b. A first division (shown in continuous line in Figure 8.12 b) divides the square unit into nine equal sections. A second division (shown as broken line 2 in Figure 8.12 b) divides one square section, of the first division, into nine equal smaller squares. A third division (shown in broken line 3 in Figure 8.12 b) further divides the second-division squares.

Figure 8.13 shows the overlapping grids of the frameworks of the division into halves and the frameworks of the division into thirds.



a b

Figure 8. 1 2 The frameworks of the division into halves (a) and thirds (b)

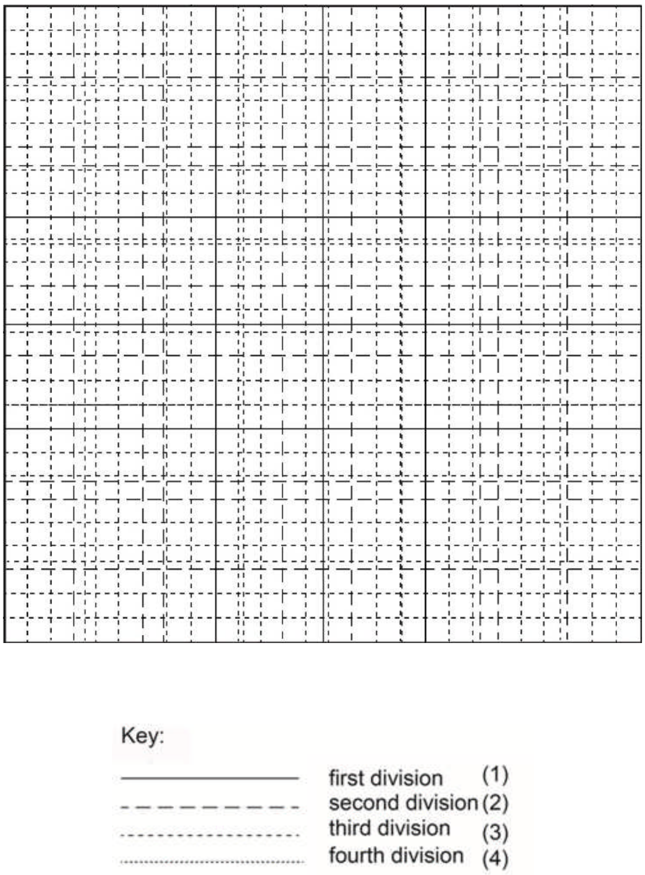


Figure 8. 1 3 The frameworks of combination grids of the division into halves and thirds

The frameworks found in this case study provided the systematic ways in division of space. The division and sub-division of halves and thirds maybe benefit for the symmetry analysis for the textile pattern design.

8.2.4 Analytical framework for case study group number 4 – Posters

The application of geometry, can be found in the composition of paintings (Bouleau, 1980, p.39), posters and various design works.

The key literature regarding to poster layout construction methods includes: Popovitch (1924); Ogden (1937); Bouleau (1980); Mayeux (1889); Coyne, Snodgrass and Martin (1994); Erickson (1986); Birkett and Jurgenson (2001); Bartlett (2007); Erickson (1986); Patricios (1973); March and Steadman (1974); Hildner (1999); Frank (2008); Dwyer (2001); Clauser (1988); Guilmain (1985 and 1987); Peden (2004); Hann (2012); Behrens (1998); Elam (2001).

The hypothesis of the following research is that although the appearance and the themes of the posters are all different, some basic geometric constructions and proportions maybe found underlying most of the cases, which can provide harmony between the parts and whole of a poster.

This case study group selected a total number of 46 posters from relevant museums' online collection in New York and London, which also fits in the time period between1980-2016. Precisely, 23 posters are selected from Museum of Modern art (New York); 17 posters from TATE Modern (London); 4 posters from Metropolitan Museum of Art (New York) and 2 posters from The British Museum (London).

Frameworks found in this case study include 9, 12, 16 grids; 4, 6 grids; 2, 3, 5 grids; 4, 6, 9 grids; 8- point star; Brunes- star- type grid proportions; Brunes star; circular proportion; diagonal grid, DIN; golden diagonals division; golden triangle; golden rectangle; golden section division; golden spiral; halving the square; Le Corbusier's grids; modular grid; overlapping squares and diagonals; root 2 rectangle; root 2 square progression; square grids; square scale and rotation and sacred-cut.

Among them, the most common frameworks are square modular grids; Brunes- star- type grid proportions; golden-section division grids; the Brunes-star and the overlapping square. These are illustrated in Figure 8.14-8.18.

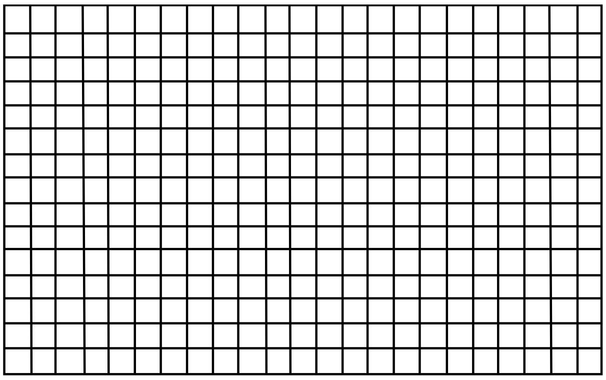


Figure 8.1 4 The square modular grids

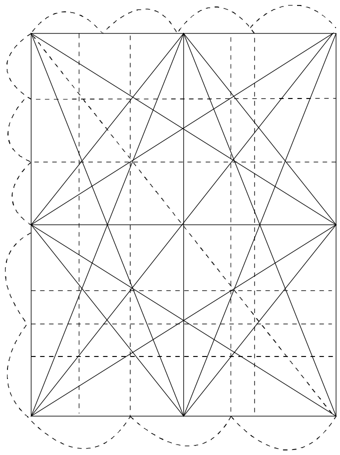


Figure 8.1 5 Brunes-star-type grid proportions

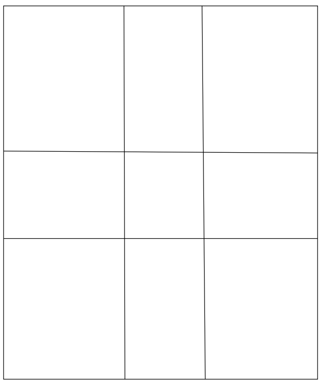


Figure 8.1 6 The golden-section division grids

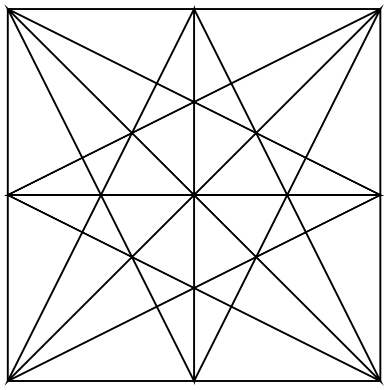


Figure 8. 1 7   The Brunes-star

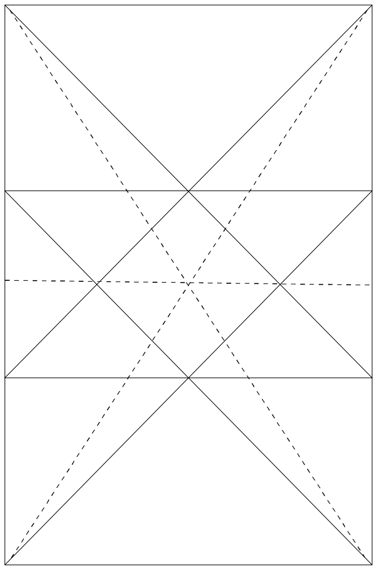


Figure 8. 1 8   The overlapping square

The frameworks found in this case study provided the space division possibilities without measurements. The frameworks generated from this case study may be of benefit for symmetry analysis in visual arts and design in general.

8.2.5 Analytical framework for case study group number 5 – Web-pages

Grids have long been used as an effective method to solve design problems. It can be seen in different design disciplines, such as newspaper layouts, magazine layouts, book pages, interior design and architectural structure.

Key literature includes: Landa (2014); Samara (2003); Hurlburt (1978); Jute (1996); Brockmann (2008); Elam (2001 and 2004); Hayes (2006); Ferland (2014); Roberts and Thrift (2002); Hann (2012); Baron (2002); Weinman (2003); Puneil, Bergman, Schein, Barkol (2009); Song, Liu, Wen, Ma (2004) and http://960.gs [Accessed 30 October 2014].

This case study aims to find common division methods, especially grids, and this was the focus when analyzing FTSE 100 (the 100 largest companies listed in the London stock exchange) homepage layouts. A total of 92 out of 100 web home pages were selected from http://shareprices.com/ftse100 [Accessed 14 October 2014]. Then each site's home-page was accessed and downloaded.

The analytical framework used for web home page layouts took into account space division methods using grids. Column grids were found to be of special importance in web-page layout design. Among them, the 12-column (Figure 8.19), 16 – column (Figure 8.20) and 24 - column grids (Figure 8.21) were found to be common guide lines in web-page layout division. Furthermore, mixed grids structure (Figure 8.22) and narrow columns grid (Figure 8.23) were also found used commonly as guidance of web-page layout.

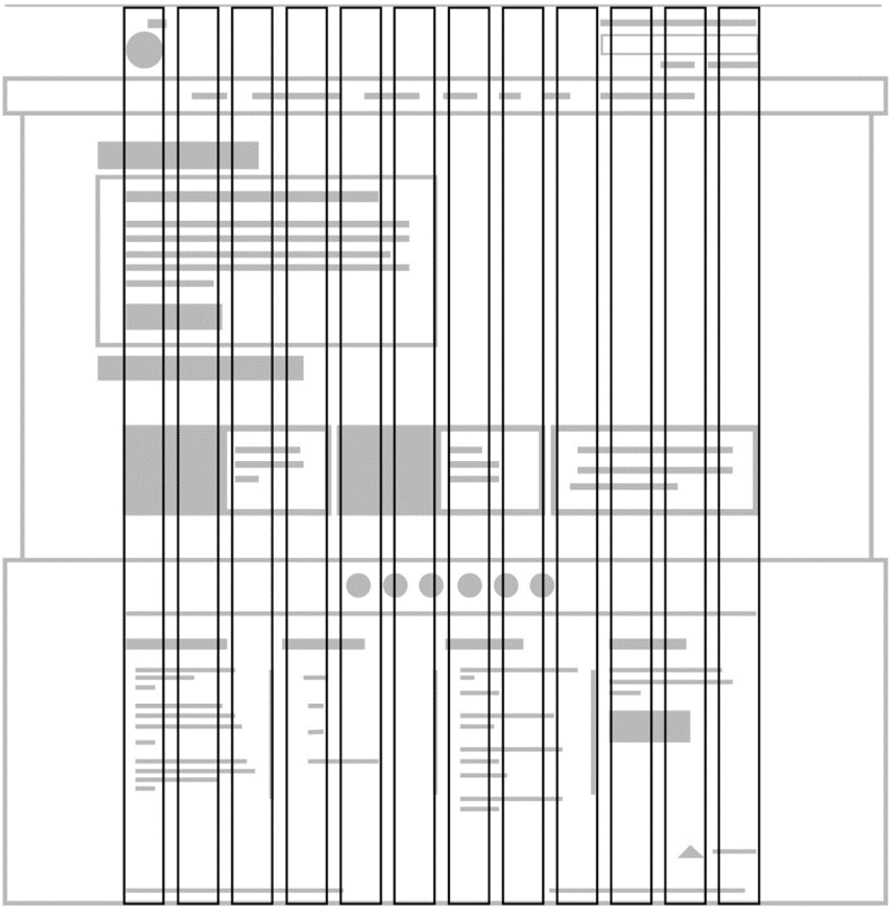


Figure 8.1 9 The 12-column grids on the BP home page

Source: Drawn from Figure 7.26

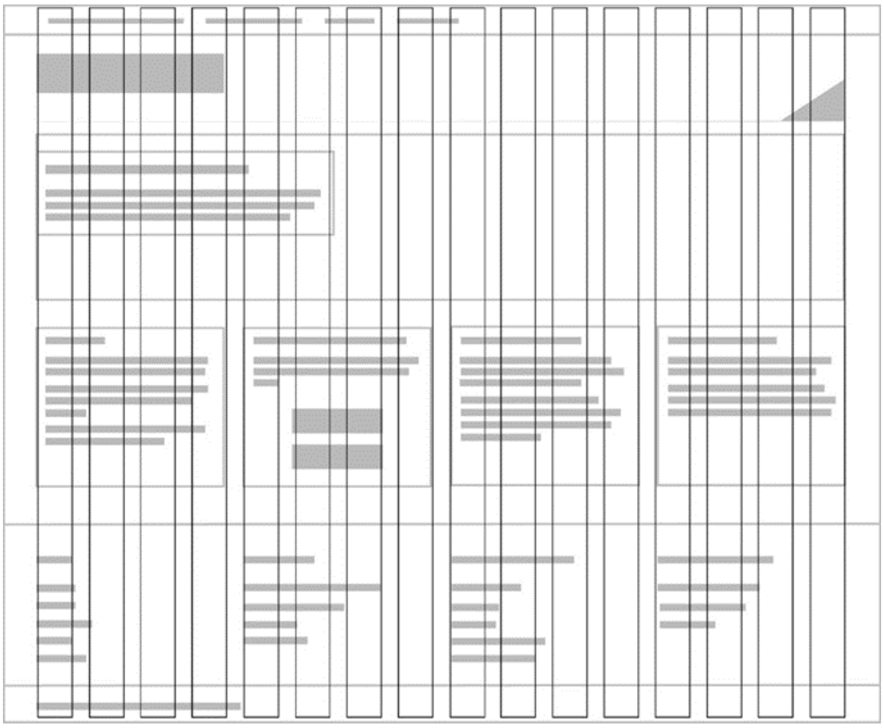


Figure 8. 2 0 The 16-column grids on the Friends Life Group home page

Source: Drawn from Figure 7.28

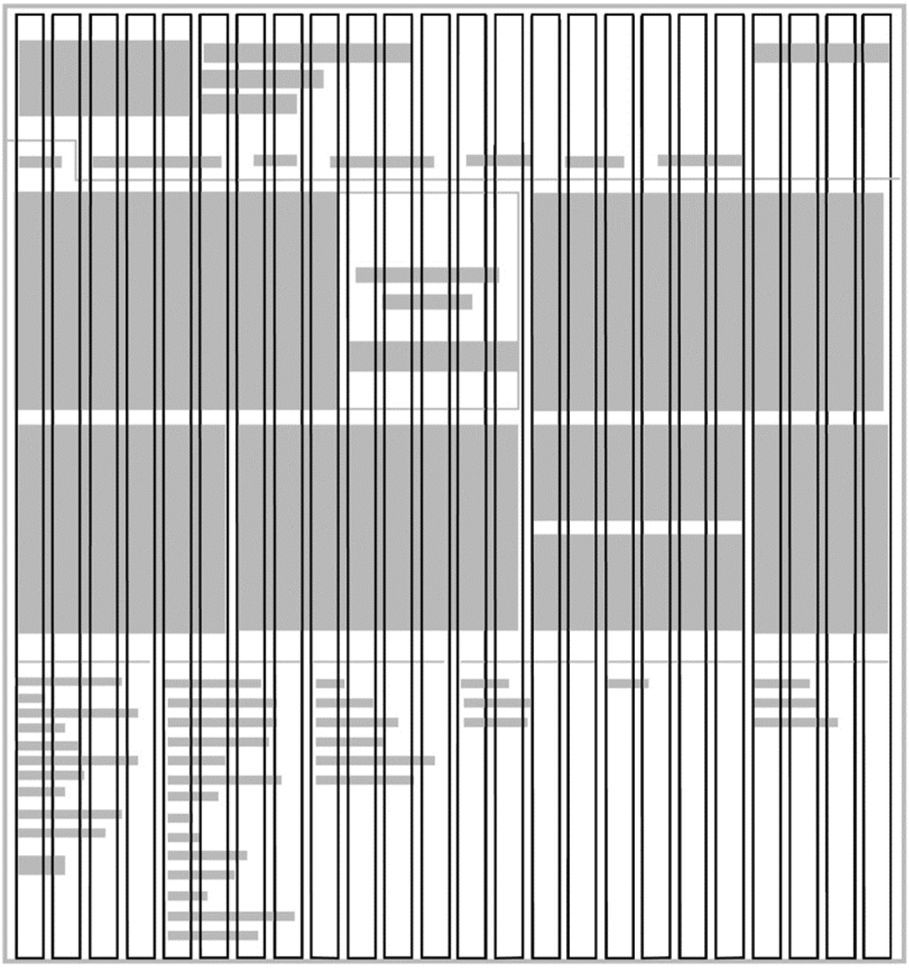


Figure 8. 2 1 The 24-column grid on the International Consolidated Airlines Group home page

Source: Drawn from Figure 7.30

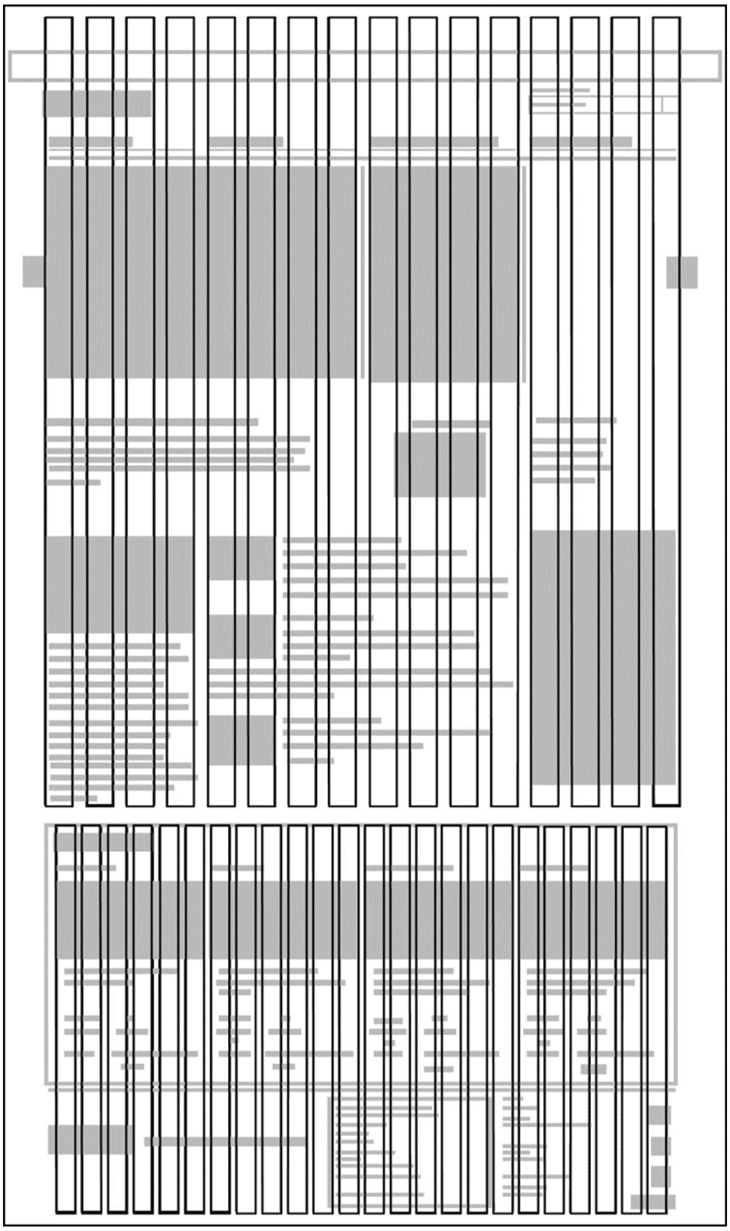


Figure 8. 2 2   The 16 and 24-column grid on the GKN Group home page

Source: Drawn from Figure 7.32

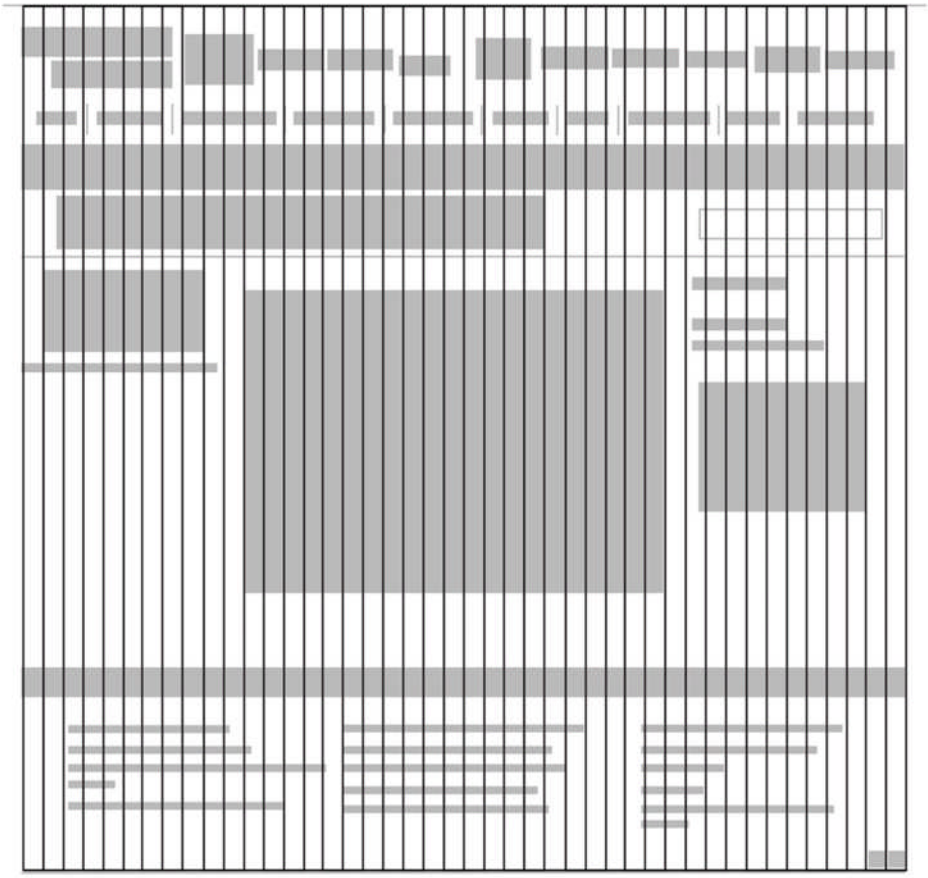


Figure 8. 2 3 The narrow column grids on the Admiral Group home page

Source: Drawn from Figure 7.34

The12-column grid, 16-column grid, 24-column grid and the narrow-column grid are illustrated in Figure10.25-10.28

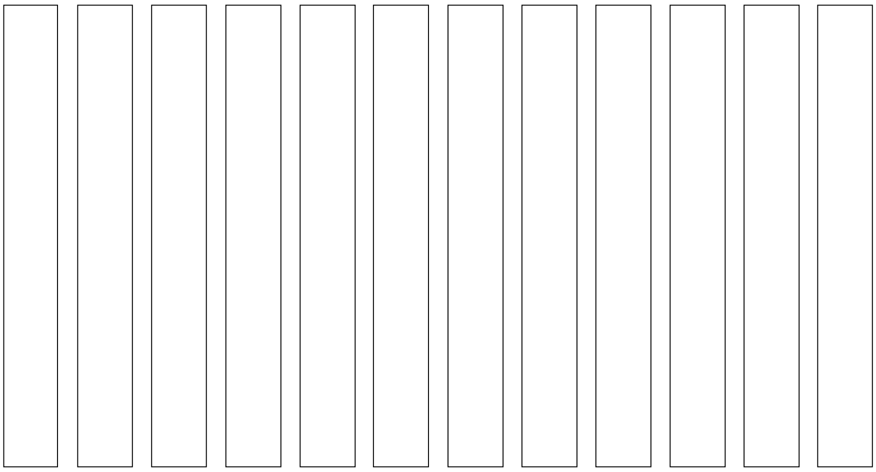


Figure 8. 2 4 The 12-column grid

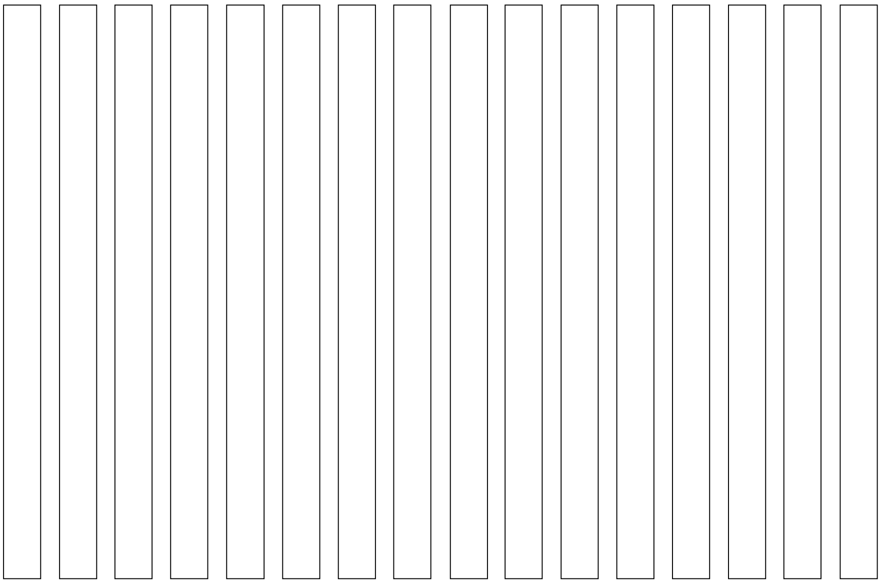


Figure 8. 2 5 The 16-column grid

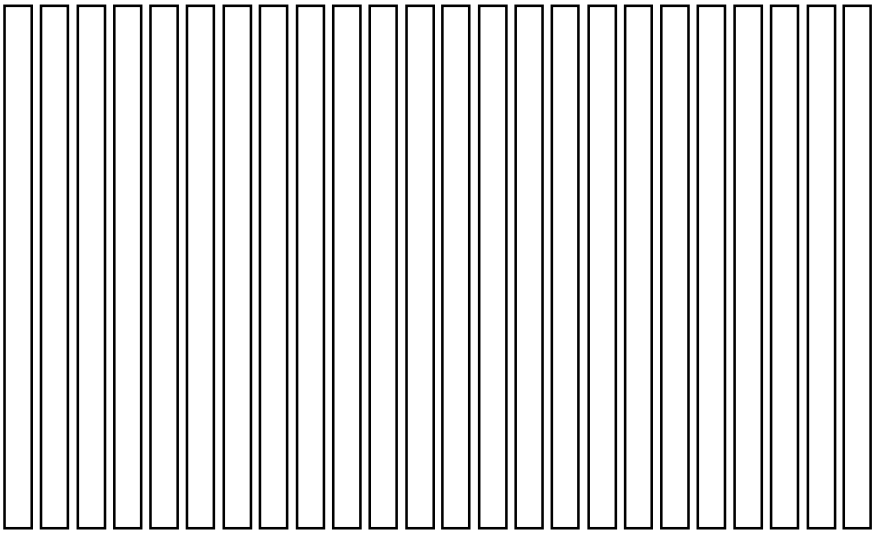


Figure 8. 2 6 The 24-column grid

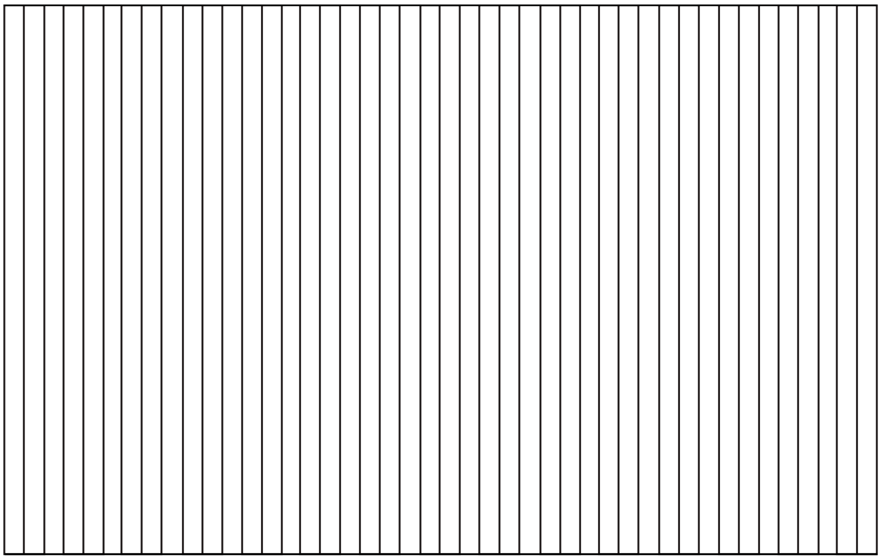


Figure 8. 2 7 The narrow-column grid

The frameworks found in this case study are 12, 16 and 24-column grids. Different combination of the columns can generate different proportional sections. This may be of benefit to book, magazine or even posters' layout design.

8.3 Possible application areas of the frameworks

Analytical frameworks could be suggested based on five case study groups. Each case has been examined and analyzed in depth. Although the frameworks summarized in section 8.2 do not fit 100 percent accurately on every case, they still govern the structure of the layout in most cases in each case group.

These analytical frameworks can be applied in wider sample sizes or in a wider range of design areas. By means of a wider sample size, for example, although this study already tried to include various selected web-site home pages, it would be still interesting to see whether the same frameworks as well as the proportions still govern the inner page of further web-sites. This would enlarge the sample sizes and comparison research may be possible.

In terms of the wider range of design areas, for example, the framework dominating in these case study groups may also dominate in proportion in building facades, photographs, carpets design and even in logo designs.

8.4 Summary

This chapter suggested frameworks for analysts, based on the findings of previous five case studies groups. Various space division methods were suggested, illustrated and explained .The research suggested that almost all design works are not made randomly, rather they follow certain rules. Some of the common geometric space division methods and proportions were even found across the case groups. The framework developed in this study may also benefit pattern designers, painters, graphic designers, architects as well as mathematics or geometry research and application.

Chapter 9 : Conclusions

This chapter includes a brief discussion relating to the fulfilment of the aims and objectives; the contribution of the research; the limitation of the research and the recommendation for the future work.

9.1 The fulfilment of research aims and objectives

The aim of this research is to explore the persistence of geometric constructions and focuses on related issues such as proportion in the visual arts, design and architecture in both historical and modern contexts. Accordingly, four objectives are designed to achieve the research aim:

- To identify the characteristics of geometric structures in two-dimensional designs.

- To explore the different functions of geometric structures in different design practices and to ascertain (for example) the circumstances when a geometric structure may provide a (hidden) guideline in the final composition or construction, or may appear as part of the design outcome.

- To establish the relationship between the characteristics of the geometric structures and their functions (e.g. if a hidden structure, how does it enable or help composition and, if part of the final design, does it have particular geometric characteristics?)

- To improve the understanding of how geometrical principles relate to space division in two-dimension design.

The first objective was dealt with in chapter 2, as this chapter reviewed the fundamental geometric concepts associated with two-dimensional designs. The geometric characteristics of structural frameworks was reviewed, including regular polygons and their derives, the common types, combinations as well as the actual functions of two dimensional grids. Further related geometric principles such as symmetry and proportion were reviewed also.

The second objective was addressed in the analytical methods revision in chapters 3, 4, 5, 6 and 7, precisely including section 3.3, 4.3, 5.3, 6.3 and 7.3. These sections review of the functions of certain geometric structures and the common proportions generated by them in the area of human body proportion, architecture, textiles, graphic design and interface design.

The third objective was addressed in the actual analysis of each case study. Examples were given in sections 3.4, 4.4, 5.4, 6.4 and 7.4.Through the actual analysis of the cases, the relationship between the characteristics of the geometric structures and their functions were observed, studied and summarized.

Chapter 8 fulfilled the fourth objective by summarizing the space division methods associated with each case study group and a range of frameworks of value to design analysts is proposed. Each case study can be considered to yield a unique framework of value to analysts considering similar case study material.

9.2 The contribution to knowledge

This thesis contributed to a better understanding of how geometric constructions function as (hidden) guidelines in design practice. In order to achieve this, this research has adopted a qualitative research approach underpinned by case study research based on the criteria of geometrical analysis. The thesis has explained why geometry structures are powerful compositional aids and has been based on large amounts of literature review along with actual case analysis. It further demonstrated that certain dynamic proportions and space division methods derived from them are of value to analysts as a range of frameworks is proposed.

This research intends to be helpful for scholarly and practical debates. Novel analytical methods are developed in all case study groups, It tried to extend the knowledge of how geometric constructions function as design aids even without measurements. Furthermore, certain space division methods and proportions are found frequently used in more than one design discipline, which indicates that certain proportions are more preferred by human eyes than others.

In this work, an effort has been made to conduct an in-depth study into how design works. It is not only an opportunity to understand the relationship between design and science, but also an important opportunity for further achievement in the area of visual art, graphic design, textiles, architecture and interface design.

The contributions from chapter 2 to chapter 8 are summarized as follows:

Chapter 2 reviews the fundamental geometric concepts associated with design. Including the geometric characteristics of structural frameworks and related geometric principles, which provides a comprehensive understanding on how geometric constructions function as (hidden) guidelines in design practice.

Chapter 3 proposed a novel 15-grid system based on the division of three was in order to study proportions of terracotta warrior standing figures. Previous literature of square grids used in ancient Egyptian paintings, ancient Greek sculptures and Assyrian sculptures provide the theoretical basis.

Chapter 4 found out that cathedral floor plans were likely to be constructed based on a square (the overlapping square of the nave, choir and transepts). Further to this, whole floor plans can be constructed by applying some simple geometric principles such as golden-section rectangles; modular shapes; sacred cut as well as root rectangles.

Chapter 5 indicated that tartan threads in a given colour were arranged at half way and/or quarter way and/or eighth way line divisions, both vertically and horizontally, within the repeat unit, meanwhile, third-way divisions and sub-divisions (at one sixth or one twelfth) of the repeat unit were common, which have a great influence on the proportions evident in the relevant tartan check designs.

Chapter 6 suggested some simple methods which have been used in poster design based mainly on the use of square derivative constructions, which can form the construction basis of the whole design without any further measurements.

Chapter 7 found two types of unusual web-page division methods: mixed-grid structure and narrow-grid columns in addition to the 12-column, 16 column as well as 24-column methods by analysing 92 web home pages selected from the FTSE100 (the top 100 companies in the London stock exchange). Horizontally web-pages are most likely to be divided into three, four and five sections and the most common proportions between the divisions in both horizontal and vertical directions are 1:1, 1:2, 2:3, 1:3 and 1:4.

Chapter 8 presents summaries of the space division methods associated with each case study group and identifies a range of frameworks of value to design analysts. Each case study can be considered to yield a unique framework of value to analysts considering similar case study material.

9.3 The limitation of the research

This section addresses the limitations of the research, especially the needs of definition, data, methods and findings.

In terms of a two-dimensional design research boundary, there is no clear definition about how many sub-categories belong to two-dimensional design, as long as the design (or material) only has length and width (but not depth), it is considered as two-dimensional. This creates difficulties for data selection.

Ten case study groups are initially selected for the purpose of this study, however, due to the time limitation, it is impossible to study all of them. Eventually, only five case study groups were further selected. Furthermore, the main concern in data collection is on the basis of information publicly available and valid. Official web-sites and published books are the main sources of the data collection in this research. It is almost impossible to check the original design works and to conduct measurements. Thus slight distortions in the data are expected.

In terms of research methods, this research has adopted a qualitative research approach underpinned by case study research based on the criteria of geometrical analysis. Limitations exist in the data collection and analysis process. Furthermore, most analytical methods for the case studies are developed based on the previous literature. Mistakes may have been generated.

The limitation of time, data selection and research methods induce the limitation of the research findings. The limitation on analysis of data may induce limitations for theory generalization.

9.4 Recommendations for further work

This section outlines some recommendations for future work.

- Expanding the analytical method

This research developed a range of novel analytical methods in all case study groups. It tried to extend the knowledge of how geometric constructions function as design aids even without measurements. The findings will benefit analytical work in the area of visual art, graphic design, textiles, architecture and interface design.

- Expanding the sample scope

This research focused on studying the space division methods largely in two-dimensional design, and all the cases selected are somehow in a square/ rectangular frame. The common division methods and proportions may be suitable for designs with circular or other shapes of frame as well, where distortions of the division lines may be shown when the shapes of frame of the design works are changed.

- Expanding the research scope

Again, the initial aim limited the research to largely two-dimensional design. It would be interesting to expand the research scope into three-dimensions. For example, in two-dimensional design, grids can be formed by equilateral triangles, squares and regular hexagons. In terms of three-dimensional, the grid unit could be a tetrahedron, cube, or hexagon, each creates a three-dimensional lattice.

- Frameworks for designers

This research presents summaries of the space division methods associated with each case study group and a range of frameworks of value to design analysts is proposed towards the end. The findings of this research may benefit practitioners as well. Further frames can be development to provide further guidance for designers and practitioners.

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Appendix A

Table 3.1 Relationship between the key points and the proposed grid division lines

Serial number		Width (Units)	Line 15	Line 14	Line 13
T1G2					
8		5	Hairline	Bottom nose	Junction of neck and shoulder
22		5	Hairline		Junction of neck and shoulder
23		4.5	Hairline	Bottom nose	1/2 grid below the junction
39		5	Hairline	Bottom nose	Junction of neck and shoulder
T1G3					
6		almost 5	Hairline		Junction of neck and shoulder
7		5	Hairline		Junction of neck and shoulder
13		4.5	Hairline		Junction of neck and shoulder
T1K					
17		5	Hairline	Bottom nose	1/2 grid below the junction
72		4.5	Hairline	Bottom nose	Junction of neck and shoulder
74		5.5	Hairline		Close to junction of neck and shoulder
155		5	Hairline	Bottom nose	Junction of neck and shoulder
T2G2					
97		5.5	Hairline		Junction of neck and shoulder
T10G5					
3		5.25	Hairline		Junction of neck and shoulder
6		4.5	Hairline		Junction of neck and shoulder
12		6	Hairline		Close to junction of neck and shoulder
15		5.5	Hairline		1/4 grid above the junction
T10G6					
35		6	Hairline	Bottom nose	1/2 grid below the junction
T10G7					
10		almost 5	Hairline		Junction of neck and shoulder
T10K					
98		5	Hairline		Junction of neck and shoulder
105		5	Hairline	Bottom nose	Junction of neck and shoulder
111		5and a bit over	Hairline	Bottom nose	1/4 grid below the junction
T19G9					
2		5.25	Hairline		Close to junction of neck and shoulder
3		5	Hairline	Bottom nose	1/2 grid below the junction
16		almost 5	Hairline	Bottom nose	Close to junction of neck and shoulder
T19G10					
2		4.5	Hairline	Bottom nose	Junction of neck and shoulder
12		5	Hairline		1/4 grid below the junction
14		5.5	Hairline		Close to junction of neck and shoulder
17		5	Hairline	Bottom nose	Close to junction of neck and shoulder
24		almost 6	Hairline		Junction of neck and shoulder
25		5	Hairline	Bottom nose	Close to junction of neck and shoulder
31		5.5	Hairline		Junction of neck and shoulder
T19K					
139		4.5	Hairline		Junction of neck and shoulder
T20G9					
58		5	Hairline		Junction of neck and shoulder
T20G10					
88		almost 5	Hairline	Bottom nose	Junction of neck and shoulder
98		4	Hairline		Junction of neck and shoulder

Continued in the next page

Serial number		Line 11	Line 9	Line 8	Line 4	Line 0
T1G2						
8		Nipples		Small of the back	Top knee	Sole of the feet
22		Nipples	Small of the back		Top knee	Sole of the feet
23			Small of the back		Top knee	Sole of the feet
39		Nipples	Small of the back		Top knee	Sole of the feet
T1G3						
6		Nipples	Small of the back		Top knee	Sole of the feet
7		Nipples	Small of the back		Top knee	Sole of the feet
13		Nipples	Small of the back		Top knee	Sole of the feet
T1K						
17		Nipples	Small of the back	Bottom of belt	Top knee	Sole of the feet
72		Nipples	Small of the back	Top of belt	Top knee	Sole of the feet
74			Small of the back		Top knee	Sole of the feet
155		Nipples		Small of the back	Top knee	Sole of the feet
T2G2						
97		Nipples	Small of the back		Top knee	Sole of the feet
T10G5						
3		Nipples	Small of the back		Top knee	Sole of the feet
6		Nipples	Small of the back		Top knee	Sole of the feet
12			Small of the back		Top knee	Sole of the feet
15		Nipples	Small of the back		Top knee	Sole of the feet
T10G6						
35			Small of the back		Top knee	Sole of the feet
T10G7						
10		Nipples	Small of the back		Top knee	Sole of the feet
T10K						
98			Small of the back	Top of belt	Top knee	Sole of the feet
105		Nipples	Small of the back	Bottom of belt	Top knee	Sole of the feet
111		Nipples	Small of the back	Bottom of belt	Top knee	Sole of the feet
T19G9						
2		Nipples	Small of the back		Top knee	Sole of the feet
3			Small of the back		Top knee	Sole of the feet
16		Nipples	Small of the back		Top knee	Sole of the feet
T19G10						
2		Nipples	Small of the back		Top knee	Sole of the feet
12			Small of the back		Top knee	Sole of the feet
14		Nipples	Small of the back		Top knee	Sole of the feet
17			Small of the back		Top knee	Sole of the feet
24		Nipples	Small of the back		Top knee	Sole of the feet
25		Nipples	Small of the back		Top knee	Sole of the feet
31		Nipples	Small of the back		Top knee	Sole of the feet
T19K						
139		Nipples	Small of the back		Top knee	Sole of the feet
T20G9						
58		Nipples	Small of the back		Top knee	Sole of the feet
T20G10						
88		Nipples	Small of the back		Top knee	Sole of the feet
98		Nipples	Small of the back		Top knee	Sole of the feet

Appendix B

Table 4.1 The summary of analysis methods in each case

Name / Methods	Ad quadratum	Brunes star	Golden rectangle	√2 rectangles	√5 rectangles	Root rectangles
Chester Cathedral	6		2	1		2
Christ Church Cathed	6		2	1		2
Durham Cathedral		2	2	2		
Ely Cathedral			4			
Exeter Cathedral				1		
Lincoln Cathedral			6			
Norwich Cathedral			1	3		
Peterborough Cathedral		2				
Ripon Cathedral			5	2		
Salisbury Cathedral			3	1		1
Southwark Cathedral			2	2		
St Albans Cathedral			2	1		1
St Giles' Cathedral			3	1		2
St Michael's of Coventry				1		1
St Paul's Cathedral		1	1	2	1	2
Wells Cathedral				3		1
Westminster Cathedral			1	2		
Winchester Cathedral			2	1		
Worcester Cathedral			1	4		2
York Minster			3	1		

Table 4.2 The summary of analysis methods in each case

Name	Methods	Sacred cut	Grids	Overlapping	Pentagons	Overlapping squares	Modular
Chester Cathedral		2	1				5
Christ Church Cathedral		2				1	3
Durham Cathedral		2					5
Ely Cathedral		1				1	6
Exeter Cathedral			1				5.5
Lincoln Cathedral			1				
Norwich Cathedral							5
Peterborough Cathedral		1					
Ripon Cathedral							
Salisbury Cathedral		2					7
Southwark Cathedral							3
St Albans Cathedral		2					6
St Giles' Cathedral							3
St Michael's of Coventry							
St Paul's Cathedral		5				2	4
Wells Cathedral		2					7
Westminster Cathedral		2				1	8
Winchester Cathedral		1					6
Worcester Cathedral							5
York Minster							4

Appendix C

Table 6.1 Summary of the poster analysis methods

Number	Name of the posters	9 12 16	4 6 grids	235 grids	469 grids	8 point star
1	SMCS Program Poster	1				
2	Punctuation					
3	Feltron Annual Reports					
4	Morisawa 10 Poster					
5	X, Poster Celebrating 10th Anniversary of "Tategumi Yokogumi" Magazine					
6	Shiseido Commemorative Poster	1				
7	Poster Celebrating 10th Anniversary of "Tategumi Yokogumi" Magazine					
8						
9	AIGA LA Presentation Poster					
10	Texas AIGA Presentation Poster					
11	Use a Condom/ Bunnies					
12	Just Say No					1
13	The Diva is Dismissed					
14	Poster for the Play "Propaganda"					
15	The Modern Poster, The Museum of Modern Art, New York					
16	The Modern Poster, The Museum of Modern Art, New York					
17	GBH, French tour poster					
18	Public Image, North American Tour Poster					
19	Poster for the magazine TENRI					
20	Poster for No Wave Festival in Bologna					
21	Poster for No Wave Festival in Paris					
22	Women Against Apartheid	diagnal lines				
23	Psie Serce (Heart of a Dog)		1			
24	Brat Naszego Boga					
25	Museum for Post and Communication, Nuremberg					
26	Ein Monument für die Zukunft. Museum Kurhaus Kleve		1	1		
27	Kleine Zeichnungen. Museum Schloss Moyland					
28	Art For Life's Sake. Kawamura Memorial Museum of Art	1				
29	Heraus - Forderung Tier. Städtische Galerie, Karlsruhe					
30	das xx. jahrhundert ein jahrhundert kunst in Deutschland. Stadtraum, Berlin					
31	Guerrilla Girls' Definition Of Hypocrite					
32						
33	Do Women Have To Be Naked To Get Into the Met. Museum?					
34	Women In America Earn Only 2/3 Of What Men Do					
35	Guerrilla Girls Review The Whitney				1	
36	Women Artists In The Andy Warhol And Tremaine Auctions At Sotheby's					
37	It's Even Worse In Europe					
38	You're Seeing Less Than Half The Picture					
39	Hidden Agender/Passing The Bucks					
40	John Russell Thinks Things Are Getting Better For Women Artists					
41	We Sell White Bread					
42	Happy					
43	Let's Promote a great Surge in Coal Production, Let's Build a Strong Native Land, All Sorts of Vegetables					
44	Associated Event: Vietnam-Chinese War					
45	Figure in Front of Mantel					
46	A Masterpiece					
47	The Most Important in the World					
48	Lake George	1				
	Total	4	2	1	1	1

Continued in the next page

Number	Name of the posters	Brunes star grids proportion			Brunes star	Circular	Diagonal grid	DIN
1	SMCS Program Poster		1		1			
2	Punctuation							
3	Feltron Annual Reports							
4	Morisawa 10 Poster				1			
5	X, Poster Celebrating 10th Anniversary of "Tategumi Yokogumi" Magazine							
6	Shiseido Commemorative Poster							
7	Poster Celebrating 10th Anniversary of "Tategumi Yokogumi" Magazine		1					
8								
9	AIGA LA Presentation Poster					1		
10	Texas AIGA Presentation Poster		1					
11	Use a Condom/ Bunnies							
12	Just Say No							
13	The Diva is Dismissed		1					
14	Poster for the Play "Propaganda"		1					
15	The Modern Poster, The Museum of Modern Art, New York						1	
16	The Modern Poster, The Museum of Modern Art, New York							
17	GBH, French tour poster							
18	Public Image, North American Tour Poster							
19	Poster for the magazine TENRI					1	1	
20	Poster for No Wave Festival in Bologna						1	
21	Poster for No Wave Festival in Paris				1			
22	Women Against Apartheid							
23	Psie Serce (Heart of a Dog)							
24	Brat Naszego Boga		1		1			
25	Museum for Post and Communication, Nuremberg							
26	Ein Monument für die Zukunft. Museum Kurhaus Kleve		1					
27	Kleine Zeichnungen. Museum Schloss Moyland		1					
28	Art For Life's Sake. Kawamura Memorial Museum of Art							
29	Heraus - Forderung Tier. Städtische Galerie, Karlsruhe				1			1
30	das xx. jahrhundert ein jahrhundert kunst in Deutschland. Stadtraum, Berlin		1					
31	Guerrilla Girls' Definition Of Hypocrite							
32								
33	Do Women Have To Be Naked To Get Into the Met. Museum?							
34	Women In America Earn Only 2/3 Of What Men Do							
35	Guerrilla Girls Review The Whitney							
36	Women Artists In The Andy Warhol And Tremaine Auctions At Sotheby's							
37	It's Even Worse In Europe							
38	You're Seeing Less Than Half The Picture							
39	Hidden Agender/Passing The Bucks							
40	John Russell Thinks Things Are Getting Better For Women Artists							
41	We Sell White Bread							
42	Happy							
43	Let's Promote a great Surge in Coal Production, Let's Build a Strong Native Land, All So		1					
44	Associated Event: Vietnam-Chinese War							
45	Figure in Front of Mantel							
46	A Masterpiece							
47	The Most Important in the World							
48	Lake George		1					
	Total		11		5	2	3	1

Continued in the next page

Number	Name of the posters	Golden diagonals		Golden triangle	Golden rec	Golden section divisio		Golden spiral
1	SMCS Program Poster							
2	Punctuation							
3	Feltron Annual Reports							
4	Morisawa 10 Poster							
5	X, Poster Celebrating 10th Anniversary of "Tategumi Yokogumi" Magazine							
6	Shiseido Commemorative Poster				1	1		
7	Poster Celebrating 10th Anniversary of "Tategumi Yokogumi" Magazine							
8								
9	AIGA LA Presentation Poster			1		1		
10	Texas AIGA Presentation Poster							
11	Use a Condom/ Bunnies							
12	Just Say No	1						
13	The Diva is Dismissed							
14	Poster for the Play "Propaganda"							
15	The Modern Poster, The Museum of Modern Art, New York							1
16	The Modern Poster, The Museum of Modern Art, New York							
17	GBH, French tour poster							
18	Public Image, North American Tour Poster							
19	Poster for the magazine TENRI							
20	Poster for No Wave Festival in Bologna							
21	Poster for No Wave Festival in Paris							
22	Women Against Apartheid							
23	Psie Serce (Heart of a Dog)							
24	Brat Naszego Boga							
25	Museum for Post and Communication, Nuremberg							
26	Ein Monument für die Zukunft. Museum Kurhaus Kleve							
27	Kleine Zeichnungen. Museum Schloss Moyland							
28	Art For Life's Sake. Kawamura Memorial Museum of Art							
29	Heraus - Forderung Tier. Städtische Galerie, Karlsruhe					1		
30	das xx. jahrhundert ein jahrhundert kunst in Deutschland. Stadtraum, Berlin				1			
31	Guerrilla Girls' Definition Of Hypocrite							
32								
33	Do Women Have To Be Naked To Get Into the Met. Museum?					1		
34	Women In America Earn Only 2/3 Of What Men Do					1		
35	Guerrilla Girls Review The Whitney							
36	Women Artists In The Andy Warhol And Tremaine Auctions At Sotheby's							
37	It's Even Worse In Europe							
38	You're Seeing Less Than Half The Picture							
39	Hidden Agender/Passing The Bucks							
40	John Russell Thinks Things Are Getting Better For Women Artists							
41	We Sell White Bread							
42	Happy					1		
43	Let's Promote a great Surge in Coal Production, Let's Build a Strong Native Land, All Sorts of Vegetables							
44	Associated Event: Vietnam-Chinese War							
45	Figure in Front of Mantel	1						
46	A Masterpiece	1						
47	The Most Important in the World	1						
48	Lake George							
	Total	4		1	2	6		1

Continued in the next page

Number	Name of the posters		Halving the square		Le Couber	Modular grid	Overlapping squares	Root 2 rec	Root 2 square progression		
1	SMCS Program Poster					1	1				
2	Punctuation					1					
3	Feltron Annual Reports					1					
4	Morisawa 10 Poster								1		
5	X, Poster Celebrating 10th Anniversary of "Tategumi Yokogumi" Magazine					1					
6	Shiseido Commemorative Poster							1			
7	Poster Celebrating 10th Anniversary of "Tategumi Yokogumi" Magazine										
8											
9	AIGA LA Presentation Poster										
10	Texas AIGA Presentation Poster						1				
11	Use a Condom/ Bunnies							1			
12	Just Say No						1				
13	The Diva is Dismissed										
14	Poster for the Play "Propaganda"				1		1				
15	The Modern Poster, The Museum of Modern Art, New York					1					
16	The Modern Poster, The Museum of Modern Art, New York					1					
17	GBH, French tour poster					1					
18	Public Image, North American Tour Poster							1			
19	Poster for the magazine TENRI					1					
20	Poster for No Wave Festival in Bologna					1					
21	Poster for No Wave Festival in Paris										
22	Women Against Apartheid										
23	Psie Serce (Heart of a Dog)										
24	Brat Naszego Boga										
25	Museum for Post and Communication, Nuremberg					1					
26	Ein Monument für die Zukunft. Museum Kurhaus Kleve										
27	Kleine Zeichnungen. Museum Schloss Moyland						1				
28	Art For Life's Sake. Kawamura Memorial Museum of Art					1					
29	Heraus - Forderung Tier. Städtische Galerie, Karlsruhe					1					
30	das xx. jahrhundert ein jahrhundert kunst in Deutschland. Stadtraum, Berlin										
31	Guerrilla Girls' Definition Of Hypocrite					1					
32											
33	Do Women Have To Be Naked To Get Into the Met. Museum?										
34	Women In America E		1								
35	Guerrilla Girls Review The Whitney										
36	Women Artists In The Andy Warhol And Tremaine Auctions At Sotheby's					1					
37	It's Even Worse In Europe					1					
38	You're Seeing Less Than Half The Picture					1					
39	Hidden Agender/Passing The Bucks					1					
40	John Russell Thinks Things Are Getting Better For Women Artists					1					
41	We Sell White Bread					1					
42	Happy					1					
43	Let's Promote a great Surge in Coal Production, Let's Build a Strong Native Land, All Sorts of Vegetables										
44	Associated Event: Vietnam-Chinese War					1					
45	Figure in Front of Mantel										
46	A Masterpiece										
47	The Most Important in the World										
48	Lake George										
	Total		1		1	21	5	3	1		

Continued in the next page

Number	Name of the posters	Square grids	Square scale and rotation			Sacred-cut	Total number of framework applied			
1	SMCS Program Poster			1			8			
2	Punctuation	1					6			
3	Feltron Annual Reports						1			
4	Morisawa 10 Poster						10			
5	X, Poster Celebrating 10th Anniversary of "Tategumi Yokogumi" Magazine						11			
6	Shiseido Commemorative Poster						16			
7	Poster Celebrating 10th Anniversary of "Tategumi Yokogumi" Magazine						15			
8										
9	AIGA LA Presentation Poster						21			
10	Texas AIGA Presentation Poster						22			
11	Use a Condom/ Bunnies						23			
12	Just Say No						27			
13	The Diva is Dismissed						27			
14	Poster for the Play "Propaganda"						31			
15	The Modern Poster, The Museum of Modern Art, New York	1					34			
16	The Modern Poster, The Museum of Modern Art, New York						33			
17	GBH, French tour poster						35			
18	Public Image, North American Tour Poster						37			
19	Poster for the magazine TENRI						41			
20	Poster for No Wave Festival in Bologna						42			
21	Poster for No Wave Festival in Paris						43			
22	Women Against Apartheid						1			
23	Psie Serce (Heart of a Dog)						47			
24	Brat Naszego Boga						50			
25	Museum for Post and Communication, Nuremberg	1					52			
26	Ein Monument für die Zukunft. Museum Kurhaus Kleve						55			
27	Kleine Zeichnungen. Museum Schloss Moyland						56			
28	Art For Life's Sake. Kawamura Memorial Museum of Art						58			
29	Heraus - Forderung Tier. Städtische Galerie, Karlsruhe	1					63			
30	das xx. jahrhundert ein jahrhundert kunst in Deutschland. Stadtraum, Berlin						62			
31	Guerrilla Girls' Definition Of Hypocrite	1					64			
32										
33	Do Women Have To Be Naked To Get Into the Met. Museum?						67			
34	Women In America Earn Only 2/3 Of What Men Do						70			
35	Guerrilla Girls Review The Whitney						71			
36	Women Artists In The Andy Warhol And Tremaine Auctions At Sotheby's	1					74			
37	It's Even Worse In Europe	1					76			
38	You're Seeing Less Than Half The Picture	1					78			
39	Hidden Agender/Passing The Bucks	1					80			
40	John Russell Thinks Things Are Getting Better For Women Artists	1					82			
41	We Sell White Bread	1					84			
42	Happy						86			
43	Let's Promote a great Surge in Coal Production, Let's Build a Strong Native Land, All Sorts of Vegetables					1	88			
44	Associated Event: Vietnam-Chinese War	1					90			
45	Figure in Front of Mantel						91			
46	A Masterpiece						93			
47	The Most Important in the World						95			
48	Lake George						98			
	Total	12		1		1				

Appendix D

Table 7.7 The vertical relationship between main elements and grid units in the 92 cases (this table runs over 7 pages)

Sample number	Page name	Grids number	Page sections	Number of grids occupied	Coloumns generated	Proportions
1	3i group	27	page header	3 18 6	3	1:2 1:3
			page content	9 2 15	2	3:05
				9 9 9	3	1:01
				5 2 6 6	4	1:1 1:3
			page footer	5 11 9	3	
2	Aberdeen Asset Management	24	page header	5 19	2	1:04
			page content	6 6 9	3	2:03
				8 8 8	3	1:01
3	Admiral Group	44	page header	8 36	2	2:09
			page content	9 8 10	3	1:2 1:1 3:7
				13 12 10	3	1:1 5:6
4	Aggreko	12	page header	3 3 3 2 1	4	1:02 2:03 1:3
			page content	3 6 3	3	1:2 1:1
				3 3 3 3	4	1:1
				2 2 2 2 2 2	6	1:1
			page footer	1 8 2	3	1:1 1:4 1:8
5	Anglo American	24	page header	5 15 4	3	1:03
			page content	12 2	2	1:06
				8 8 8	3	1:01
				3 2 2 7 7	5	1:1 2:3 1:3
			page footer	5 19	2	1:04
6	Antofagasta	24	page header	6 2 16	3	1:3 1:8 3:8
			page content	11 13	2	
				14 10	2	7:05
				8 8 8	3	1:01
			page footer	6 2 2 3	4	2:3 1:3 1:2
7	ARM Holdings	82	page header	31 37 14		
			page content	13 4 6 36	5	2:3 1:6 1:3
				45 37		
			page footer	24 49 9	3	3:08
8	Ashtead Group	24	page header	4 14 6	3	2:3 2:7 3:7
			page content	6 12 6	3	1:02
				12 12	2	1:01
			page footer	12 6 6	3	1:02
9	Associated British Foods	66	page header	12 43 11	3	1:01
			page content	28 38	2	
				13 13 13 13 13	5	1:01
				22 22 22	3	1:01
				4 13 4 13…	4	1:03
10	AstraZeneca	22	page header	1 3 19	3	
			page content	4 15 3	3	1:05
				4 6 6 6	4	2:3 1:1
			page footer	4 12 6	3	1:2 1:3 2:3
11	Aviva	12&7				
		12	page header	2 7 3	3	
			page content	3 5 7	3	
				2 2 2 2 2 2	6	1:01
				4 4 4	3	1:01
		7		1 1 1 1 1 2	6	1:1 1:2
12	Babcock International Group	12&7				
		12	page header	3 3 3 3	4	1:01
			page content	4 7 1	3	1:04
				6 6	2	1:01
				3 3 3 3	4	1:01
		7		1 1 1 1 1 1 1	7	1:01
			page footer	1.5 4 1.5	3	3:08
13	BAE Systems	24	page header	2 16 6	3	1:3 1:8 3:8
			page content	9 9 6	3	1:1 2:3
				8 8 8	3	1:01
				11 1 11 1	2	1:01
				8 8 8	3	1:01
			page footer	8 10 6	3	3:4 3:5 4:5
14	BG Group	24	page header	3 3 18 3	4	1:1 1:6
			page content	7 17	2	
				8 8 8 8	4	1:01
			page footer	12 4 6 12	2	1:1 1:2 1:3 2:3
15	BHP Billiton	24	page header	1 10 5 8	2	1:2 4:5
			page content	17 7	2	
				12 12	2	1:01
				6 6 6 6	4	1:01
				6 18	2	1:03
			page footer	12 9 3	3	1:3 1:4 3:4

Sample number	Page name	Grids number	Page sections	Number of grids occupied	Coloumns generated	Proportions
16	BP	12	page header	1 8 3	3	1:03
			page content	6 6	2	1:01
				4 4 4	3	1:01
				3 3 3 3	4	1:01
			page footer	4 4 4	3	1:01
17	British American Tobacco	12	page header	2 2 8	3	1:1 1:4
			page content	8 4	2	1:02
				3 3 3 3	4	1:01
				4 4 4	3	1:01
				3 3 3 3	4	1:01
			page footer	3 7 2	3	2:03
18	British Land Co	12&11				
		12	page header	3 5 2 2	4	1:1 2:3 3:5 2:5
			page content	8 4	2	1:02
				2 7 3	3	2:03
				5 7	2	5:07
				3 3 3 3	4	1:01
		7	page footer	1 1 1 1 3	5	1:1 1:3
19	British Sky Broadcasting Group	43&12				
		43	page header	5 38	2	
			page content	9 11	2	1:01
		12	page footer	2 2 2 2 2 2	6	1:01
20	BT Group	24	page header	8 5 6 5	4	1:1 3:4 5:8
			page content	8 8 8	3	1:01
				4 4 4 4 4 4	6	1:01
21	Bunzl	12 or 24				
		12	page header	1 3 6	3	1:2 1:3
			page content	3 3 6	3	1:02
				4 3 5	3	3:4 3:5 4:5
				4 4 4	3	1:01
				3 3 3 3	4	1:01
				2 3 7	3	2:03
		24	page header	2 6 12	3	1:2 1:6
			page content	6 6 12	3	1:1 1:2
				8 6 10	3	3:4 3:5 4:5
				8 8 8	3	1:01
				6 6 6 6	4	1:01
			page footer	3 7 14	3	1:02
22	Burberry Group	16	page header	2 10 4	3	1:2 2:5 1:5
			page content	2 14	2	1:07
				2 5 4 5	4	1:1 1:2 2:5 1:5
23	Capita	24	page header	4 20	2	1:05
			page content	2 14 8	3	1:4 1:7 4:7
				16 8	2	1:02
				8 8 8	3	1:01
			page footer	13 7 1 3	3	1:02
24	Carnival	24	page header	3 3 7 8 3	5	1:01
			page content	6 9 19	3	1:2 2:3
				3 18 3	3	1:1 1:6
				8 8 8	3	1:01
				6 4 4 5 5	3	1:1 5:6
				3 3 3 3 3 3 2 4	6	1:1 1:2 2:3 3:4
25	Coca-Cola HBC AG (CDI)	64	page header	21 21 24	3	7:08
			page content	37 29	2	
				15 13 12 12	4	4:05
				20 20 20	3	1:01
			page footer	28 19 19	2	
26	Compass Group	6	page header	2 4	2	1:02
			page content	2 2 2	3	1:01
				1 1 1 1 1 1	6	1:01
			page footer	4 2	2	1:02
27	CRH	20	page header	8 2 5 5	4	1:2 5:8
			page content	8 1 7 4	4	1:1 1:2 1:4
				2 3 2 3 2	5	1:1 2:3
			page footer	10 8 2	3	1:4 1:5 4:5
28	Diageo	24	page header	4 6 9 5	4	2:3 4:5
			page content	16 8	2	1:02
				5 6 5 8	4	1:1 3:4
				4 4 4 4 4 4	6	1:01
			page footer	11 3	2	1:04
29	Direct Line Insurance Group	12	page header	3 2 7	3	2:03
			page content	5 7	2	5:07
				8 4	2	1:02
				4 4 4	3	1:01
			page footer	1 2 2 2 2 2 1	5	1:1 1:2
30	Dixons Carphone	12	page header	4 4 4	3	1:01
			page content	1 10 1	3	1:10
				2 6 2 2	4	1:1 1:3
				4 4 4	3	1:01
			page footer	5 3 4	3	3:4 3:5 4:5

Sample number	Page name	Grids number	Page sections	Number of grids occupied	Coloumns generated	Proportions
31	EasyJet	24	page header	2 16 6	3	1:02
			page content	8 11 5	3	1:2 5:8
				8 8 4 4	4	1:1 1:2
				6 6 6 6	4	1:01
				15 9	2	3:05
				4 4 4 3 5	5	3:4 3:5 4:5
				12 12	2	1:01
32	Experian	31	page header	5 2 16 8	4	1:2 2:5 1:8
			page content	13 7 11	3	
				18 13	2	
				7 16 8	3	1:02
				7 3 7 3 11	3	
			page footer	24 7	2	
33	Fresnillo	12	page header	2 1 8 1	2	1:2 1:4
			page content	1 4 7	2	
				4 4 4	3	1:01
			page footer	2 1 6 3	4	1:2 1:3 2:3
34	Friends Life Group	16	page header	4 12	2	1:03
			page content	6 10	2	3:05
				4 4 4 4	4	1:01
				4 4 4 4	4	1:01
			page footer	4 12	2	1:03
35	G4s	24	page header	2 5 5 5	4	
			page content	11 13	2	
				6 6 6 6	4	1:01
				12 12	2	1:01
				8 8 8	3	1:01
				12 12	2	1:01
				16 8	2	1:02
36	GKN	16&24				
		16	page header	3 9 4	3	1:03
			page content	8 4 4	3	1:1 1:2
				4 8 4	3	1:1 1:2
		24		4 20	2	1:05
				6 6 6 6	4	1:01
			page footer	10 1 6 7	3	3:05
37	GlaxoSmithKline	16	page header	2 3 7 14	3	1:2 2:3 1:7
			page content	10 6	2	3:05
				4 4 4 4	4	1:01
			page footer	8 4 4	3	1:1 1:2
38	Hammerson	24	page content	6 2 6 2 5 3	4	1:2 1:3 2:3
				8 8 8	3	1:01
				6 14 4	4	2:03
			page footer	17 2 5	2	2:05
39	Hargreaves Lansdown	12	page header	2 7 3	3	2:03
			page content	3 6 3	3	1:1 1:2
				3 3 3 3	4	1:01
				4 4 4	3	1:01
			page footer	1 10 1	1	1:10
40	HSBC Holdings	11	page header	1 2 8	2	1:2 1:4
			page content	1 6 4	3	2:3 1:4 1:6
				1 9 1	3	1:09
				1 4 5 1	2	4:5 1:4 1:5
				2 2 7	3	2:07
				1 10	1	1:10
				1 4 5 1	2	4:5 1:4 1:5
				1 4 2 2 2	3	1:2 1:4
				1 3 3 3 1	2	1:1 1:3
41	IMI	24	page header	2 3 8 7 4	3	1:3 1:4 2:3
			page content	8 8	2	1:01
				6 10 8	3	3:4 3:5 4:5
42	Imperial Tobacco Group	12 or 16				
		12	page header	2 7 3	3	2:03
			page content	6 6	2	1:01
				3 3 3 3	4	1:01
				6 6	2	1:01
			page footer	6 3 3	3	1:1 1:2
		16	page header	3 9 4	3	1:3 3:4
			page content	8 8	2	1:01
				4 4 4 4	4	1:01
				8 8	2	1:01
			page footer	6 2 2 2 3 1	3	1:2 1:3 2:3
43	InterContinental Hotels Group	24	page header	3 15 6	3	1:3 1:2 3:5
			page content	12 6 6	3	1:1 1:2
				12 12	2	1:01
				8 8 8	3	1:01
				6 6 6 6	4	1:01
			page footer	4 2 2 4 4 2 4 2	4	1:1 1:2
44	International Consolidated Airlines Group	24	page header	11 9 4	3	
			page content	9 5 10	3	1:2
				6 8 6 4	4	2:3 3:4 1:2
				4 4 4 4 4 4	6	1:01

Sample number	Page name	Grids number	Page sections	Number of grids occupied	Coloumns generated	Proportions
45	Intertek Group	68	page header	1 8 3 56	2	1:3 1:7
			page content	3 18 3512	4	1:4 2:3
				24 28 16	3	2:3 6:7 4:7
46	Intu Properties	24	page header	5 19	2	
			page content	1 11 12	3	
				8 8 8	3	1:01
				6 6 6 6	4	1:01
			page footer	1 10 11	3	1:10
47	Johnson Matthey	16	page header	7 9	2	
			page content	4 4 4 4	4	1:01
			page footer	3 3 10	2	
48	Kingfisher	10&24				
		10	page header	2 6 2	3	1:1 1:3
			page content	2 4 2 2	4	1:1 1:2
				2 8	2	1:04
				4 6	2	2:03
		24		6 6 6 6	4	1:01
			page footer	4 2 3 5 8 2	3	1:1 1:2 2:3 3:5 5:8
49	Land Securities Group	6	page header	3 3	2	1:01
			page content	4 1 1	3	1:1 1:4
50	Legal & General Group	19	page header	2 12 5	3	1:06
			page content	1 10 8	3	4:05
				7 7 5	3	5:07
				13 1 5	3	
				14 5	2	
				1 2 3	3	1:2 1:3
			page footer	2 15 2	3	1:1 1:7
51	Lloyds Banking Group	12	page header	3 1 4 1 3	3	1:1 3:4
			page content	1 4 7	3	
				4 4 4	3	1:01
				3 3 3 3	4	1:01
				4 4 4	3	1:01
				6 6	2	1:01
52	Marks & Spencer Group	12	page header	2 3 5 2	4	1 :1 2:3 2:5 3:5
			page content	6 6	2	1:01
				4 4 4	3	1:01
				2 2 2 2 1 3	3	1:1 1:2 1:3
			page footer	5 2 5	3	1:1 2:5
53	Meggitt	24	page header	6 1 17	3	
			page content	6 1 10 1 6	3	1:1 3:5
				6 1 5 5 5 1	4	1:5 5:6
54	Mondi	25	page header	4 7 8 6	4	1:2 1:3 2:3
			page content	1 6 2 4 1 4 8	4	1:1 1:2 2:3 3:4
				1 11 110 2	2	1:2 1:5
				6 6 1 6 6	4	1:1 1:6
				5 5 5 5 5	5	1:01
55	Morrison (Wm) Supermarkets	24	page header	4 20	2	1:05
			page content	18 6	2	1:03
				5 19	2	
			page footer	10 5 9	3	1:02
56	National Grid	24	page header	5 9 10	3	1:02
			page content	15 9	2	3:05
				8 8 8	3	1:01
				14 1 8 1	2	1:1 4:7
				6 18	2	1:03
			page footer	4 3 15 2	2	1:2 1:5 2:3 4:3
57	Next	27&7				
		27	page header	1 4 4 18	3	1:1 2:9
			page content	2 8 17	3	1:04
				9 1 17	3	
				2 7 1 8 8 1	3	1:1 1:4 1:2
		7		1 1 1 1 1 1 1	7	1:01
			page footer	1 5 1	2	1:1 1:5
58	Old Mutual	24	page header	6 8 5 5	3	1:1 3:4 5:8
			page content	11 2 11	2	1:01
				8 8 8	3	1:01
				6 6 6 6	4	1:01
			page footer	2 17 1 4	3	1:07
59	Pearson	63	page header	17 32 14	3	7:16
			page content	46 1 16	2	
				22 1 23 1 16	3	1:01
			page footer	14 44 5	3	
60	Petrofac Ltd	16	page header	3 5 4 4	3	1:1 3:4 3:5
			page content	12 4	2	1:03
				8 4 4	3	1:1 1:2
				8 8	2	1:01
				4 4 8	3	1:1 1:2
				3 4 9	3	1:3 3:4
			page footer	2 2 5 7	3	1:1 2:5 5:7

Sample number	Page name	Grids number	Page sections	Number of grids occupied	Coloumns generated	Proportions
61	Prudential	24	page header	2 4 14 4	4	1:1 1:2 1:7
			page content	6 1 17	3	
				6 1 4 4 4 1	4	1:1 2:3
			page footer	7 17	2	
62	Randgold Resources Ltd.	12	page header	3 4 5	2	3:4 4:5 3:5
			page content	6 6	2	1:01
				3 3 3 3	4	1:01
			page footer	7 2 3	3	2:03
63	Reckitt Benckiser	16	page header	2 3 7 4	3	1:2 3:4
			page content	12 4	2	1:03
				4 4 4 4	4	1:01
			page footer	13 3	2	
64	Reed Elsevier	37&7				
		37	page header	8 7 14 1 7	4	1:2 4:7
			page content	28 9	2	
				9 9 9 9 1	4	1:01
				28 9	2	
		7		111111	5	1:01
			page footer	3 4	2	3:04
65	Rio Tinto	24	page header	3 21	2	1:07
			page content	10 14	2	5:07
				8 8 8	3	1:01
				5 5 6 2 6	4	1:1 1:3 5:6
			page footer	12 4 8	3	1:2 1:3 2:3
66	Rolls-Royce Holdings	24	page header	6 3 11 1 3	3	1:1 1:2
			page content	10 14	2	5:07
				8 16	2	1:02
				8 8 8	3	1:01
				4 9 11	3	
			page footer	6 12 6	2	1:1 1:2
67	Royal Bank of Scotland Group	41	page header	4 34 12	3	1:03
			page content	23 27	2	
				8 2 8 2 9 12 9	4	1:1 2:3 3:4
			page footer	38 12	2	
68	Royal Dutch Shell	28	page header	6 22	2	
			page content	5 1 11 11	3	1:05
				6 17 5	3	5:06
			page footer	6 6 5 5 5 1	4	1:1 1:5 6:5
69	Royal Mail	24	page header	3 16 4 1	3	1:3 1:4 3:4
			page content	7 7 10	3	7:10
				1 7 1 6 1 7 1	3	1:1 6:7
				2 4 2 4 4 5 3	4	1:1 1:2 2:3
			page footer	17 6 1	3	
70	RSA Insurance Group	48	page header	5 7 26 10	4	1:02
			page content	13 35	2	
				12 1 12 1 10 2 10	4	1:1 5:6 1:5 1:6
				7 2 8 1 7 2 9 2 9 1	5	1:1 1:4
			page footer	17 31	2	
71	Sage Group	12	page header	2 7 3	3	2:03
			page content	3 9	2	1:03
				4 4 4	3	1:01
			page footer	3 9	2	1:03
72	Sainsbury	12	page header	3 2 5 2	3	1:1 2:3 2:5 3:5
			page content	5 7	2	5:07
				4 4 4	3	1:01
				3 3 3 3	4	1:01
			page footer	1 7 4	3	1:4 1:7 4:7
73	Schroders	24	page header	3 12 5 4	4	1:3 1:4 3:4
			page content	11 11 2	3	1:01
				9 10 4 1	3	
				12 12	2	1:01
			page footer	11 13	2	
74	Severn Trent	12 or 24				
		12	page header	2 2 8	3	1:1 1:4
			page content	4 8	2	1:02
				3 3 3 3	4	1:01
			page footer	9 3	2	1:03
		24	page header	3 5 16	3	3:05
			page content	8 16	2	1:02
				6 6 6 6	4	1:01
			page footer	17 7	2	
75	Smith & Nephew	12&16				
		12	page header	3 6 3	3	1:1 1:2
			page content	9 3	2	1:03
				3 3 3 3	4	1:01
			page footer	3 1 8	2	
		16	page header	4 7 5	3	4:05
			page content	12 4	2	1:03
				4 4 4 4	4	1:01
			page footer	3 2 11	2	

Sample number	Page name	Grids number	Page sections	Number of grids occupied	Coloumns generated	Proportions
76	Smiths Group	30	page header	5 10 8 7	4	1:2 4:5 5:8
			page content	4 19 7	3	
				10 10 10	3	1:01
				20 10	2	1:02
			page footer	14 6 5 5	4	1:1 5:6
77	Sports Direct International	12	page header	4 5 3	3	3:4 3:5 4:5
			page content	4 8	2	1:02
				9 3	2	1:03
				4 4 4	3	1:01
				6 6	2	1:01
			page footer	3 8 1	2	1:3 1:8 3:8
78	SSE	24	page header	3 14 6 1	3	1:2 3:7
			page content	11 10 2	2	1:05
				8 8 8	3	1:01
				6 6 6 6	4	1:01
				4 16 4	3	1:1 1:4
				10 4 10	3	1:1 2:5
				4 4 4 4 4 4	6	1:01
			page footer	8 8 8	3	1:01
79	St James's Place	12	page header	2 8 2	2	1:1 1:4
			page content	4 1 7	2	1:4 1:7
				6 6	2	1:01
				3 3 3 3	4	1:01
				4 1 7	2	1:4 1:7
			page footer	8 2 2	2	1:1 1:4
80	Standard Chartered	24	page header	4 6 14	3	2:3 3:7 2:7
			page content	4 10 10	3	1:1 2:5
				14 10	2	5:07
				10 14	2	5:07
				19 5	2	
				5 19	2	
				2 1 3 1 3 3 1 3 2 4 1	6	1:1 1:2 1:3 1:4 2:3
81	Standard Life	24	page header	6 13 5	3	5:06
			page content	2 22	2	1:11
				6 18	2	1:03
				8 8 8	3	1:01
			page footer	6 18	2	1:03
82	Tesco	66	page header	9 2 10 18 27	4	1:3 1:2 1:5
			page content	13 53	2	
				15 2 15 2 15 2 15	4	1:01
				32 2 32	2	1:01
				7 5 9 2 9 4	5	1:1 1:2
			page footer	17 36 13	2	
83	Travis Perkins	65	page header	32 32 1	2	1:01
			page content	1 39 5 19 1	2	1:01
				1 46 1 16 1	2	1:01
				1 29 33 1	2	1:01
				1 36 27 1	2	1:1 3:4
			page footer	1 22 42	2	

Sample number	Page name	Grids number	Page sections	Number of grids occupied	Coloumns generated	Proportions
84	TUI Travel	24&60				
		24	page header	8 16	2	1:02
			page content	7 17	2	
				6 12 6	3	1:1 1:2
		60	page footer	29 1 10 6 4 9 1	4	1:1 2:3 2:5
85	Tullow Oil	24	page header	2 2 4 11 5	2	1:1 1:2 1:4 1:5 2:5
			page content	18 5	2	
				13 11	2	
				6 6 6 6	4	1:01
			page footer	3 3 17 1	2	1:01
86	Unilever	24	page header	2 7 7 8	3	1:1 1:4 7:8
			page content	12 12	2	1:01
				7 17	2	
				8 8 8	3	1:01
87	United Utilities Group	12&16				
		12	page header	2 6 4	3	1:2 1:3 2:3
			page content	4 5 3	3	3:4 4:5 3:5
				4 8	2	1:02
				4 4 4	3	1:01
		16		2 2 2 2 2 2 2 2	4	1:01
			page footer	10 6	2	3:05
88	Vodafone Group	12&24				
		12	page header	1 8 3	2	1:3 1:8 3:8
			page content	4 8	2	1:02
				4 4 4	3	1:01
		24		4 4 4 4 4 4	6	1:01
			page footer	21 3	2	1:07
89	Weir Group	12	page header	2 4 4 12	3	1:1 1:2 1:3 1:6
			page content	10 2	2	1:05
				4 4 4	3	1:01
				2 1 2 1 3 1 2	4	1:1 1:2 1:3 2:3
			page footer	4 4 4	3	1:01
90	Whitbread:	24	page header	6 13 5	3	
			page content	4 4 4 4 4 4	6	1:01
				14 10	2	5:07
				18 6	2	1:03
				9 9 6	3	2:3 1:1
				4 4 4 4 4 4	6	1:01
				10 3 11	3	
			page footer	5 10 9	3	1:02
91	Wolseley	12	page header	5 3 4	1	3 :4 3:5 4 :5
			page content	4 4 4	3	1:01
				3 3 3 3	4	1:01
			page footer	3 6 3	3	1:1 1:2
92	WPP	24	page header	3 7 10 4	4	3:4 2:5
			page content	4 1 8 8 3	3	1:2 1:1 3:4
				4 1 8 4 4 3	4	1:1 1:2
			page footer	10 2 10 2	2	1:1 1:5

Table 7.8 The horizontal relationship between main elements and grid units in the 92 cases (this table runs over 6 pages)

Sample number	Page name	Grids number	Page sections	Number of grids occupied	Sections generated	Proportions
1	3i group	35	page header	3	4	1:3 1:5 3:5
			page content	9		
				15		
				8		
2	Aberdeen Asset Management	29	page header	4	4	1:2 2:5 4:5
			page content	10		
				7		
				8		
3	Admiral Group	43	page header	7	5	1:1 1:3 1:4
			page content	2		
				24		
				2		
				8		
4	Aggreko	39	page header	3	4	3:5 5:8
			page content	23		
				8		
				5		
5	Anglo American	42	page header	3	5	1:2 3:5 5:8
			page content	10		
				16		
				8		
			page footer	5		
6	Antofagasta	30	page header	2	4	1:2 3:5
			page content	9		
				15		
			page footer	4		
7	ARM Holdings	54	page header	7	5	1:2 1:31:4 1:8 2:3
			page content	3		
				24		
				12		
			page footer	8		
8	Ashtead Group	49	page header	4	4	2:3 1:7
			page content	11		
				28		
			page footer	6		
9	Associated British Foods	102	page header	2	5	2:3 1:23 17:23
			page content	34		
				3		
				46		
				17		
10	AstraZeneca	26	page header	2	4	1:2 1:5
			page content	10		
				13		
			page footer	1		
11	Aviva	37	page header	3	6	1:1 1:2 3:4
			page content	6		
				7		
				1		
				8		
				7		
				1		
				4		
12	Babcock International Group	36	page header	3	5	1:03
			page content	7		
				16		
				9		
			page footer	1		
13	BAE Systems	77	page header	3	5	1:1 9:10
			page content	13		
				30		
				27		
			page footer	4		
14	BG Group	32	page header	1	4	1:5 1:7
			page content	7		
				19		
			page footer	5		
15	BHP Billiton	26	page header	4	5	1:4 1:5 2:3 2:5 3:5
			page content	10		
				6		
				5		
			page footer	1		

Sample number	Page name	Grids number	Page sections	Number of grids occupied	Sections generated	Proportions
16	BP	21	page header	3	4	1:03
			page content	10		
				7		
			page footer	1		
17	British American Tobacco	18	page header	2	4	1:2 1:4
			page content	4		
				11		
			page footer	1		
18	British Land Co	29	page header	2	4	1:3 1:5 3:5
			page content	10		
				11		
				6		
19	British Sky Broadcasting Group	54	page header	6	4	1:4 2:3 1:7 4:7
			page content	28		
				16		
			page footer	4		
20	BT Group	46	page header	5	4	5:06
			page content	22		
				13		
				6		
21	Bunzl	29	page content	14	3	2:3 2:7
				9		
				6		
22	Burberry Group	12	page header	1	3	1:5 1:6 5:6
			page content	6		
				5		
23	Capita	37	page header	2	4	1:01
			page content	2		
				31		
			page footer	2		
24	Carnival	25	page header	2	4	1:2 1:6 11:12
			page content	11		
				1		
				12		
25	Coca-Cola HBC AG (CDI)	86	page header	8	6	1:2 1:4
			page content	13		
				2		
				27		
				32		
			page footer	4		
26	Compass Group	27	page header	3	7	1:1 1:2 1:3
			page content	5		
				6		
				5		
				5		
				7		
			page footer	1		
27	CRH	20	page header	14	3	1:05
			page content	1		
				5		
28	Diageo	29	page header	2	4	1:1 1:4
			page content	17		
				8		
			page footer	2		
29	Direct Line Insurance Group	24	page header	5	5	1:1 4:5
			page content	5		
				5		
				5		
			page footer	4		
30	Dixons Carphone	29	page header	2	6	1:1 1:4 1:2 4:5
			page content	5		
				10		
				8		
				2		
			page footer	2		

Sample number	Page name	Grids number	Page sections	Number of grids occupied	Sections generated	Proportions
31	EasyJet	40	page header	3	5	1:1 1:2 1:4 5:6
			page content	10		
				5		
				10		
				12		
32	Experian	47	page header	6	6	1:2 1:3 1:5 3:5
			page content	15		
				10		
				9		
				4		
			page footer	3		
33	Fresnillo	29	page header	12	3	3:04
			page content	16		
			page footer	1		
34	Friends Life Group	14	page header	3	5	1:1 3:4
			page content	3		
				4		
				3		
			page footer	1		
35	G4s	60	page header	3	8	2:3 1:3 1:2 3:5
			page content	12		
				5		
				7		
				15		
				10		
				6		
			page footer	2		
36	GKN	29	page header	3	5	1:1 1:3
			page content	9		
				7		
				7		
			page footer	3		
37	GlaxoSmithKline	25	page header	2	4	1:1 1:4
			page content	8		
				13		
			page footer	2		
38	Hammerson	36	page content	5	5	1:1 2:5 5:7
				11		
				7		
				11		
			page footer	2		
39	Hargreaves Lansdown	27	page header	1	5	1:1 3:4
			page content	6		
				6		
				6		
				8		
40	HSBC Holdings	24	page header	1	7	1:1 3:4 3:5 1:5 5:7
			page content	4		
				3		
				5		
				1		
				7		
				3		
41	IMI	28	page header	2	4	1:3 1:4 1:5
			page content	8		
				15		
			page footer	3		
42	Imperial Tobacco Group	29		7	4	5:6 6:7 5:7
			page header	11		
			page content	5		
				6		
43	InterContinental Hotels Group	53	page header	4	5	1:1 1:2 1:5
			page content	10		
				20		
				29		
			page footer	10		
44	International Consolidated Airlines Group	27	page header	5	4	1:1 1:2 5:6
			page content	6		
				6		
				10		
45	Intertek Group	59	page header	2	5	1:2 1:3
			page content	8		
				25		
				24		
				1		

Sample number	Page name	Grids number	Page sections	Number of grids occupied	Sections generated	Proportions
46	Intu Properties	59	page header	6	5	1:2 2:3 3:4
			page content	8		
				4		
				27		
			page footer	14		
47	Johnson Matthey	17	page header	6	4	1:1 1:2 2:3
			page content	4		
				3		
			page footer	4		
48	Kingfisher	23	page header	2	7	1:1 1:2 1:3 2:3 3:4
			page content	4		
				10		
				2		
				1		
				3		
			page footer	1		
49	Land Securities Group	15	page header	2	3	1:01
			page content	11		
				2		
50	Legal & General Group	41	page header	10	5	
			page content	8		
				15		
				5		
			page footer	3		
51	Lloyds Banking Group	29	page header	2	5	1:2 2:3 1:4 1:6
			page content	6		
				3		
				12		
				6		
52	Marks & Spencer Group	29	page header	3	4	1:1 1:2 3:7
			page content	6		
				14		
			page footer	6		
53	Meggitt	30	page header	2	5	1:1 1:6 2:5 3:4
			page content	5		
				9		
				12		
				2		
54	Mondi	15	page header	3	3	1:3 1:4
			page content	12		
				1		
55	Morrison (Wm) Supermarkets	31	page header	3	4	1:1 1:2
			page content	6		
				19		
			page footer	3		
56	National Grid	51	page header	4	5	1:2 1:4 1:7 1:8
			page content	9		
				28		
				8		
			page footer	1		
57	Next	53	page header	2	6	1:1 1:2 1:3 1:5
			page content	25		
				10		
				10		
				6		
			page footer	1		
58	Old Mutual	36	page header	5	5	1:1 1:2
			page content	10		
				9		
				10		
			page footer	2		
59	Pearson	93	page header	14	3	
			page content	76		
			page footer	3		
60	Petrofac Ltd	27	page header	2	7	1:1 1:2 1:3 2:5 3:5 5:6
			page content	5		
				5		
				5		
				6		
				1		
			page footer	3		

Sample number	Page name	Grids number	Page sections	Number of grids occupied	Sections generated	Proportions
61	Prudential	27	page header	5	4	1:1 1:2
			page content	7		
				10		
			page footer	5		
62	Randgold Resources Ltd.	10	page header	2	4	1:2 1:3 3:4
			page content	3		
				4		
			page footer	1		
63	Reckitt Benckiser	17	page header	2	6	1:1 2:3
			page content	3		
				3		
				3		
				3		
			page footer	3		
64	Reed Elsevier	49	page header	4	5	1:1 2:5 2:3
			page content	10		
				10		
				15		
			page footer	10		
65	Rio Tinto	45	page header	5	4	1:1 1:2 1:4
			page content	10		
				20		
			page footer	10		
66	Rolls-Royce Holdings	33	page header	2	6	1:1 1:2 1:3 3:4
			page content	12		
				9		
				4		
				4		
			page footer	2		
67	Royal Bank of Scotland Group	41	page header	5	5	1:2 4:5
			page content	4		
				19		
				11		
			page footer	2		
68	Royal Dutch Shell	37	page header	5	5	1:3 1:4 2:3 3:4 3:5
			page content	9		
				12		
				3		
			page footer	8		
69	Royal Mail	41	page header	4	5	1:1 1:2 2:5 4:5
			page content	10		
				11		
				8		
			page footer	8		
70	RSA Insurance Group	56	page header	6	4	2:3 1:4 3:8 5:8
			page content	16		
				24		
			page footer	10		
71	Sage Group	23	page header	16	3	
			page content	15		
			page footer	2		
72	Sainsbury	29	page header	2	7	1:1 1:2 1:3 2:3
			page content	6		
				6		
				3		
				6		
				2		
			page footer	3		
73	Schroders	25	page header	2		1:1 2:3
			page content	7		
				2		
				11		
			page footer	3		
74	Severn Trent	34	page header	1	4	8:09
			page content	9		
				11		
				8		
			page header	1	4	
			page content	11		4:07
				14		
				8		
75	Smith & Nephew		page header	4	3	1:01
			page content	21		
			page footer	4		
			page header	2	3	2:03
			page content	13		
				3		

Sample number	Page name	Grids number	Page sections	Number of grids occupied	Sections generated	Proportions
76	Smiths Group	48	page header	3	4	1:2 1:6 1:7 2:7
			page content	18		
				21		
			page footer	6		
77	Sports Direct International	18	page header	2	4	1:2 1:5 2:5
			page content	5		
				10		
			page footer	1		
78	SSE	77	page header	6	5	1:1 1:4 1:5 4:5
			page content	11		
				24		
				6		
			page footer	30		
79	St James's Place	22	page header	2	7	1:1 1:2 2:3
			page content	4		
				1		
				3		
				6		
				3		
			page footer	3		
80	Standard Chartered	36	page header	10	3	4:5 4:9 5:9
			page content	18		
				8		
81	Standard Life	35	page header	4	4	1:2 2:3 3:4
			page content	8		
				6		
			page footer	17		
82	Tesco	92	page header	15	4	5:8 2:3
			page content	24		
				37		
				16		
83	Travis Perkins	76	page header	15	3	5:09
			page content	27		
				34		
84	TUI Travel	31	page header	2	6	1:2 2:3 3:4
			page content	8		
				3		
				11		
				6		
			page footer	1		
85	Tullow Oil	32	page header	4	4	1:2 1:4 2:9 1:9
			page content	9		
				18		
			page footer	1		
86	Unilever	22	page header	5	4	1:3 2:3 5:6
			page content	6		
				2		
				9		
87	United Utilities Group	31	page header	6	4	1:1 1:2 3:8
			page content	16		
				6		
			page footer	3		
88	Vodafone Group	26	page header	3	4	1:1 1:3 3:4
			page content	9		
				9		
			page footer	4		
89	Weir Group	29	page header	6	4	1:1 2:3 5:6 5:9
			page content	9		
				9		
			page footer	5		
90	Whitbread:	51	page header	11	3	1:19
			page content	38		
			page footer	2		
91	Wolseley	29	page header	3	3	5:08
			page content	10		
			page footer	16		
92	WPP	21	page header	3	5	1:1 1:2 1:3
			page content	3		
				7		
				6		
			page footer	2		