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The purpose of this study was to gain a better understanding of proportion as it pertains to interior design. The historical significance and conceptions of proportion in design today were reviewed.

Broadly defined, proportion is the quantitative relationship between objects and areas. It is the relationship of sizes and shapes. Since scale refers to size it is related to proportion. Sizes of things are compared to sizes with which one is familiar. Basic to all sizes is the size of man. The human scale is the basis for design since all designs are executed for human beings to enjoy. The relationship of sizes between parts of an object, between objects, and between objects and the whole is of concern to a designer. In interior design proportion is concerned with the quantitative relationship of two or more of the design elements--line, form, color, texture, light, pattern, and space--to themselves, to each other, and to the whole.

Throughout history proportion has been closely linked with both nature and mathematics. During certain periods of history, systems of proportion for architecture were more or less accepted, with different systems predominating at different times. Presently, subjectivism influences design which in turn discounts the possibility of any universally accepted system of proportion.

Critics argue the significance of science in art. Some think that the use of a system of proportion is necessary

in architecture in order to obtain a meaningful relationship of sizes. Others think such scientific application of parts to each other and to the whole stifles creativity. However, systems of proportion can be a means to an end. They can be used as a guide, or a check, if a designer so chooses. Pleasing relationships of shapes and sizes can be achieved through the use of a proportional system. If a proportional system will aid a designer, it may be best for him to use one. Others may find systematic applications stifling.

In design a pleasing relationship of design elements is sought but sometimes is quite difficult to obtain. In practice the use of each element of design affects the final proportion. In addition, one design element may influence the effect of another design element. For those persons who have an "eye" for recognizing good proportion the many variables are not studied separately. Rather, the total effect of combinations of the design elements is considered. Interior designers need to develop the ability to judge the effect of each element of design to the whole, because proportion is the key to a pleasing finished design.

PROPORTION AS IT RELATES TO INTERIOR DESIGN

by

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CONTENTS

LIST OF ILLUSTRATIONS

INTRODUCTION

The professional goal of most interior design students is to become a successful designer. The ambitious and talented student of design may attain this goal through education and experience. Interior design involves creating for the enjoyment and comfort of people; it is the responsibility of the interior designer to arrange the various elements of design in pleasing relationships. Good design may be created when one is aware of the principles of design as one uses the elements of design.

The writer considers the principle of proportion to be one of the most important principles of design. It is the proportion of the design elements--line, form, color, texture, light, pattern, and space--which has a significant influence on the esthetic quality of an interior. The proper relationship of some or all of the elements of design results in good design. How to obtain the proper relationship of the design elements is of great interest to the design student.

The purpose of this study was to gain a better understanding of the importance of the principle of proportion in design. This was accomplished by surveying selected writings on proportion to discover first, the theories, propositions, and significance of proportion in the past and second, ideas concerning proportion today as it relates to interior design.

I. PROPORTION - MEANINGS AND INTERPRETATIONS

In interior design the word proportion can be defined as the quantitative relationship of two or more of the design elements--line, form, color, texture, light, pattern, and space--to themselves, to each other, and to the whole design.

Proportion as a noun was defined by Webster as

> the relation of one part to another or to the whole with respect to magnitude, quantity, or degree: RATIO . . . harmonious relation of parts to each other or to the whole: BALANCE, SYMMETRY . . . the equality of two ratios: a relation among quantities such that the quotient of the first divided by the second equals the third divided by the fourth (as 4:2 = 10:5 or 4/2 = 10/5 or 4:2 :: 10:5)--called also geometrical proportion (29:1819).

Mathematicians speak of ratios and proportion with ratios meaning the relationship between two measures and proportion referring to three or more measures (28:212). Geometrical proportion as defined by Webster may be of little interest to the experienced designer but may be of help to the design student who is seeking to train his eye to recognize good proportion in design. Learning to look at the relative amounts of the design elements that he is using and making judgments regarding the esthetic quality obtained is of great aid to the student.

Proportion has been defined in connotations related to design. Vitruvius, the Roman from whom history finds the first written accounts on theories of proportion, defined proportion as "the commensuration of the various constituent parts with the whole" (30:3). Proportion in an architectural composition is "the relation of one part to another and to the whole, especially in respect to size and position; the relative dimensions and arrangement of parts, as of a room in regard to its height, width, and length . . ." (24:222). Rathbone considered proportion as the "ratio of the dimensions of one part of an object to those of another part, such as the relationship of its height to its width or depth" (20:30). Van Dommelen stated that proportion is the "consideration of weight and shape and division of an object" (27:14). Thus, a broad definition of proportion is the relation of one part to another or to the whole.

Grillo spoke of proportion as being a rapport between two dimensions which can have a meaning without a sense of measure attached to it. This is known as absolute proportion. In geometry the rapport 1/1 of a square is absolutely true for any square whether one inch or one mile square. Thus, absolute proportion "defines the characteristics of a figure regardless of size" (11:145). However, relative proportion requires a unit of measure and as such involves size because, in making a comparison of the proportion of one object to another object, it is necessary to refer to a dimension with which one is familiar to decide if one object is bigger or smaller than another one. To evaluate a dimension, one has to refer to a "unit of measure set once and for all" (11:145). Relative proportion thus refers the design to a scale (11:145).

Some designers consider scale a part of proportion in relating it to design; scale will be treated in this manner in this paper. For the present, scale will be defined as the size of an object or area. Obst stated that in interior design "proportion means the relationship of sizes or areas to one another or to a whole. The word scale is used to indicate the sizes of smaller parts or details of a room in relation to the whole" (19:19). Whiton wrote of proportion as being a less technical term than scale, often referring to size and shape of forms and masses in relation to their ideal dimension (31:772). For instance, if the arms of a chair are too large as compared to the size the arms should be ideally, then the chair is said to be out of proportion. When a chair small in scale is next to one large in scale, they may be considered out of proportion to one another.

An interior designer considers proportion as the amount of the design elements--line, form, color, texture, light, pattern, and space--as they relate to themselves, to each other, and to the whole. The interior designer must consider the proportion of the straight to curved lines and vertical to horizontal lines as well as weight of lines, the proportion of sizes and shapes of furniture and accessories, the proportion of bright and greyed color, the proportion of smooth and rough textures, the proportion of light and shadow, the proportion of pattern shapes, and the proportion of open and occupied space. These considerations denote the relationship of the design elements to themselves. The relationship of these elements to each other might be line to form, color to texture, color to form, pattern to texture, space to pattern, or light to color. Each of these elements should relate properly to the whole. As Ball so aptly stated--"proportion is the quantitative basis underlying all art" (1:16).

Proportion, good or bad, is present in all designs and is altered when a design element is changed. In an interior just one element--the color of a wall, chair, or even a vase--can be changed; or several elements such as pattern, texture, and color in one item--the drapery--can be altered. Good proportion in a design "depends upon the relative importance given to its subdivisions, or the degree of subordination of its parts, . . . according to the just value of each in the general scheme, and upon their mutual disposition, so as to secure harmony and balance by agreeable contrasts" (24:222).

The designer is definitely concerned with visual proportion which is the "proportional relationships which please the eye in themselves" (23:4), but he must also consider the proportional relationships of the design elements as they are suited to a particular function or functions.

For example, a small room may be visually excellent in proportion with a deep pile carpet, silk wallpaper, and rich velvets and velours on the sofa and the chairs. However, if the room were to be used by a child for making model airplanes or creating compositions with finger paints, then the proportion of the design elements as suited to the use of the room would be completely out of character. Therefore, an interior designer needs to consider visual proportion in conjunction with function.

Jenkins stated that the term proportion is

> customarily restricted in application to the artist's treatment of his subject-matter. An artist--and hence, his work--is said to exhibit proportion when he respects and adheres to the true worth and significance of the different elements of his subject, and gives to the various aspects of this subject the emphasis that they deserve. The use of the term thus involves an assumption about comparative values in the real world, and works are praised or condemned by this criterion as they make agreeable or disagreeable judgments concerning the relative importance of these values (22:812).

If proportion is inherent in a design, one may want to know how to obtain good proportion in a design. Designers and artists speak of applying the principle of proportion to achieve good proportion; however, most designers and artists do not define what the principle of proportion is. Since the principle of proportion is considered one of the principles of design, perhaps it would be helpful to know the meaning of a design principle. The Encyclopedia of the Arts defines principles of design as formulas which have been "worked out to help the artist plan his efforts and check his results . . . . They might be described as those subordinate types of organization which stand out most clearly within the organization of the whole work" (22:279). These principles help to manage properly the internal relationships in a design.

Proportion as a design principle according to the Encyclopedia of World Art is

> a space concept that concerns the relationship of the elements as to size, scale, quality, purpose, variety, or meaning. Proper application of the principle requires using the "right" amount and distribution, which vary for each work and the particular purpose of the artist (5:358).

Goldstein mentions that the principle of proportion is sometimes called the "law of relationships" (9:62). Thus, good proportion is achieved by a proper relationship of the elements of design. "Some people have an instinct for good proportion, and whatever combinations they plan are sure to please the eye, but most people have to acquire this trait" (9:63). To the trained eye proportion can be judged unconsciously or consciously. Sometimes this principle of proportion is referred to as "taste" which means that the "selection displays the artist's sensitivity, discrimination and awareness of proportion relationships" (5:358). Therefore, the principle of proportion seems to include standards or guidelines by which one can judge proportion. To be able to make a judgment of proportion in design, one must have some criteria on which to base this judgment.

Proportion as a mathematical concept has gained importance in the visual arts by supplying a set of norms.

> The search for balance, for unity, for 'style', the need to fix art within a technical rationalization in an intelligible language of forms and the psychophysiological structure of vision itself have induced the artist to base himself largely on geometric forms and their proportional relationships, be it either intuitively or consciously, even on a theoretical level (7:716).

Throughout the years standards of proportion have been discussed and theorized. It may be possible that some of these theories can furnish the design student some standards which can act as guidelines in his judgment of proportion and show how certain standards have aided others in judging. These theories may serve as guidelines in training the eye to judge visual proportion. The forms and shapes used and their relationships to each other and to the whole may aid the design student in selecting a means to obtaining criteria on which he can base his judgment of proportion.

II. PROPORTION - HISTORY AND SYSTEMS

The history of the systems of proportion is not a clear cut progression of ideas. Rather, those interested in proportion throughout history tended to search for systems from other civilizations and to use or repeat ideas from time to time. Today all systems are rejected by many designers. However, many designers find some systems useful from time to time, but none rely on systems exclusively. This chapter will first develop the historical development of systems of proportion and then explain how these systems can be analyzed.

Historically speaking, the discussion of proportion can begin with the Bible. Nikolaus Pevsner commented

> Without the Bible no Modulor. The <u>locus classici</u> are Wisdom of Solomon xi. 20: 'God has ordered all things in measure and number and weight', and Proverbs viii. 27: 'When he set a compass upon the face of the earth'. There you have from the outset your best authority for the faith in both arithmetical and geometrical relations (38:456).

Two Greeks, Pythagoras and Plato, were influential in the historical development of proportion. The mathematical concept of proportion which has significance today came from the Greeks.

Pythagoras, usually named the real founder of theoretical geometry, recognized the three most important types of proportion which determined the consonances of the musical scale.

> Pythagoras was the first to connect the relations between the length of vibrating strings to produce the harmonies of octave or diapason, fifth or diapente and fourth or diatessaron with the harmony of the spheres (38:456).

The first type is the geometrical proportion in which the first term is to the second as the second is to the third, such as 1 : 2 : 4. It is this proportion that determines the octave. In the second type, known as the "arithmetic proportion," the second term exceeds the first by the same amount as the third exceeds the second, such as the proportion 2 : 3 : 4. The arithmetic proportion determines the division of the octave into fifth and fourth. "Harmonic proportion," the third type, occurs when the distance of the two extremes from the mean is the same fraction of their own quantity; for example, in the proportion 6 : 8 : 12 the mean 8 exceeds 6 by 1/3 of 6 and is exceeded by 12 by 1/3 of 12. This divides the octave into fourth and fifth (32:11). Pythagoras believed that the "ultimate truth about the structure of the universe lay in certain ratios and proportions" (33:203). The era of the mathematical approach to nature thus began.

Plato employed two different kinds of Pythagorean mathematics in the _Timaeus_. The numerical ratios derived from the harmonic intervals of the Greek musical scale was his explanation and division of the world-soul. The order and the harmony of the cosmos were based on certain numbers and their multiples in the following progressions 1, 2, 4, 8, etc. and 1, 3, 9, 27. The relationship between these numbers was the musical consonance of the universe. "There is no direct evidence that the Greeks translated either the 'world-soul harmonic intervals' or the musical ratios into architectural ratios" (32:186) but later scholars believed this to be true.

Plato contended that everything was arranged according to number. Numbers with their symbolism and mysticism have influenced human thought through the years. Just as Pythagoras selected the number 3 as the perfect number because it had a beginning, a middle, and an end, others have chosen a different number. In the Middle Ages the number 4 had special meaning as it represented the "four winds, the four cardinal points, the phases of the moon, and the four seasons . . ." (7:719).

In addition to placing importance on numbers and their ratios, Plato considered certain forms to be of equal importance. Concerning his "atom theory, the ordering of Chaos," Plato returned to the most perfect geometrical configurations, namely tethrahedron, octahedron, cube, icosahedron, and dodecahedron, the only five solids possessing equal sides, equal faces, and equal angles (32:11). The basic element in the construction of the regular tetrahedron, octahedron, and icosahedron is the equilateral triangle. Each face of the cube can be divided by the diagonal resulting in two right-angled isosceles triangles. The dodecahedron pentagonal faces are composed of isosceles triangles in which each of the angles at the base is double the vertical angle (72° and 36°). Wittkower contended that the emotional importance placed on these basic figures of geometry greatly influenced the European ideas of proportion (32:12).

Written evidence on architectural proportion used by the Egyptians and the Greeks has yet to be found, but scholars have attempted to analyze their architecture according to a particular system of proportion. The results of some of these studies indicate that there was a theory of proportion used because there was a consistent repetition of certain ratios of proportions for the size and spacing of the elements of a building.

Vitruvius, the author of the earliest known writing on architecture, was concerned more with a theory of proportion in practice than in the aspect of esthetics. He used the module to give the proportions of an order so that it could be constructed to any size desired (23:17). His thoughts on proportion were discussed by Scholfield at length. There have been references stating that Vitruvius made an analogy between musical harmony and architecture but Scholfield found no trace of this. Scholfield believed that Vitruvius had in his mind a system of proportion which was both analytical and commensurable (23:31).

Vitruvius also stressed the proportions of the well-formed human figure as a basis of proportions to be used for design. Rather than using the sizes or parts of the human figure he advocated the use of the proportions of the human figure. The sizes of the parts were expressed in terms of the whole (23:21). Because of the confusion of this analogy Licklider commented that for this system to be effective it must be adjusted to each design. To use it effectively, one should reject the fractions that are not sub-multiples of the whole. This system falls into mathematical symmetry and a building with a consistent set of relationships can be partially understood by a spectator (17:37-38). This relation of the sub-multiples of a number is known as the secondary harmonic progression and Licklider commented that

> 'Harmonic' systems provide the designer with the means to relate systematically large and small dimensions, to each other, and to the whole building. But they carry with them a very limited choice of clearly desirable dimensions (17:39).

During the history of European art there were two different classes of proportion, both being derived from the Pythagoreo-Platonic world of ideas. Pythagoreo-Platonic geometry was preferred in the Middle Ages whereas the numerical or the arithmetical side of that custom was favored in the Renaissance and classical periods (32:15). The arithmetic proportions summarized in the ratios of the Greek musical scale consist of integral numbers or commensurable ratios. The geometrical proportions cannot be expressed by integral numbers or simple fractions; therefore, such proportions are termed incommensurable or irrational (32:16).

The bases of medieval esthetics were the equilateral triangle, the right-angled isosceles triangle, the square, the pentagon and the derivative figures like the octagon and decagon (32:12). It is often argued whether or not the medieval builders designed according to fixed proportion. The nineteenth century Romanticists believed they did (38:456).

Renaissance esthetics was primarily based on the commensurability of measure in nature. The attitude toward proportion was determined by a new organic approach to nature which included the empirical procedure of measuring and was aimed at showing that everything was related to everything by number (32:16).

Leonardo da Vinci in his studies in proportion used numerical proportions exclusively. He measured and compared the proportion of one part of the body with another (32:16-17). Villard de Honnecourt showed figures by which the proportions were determined by a framework of Pythogorean geometry (32:17). Thus, the Renaissance artist tended to extract a metrical norm from nature that surrounded him and the medieval artist "tends to project a preestablished geometrical norm into his imagery" (32:17).

Wittkower pointed out that the metrical systems were used in the Middle Ages also and that geometry was also used in the Renaissance, but he thinks that the same numerical and geometrical proportions did not have the same meaning in the Middle Ages and the Renaissance. His explanation was that the metrical proportions used in the Middle Ages were for a practical expedient and hardly ever as an integrated principle to which all the parts would conform. During the Renaissance, however, metrical proportion was, in Wittkower's opinion, the guiding principle of order which would reveal the harmony between the parts and the whole (32:17). It was the architects of the Renaissance who employed the module system of Vitruvius which was the only way of guaranteeing a rational numerical relationship throughout a whole building.

Scholfield stated

> 'Symmetry' in a building depends on the use of dimensions which can be expressed in terms of the size of a particular part, or module. But it also depends on the principle of 'proportion', by means of which the sizes of all the parts are related to the size of the whole. It should not merely be possible to express 'symmetries', or comparative sizes of the parts of a building in terms of a module, but these sizes must also be aliquot parts of the size of the whole (23:25).

In referring to geometry and its use in the two eras, Wittkower used the square as an example because it was important during the Middle Ages and the Renaissance. The medieval artists setting the square within a square termed it "just measure," but the Renaissance artists rejected this idea of a square within a square perhaps because of the incommensurability of this configuration. However, the Renaissance artists did notice the simple numerical ratios of the sides of a square, and in this ratio 1 : 1 they found beauty and perfect harmony. Therefore, Wittkower deducted that in a simple geometrical figure as the square it appeared that it "can be used in a metrical and rational as well as in a geometrical but irrational context, and can elicit completely different reactions" (32:17).

The main source of the Renaissance theory of proportion was from Vitruvius when his work was rediscovered in the fifteenth century. Three basic ideas of the importance of proportion were handed down to the Renaissance from Vitruvius: proportion was important as a source of beauty, as being concerned with the relationship of the parts to each other and to the whole, and as being subject to reason and rules rather than intuition (23:34). Also his use of the harmonic scale in which the main dimensions are submultiples of the whole was important in the Renaissance. The analogy between the human figure and architecture became an obsession with the Renaissance artists and Scholfield intimated that perhaps this was due to their misunderstanding of Vitruvius' beliefs.

The Renaissance looked back to Greece and Rome and a continuation of Vitruvius. Proportional relationships based on the human figure were prominent whether drawn in the square or a circle or some other form. Luca Pacioli said, as quoted by Wittkower, "from the human body derive all measures . . . and in it is to be found all and every ratio and proportion by which God reveals the innermost secrets of nature" (38:457).

Wittkower concerned his discussion of proportion with the wider neo-Platonist philosophy of the Renaissance and showed how the application of musical proportions to architecture was suggested by the way in which Plato applied them to cosmology. Scholfield, on the other hand, was more concerned with the theory of proportion itself (23:34-35).

The scientific approach to art prospered in the Renaissance and in the early Renaissance no one doubted the objective causes of beauty. Alberti, as recorded by Scholfield, quoted: 'I shall define Beauty to be a harmony of all the parts in whatsoever subject it appear, fitted together with such proportion and connexion that nothing could be added, diminished or altered, but for the worse . . .' (23:38).

Alberti used the harmonic scale to express the proportions of the orders and even to plan the proportions of whole buildings systematically. Scholfield noted that Alberti seemed to be "aware of the possible relationship between the use of the harmonic scale and the generation of geometric progression" (23:39). The characteristic feature of the system is that the dimensions of even the smallest parts are secured from those of the larger parts by successive sub-divisions (23:39).

The idea regarding proportion as subject to rules and reason in the Renaissance lost ground in the seventeenth century and became subject to intuition. Many writers of this period thought the subjective element played at least some part in controlling one's sense of beauty. Thoughts on proportion in the eighteenth century were mainly concerned with whether "proportion was pleasing to the eye in itself, or indirectly through the operation of some other factor" (23:76).

The theory of proportion in the Renaissance was overthrown because of several arguments. Those writers critical of a theory of proportion, concluded Scholfield, were of the opinion that "proportion was a varying and subjective factor in design, determined by the taste of the individual designers, and that no rules or principles could be established for its control" (23:79). They rejected the ideas that "simply commensurable ratios were pleasing to the eye . . . that any particular relations were pleasing to the eye . . . that proportion could make an independent contribution to the beauty of objects at all" (23:79).

The eighteenth century was a period in which an attempt was made to reduce the theory of proportion to a theory of fitness. However, present day designers think that sometimes when the requirements of fitness--factors of structure and use--have been fulfilled a choice remains between proportions appearing pleasant and those appearing unpleasant (23:4).

Proportion was important because of the varying and subjective influences of "custom, knowledge of fitness, or a combination of both" (23:79). For the first time the idea of fitness or function entered as a cause of the beauty of proportion. However, as Scholfield pointed out, function determines the proportion of a design to some degree but there is usually room for proportion to act as an "independent cause of visual delight" (23:80). Scholfield also contended that

> all that is required to reinstate the theory of proportion on these lines is an explanation of how proportion actually works, to take the place of the discarded idea that its beauty is due to the pleasing effect of particular ratios (23:80).

Scholfield spoke of Barca's theory at the end of the eighteenth century which probably had little effect at the time because of the sweep of subjectivism. Barca's system contained two rules of proportion. One was the use of simply commensurable ratios which acted only as a means to an end, and the other was the repetition of ratios which involved the repetition of similar shapes (23:80).

The nineteenth century, because of the failure of the theory of proportion, became a period of trial and error in architecture and a time in which revivals of past theories became of interest. The lack of a universal theory resulted in the beginning of a broader theory in which both commensurable and incommensurable ratios were considered no more than means to an end (23:81).

The romanticism of the nineteenth century relegated the problem of proportion to personal intuition, and this method of incorporating proportion into design continues to be prevalent today. Scholfield remarked that, even though Ruskin was usually associated with the intuitive school, he did contribute to the theory of proportion in his

> distinction between 'apparent' proportion, 'the sensible relation of qualities', and 'constructive' proportion, 'the adaptation of qualities to functions'. 'Apparent proportion' is 'one of the most important means of obtaining unity amongst things which otherwise must have remained distinct', and 'may be considered as lying at the root of most of our impressions of the beautiful'. 'Constructive proportion', on the other hand, 'is agreeable, not (necessarily) to the eye, but to the mind, which is cognizant of the function to be performed' (23:83).

Intellectuals of the period who were concerned because the Renaissance theory of proportion did not result in beautiful proportions continued to think that the answer must lie somewhere else. Thus, the Gothic and Greek works became important to analysts who believed that therein perhaps the key to the solution would be found. The analysis of the archaelogical material was attempted by two methods in the nineteenth century.

The numerical analysis was applied mainly to the Greek designs. This analysis was the actual linear measurement of the buildings and was used because it was assumed that the Greeks had based their methods on arithmetic. However, as Scholfield noted, this method of analysis did not show that the Greeks had used simply commensurable ratios and this was contrary to the expectations of the analysts (23:97).

Geometrical analysis was applied mainly to the Gothic architecture since the designers of that era were known to have been interested in geometry. However, as Scholfield pointed out, geometry was not as reliable in analysis as was arithmetic. He was of the opinion that Hambidge's analyses were to be preferred over others' analyses. Hambidge believed the Greek designs to have employed geometry but he did not think this fact presented any "obstacle to making use of the enormous advantages which arithmetic offered for analysis" (23:97).

The geometrical systems used in analysis included the square, equilateral triangle, polygons with emphasis on the pentagon and the decagon, and the controlling circles. Since these systems lacked the precision of arithmetical methods as attempts to reconstruct ancient systems of design, they were "inevitably highly speculative in the absence of direct literary evidence on the subject" (23:106).

The analytical systems of the past "were based on the simple arithmetic of commensurable ratios" (23:110). The arithmetical technique for working with incommensurable ratios was not well known in the Renaissance, but the recent systems of Hambidge and Le Corbusier combine the advantages of an analytical system with the use of incommensurable ratios. These analytical systems reduce the problem of proportion from two or three dimensions to one.

The nineteenth century also saw the use and study of the golden section.

> What Euclid (vi,30) calls 'to cut a line in extreme and mean ratio' is nowadays called the Golden Section, in which the smaller part is related to the larger as the larger to the whole, and this proportion is, of course, incommensurable (32:16).

Scholfield was hesitant to say that it was rediscovered, but he did think that the "importance of the golden section in the Renaissance has been much exaggerated, and the evidence for its use in Greek design is entirely indirect" (23:98).

Zeising, according to Scholfield, was the first nineteenth century writer to try to apply the golden section to art as '. . . the key to all morphology, both in nature and art' (23:98). Even though his work was considered unscientific, it generated quite a bit of interest. Also in the nineteenth century, Fechner, known as the founder of experimental aesthetics, carried out experiments to show people's preferences of simple forms. The golden rectangle seemed to be the preferred choice in rectangles but the choice was not definite enough to be very convincing (23:99). The golden section, in discussions on proportion, seems to be important in the twentieth century, and its significance will be seen in some of the discussion of proportional systems.

Proportional systems can be analyzed as mathematical and geometrical systems. Very few basic systems are used even though designers' intentions regarding the use of proportional systems may be quite varied. In this light

> the different proportional systems are more or less perfect approximations of a few basic geometrical approaches; and each of them may be regarded as a more or less successful search for the system that will yield the greatest number of similar shapes, similarly related (17:35-36).

The systems of proportion can be divided in two different ways, either by the practical method which is used to put them into effect, or by the type of mathematical relationships which they include. If they are classified according to the practical method of use, systems of proportion fall into two main groups. Geometrical systems which aim directly at the repetition of similar shapes comprise the first group. In this group the patterns of proportional relationships develop automatically among the linear dimensions (23:12). "Geometrical systems of proportion give the designer direct control over the shapes which he is using, but the linear dimensions of the design are left to take care of themselves" (23:12-13). Systems in the second group are described as analytical systems in that the problem of proportion is reduced from the manipulation of shapes in two or three dimensions to the manipulation of lengths in one dimension at a time. Since an architect is concerned with actual dimensions for his design to be carried out, he may prefer the analytical system for most purposes (23:12-13).

The other way of classifying systems of proportion, which is the type of mathematical relationships they embody, is to divide them into commensurable and incommensurable systems. Commensurable systems are those in which dimensions are related by geometric progressions based on whole numbers. Incommensurable systems are dimensions which are often based on other numbers or relationship of numbers like the golden number (23:13). A first term is to a second as the second is to the whole.

Scholfield explained what he considered to be probably the most valuable progression of all.

> This is the geometric progression based on the number ϕ, which is equal to $\frac{1 + \sqrt{5}}{2}$, or 1.618.... It is the properties of this progression which account for the importance in architecture of the golden section whose ratio is $\phi : 1$.
>
> This geometric progression $1, \phi, \phi^2, \phi^3, \ldots$, has many useful additive properties of its own, of which $1 + \phi = \phi^2$ is the most important. But when it is combined with other progressions, its additive powers are so enormously increased that systems of proportion based upon it show a singular flexibility (23:11).[1]

Hambidge was more of an analyst than a designer. He attached importance to the geometric progression for he believed that an example of dynamic symmetry was any "genuine system of proportion based on the use of incommensurable ratios (23:116-117). Dynamic symmetry is suggestive of life and movement. "The basic principles underlying the greatest

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[1]Refer to the Appendix for a further detailed discussion on the mathematics of visual proportion.

art so far produced in the world may be found in the proportions of the human figure and in the growing plant" (12:xi). Static symmetry, as opposed to this dynamic symmetry, is a symmetry which has a sort of fixed entity or state such as the crystal (12:xi). Also, he believed the root-rectangles play an important part in dynamic symmetry from a geometrical point of view because these rectangles have sides which are commensurable in the areas of the squares upon them rather than in length (23:118).

Whereas dynamic symmetry holds a geometrical element, an entirely analytical method of proportion was offered by Le Corbusier's Modulor. It consists of two scales with the dimensions of the "blue" scale being double those of the "red" scale, and the divisions of each scale are based on the golden section series. The scale consists of two features. One is the relationship of the scale to the human figure and the second is that the scale is intended to link the metric system and the system of feet and inches (23:123).

The new Modulor expresses the two scales in terms of half-inches with the red scale using the half-inch module and the blue scale using the inch module. Six feet represents the height of a man, and since 6 feet is equal to 144 half-inches and 144 is a Fibonacci number, the scale can be derived as follows:

Red	4 in.	6½ in.	10½ in.	17 in.	27½ in.	. . .
Blue	8 in.	13 in.	21 in.	34 in.	55 in.	. . .

The Fibonacci series was discovered showing that in a series of numbers in which each number, after the number one, was the sum of the two preceding numbers and that as the arithmetical ratio between each two approximated the golden section and came closer to it, the higher the number. The series is:

1 2 3 5 8 13 21 34 55 89 144 . . .

The convenience of this series in which a rectangle has its sides in the ratio of 2 : 3 or 3 : 5 caused designers to refer to the resultant figures as "golden rectangles." The larger the number, the closer the rectangle will approach that of a true golden rectangle. (See Figure 1).

Scholfield commented that the Modulor displays the same limitations found in Palladio's system. It links the whole structure together in that the parts relate to each other, but it does not succeed in relating them to the whole (23:124). Wittkower felt that whatever opinion one might have concerning Le Corbusier's Modulor, it was the "first consistent synthesis since the breakdown of the older systems, reflecting our own civilization . . ." (32:18). Le Corbusier has set forth in his Modulor a system for man in his environment instead of universals, converting from absolute to relative standards. The elements of the Modulor are combined into a system of geometrical and numerical ratios: the basic principle of symmetry is mixed with two deviating series of irrational numbers derived from the

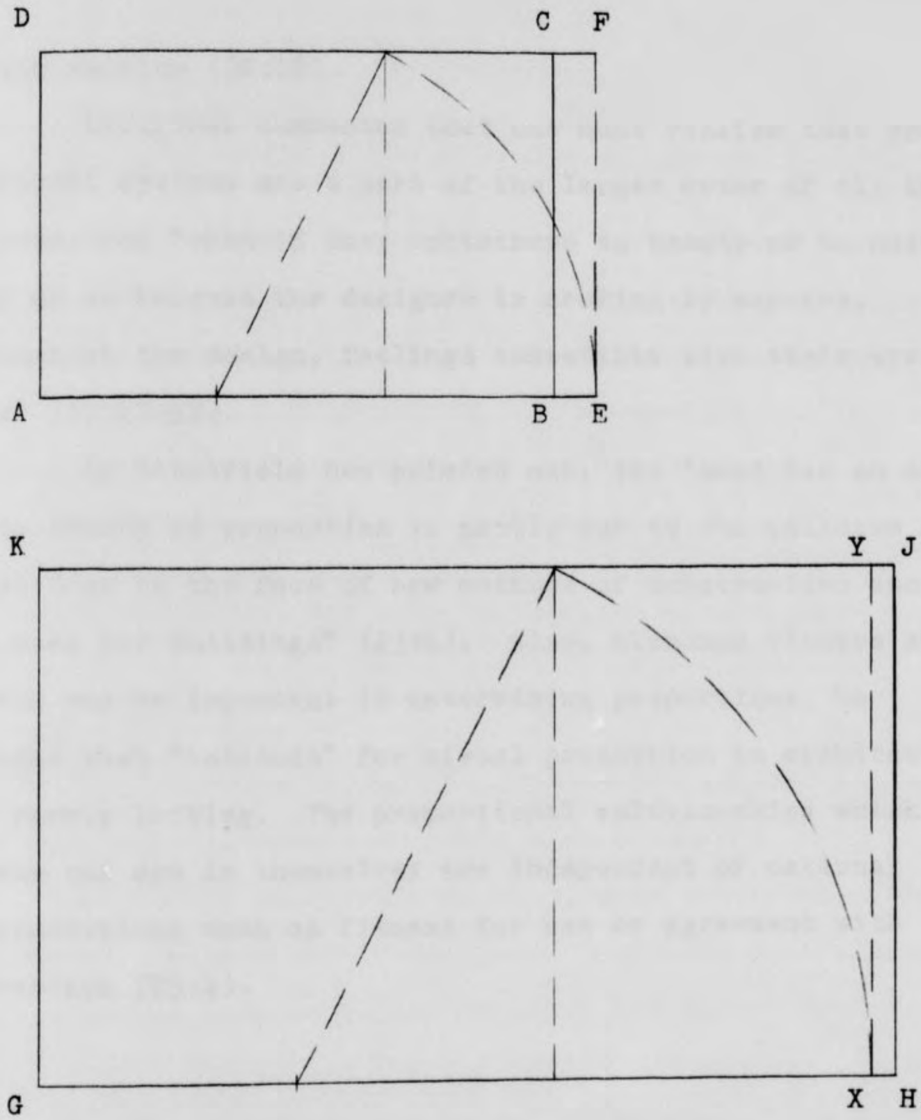

Figure 1. The Relationship between Golden Rectangles and Rectangles Formed from the Fibonnaci Numbers.

Rectangle ABCD uses the Fibonnaci numbers (ratio 2 : 3), and rectangle AEFD is a golden rectangle. As the Fibonnaci numbers increase in the rectangle GHJK, ratio 3 : 5, the closer a golden rectangle, GXYK, is approximated.

golden section (32:18).

Licklider commented that one must realize that proportional systems are a part of the larger order of all that is seen; and "that if they contribute to beauty or to unity they do so because the designer is seeking to express, throughout the design, feelings compatible with their systems" (17:47-48).

As Scholfield has pointed out, the "need for an adequate theory of proportion is partly due to the collapse of traditions in the face of new methods of construction and new uses for buildings" (23:4). Also, although fitness and custom may be important in determining proportions, he thought that "latitude" for visual proportion in architecture was rarely lacking. The proportional relationships which please the eye in themselves are independent of external considerations such as fitness for use or agreement with convention (23:4).

III. PROPORTION - COMPATABILITY IN ART AND SCIENCE

Until the eighteenth century, as Wittkower pointed out, it "was never doubted that objective standards of proportion are necessary in a work of art, even though nobody was so naive as to think that absolute measures can be perceived" (32:17). During the eighteenth century this Pythagoreo-Platonic tradition gave way to the idea that

> beauty and proportion were no longer regarded as being universal, but were turned into psychological phenomena originating and existing in the mind of the artist. Beauty and proportion became dependent on what was believed to be an irrational creative urge (32:17-18).

The artist in his rejection of proportional systems had to find his bearings purely by subjective standards.

Since the eighteenth century, when the proportional systems of the past were questioned, there has been a constant exchange between people favoring the use of systems of proportion in design and those offering a rebuttal. This indicates that all designers do not agree that it is desirable to have compatability between the art and science of proportion. To some twentieth century scholars science is necessary in art; to others there is no art with science.

Ghyka strongly adhered to the belief that the knowledge of the science of space and of the theory of proportions provides an infinite variety of choices within the realm of "symphonic composition" rather than hindering the creative power of the artist (8:174). Jean Vignot, the Gothic Master Builder, in 1392, as quoted by Ghyka, said, "Ars Sine Scientia Nihil" (8:174).

Architecture, according to Claude Bragdon, is based primarily upon geometry but that it is possible to express all spatial relations numerically

> for arithmetic, not geometry, is the universal science of quantity. The relation of masses one to another--of voids to solids, and of heights and lengths to widths--form ratios; and when such ratios are simple and harmonious, architecture may be said, in Walter Pater's famous phrase, to 'aspire towards the condition of music' (2:91).

Teague was of the opinion that design is one art and geometry another. Designs which develop are usually shaped by the artist's sense of rightness operating on the factors of function, materials, and techniques. The designer may refine his design but at no time would it be possible "to apply elaborate and erudite mathematical formulas to the creation of simple unity" (25:141). It is the designer's innate but trained and experienced sense of rightness that selects the one right form from among many possibilities (25:141).

Ball said,

> Artists usually attain satisfactory shape delineation because of intuitive coordination of hand, eye, and brain. Centuries of gauging the rate of change in natural forms has given man this power. The artist needs to remember that the laws governing all natural phenomena likewise govern art. Ratios and proportions can unify and intensify by repetition

> and ordered variation, integrate by interlocking and make the design dynamic by establishing rhythms. The artist must accomplish similar results (1:83).

To Grillo, all problems of proportion cannot be solved by logic. However, logical rules can dictate some sort of proportion in openings, for example. The first windows were horizontal due to the natural shape in which the eyes have greater vision, the horizontal ellipse. Also, doorways were vertical because of the height of the person. When one deals with areas, volumes, and anything bigger than a small house, common sense ceases to be enough. This is the time when "art, experience, and intuition, meet a branch of science that touches physics by only one corner: metaphysics" (11:141).

After discussing some of the "fascinating relations which order shapes and their behavior in space," Ball continued with

> these thoughts provide an initial glimpse of the truth that there is no beauty without some kind of order. Mathematics is capable of demonstrating this order because it is a method of reasoning from cause to effect about those things which can be measured, counted, and related (1:82).

Since most compound sensations and their resulting affections are beyond measure at present, "mathematical proportions can be used by the artist as training for sensitivity to such complexity" (1:82). Grossman, on the other hand, commented that the Greeks recognized that the creative impulse was the primal force and that mathematics disciplined their artistic sense and was a refinement but did not control it. This principle, basic to any understanding of mathematics in art, governs in present day conditions (37:33).

The movement against the classical concepts of harmony in the seventeenth and eighteenth centuries erupted from the idea that

> proportions were not objective qualities that existed in the thing viewed, but were sensations experienced by the viewer. Hence, such considerations as his position at the time, his ability to perceive well, and his actual feelings at the time affected such appreciation of proportions (37:34).

A debate was held at the Royal Institute of British Architects in 1957 on the motion "that Systems of Proportion make good design easier and bad design more difficult." This was based on Einstein's statement concerning Le Corbusier's Modulor. "It is a scale of proportions which makes the bad difficult and the good easy . . . it makes your task more certain" (4:192) was the foundation for the debate. Maxwell Fry, in favor of the motion, commented that even though systems of proportion are forms of abstraction they are useful. He did not claim that by means of numbers and scale that one produces beauty but did claim that a system of proportion is a help to the designer in that it can be used to refine his own feelings and intuitive design. The application of what is known about the mathematical relationships in nature can help to refine the artist's design. He believed that there are many systems of proportion. Just as the medieval builders had systems of proportion such as triangles, the Renaissance used forms such as squares and cubes (38:458).

Against the motion, Misha Black quoted Francis Bacon: "There lives no man on earth who can give a final judgement upon what the most beautiful shape may be" (38:458). Black was of the opinion that none of the systems of proportion provide a final solution and are today irrelevant to the design problems. He acknowledged that mathematical pattern governs all life in this world and that this pattern determines all energy and growth and is echoed in the sublime creations of men, but he maintained that to use a mathematical principle in attempting to produce a work of art is in the opposite direction. The system of rectilinear grid is in his opinion, a restriction. The "simple 12-in. rule with its feet and inches developed from the arm's yard, the man's foot and the thumb . . ." (38:459) is what Black employed.

In defense of the motion W. E. Tatton Brown commented that proportional systems in their right place are "harmless and even useful." Those designers against systems of proportions perhaps envision that somehow or other these systems will succeed and will be a substitute for creative genius. However, said Brown, they are succumbing to the fallacy of "mistaking the instrument for the hand which guides it" (38:459). The eighteenth century Rationalists were responsible for the anarchy in design. Hume and Burke overthrew systems of proportion as a basis for design and "Ruskin declared that possible proportions are as infinite as possible airs in music and it must be left to the inspiration of the artist to invent beautiful proportions" (38:460). Systems of proportion in Brown's opinion serve as a useful tool to three classes of persons:

> (1) to the critic in enabling him to interpret new works of creative genius in terms that we can all understand; (2) to the student, as a training of hand and eye in sensibility and in the study of the past; and (3) to the designer as a check after his first flush of inspiration (38:460).

Peter Smithson, speaking against the motion, suggested that systems of proportion "only touch the fringe of the problem of values in architecture and, if anything, confuse the issue both of the creative process and the environment as received" (38:461). He was not against systems of control which arise naturally from a building's organization patterns but against systems of proportion that claim universal validity rather than validity at a particular time in a particular place (38:461).

The idea that one should become familiar with and become persuaded into habits of thinking in proportions was suggested by W. A. Allen. An awareness of the usefulness of proportion and systems of proportion comes in a student's introduction to and training in architecture and should become a habit of mind so that as one designs, the pencil moves in a sense of proportion. It should be subconscious (38:461).

D. H. McMorran, quite concerned that the motion contained a wrong and useless statement, did, nevertheless, support it. His comment pertaining to the wording was that good design is difficult and always will be difficult and bad design is too easy. A work of art must have unity if it is worth viewing, and to achieve unity in a design, some system of harmonious proportion must go through it (38:462).

One comment by L. N. Fraser, a student, was that it seemed necessary to have a system of proportion allied to a scale, a system of proportion related to an absolute scale of the human body (38:462). Wittkower remarked that there were never any universal systems of proportion in the past. "It was only that the people who practised those systems believed that their own systems were universal systems" (38:462). Since the belief in absolute values has perished, it is of no importance that the individual architect fight for a system of general values until a broader foundation is formed (38:462).

Arthol W. Brentnall made the distinction between proportion and a definite measure: proportion has nothing to do with any linear measurement. The advantage of having some system of proportion is that it can act as a guide and not as the basis of the design because, to Brentnall, all good design is purely emotional (38:462).

Actually, it seems that, instead of speaking for or against the motion as it was stated, the participants were debating the issue that the use of proportional systems is necessary to achieve good design. The motion was defeated with 60 against and 48 for it, but there were indications that some of those participants voting negatively used some kind of guide or check for their own creative design. More than likely each had a method whether it was a previously established system or his own innovation.

Other designers of the twentieth century have expressed their views on the use of proportional systems. Teague did not think that mathematical formulas help a designer to create. Formulas can be useful both to train the designer's mental and physical eye in right proportions and to test and correct the proportions established by his eye (25:142).

> Now proportion is the most effective means of creating unity among diverse parts of an object . . . if we feel or see a rhythmic recurrence of the same ratios among line, dimensions, areas, masses, colors, we feel that these elements are bound together indissolubly in one identity, so that no part can be removed or altered without disturbing the rhythm of the whole (25:142-143).

Thus, one tries instinctively to create right proportions among the design elements with which he works (25:143). In design one works with quanitites and ratios of quantities, and Teague agreed that there must be mathematical formulas to express the result one desires. However, Teague recognized the fact that one cannot begin designing with these formulas. Just as a composer's ear must be trained to know true harmony of tones, so must the designer's eye be trained to see right proportion of lines and areas (25:143).

Licklider questioned the designer's use of proportional systems to create beauty. He agreed that systems can be recommended if they aid the designer to make finer works of art; that is, if what is permanently beautiful about these systems is geometrical and mathematical conformation in the abstract--beautiful ideas rather than beautiful building parts. On the other hand, he did not highly recommend the systems for the purpose of achieving beauty and unity. His explanation was that "the history of taste makes it quite clear that these qualities have been different things to different people at different times" (17:48).

According to Licklider the importance of visual proportion systems is that they produce two kinds of order.

> They place an order of dimensions and relationships in the design which (when it is seen) may be used to control whatever the designer wishes to express in his design; and they place in the mind of the designer an order of divisions and relationships which . . . can be a much needed stimulus to his imagination (17:49).

Bragdon, in his essays on The Beautiful Necessity, stated,

> The trained eye, and not an arithmetical formula, determines what is, and what is not, beautiful proportion. Nevertheless the fact that the eye instinctively rejects certain proportions as unpleasing, and accepts others as satisfactory, is an indication of the existence of laws of space, based upon number, not unlike those which govern musical harmony (2:91).

It has been argued that certain shapes are more pleasing to the eye than others. Some artists say the square is not beautiful; others say it is. Also, in the Renaissance the preferred rectangles were the ones whose sides had the simple numerical relationships of musical consonance, but today the preferred rectangles seem to be those whose sides are in the ratio of the golden section (23:5). However, the key of proportion seems to be the relationships between the shapes rather than the shapes themselves.

Scholfield discussed the proportional relationships which are significant to the eye. The three important relationships which the eye can recognize include sizes as well as shapes. First, the eye has the notable power of recognizing relationships between objects possessing the same shape. Objects having the same size as well as the same shape under comparatively favorable conditions is the second relationship. The third relationship which is the most difficult to recognize is that of the same size but different shapes (23:6).

The first relationship of similarity of shape leads Scholfield to define the object of architectural proportion "as the creation of visible order by the repetition of similar shapes" (23:6). Interior designers need to concern themselves with the relationships of some or all of the design elements in each design problem, however, there may be several methods of obtaining proportional relationships of shape which could act as guidelines for the interior design student. A designer basically creates with order as a goal and a proportional system can be a means to this end. To arrive at geometric shapes related to each other a student may construct either of two, the golden rectangle or the root rectangles.

The golden rectangle is constructed easily by two different methods. Possibly the simplest method starts with a square. See Figure 2. By this method, one side of square ABCD, AB, is bisected in order to obtain point E. A line can be drawn from E to C and line AB can be extended to F making EF equal to EC. By completing the rectangle AFGD a golden rectangle is formed in which the smaller area is to the larger area as the larger is to the whole:
BFGC : ABCD :: ABCD : AFGD.

A second method of constructing the golden rectangle starts with the given length of the longer side of the desired golden rectangle. This given length HK can be divided into its extreme and mean ratios as shown in Figure 3. Bisect HK to obtain J. Extend a perpendicular line LK at the end of K equal to JK. Using L as the pivot, cut HL equal to the length of LK. Mark this point O. Using H as the center, cut HK equal to the length of HO. Mark this point P. The lengths PK, HP, and HK now form a true proportion based on the ratios PK : HP :: HP : HK.

Figure 4 illustrates how, by constructing a

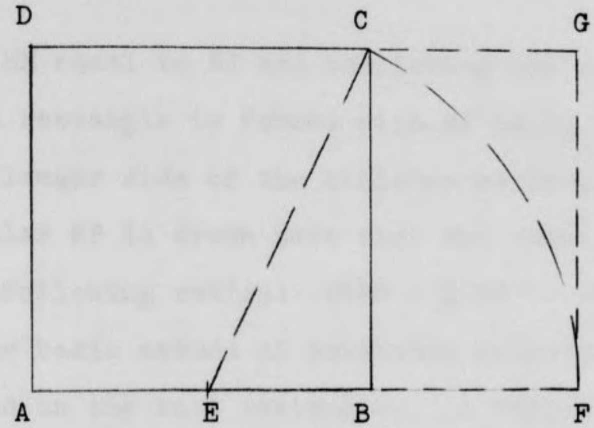

Figure 2. The Construction of a Golden Rectangle from a Square.

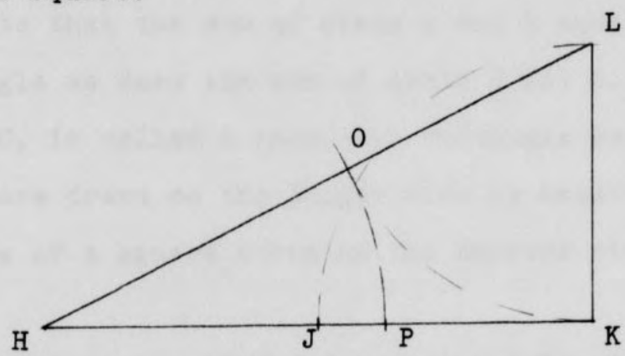

Figure 3. The Construction of a Golden Section from a Given Length.

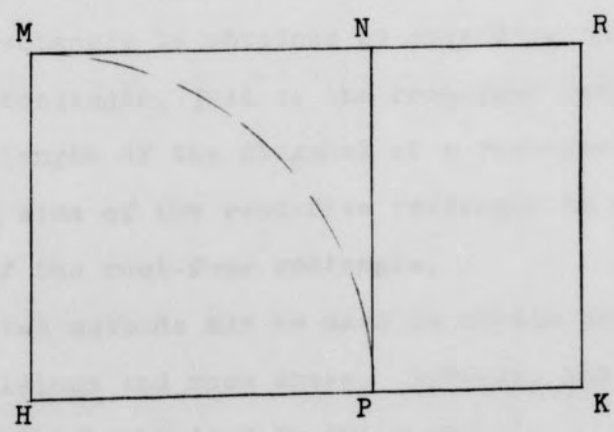

Figure 4. The Construction of a Golden Rectangle from a Given Golden Section.

perpendicular HM equal to HP and completing the rectangle HKRM, a golden rectangle is formed with HK being the given length of the longer side of the finished rectangle. When the perpendicular NP is drawn note that the areas formed result in the following ratios: PKRN : HPNM :: HPNM : HKRM.

Another basic method of obtaining proportional shapes is based on the root rectangles. A root-five rectangle is based on a double golden-section rectangle. See Figure 5. Note that the sum of areas A and B equals a golden rectangle as does the sum of areas B and C. This rectangle, ABC, is called a root-five rectangle because the area of a square drawn on the longer side is exactly five times the area of a square drawn on the shorter side of the rectangle.

The construction of four root rectangles is shown in Figure 6. A root-two rectangle is formed by extending a side of a square the length of the diagonal of that square. A root-three rectangle is obtained by extending the diagonal of a root-two rectangle, just as the root-four rectangle is formed by the length of the diagonal of a root-three rectangle. The long side of the root-five rectangle is equal to the diagonal of the root-four rectangle.

These two methods may be used to obtain proportional shapes for buildings and room areas. However, the design student should not be limited to their use.

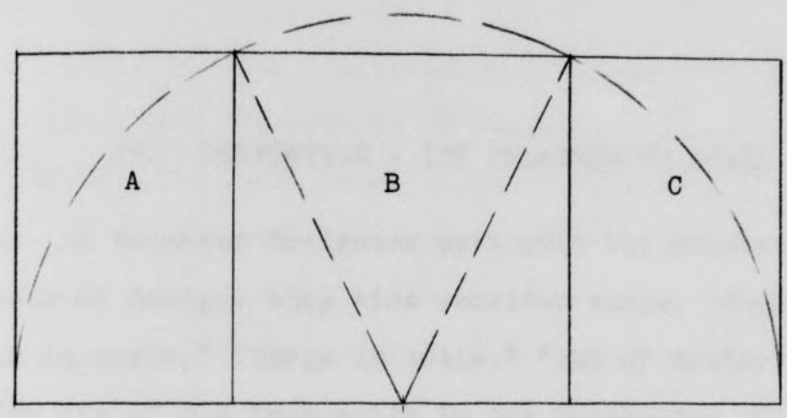

Figure 5. The Construction of a Root-five Rectangle from a Square.

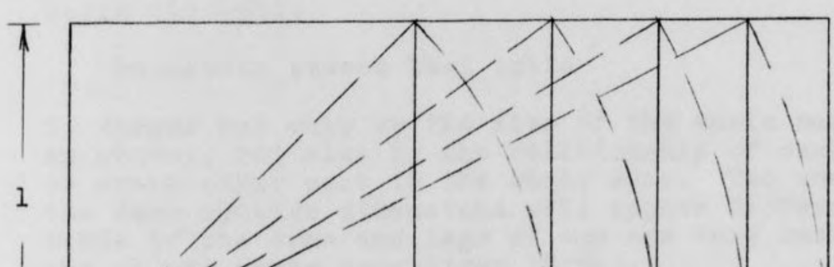

Figure 6. The Construction of Four Root Rectangles from a Square.

IV. PROPORTION - ITS RELATION TO SCALE

As interior designers work with the proportions of the elements of design, they also consider scale. The expressions "small in scale," "large in scale," "out of scale," "in scale," and "to scale" are frequently in the vocabulary of the designer.

Grillo in discussing scale spoke of it as the

> feeling of a design fitting its space and surroundings . . . . A design may be good in all other respect, but if its scale does not fit where it belongs, it is wrong--while many a design in poor taste is admissible if it possesses the quality of scale (11:151).

Goldstein stated that scale

> is judged not only by the size of the whole mass of an object, but also by the relationship of each part to every other part to the whole mass. Two chairs of the same outside dimensions will appear different in scale if the arms and legs of one are very heavy, and of the other very light (9:84).

Scale can mean that the sizes of the parts making up an object have a pleasing relationship to the object and to each other, whether the object is a chair or a building. Or, scale can mean that the size of the object is in good proportion to the objects combined with it. If, in a grouping of large glass bottles and containers, a very small glass vessel is placed with them, it will probably look "small in scale" and will not be in good proportion with the others.

Scale has been defined as the size of an object or area. One might say that it is related to the expected size of an object or area because a person will judge the scale or size of an object as he compares it to similar objects with which he is familiar. "Scale, therefore refers to the size of objects in comparison to the size customarily seen" (31:770).

One's judgment of an object's size or scale is based on definite dimensions of certain objects. Some of these dimensions of objects are fixed either for practical or economical use and others are fixed by chance. It is only by comparison that things are considered small or large. D'Arcy Thompson says, "The scale of human observation and experience lies within the narrow bounds of inches, feet or miles, all measured in terms drawn from our own selves or our own doings" (26:24).

If a person expects to see a chair of a particular size for its particular function--easy chair or dining chair--but finds it smaller than he anticipated, he will then consider it "small in scale." Also, if a three story store is built between two gigantic skyscrapers, it could certainly appear "small in scale." The opposite will be true if a person is accustomed to seeing a dining table of delicate lines which will seat six people and then he views a massive table with heavy lines capable of seating eight people. The massive table then will be considered "large in scale." Or, if a large three-story house is erected in the surroundings of relatively small one-story houses, then it may be considered "large in scale."

> But the spectator's idea of the normal appearance of people and familiar shapes--seen against a building--fluctuates with his intellectual and emotional bias concerning the building's function, its place in the community, and even with its materials and method of construction. Where large-scale or small-scale designs coincide with his expectations, he may experience variations in scale--and eloquent expressive qualities--without a disastrous break into clinical speculation about sizes (17:144).

The scale and proportions of a building or of a room can affect how comfortable one feels in its surroundings. Rooms of extremely large scale might make one feel small and perhaps insignificant. Also, a room designed to the small scale of children will be quite delightfully accepted by the children but an adult would perhaps feel like a giant in it. However, when the use of a room determines its size, then the viewer thinks of the purpose of the room and relates it to whether he thinks it is "large in scale" or "small in scale." If, when he views a large room he expects to see a large room, then it is "in scale."

If one speaks of scale as magnitude, the size of a room, particularly the height of the ceiling, may indicate that it is "large in scale." The proportion of this height to the width and depth may not give a feeling of shelter. Richard Neutra wrote of his childhood and mentioned that because the ceiling in the parlor was uncomfortably high to him he used to sit and play under the piano (18:25). The proportion of space to visual surroundings under the piano was more "in scale" with his size.

Designers talking about objects or areas being "out of scale" or "in scale" are referring to these objects or areas being consistently well proportioned in themselves as well as with their surroundings. If a small table with delicate legs is supporting an apparently heavy top, then the table will be "out of scale." However, a small table is "in scale" if its parts consist of relationships pleasing to each other and to the table as a whole. If this small table which is "in scale" with itself is put in a large room in which the rest of the furniture and accessories are well proportioned to each other and to the room, it will be "out of scale." In addition to being "out of scale" with the surroundings, it may create an unpleasing proportion in the room. Many times when designers speak of "out of scale," they indicate that the relative dimensions of an object do not go well together which in turn means that the dimensions are out of proportion. When the relative dimensions of an object do go well together, the object is "in scale" or well proportioned (10:114).

When a designer talks of designing something "to scale," he means that he will design it "according to the proportions of an established scale of measurement" (29:2023). For instance, if certain proportions are drawn to a scale of one inch representing one foot, the same relative proportions will remain if they are increased to the one foot measure. When a model is completely executed according to an established scale such as a chair model of 1/8" = 1" and viewed in a photograph it will appear to be the intended size of the actual chair if there is no reference to a full size object with which one is familiar in the photograph. Therefore, the designer needs to be able to visualize or relate a design which is drawn to an established scale to the actual size of the completed composition. A design student may find that it is difficult to judge proportions of size when drawn to a small scale because the human scale is not visually present.

Licklider described the idea of human scale when he referred to architecture as having "to do solely with the spectator's impressions of the size of a building, relative to his own size and position, and relative to these shapes with customary recognizable sizes" (17:70). Since one judges things around him in relation to himself, the size of his body serves as a measuring rod. As Walter Gropius stated, "Our body is the scale unit which enables us to establish a finite framework of relationships within the infinite space . . . . One's emotional interest in an object may be altered merely by a change of its size, deviating from the expected norm" (36:301).

"The way in which a person expects to see people and familiar objects in relation to a building varies with the culture, the building, and even from room to room, according to his preconceptions and his past emotional experiences" (17:91). In traveling to another part of the world, a person may feel uncomfortable if the scale of the hotel is small with small rooms in which the windows and doors are small as compared to the scale of his home. However, the inhabitants of this country may be of small stature, and, the scale of this building is probably suitable and natural to them because it is what they have been accustomed to. These same inhabitants may consider a building of ours "large in scale" whereas it is natural to us. A building is in human scale, stated Licklider, when "it is designed so that the human figure and other objects with recognizable size look normal in it and against it" (17:70).

Cecil Elliott discussed the variety of scale as he talked about graphic scale, personal scale, building scale, and conceptual scale. Graphic scale is the scale utilized for architectural drawing. The personal scale is the one incorporating a compromise between illusion and reality. One can assume approximate sizes of objects and it is against these objects that the size of a building is judged. However, with the size of building parts changing, sometimes it is difficult to judge sizes. Building scale refers to the size of buildings for particular functions. The relationship between building scale and personal scale is known as conceptual scale. It is, for example, the transitional act from the street to the individual offices of a large building. The lobby, because of large crowds at certain times of day, needs to be large but at the same time needs to exhibit the personal scale (34:93-95). Elliott illustrates these aspects of scale by relating them to each stage of the design of a building.

> Drawings are made (graphic scale) to determine the arrangement of useful spaces and shapes (personal scale) within a single form or a complex of forms (building scale) established by the practice of the art of architecture (conceptual scale) (34:95).

Scale in a room or building must be maintained and its dominant proportions must be sustained. The proportional scheme in a larger building should be brought down so that it relates to the personal scale if the "full emotional impact of size is to be felt" (25:185).

Licklider wrote that dimensions established by harmonic proportional systems might be useful to human scale treatment. Even though he did not advocate the use of systems of proportion, he thought that these dimensions might make it easier to regulate scale treatment from room to room and from a room to the whole interior. It is this geometrical scheme of harmonic systems that aids in controlling a spectator's impressions of size (17:150-151).

The order created by systems of proportion can aid in establishing a measure which can influence recognizable sizes throughout a design. To maintain human scale through the interdependence of parts should be an architect's concern as he designs for "the continuous experience of a spectator who moves within and around a building at will . . ." (17:151).

The sizes of the objects or areas in the room should be of the correct scale for the particular design for good proportion to be present in each interior. Whiton said,

> There is a proper scale for everything used in a room, whether it be the architecture, the furniture, the accessories, the patterns or the texture of objects. The decision as to the proper scale must come from the experienced eye, and it is of the utmost importance in good design and decoration (31:772).

V. ELEMENTS OF DESIGN AND PROPORTION IN INTERIORS

Deciding on the proportion of the elements in addition to deciding on the proper scale in an interior can be quite difficult for the interior design student. How design elements will relate to themselves and to each other is knowledge that results from experience in design combined with talent. "A keen sense of proportion, of its relative value and its practical or psychological value, is one of the most precious qualities of a good designer, and also the hardest to master" (11:144). The sense of proportion, a natural born sense, is in a latent stage in everybody and can be developed by education (11:144).

William B. Foxhall in referring to Gerald Luss's beliefs about the role of an interior designer stated that the architecture of interiors is not different from the profession of architecture.

> It is more properly a concentration of attention to the intimate details of the total environment of people and their operating relationships--the fulfillment, if you will, of the primary function for which architecture of the building itself is the framing expression (35:112).

Not every interior is designed but every interior is somewhat planned. Interior design incorporates "space planning . . . most elementary part of interior design . . . . Decorating, too, although it calls for special talents, is a secondary part of the interior design job" (35:112). In commercial buildings the important function of the interior designer

> lies in his ability to analyze the relationships of people . . . where the flow of information and materials is a primary factor in the arrangement of mechanical equipment, utilities and furnishings in a total working environment (35:112).

The proper proportion of the elements of design within a specific area results in a well proportioned and functional design.

Raymond, in discussing the effects of proportion, said that they "are not determined by actual measurements, but by what the measurements appear to be, after perspective and the methods associated with it have made them appear as they do" (21:335). This point is illustrated by the Greeks who were very conscious of proportion in architecture and who used certain variations in the main lines of their buildings. In the Parthenon the long lines of the entablature were curved slightly upwards towards the center because long horizontal lines appear to sag in the middle. In the distance of about 230 feet the curved line deviated from the straight line only about three inches. Also, the columns were slightly inclined inward which prevented the appearance of their spreading outwards at the top. The total amount of inclination was not more than two inches. The variation made in the end columns was that of making them a little thicker than the other columns as well as a little closer to the adjacent columns to compensate for the fact that dark objects against a light background seem thinner than light objects seen against a dark background. In 438 B.C. when the Parthenon, which has been considered to be the most perfect in design of all the Greek temples, was completed (3:31), the use of some of the design elements were manipulated to achieve good visual proportion.

Sir Leonard Woolley discussed the effect of optical illusions in architecture before the Greeks:

> When first we started the work of drawing out the plan and elevations of the Ziggurat we were puzzled to find that the different measurements never seemed to agree; then it was discovered that in the whole building there is not a single straight line, and that what we had assumed to be such were in fact carefully calculated curves. The walls not only slope inwards, but the line from top to bottom is slightly convex; on the ground plan the wall line from corner to corner of the building has a distinct outward bend, so that sighting along it one can only see as far as the centre; the architect has aimed at an optical illusion which the Greek builders of the Parthenon at Athens were to achieve many centuries afterwards, the curves being so slight as not to be apparent, yet enough to give to the eye an appearance of strength where a straight line might by contrast with the mass behind it have seemed incurved and weak. The employment of such a device does great credit to the builders of the twenty-third century before Christ (15:44).

Literature reveals theories of proportion or probable theories that artists used in ages past in their creation of architecture or pictorial compositions. In interior design it is left up to the designer to incorporate some or all of the many variables of the design elements in the best proportional relationship without any complete set of rules to guide him. If there are no rules in interior design, how does one acquire or improve his creative approach.

Gropius contended that

> the design student must learn to see; he must know the effect of optical illusions, the psychological influence of shapes, colors, and textures, the effects of contrast, direction, tension, and repose; and he must learn to grasp the significance of the human scale (36:300).

Grillo mentioned that

> the essence of life in a building is movements, and we have to consider all the infinite variety of fields of vision involved in the successive motion of man as he walks from one place to the other (11:129).

As Grillo pointed out, "the three dimensions that limit the volume of an office, a living room, or an auditorium, can be expressed in an infinite variety of proportions" (11:144).

Modern science and research have opened the way for the imagination of the artist in design. In the past, materials dictated limitations, but now proportion has reached a new value in today's architecture. For example, walls formerly were the bearing members of a structure; now they can divide open space into areas. This change in purpose frees the designer to use walls primarily as a design factor. "We are left with wide open areas to distribute into spaces. The whole issue of the design battle will depend on the value of the proportion we decide to give each of these areas" (11:141).

However, sometimes the structural plan of a building is important because it concerns the distribution of supports bearing the weight and the effective use of spaces for their specific purposes. It is also important because it determines the size, proportions, modulation, and design of the space (6:184).

In the early nineteenth century Percier and Fontaine as quoted by The Encyclopedia of World Art wrote concerning the structure and its interior.

> Furnishings are overly bound to the decoration of interiors in order that the architect may be indifferent to them. When, in spirit, decoration is separated from construction and does not operate in accord with it, decoration soon abandons itself to every form of absurdity and contradiction. Not only will it pervert the essential forms of the building; it will cause them to vanish. Mirrors placed without judgment and tapestries placed at random will open up voids where there should be solids, solids where there should be voids. Structure should be to buildings what the skeleton is to the human body. It should be beautiful without being masked completely. And it is the structure, varying according to country, clime, and type of building, that determines the character of the decoration. But whatever the size and importance of the building, the finished work will lack spiritual meaning if the decoration is not planned along with the construction, if the basic form of the building does not seem in accord with details, if finally, one perceives that the building is the product of two wills in discord (6:198-199).

In the beginning stages of an interior design problem, the designer must first consider the size of the room or rooms in which he is to concentrate his efforts and he needs to consider the functions of these areas. Even though he could be concerned with visual proportion only, as in a display room in a store, usually he must consider the uses of the rooms. Once the size or scale of the room is studied, then he is ready to proceed with the relationships of the design elements--the proportion of line, form, color, texture, light, pattern, and space to achieve his goal.

Whether it divides the ceiling from the walls, outlines a window, or forms the shape of a piece of furniture, line, as a design element, is always present in an interior. Lines may be horizontal or vertical, straight or curved, heavy or light. It is the relationship of these lines and the quantities of each which help determine the order of the interior. It is usually suggested that either horizontal lines or vertical lines predominate and not be used in equal quantities. Since line may be used to change the apparent height or length, it is a very useful element in interior design.

Goldstein verifies the generalization that vertical lines add height and horizontal lines add width to an area or object. She also says, "Vertical lines can be so arranged that they will carry the eye from one line to the next, and while they still add height to an object they will also add width" (9:74). The proper use of lines can apparently alter proportions. If the ceiling is lower than desired, one way to "raise" it would be to emphasize the vertical lines. A low ceiling in a room may appear higher if the walls have a suggestion of vertical stripes in the paper (9:79). However, too many vertical lines may tend to carry the eye across rather than upward and result in the ceiling looking as low or lower than it actually is. In a room with a high ceiling the use of horizontal lines on the walls could make the ceiling appear lower.

Straight and curved lines may be used in an interior, but generally the proportion of straight should be greater than the curved. When the interior has curved walls or is enclosed by a dome, the curved lines may predominate.

The use of heavy or light lines needs to be considered in each interior, too. Heavy lines will tend to make a room appear smaller; light lines may make a room appear larger. For a sense of stability a large room usually demands heavy lines whereas the use of light lines in a small area is usually more in proportion.

Forms are encompassed by lines and it is the various shapes and their proportions in an interior which help determine whether or not the effect is pleasing. The scale of furniture and other forms are related to the whole area. For a small room, furniture light in scale--light meaning in apparent weight--and simple in design results in pleasing porportion. There needs to be a variety of forms for interest, but if too many shapes are used, the room may appear cluttered. Perhaps an interior with only a few shapes can acquire greater variety through the use of different proportions of color.

Within the new architectural structures Le Corbusier considers that:

> It is through polychromy that the sensational play, the colored epic, soft, violent, can be introduced into a house. Using just those organic necessities of the modern plan, I have seen that tumults can be disciplined by color, lyrical space can be created, classification realized, dimensions enlarged and the feeling for architecture made to burst forth in joy (16:50).

If a room is small for the intended use, the designer should strive to enlarge the area visually. This can be done through knowledge of the effect of the design elements on proportion. For example, the room will appear larger when the walls are painted a light color. One can agree with Gropius in that:

> Colors can be active or passive; planes or walls can be made to advance or recede by color treatment. The dimensions of a room thus appear to be different from what the actual measurement tells us. In fact the designer--if he masters these means--can create illusions which seem to belie the facts of measurement and construction (36:301).

Gropius also pointed out that

> color and texture of surfaces have an effective existence of their own, sending out physical energies which can be measured. Such effect can be warm or cold, advancing or receding, bright or dark, light or heavy, in tension or in suspension, or even attractive or repulsive (36:301).

Texture can be anything between smooth and coarse. If all coarse or medium coarse texture is used in a room in the upholstery, draperies, floor coverings, and the wall surface, the proportion of rough to smooth texture will be displeasing. Rough texture also tends to make an area smaller. Heavy textured coarse fabrics are apt to overpower small scaled furniture. There should be good proportion of textures in relation to the size and use of a room.

Varying amounts of light in interiors are decided according to purpose--functional and esthetic. Today's architecture incorporates window walls which may result in too much light for certain functions. Grillo thinks that these window walls have "blunted our sensitivity to the special value of light" (11:126).

> Light may hurt, like in some airport restaurants where the view is commanded by 90% of a glaring and merciless sky; or light may soothe and be warm to the heart like a friendly presence, dearly felt, but never imposed (11:127).

The proportion of light--whether it is natural or artificial, direct or indirect, or both--will either decrease or increase the size of a room. If there is a greater proportion of general lighting, the room will appear larger. Areas which use direct or specific lighting result in bright areas and contrasting dark areas. The shadows created by area lighting create patterns which in turn fill up the room making it appear smaller. However, some shadow is desirable because a room needs a feeling of solidity and depth.

Sources of light can be the sun through the windows, glass doors, and skylights; lamps; cornice or valance lighting; ceiling lights; spot lights; or decorative lighting fixtures. Each gives a different type of light and an interior pleasing to look at will have a good proportion of two or more types of lighting. The function of the room will again determine whether or not one lighting plan is better proportioned for the purpose than another. It is true that a particular lighting system could be recommended for visual proportion alone. With very little light in a room shadows increase, and the proportion of light to shadow will be small and seeing will be difficult. However, this effect may be a pleasing atmosphere. Light could be considered the most needed element in proportion as it must be present in order that an interior can be seen. Grillo says, ". . . light must be modulated for every different mood and activity of man" (11:127).

Even though pattern is created by shadows, patterns are usually thought to be those designs in fabrics, wall coverings, and floor coverings. There should be a good proportion between patterned areas and plain areas. The less pattern in a room, the more spacious it appears. The larger the patterns, the smaller the room appears. Also, if small scale furniture is used, large patterns in upholstery or drapery may be out of proportion to the furniture. Therefore, the proportion of pattern as well as the size of the patterns used influence the apparent size of a room.

Space may be considered open or occupied. Furniture or accessories occupy space and it is the areas between these items which is open. The relationship of open space to the areas of mass can influence the apparent size of a room. It is difficult to judge the size of a room in which there is no familiar shape. It is when some of the open space is filled with familiar forms that the apparent size is established. Objects small in relative scale tend to make an area seem larger whereas objects large in scale tend to decrease the apparent size of an area. Considering space as an area between volumes, one can say that it is, for example, the amount of wall space not covered with pictures or hangings, wall space and its relation to windows and doors, or the relation of an open area in a room to those areas displaced by furniture or surface objects. Or, it can include a wall which is covered entirely with drapery in which the drapery may be referred to as the "space." The drapery can then become the "wall space" or background space with objects in the foreground.

There needs to be pleasing proportions between the open and occupied spaces. If a room is overly filled with furniture and objects, it will appear crowded; the proportion of occupied space to that of open would be too great. On the other hand, if there are just a sofa and two or three chairs in a large room, then the open space will be out of proportion to the occupied space. If, however, this room functions as a corridor or an entrance area in a large building, then these few pieces of furniture perhaps will not seem out of proportion with the area. Thus, function does seem to enter into the judgment of proportion of occupied space versus open space.

In arranging groups of objects one may find it desirable to group several pictures together so that they will create a pleasing proportion with a particular wall space. Goldstein wrote that it is usually true

> if single units or objects in a group are to be viewed as units, they may be separated by spaces wider than the unit measure; but if objects are to be seen as a group, the spaces between them should be smaller than the size of the objects. If this group is to be related to another near it, the space between the two should be smaller than the space occupied by either (9:72-73).

Licklider commented on the fact that shapes of a proportional system are not only modified by perspective but also by the interdependence of the many things seen at the same time.

> Simple visual experiments show that all of the shapes, thicknesses, colours and values of light and dark outside the system affect our experience of the proportioned shapes, and may even prevent their recognition (17:46).

Le Corbusier in speaking of architecture and the arts referred to architecture as beginning to reorganize everything from the skeleton through to the skin.

> Animating this skeleton, architecture has edified an authentic symphony through light and the manner in which this light clarifies walls; its lyricism is made of intensely real psychophysiological events, its controls are proportion (16:49).

His concern that the great art production has remained indifferent to the contemporary architectural event is of value when he spoke of the walls being turned over to unprepared minds. Walls are beautiful in their proportion and an inappropriate style of painting or statuary will kill the wholesome clear speech of architecture (16:49-50).

Warner was of the opinion that the principle of proportion is the most frequently violated design principle in home furnishings (28:211). A good example in the home furnishings trade is the incompatibility of the showroom display and one's home. It is most important in appealing to the customer's interest to display furniture and accessories as near as possible in the proportion in which it might appear in a home. Ceilings in retail stores are generally higher than those in houses so the proportion of wall space to the furniture is usually greater than it would be in houses. It is important that a customer be able to relate a room display in the store to her home. One way would be to lower the ceiling visually to an eight foot height by establishing a horizontal line at this height at which wallpaper or a paint color would terminate.

The interior designer has the difficult task of coordinating the work of the architect, furniture designers, and industrial designers. The interior designer has the spaces provided by the architect or builder and the furniture and appliances created by mass production, to combine in creating the finished designs that are in good proportion. It would seem that mass production in building and furniture would aid in developing pleasing proportions; however, it is often most difficult.

VI. SUMMARY

The purpose of this study was to gain a better understanding of proportion as it pertains to interior design. The historical significance and conceptions of proportion in design today were reviewed.

Broadly defined, proportion is the quantitative relationship between objects and areas. It is the relationship of sizes and shapes. Since scale refers to size it is related to proportion. Sizes of things are compared to sizes with which one is familiar. Basic to all sizes is the size of man. The human scale is the basis for design since all designs are executed for human beings to use or to enjoy. The relationship of sizes between parts of an object, between objects, and between objects and the whole is of concern to a designer. In interior design proportion is concerned with the quantitative relationship of two or more of the design elements--line, form, color, texture, light, pattern, and space--to themselves, to each other, and to the whole.

Designers have written of applying the principle of proportion but rarely have attempted to define it. Since the elements of design are applied to achieve proportion, the application of the principle of proportion depends on the judgment made by the designer. The ability to discern good proportion is necessary. Then, as the design elements are used, they are changed when necessary in order to arrive at a design exhibiting good proportion.

Throughout history proportion has been closely linked with both nature and mathematics. During certain periods of history, systems of proportion for architecture were more or less accepted, with different systems predominating at different times. Presently, subjectivism influences design which in turn discounts the possibility of any universally accepted system of proportion.

Critics argue the significance of science in art. Some think that the use of a system of proportion is necessary in architecture in order to obtain a meaningful relationship of sizes. Others think such scientific application of parts to each other and to the whole stifles creativity. However, systems of proportion can be a means to an end. They can be used as a guide, or a check, if a designer so chooses. Pleasing relationships of shapes and sizes can be achieved through the use of a proportional system. If a proportional system will aid a designer, it may be best for him to use one. Others may find systematic applications stifling.

In design a pleasing relationship of design elements is sought but sometimes is quite difficult to obtain. In practice the use of each element of design--line, form, color, texture, light, pattern, and space--affects the final proportion. In addition, one design element may influence the effect of another design element. Therefore, their interrelationship needs to be studied. For those persons who have an "eye" for recognizing good proportion the many variables are not studied separately. Rather, the total effect of combinations of the design elements is considered. Interior designers need to develop the ability to judge the effect of each element of design to the whole.

It is the interior designer who has to manipulate the design elements to try to achieve good proportion in a finished area. Sometimes designers who have not been consulted before the proportions have been determined are faced with the problem of poor proportions in room sizes and in placement of windows and doors. It seems advisable that the designer of an interior should be included in the architectural planning to help proportion the interior dimensions to the best advantage in order that the desired room design may be achieved.

Plotinus quoted:

> What is it, that impresses you when you look at something, attracts you, captivates you and fills you with joy? We are all agreed, I may say, that it is the inter-relation of parts toward one another and towards the whole, with the added element of beauty in color, which constitutes beauty as perceived by the eye, in other words, that beauty in visible things as in everything else consists of symmetry and proportion (14:53).

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APPENDIX

THE MATHEMATICS OF VISUAL PROPORTION

It will be convenient to restrict the discussion to problems of straight lines and rectangles. This will not be too unrealistic, as problems of this kind are those with which the modern architect is most often concerned.

Simple mathematical proportion consists of the equality of two ratios, e.g.

$$\frac{a}{b} = \frac{c}{d}.$$

The connexion between this type of proportion and similarity of shape is an obvious one over which we need not spend much time.

If we divide two straight lines of different lengths in the same ratio, we are making use of simple mathematical proportion. At the same time the equality of ratio is easily recognized by the eye. It can be said in a sense that the two figures which we have produced are of the same 'shape'. If we draw two rectangles of the same shape, the similarity of shape is again easily recognized. The ratios of the sides of the two rectangles are equal, so we have again made use of simple mathematical proportion. We may not have done so consciously, as we could use a geometrical method of drawing similar rectangles which does not require us to consider the relations between their linear dimensions. But whatever method we use, the linear dimensions will, in fact, conform to the pattern of simple mathematical proportion.

When we are dealing, not with separate rectangles, but with rectangles which are connected together in various ways, more complicated patterns of mathematical proportion may be developed among their linear dimensions. If, for instance, we draw two rectangles of the same shape but of different sizes, with one side in common, we are making use of continued proportion:

$$\frac{a}{b} = \frac{b}{c}.$$

If these ratios are equal to $\underline{x}$, and if we make $\underline{c}$ equal to one unit of length, it is easy to see that the lengths of the sides of the rectangles become 1, $\underline{x}$ and $\underline{x}^2$ units of length. The pattern of proportional relationships which has been generated between the linear dimensions is, in fact, that of a geometric progression.

It should be clear that the further we go in repeating similar shapes in a design, the more we tend to bind the linear dimensions of the design together in a pattern of relationships of mathematical proportion. In the simple case which we have just considered, it is the pattern of the single geometric progression which is generated:

$$1 \quad a \quad a^2 \quad a^3 \quad \ldots$$

A slightly more complicated pattern is formed by two superimposed geometric progressions:

$$\begin{matrix} 1 & a & a^2 & a^3 & \ldots \\ b & ab & a^2b & a^3b & \ldots \end{matrix}$$

A still more complicated pattern which includes the others as parts of itself is the double geometric progression:

1	a	a^2	a^3	...
b	ab	a^2b	a^3b	...
b^2	ab^2	a^2b^2	a^3b^2	...
b^3	ab^3	a^2b^3	a^3b^3	...
⋮	⋮	⋮	⋮	

The solution of some problems of proportion may even require the use of a triple geometric progression.

If we use a scale of linear dimensions with a prearranged pattern of proportional relationships, like that of the geometric progression, it is a very simple matter to draw rectangles of the same shape but of different sizes, or of a limited number of shapes. The repetition of ratios embodied in the geometric progression leads to the repetition of shapes in two dimensions. What is perhaps not so obvious is that the converse is also true. The repetition of shapes in two dimensions leads to the repetition of ratios, and to the development of patterns of proportional relationships between the linear dimensions of the design.

. . . .

So far we have found nothing to decide what particular ratios are likely to be repeated, and what particular values can be given to a and b in our geometric progressions. Now it is not enough that the linear dimensions of a design should be connected by a pattern of proportional relationships. We have already seen how, in building up a design in two dimensions, the smaller parts must add up to form larger parts, and the larger parts must add up eventually to form a whole. For this to be possible, we must be able to add the linear dimensions together to form larger dimensions belonging to the same pattern of proportional relationships. Our geometric progressions, whether single or compound, must not only possess the normal property of embodying a pattern of repeated ratios. They must also possess a wide range of additive properties, by means of which smaller terms of the progressions can be added together to form larger terms.

As a matter of fact, only certain geometric progressions and combinations of geometric progressions have properties of this kind at all, and some have a richer variety of useful additive properties than others. It is therefore no accident that in tracing the history of our subject we shall find comparatively few patterns of proportional relationships, generated automatically or used deliberately in the solution of problems of architectural proportion.

Of these the simplest is the geometric progression:

$$1 \quad 2 \quad 4 \quad 8 \quad 16 \quad \ldots$$

This has only one set of additive properties: $1 + 1 = 2$, $2 + 2 = 4$, etc. One way of adding to them is to superimpose two geometric progressions:

$$\begin{array}{ccccccccc} 1 & & 2 & & 4 & & 8 & & 16 & & \ldots \\ & 3 & & 6 & & 12 & & 24 & & \ldots \end{array}$$

This has the additional sets of additive properties $1 + 2 = 3$, $2 + 4 = 6$, etc., and $1 + 3 = 4$, $2 + 6 = 8$, etc.

Another set of additive properties is given by adding a third geometric progression:

$$\begin{array}{ccccccccc} 1 & & 2 & & 4 & & 8 & & 16 & & \ldots \\ & 3 & & 6 & & 12 & & 24 & & \ldots \\ & & 9 & & 18 & & \ldots \end{array}$$

The additional additive properties are $1 + 8 = 9$, $2 + 16 = 18$, etc. We are well on the way here to a double geometric progression which we shall find playing an important part in the Renaissance theory of proportion, and which can be generated by the use of simple shapes like the square and double square. Its value is limited, however, by the rather restricted range of its additive properties.

Other progressions which occur in practice are based, not on whole numbers, but on square roots, such as the progression

$$1 \quad \sqrt{2} \quad 2 \quad 2\sqrt{2} \quad 4 \quad \ldots$$

This has the additive properties $1 + 1 = 2$, $\sqrt{2} + \sqrt{2} = 2\sqrt{2}$, etc. Then there is the related progression based on the number θ, which is equal to $1 + \sqrt{2}$, or $2{\cdot}414\ldots$:

$$1 \quad \theta \quad \theta^2 \quad \theta^3 \quad \ldots$$

The characteristic additive property of this progression is

$1 + 2\theta = \theta^2$.

These two progressions can be combined effectively in a double geometric progression based on θ and $\sqrt{2}$:

$$\begin{array}{ccccc} 1 & \theta & \theta^2 & \theta^3 & \cdots \\ \sqrt{2} & \sqrt{2}\theta & \sqrt{2}\theta^2 & \sqrt{2}\theta^3 & \cdots \\ 2 & 2\theta & 2\theta^2 & 2\theta^3 & \cdots \\ 2\sqrt{2} & 2\sqrt{2}\theta & 2\sqrt{2}\theta^2 & 2\sqrt{2}\theta^3 & \cdots \\ \vdots & \vdots & \vdots & \vdots & \end{array}$$

This has a number of additive properties, including $1 + 1 = 2$, $1 + \sqrt{2} = \theta$, $1 + \theta = \sqrt{2}\theta$, $1 + 2\theta = \theta^2$, and $1 + \theta^2 = 2\sqrt{2}\theta$. The double geometric progression has thus not only the additive properties of the two single geometric progressions from which it is formed, but additional additive properties of its own as well; and we shall encounter several systems of proportion making use of the simple pattern of proportional relationships embodied in it. Their effectiveness is due to the fairly wide range of additive properties which it possesses.

Other systems of proportion produce different patterns of proportional relationships, such as the triple geometric progression based on the numbers $\sqrt{3}$, $1 + \sqrt{3}$ and 2, which may be generated, for instance, by the use of the 30°-60° and 45° set-squares.

. . . .

All the systems of proportion which we shall examine will be found to generate characteristic geometric progressions of the type which we have been discussing. Their value depends largely on the variety of additive properties which these geometric progressions possess. Judged from this point of view, systems based on whole numbers alone seem less likely to be effective than systems based on irrational numbers like ϕ and θ; of these, systems based on ϕ seem most likely to be effective.

Finally, there is one more property of these numbers which must be described here. The numbers ϕ and θ are irrational, and their use in architecture produces dimensions which are incommensurable. This is clearly a disadvantage for ordinary architectural purposes, but it is one which can easily be overcome. The progression 1, ϕ, ϕ^2, ϕ^3, ... can be replaced by the Fibonacci series 1, 2, 3, 5, 8, 13, 21, ..., in which successive pairs of numbers are added together to form the next number. This series has exactly the same additive properties as the ϕ progression. It is not, of course, a true geometric progression, but the ratio of successive pairs of numbers approximates more and more closely to ϕ:1 as the series goes on. The Fibonacci series therefore forms a satisfactory whole-number substitute for the ϕ progression. The progression 1, θ, θ^2, θ^3, ... can be replaced in the same way by Pell's series, 1, 2, 5, 12, 29, ... (23:7-11).