Abstract of Thesis

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Abstract

This thesis is concerned with some educational methods for teaching structural engineering to architectural students. After citing evidence for and against, the thesis argued that structural knowledge is essential as one of the generators in architectural design. A review of literature indicated that there is little unanimity about the content of the structural curriculum and a discussion followed on the structural knowledge and skills necessary from the architect for fruitful collaboration with the structural consultant. This part concluded with a list of general objectives for teaching structures to architects.

As architectural design is closely concerned with creativity, this was examined in terms of architectural creativity and of teaching methods for structures. Modes of thinking as logic, association and bisociation of ideas and gestalt, in addition to the pyschological approach were discussed for relevancy in this context. A brief schema of the architects' process of creativity was produced. From that examination there emerges those qualities which are required for selecting and developing architectural/structural systems or relevant elements. A distinction was made between the serviceable product and the communication of feelings, perception and knowledge and the teaching methods reflect the difference found in the classification.

Some teaching methods specific to structures were discussed, tested and developed for the efficiency in promoting those qualities found necessary for architectural/structural creativity. Programmed Learning was then tested and dicussed in terms of acquiring and transferring knowledge, attitude of the student, and the role of the teacher. Possible formats were suggested and tested including a comparison between using mathematics and not using mathematics to explain statically indeterminate systems.

Notes

1. Three copies of the thesis, each of which must be accompanied by an Abstract which must be bound in to precede the thesis, must be lodged with the Assistant Secretary, Registration Office, together with a completed Submission of Thesis form and an additional copy of the abstract.
2. The Abstract should not normally exceed 200 words and should set forth the main argument and conclusions of the thesis. The abstract must be in typescript and be written in English.

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TABLE OF CONTENTS

Pages

Chapter 1 INTRODUCTION TO AND INTENTION OF THESIS

Chapter 2 REVIEW AND DISCUSSION OF LITERATURE

Chapter 3 ARCHITECTURAL CREATIVITY

Chapter 4 TEACHING METHODS ADAPTED FROM THE CONCLUSIONS OF CHAPTERS 2 AND 3

INTRODUCTION TO AND INTENTION OF THESIS Chapter 1

1.1 INTRODUCTION

With some exceptions it is generally acknowledged by architectural schools in the U.K., Europe, North and South America and Australia, that a knowledge of structural theory is essential for architects. Architectural teachers are not, however, unanimous about the range of the necessary structural knowledge. The teaching of such theory is generally in two parts. The first part concerns the teaching of abstract structural theory of elements. The methods of imparting this knowledge vary; it can be of the rigorous mathematical type as used by engineers, or it can be an appreciation, or achieving a sense of structure using minimal arithmetic such as Morgan (1964) or it can be of the arithmetical/literary approach of Rosenthal (1962). There is some common ground between the educational objectives of engineers and of architectural engineering and this is reflected in the basic vocabulary such as statics and the understanding of the structural behaviour of beams and columns. There are, however, basic differences between the educational objectives of the two professions. The architectural students have to apply structural principles along with other principles to the broad set of circumstances surrounding the design project. As a result there is often a conflict between the structural requirements and those of the other diverse elements of the buildings. The second division of teaching structures to architects is concerned therefore with the transfer of that knowledge to the architectural design. In practice this is done with the aid of engineering consultants except for simple structures. Educational practice has tended to simulate this position by using consultants - either structural engineers in practice or the existing teaching staff - to provide the requisite information for a design project.

Problems arise with the time available for teaching, the abilities of the architectural student to assimilate structural knowledge and the adaptation or transfer of structural knowledge to the architectural design. If the teaching methods are a replica of the rigorous mathematical approach of engineering education there will be conflicts. Conflict in the time available to the architectural student for the subject in isolation, conflict in the educational objectives of that subject and conflict in the relationship between student's knowledge of structures at any given time and the structural knowledge required when engaged in an architectural design project.

The last conflict arises when the architectural student will be set design problems early in his academic career which demand a knowledge of structures, which in some cases may require 3 or 4 years to learn. By his final year, the student will be manipulating complex structural forms such as hypers and suspensions which are of post-graduate engineering standard. This means that some of the early design projects may demand structural knowledge which has still to be given to the student. This induces another problem. The author has previously argued - Carmichael (1967) - that if the curriculum of basic vocabulary is completed too late in architectural study, the student will be accustomed early in his career to making design decisions based on inadequate technical information. This dilemma has caused a number of schools to add to their limited use of rigorous mathematical approach, a learning based on the use of models, Mitchell (1967), to quickly explain a structural action. For transferring structural knowledge most schools use the design project. The problem with the use of consultants is that the student is not in an equal position with the consultant, his consultant is either his teacher of structures or an outside experienced engineer. As a consequence the student generally accepts the consultant's advice without question, with the result that the teacher can be accused of assessing his own scheme and not the student's. There is a problem of how the student should use his consultants and what if any, structural knowledge is required from the student for this purpose. If the student receives only the knowledge of behaviour of structural elements, teachers tend to ask the student to confirm some simple element by calculation. This does not appear to be the only structural ability required by the architect. The transferring of information or theories to a realistic problem requiring an unique solution is one of the most critical aspects of architectural education. We should not expect the student to adapt his structural grammar to the design project in a sophisticated manner as soon as he has learnt the grammar. We do not, for example, expect a school pupil to write in the style of Cicero immediately after learning some rudiments of latin grammar. There ought to be a logical sequence starting from the learning of fundamental structural theory to giving purpose to these theories and then to the broad design project.

1.2 PROPOSALS

To answer some of these problems it is proposed to suggest, develop and test some educational methods for teaching the structural engineering content of the architectural students' curriculum. Such a content will have two main divisions that of the abstract knowledge and that of the transfer of that knowledge to architectural design. Therefore, the questions which must be answered is "what kind of structural knowledge is required especially when consulting engineers are used in practice - how can such knowledge be learned quickly in the early years of university and which teaching methods can help to transfer the acquired knowledge". As architectural design is closely concerned with creativity, any proposed teaching methods must be scrutinised for their qualities in nourishing the appropriate creativity.

The thesis will be divided into three parts dealing with -

1. The general objectives of teaching structural engineering to architectural students.
2. The general qualities of architectural creativity on which some teaching methods can be based.
3. Some teaching methods based on the conclusions of the first two parts.

References:-

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REVIEW AND DISCUSSION OF LITERATURE Chapter 2

2.1 Review of Literature

Before reviewing the literature on the kind of structural skills required by architects, a definition of 'Structure' is required. For this paper, structure is defined as the material form which resists and redirects the physical forces generated by the environment, particularly gravity, to the ground. The form and the materials should perform the function safely and economically, while consistent with the creation or preservation of the delight and efficiency of the rest of the architecture. Thus 'structure' can involve both abstract and measurable behaviour of external forces and systems, the resistance of materials, the choice and development of systems in accord with other components of the architecture, and the construction of the structural elements and systems. The largely theoretical behaviour of stresses must be combined with the knowledge of how materials are formed and handled, how they catch fire and react to decay. This combination in turn must have a valency with the proposed architectural space.

In previous epochs of architecture recognised as great such as those of the golden ages of Greece and Rome, of the Renaissance and of the Gothic era, 'structure' has been intimately bound up with architecture. This intimacy is seen in the writings of Vitruvius of the 1st century and Anthemius and Isodorus of the 6th century, Villard de Honnecourt of the 13th century and Wren of the 17th century. In the architecture of those eras there can be seen a close identity of the structure to the form and function of the buildings. That was due partly to the way in which the knowledge of structures was gained by the builder. Until about 1750 the required structural knowledge was gained according to authors such as Sir Bannister Fletcher (1961), Pevsner (1960), Mainstone (1963) and Harris (1961) by observation, intuition based on geometric concepts and awareness of how the human body reacted to forces, personal experience in working with the materials and receiving dogmatic rules such as Vitruvius' instructions on how to build a column (1931). This craftsman's approach enabled men to conceive and build some structures which eternally satisfy. It would also on occasions lead to disastrous failures such as the Tower at York Minster, Dowrick(1971), and lead also to reliance on superstition as when theorems of Pythagoras were replaced by measurements based on Noah's Ark. The main weakness was that such knowledge could not predict the structural behaviour of new materials and of the new structural systems brought about by new constructional methods which allowed continuous structures to be formed. Neither was it in accord with the logical, objective and rapidly progressive attitude of science.

The advent of the machine, the availability of new materials and the objectivity of scientific research (in particular the use of tests, measurements and analysis) aroused the architects to realign their previous design philosophy towards one based on function. This view is epitomised in a Corbusier statement (1927) that "a house is a machine for living in". This change of attitude was reinforced not only by the demand from industrialists for wide span buildings but by the success of innovators such as the Chicago School of architects, Labrouste, Perret, Paxton and his fellow international exhibition architects. As a result, 'structure', after a period of feeble influence, was confirmed in the early stages of the 'modern movement' to be one of the principal generators of the architectural design process.

This development in knowledge and technique, however, largely erased the craftsman's approach and brought about a specialisation and a division in the design process. The behaviour of a structural system is now so complex that even some structural engineers specialise in particular areas of the field. It is therefore manifest that the discrepancy between the vastness of the requisite knowledge and the limitations of the single human mind demands that the architect consult with specialists. Therefore in the present situation the manipulation of structural knowledge by the architect is largely accomplished by collaborating with engineering specialists except for the design of simple buildings.

The possible methods of using consultants are:- 1. the architect as leader with specialist help by either a consultant engineering firm or using the design services of industry or in a combined team from one architectural/engineering firm. 2. the engineer as the leader with architectural consultancy or as in France, study groups of engineers with salaried architects. 3. the architect and engineer combined within one man and 4. the committee. All the categories except the first category are irrelevant to this study. The arrangements by which the architect uses his specialist, whether from his own firm, an outside consultancy or from industry are substantially the same for the purposes of this study. The question posed will be the same for all arrangements - what structural skill and knowledge in an architect are required to make design collaboration with engineers more fruitful? One other proviso is made - when considering the type of building on which collaboration occurs, there will be no examination of innovating design in which engineering has a larger influence than normal, such as large span buildings by Torroja, Nervi and Morandi. This is done because such buildings are generally outside the type of project that the average professional will handle and also because the apecial arguments which the type supports may not be applicable to the general run of architecture. What will be examined will be the collaboration on the large remaining body of architecture in which structure retains a varying but nonetheless positive degree of influence.

The R.I.B.A's plan of work asks for the engineers to be consulted as early as the feasibility stage but this gives no indication of the kind of collaboration. Those authors who have pronounced vary considerably in their opinions. Makowski (1962) claims that "It is the architect who decides on the shape of the structure and in the early stages of design has to make structural decisions". Arup (1960) agrees with this when he claims that "often it is the architect who makes the main structural dispositions".

One interpretation of these statements could be that the architect must thoroughly understand the possible structural characteristics of the early proposals and develop, whether in a major or a minor way, those characteristics during the design. Authors such as Chackett (1957) require "architects to co-operate intelligently with the engineer". However such co-operation need not be of that standard if another interpretation of Arup's claim is made. That is to say, the architect may make his 'structural disposition' in a negative manner. Architects like Corbusier in La Ville Savoie or P. Johnson in most of his buildings appear not to consider consciously the structural requirement. In such cases the engineer, in endeavouring to make the building 'stand up', has to dispose his system after the main ideas have been completed. In part this attitude is derived from the ideas of architectural education of Gropius (1935) at the Bauhaus where the study of architecture was initiated by manipulating abstract shapes to achieve significant form without reference to the comparative strength of the model and genuine materials. Thus if the structure is not a generator in the design, the structural knowledge required will be practically negligible. A position slightly akin to Arup and Breuer (1962) would be Newby's (1962) claim that "the architects' tools are his consultants". This epigram implies that the architect must have sufficient structural knowledge to discern the problem of what has to be done, to know when to consult, to know what the consultant can do, and to be able to work within the discipline imposed by the tools towards the general architectural/structural aim.

The architect must therefore be able to judge quality in the area of 'structures'. This not only implies being able to judge the potential and limitation of the 'structure' but also the potential and limitation of the consultants and to distinguish between facts and advertising propaganda. Most practising architects know what consulting resources are available to him since he, in agreement with the client, employs the consultant, but Harris (1961) has pointed out some of the engineering misconceptions which he believes architects to have. It should be noted that this kind of consultancy requires some social skill for adequate communication to occur when conflicts arise. More important is the considerable responsibility of the architect to judge objectively the factors involving such conflicts, or the co-ordination between the specialist structural conditions and the remaining architectural requirements. Such conflicts sometimes require detailed knowledge and yet most agree with Gordon (1961) that "while the knowledge must be sufficient, it must be not so much that there is a danger of duplication or distraction". An omission in this approach is that the architect by himself must provide the initial structural basis when he first plans the architectural spaces. The practising architect has the necessary experience but the architectural student has not, either with the initial planning or with the conflicts that arise.

Arup's (1960) argument for requiring structural knowledge by the architect concerns his position as leader of the design team: "it is necessary in the art of leadership to have the ability to understand and appreciate the point of view of others". How extensive such understanding is to be is not precise. Nervi's contention (1966) is that it must be considerable when he compares an architect designing without any knowledge of structure with "a composer trying to compose music wihtout knowing how to play an instrument". This view is substantiated by authors such as Gordon (1961), Duncan (1962) and Sarger (1962).

It is significant that while there are eminent engineers asking that architects should have structural knowledge some architects believe that they can avoid making such decisions by passing over the problem to the engineer at a late stage in the design in a similar manner to the medical specialist who, after the initial consultation, has the entire responsibility.

Most opinions judging by the curriculum of architectural schools reflect Chackett's (1957) opinion that the architect should have "some idea of the bones of structure", but this is no means a precise description. It could be that the extent of knowledge for such collaboration could be little more than a catalogue of conventional structural systems or it could be that "architects should be part engineers". Arup (1960).

2.2 Discussion on the relevance of structure in design.

It would appear for such a review that an answer to the questions about the extent of an architect's structural skill and knowledge could be that they need only be negligible and the skill purely a social one, or that he should be part engineer with a thorough understanding of structural behaviour. Particular aspects have been considered but it is necessary to have a general discussion on this issue.

From the previous section it can be seen that architects collaborate with the engineer specialist in vastly different ways. These ways reflect the varying views of architecture as a creative product. As it has to be used partly for the physical service of man, it has considerable objective criteria to satisfy and as it is concerned with large quantities of materials the product has to have extensive technology to realise the design idea. But architecture is also concerned with subjective qualities such as beauty and has a social responsibility towards society. These extremes of values - aesthetic, technical and social - in the architectural product can bring about a polarisation in the appreciation of the product and this has had a direct influence in method of education and the emphasis to be placed on such technologies as structural knowledge.

The conventional description of this polarisation is to describe it as the rival schools of Rationalist and Romantic. The Romantics encourage the view that architecture, because of the considerable amount of artistic communication to the user, should be judged solely in terms of this expression as are the 'arts' of music, painting and literature. This doctrine must be examined as at the extreme it could lead to an almost total repudiation of the functional and material constituents which embraces 'structures'. This view needs to be examined in a general manner and will take place in a later section, but at this juncture it is relevant to consider it in terms of whether the required structural knowledge is negligible.

The extreme side of the non functional argument rests with Johnson (1955) when he says "Mies's best architecture is his school of architecture where he denies all the functions of the school, you cannot have a secretary, draughts cannot be kept out, you cannot have separate classes". Mendelsohn (1960) agrees "The Guggenheim Museum is totally impossible, it does not work - but what a room". Although these remarks are about one-room architecture, they illustrate views held by some about architecture. Generally such architects trust that the engineer can "make the building stand up somehow". As suggested this in part is derived from an interpretation of the Bauhaus's educational philosophy of achieving form as constructed sculpture in that it tends to be detached from constructional consideration. While the model material and form may be of sufficient strength at that scale, the designers in manipulating form with materials such as cardboard have disregarded the dissimilarity in strength, stability and dead weight between that of the model and that of the full scale building. Thus the eventual dimensions of the building could distort the proportion and economy of the architecture. The attempt to solve this contrived dichotomy can be seen in some of Le Corbusier's buildings. Corbusier was conscious of the need for the technical requirements but his later buildings appear to be sculptural rather than rational. Collins (1971) in examining Corbusier's later buildings concludes that it is impossible to marry the technical requirements with the sculptural approach - "the fusion between rationalism and abstract sculpture is never complete in any of his (Corbusier's) buildings for the good reason that their ideals are antithetical". To substantiate this, the Aluminaire houses on Long Island, designed by Le Corbusier's disciples Kocher and Frey (Banham 1969), can be cited to represent the collision between Corbusier's sculptured theories and the structural technology required to make the theory realisable. It is argued by some including Johnson (1955) that where such a collision occurs the artistic expression must dominate and buildings such as Ronchamp Church or the Guggenheim Museum appear to testify to this. With this approach there is more reliance placed on intuition than on the rational, and the painter Mondrian's (1969) statement springs to mind - "intuition is troubled by intelligence". The implications of this are sufficiently important to be dealt with in a separate section. It is sufficient at the moment to suggest that there is a danger in using such a tenet in architectural education. If students are encouraged to ignore their product's discipline, their decisions will be wholly arbitrary or mannerist or incomplete. The dimensions of judgement of an inexperienced designer depend on his mood of the moment or upon surface irrelevancies. This view of the problem tends to distort, and reputable design decisions become unlikely. The student cannot be expected to display judgement seen in the experienced designer.

The view opposite to that of the artist/architect is that of the professional/architect where the aim is to generate sensitively an answer in combination with technology whether structural or otherwise. This is not to disagree that there should be no influence from the arts but that the spatial quality 'which distinguishes architecture from the painting and sculpture" Pevsner (1960) should be based on the total criteria for the building.

Part of the total criteria of the spatial quality is the strongly coercive structural requirements. If ignored, one consequence is unnecessary expense in achieving the desired subjective result, as in the Sydney Opera House or in Saarinen's MIT Auditorium or in Le Corbusier's buildings. This consequence derives from the conclusion that a structural system is indispensable in architecture by its very nature. The form of any organism cannot function properly without a structural system. Only through structure can space be spanned and the beginnings of environmental control operate. Only through structure and construction can the original concept of space and volume be maintained in the face of climate, gravity and use. The architect must realise where there are problems of structure which require an early absorption for a unified product.

If the structural requirements are completely ignored, the unity of the architecture must be disturbed because the relationship which the structure has with the other components have been destroyed. It has been argued (Joedicke 1969) that it could be that a few brilliant experienced architects could conceive a form which, while not adaptable to existing structural means could be built by means of new discoveries in building materials. This is so near the position of the crank scientist that it is dangerous to consider it as an educational strategy or even as a prop. Such architectural forms are always in danger, certainly in the hands of students, of becoming artificial, fashionable or mere pattern forming.

If structure appears to the user as unsound, or gives the impression that the architect is unsure of the structural behaviour, this will detract from the harmony and delight of the architecture. Such occurs when paraboloid roofs are enclosed at outer edges with what could be bearing walls, or when the user feels unsure of the strength and stability of a structure, such as when walking across a flexible plank. This comes from not understanding the essential structural behaviour, and consequently the form and shape are derived without understanding even although the solution appears strongly influenced by structure. Candella's Mexico University and Niemeyer's T.V.Station in Rio de Janiero are such examples. It is not a question of obviously displaying or not displaying the structural system. Rather, there should not be any sham or demonstration of lack of understanding by the architect. While the structure may have to be ingeniously designed by the engineer in order to cover up a lack of understanding by the architect, such efforts are generally exposed to the detriment of the architecture. Another result from such misunderstanding is the wastefulness arising, especially if the faulty architectural/structural decision has to be rectified at a later date in the design. Most of all, the architect in this approach is excluding a helpful generator in the design process, even of an apparently sculptured building. For example Saarinen's T.W.A. building at New York unifies the structural behaviour with the subjective expression of movement (Joedicke 1969). On a similar vein Lloyd Wright's (1970) statement that "architecture is the scientific art of making structure express ideas" is not equating structure with architecture but making structure as one of architectural generators for function and delight.

The above discussion has been against the argument that the structural knowledge required is nil. The main refutation of that argument is that architects cannot ignore the structure during the design even if there are engineering consultants in the team. It is not to be denied on the other hand that some engineers believe that almost any form can be built using ingenuity and the computer. But Happold (1971) insists that there is a critical assumption to be made - "the assumption that the structure should stand up had already been made". In other words the architect has to conceive a form which is structurally sound. Presumably luck must not be involved in such a conception and therefore it becomes another argument that the architect, even with the engineer's help, must clearly understand the main aspects of the behaviour of structural systems. It could be argued in passing that the engineer's attitude to the linear process of ingenuity and confirmation arises mainly because of his educational training if, as is usually the case, that training does not involve design. If, however, the architect only has to concern himself with the structural fesibility of his space planning then this will omit the dynamism of the design process. If there is to be integration of all the components of design there will be an oscillation between all the technical, aesthetic and social components during the design. The collaboration between engineer and architect is not the equivalent of the medical specialist taking over from the general practitioner. In medicine this isolation can be formed, whereas in design each give their skills which inter-relate and are not independent. Whether it is the strategy of employing the consultant after most of the other decisions have been made or if the consultant is used in limited but isolated packages, the process will miss out the essential metabolic action in design. Therefore the architect must have considerable structural knowledge for design competence. Structural logic is a fertile source of architectural ideas, and it is significant that the pioneers of the 'modern movement' used structures to "purify their ideas" Joedicke (1969). While they did exaggerate the importance of structures on occasion, they recognised the vital ingredient of architecture and firmly related architecture to structural technology just as crafts had been previously. Architects such as Mies, Skidmore Owens and Merrill, and even futuristic groups such as Archigram used structure as a basic ordering device. The architecture of Mies Van der Rohe is based on structural steel's preference for equal rectangular bays - (giving dominating deep beams)- absence of interior supporting elements (giving freedom in use of space) and structural continuity of the system (giving cantilever and joint details). It is undoubtedly clear that the structural system could force the architecture to languish. Some of the

Rationalist school based their aesthetic theory on the structural function. This early modern movement's idea of clarifying the structural function became exaggerated to show either at any cost the bones of the structure or to a 'Brutalist' rationale. As a result, a justified reaction occurred.

Another development between the Rationalist and the Romantic school must be noticed. Until recently the argument between these schools was concerned with aesthetics, but under the influence of the computer and the sociologist, the Rationalist approach must now include those who magnify the physical efficiency and wish to eliminate any subjective, particularly aesthetic, content. This view regards design as an algorithmic problem requiring a statistical optimisation of all the factors involved. Although optimisation has a social connotation when beautiful form is weighed against the need for shelter for a large number of people, optimisation for structural systems is confined within the restricted area of minimum weight or cost or erection time. Such optimisation could tend to minimise the humane environment. A Fuller dome, or a tent, has not only the entrance problems of the igloo and the problem in the use of peripheral space, it can only give the required options for human behaviour and comfort by being gigantic. At any other scale, other criteria are important and the structural design becomes indeterminate - i.e. non-linear.

There is some truth however, in this optimisation of structure but it is concerned with limits rather than unique solution. These limits are imposed by qualities of the structural principles. Stresses increase with size even though the form proportionally remains the same; a structural element of a given material of given proportions has maximum and minimum limits to itsspan. Galileo, 300 years ago (Translated 1965 ed), laid down this principle which D'Arcy Thompson (1959) confirmed in the field of biology. This is not unique optimisation for a given set of circumstances for there is a variety of structural means more or less equally efficient in themselves just as there is a variety of forms of fish adapting to the pressures of the ocean and of birds supporting themselves on air currents. Such variety, although having limits, is still optimum to a degree, but not uniquely optimum and as such is not amenable to a linear process of optimisation. It will be argued later that the choice of the technical means to satisfy human needs and efficiency of buildings, embodies the use of subjective values. To ignore these values does not eliminate their use; to put only a number to represent them can be too crude. The fault of assuming that qualitative and quantitative analysis is automatically correlated is shown in the acoustic design of New York Philharmonic Hall (Collins 1971). There are the same non-mathematical judgements required in architectural/structural problems which are therefore not intimately related to optimisation or to be explained or deduced by reason. The various stages in the design of the Madrid Race-course Stadium by Torroja have the first three designs optimised but the final solution which raised it above the mundane cannot be explained in this fashion (Torroja 1967). If this occurs in the relatively limited sphere of stadia design, it must occur even more so in more complex buildings. Even the strongly structural architecture of Nervi, Torroja and Maillart is modified and developed within the culture, economy and climate of their region. The structural form cannot be generated sui generis; the Gothic cathedral is cited as an example of optimisation in structure, but more important in the development of such architecture is the inter-relation of the requirements of the ritual, the natural light, the materials - timber and stone - as well as the culture of the time, with the structural system. Tracing the influence on the total development of this would be an important part in structural education. A strength in the architect's skills is in being able to consider the total organisation of a building but because of a vast range of choice and intermediate values there will always be critical design decisions which are not amenable to precise measurement. This indicates there must not be a total reliance on abstract teaching if the interrelationship of the structure with subjective values requires physical and mental experiences to be absorbed by the student before designing, certainly at the beginning of the abstract teaching. Therefore to eliminate intermedia, students should analyse and experience actual buildings. The question is also raised about the exclusive use of abstract and mathematical treatment of structure in architectural teaching. Torroja (1967) suggests another aspect in engineering/architecture collaboration when he claims that the pure analyst in general is not a good designer. Nervi (1961) agrees when he suggests that "Didactic experience has shown that young people capable of understanding basic maths, science and construction and also capable of the heat of inspiration of a really artistic nature are in the exception". One other matter to emerge from those authorities is that engineering education and the engineer's temperament encourage the engineer to develop along a path of specialisation which often omits the concern with entities, yet the engineer and architect are complementary and unable to be completely separated.

2.3 Summary

In order to consider what structural knowledge is necessary for fruitful collaboration two contrasting views of architecture - Romantic and Rationalist - were examined. Buildings such as Ronchamp Church and the Guggenheim Museum suggested that 'structure' was largely ignored during the early design. This abstract sculptural approach to design was, it was suggested, derived from what is accepted as the Bauhaus educational system of manipulating forms. This approach was opposed because of the discrepancies between the model material and the actual material, and because the structural requirements are so indispensable not only for safety and economy but also as a generator or basic ordering device. If 'structure' is not considered then the basic unity can be disturbed. If consultants are used solely to respect safety and economy then the essential dynamism in the metabolic action between the components of the building is omitted. In this argument it was suggested that there is little similarity between the consultants in medicine and in architecture but that an attempt is often made to do so. There are often occasions in which the 'structure' is not a predominating influence but even under that condition it is still a coercive influence. There are cycles in architecture which play down the structural system and to-day it appears that architecture is approaching a replica of the historical trend of Gothic architecture. The lesson to be learnt is even if the structure is not intended to be clearly expressed it must be clearly understood. Whether it was Doric simplicity or Rococco exuberance, the master designer was in control of his chosen structural system, materials and technique for developing and maintaining his original concept.

Unlike these periods, there are to-day many possible structural forms but each require an integrity, clarity in integration and ability from the designer which allows him to discern where and how to compromise, knowing which particular structural conditions are obligatory or which conditions can be subservient or amended. The argument for structures being a predominating influence can be carried to excess, it was argued, particularly with the mathematical optimisation of form or rigidly basing an aesthetic value on structural honesty. It was argued that structural form cannot be generated without considering impinging factors and the example of the development of Gothic cathedrals with their interplay of function, light, material and structure was cited in support. Questions arise about the conflict between intelligence and intuition of developing 'structures' and the importance of structural material if architecture is regarded as an art form but it has been concluded that in the early educational years of an architect he should have a 'part engineer's' knowledge. This knowledge is not of the same completeness as the consultant but it is not a limited completeness. Such a completeness is more akin to knowing the pattern of the main transport communication system without a detailed knowledge of all the major and minor routes or of the intricacies of vehicle design.

2.4 Literature on Structural Content

The next section will review publications which have made a detailed delineation of the content and extent of the structural knowledge required for architectural students. This will inevitably be intertwined with the choice of methods of obtaining such knowledge. Most authors and most architectural curricula agree that the basic knowledge should be of the types of load on buildings, foundations, the understanding of the manner in which material is fabricated or assembled and the knowledge of the three interconnected concepts of equilibrium, strength resistance and stability of both elements and the total system. The first divergence occurs when there is disagreement on the amount of detailed knowledge required of walls and statically determinate or indeterminate beams and columns in concrete, timber and steel. Until about 1950 structures were taught in architectural schools. A considerable number of schools maintain this approach e.g. Davies (1961) maintained "that there is no easy way of imparting a sense of structure except through maths". Many of the existing architectural text books such as Timoshenko and Young (1968) or Jackson (1962) testify to this approach. It was, however, argued by authors such as Salvadori and Heller (1963), Torroja (1967) and Rosenthal (1962) that the broad concepts could be given by mainly verbal descriptions. Nervi on the other hand, preferred vector diagrams, a combination of graphics and mathematics. Engels (1968) insisted on a completely graphic approach. Variation on this visual approach was made by Mitchell (1967) and Coldicutt (1965) when models were used to explain the structural behaviour. Cowan (1968) also used laboratory experiences to explain the structural behaviour. It was conceded even by Engels (1967), the most graphic of the demonstrators, that rudiments of the basic could be given by simple algebra as opposed to complex mathematics, but it was contested that the knowledge of mathematical analysis as a means of gaining insight of structural behaviour would also stimulate creative application. Another divergence occurred when either materials such as timber, steel and concrete were used as the source of learning, as with Morgan (1964), Rosenthal (1962) on the other hand maintained that the abstract principles of stress and strain were the genesis. Inevitably there were others, Torroja (1967) and Lisborg (1961) who had sections based on both Views. Allan (1952) was one of the first to state, however, that there was too much emphasis on analysis of stress, at the expense of knowing what the various kinds of structural systems were available and Nervi's view on the dichotomy between analysis and design previously given is apposite. However, Allan did recognise that architects required sufficient knowledge of the systems characteristics and possibilities, which implies some knowledge of stress and strain. This facet of structural knowledge is given by Lisborg (1951), Cassie and Napper (1952), Torroja (1967) and Engels (1967), who all give a survey of structural forms and the fundamental reasons for their existence. Lisborg and Engels also classify elements by means of their stress behaviour. Some of those systems can be understood from the basic knowledge of structural behaviour stated at the beginning of this section, but others, such as the behaviour of grids and membranes, are difficult both from ability required and time available to be explained mathematically. Samuely (1952) was one of the first to describe such systems using the simplified basic knowledge and Salvadori (1963), Engels (1967) and Siegal (1962) continued this approach.

2.5 Discussion on the Structural Content

There therefore seem to be two questions still unresolved. These concern the content of the structural knowledge and the methods of imparting such knowledge. The first can be divided into (a) the kind of structural knowledge required and (b) the minimum level of such knowledge. The kind of structural knowledge required of the student is in general terms easy to describe - he must be concerned with visualising in the context of all the other factors influencing the design possible structural systems or forms, evaluating the relative importance and relationships with the other functions of the building, then exploring the potential of the structure for its affinity to the architectural space and functions and then to continue the constructive metabolism of the design process. The basic knowledge for this is derived from the interconnected concepts of equilibrium, strength resistance and stability of both elements and system, and an understanding of the manner in which material is made and connected.

To identify the minimum level of subordinate knowledge is one of the most critical as well as formidable decisions to be made, but it has to be made and we must be concerned too with the amount of academic time used to present basic knowledge. All technical subjects appear to have the intrinsic quality of absorbing large portions of time and it is therefore important to gauge the minimum level of structural knowledge so that the student's mind at this formative stage can also be exercised in judgement as well as imagination.

This argument must not lead us to underestimate the structural content of the architectural course. There is the widely held opinion that all technical fundamentals can and ought to be easily condensed and that in practice, since the qualified architect is able to call on specialist advice, the content of the structures course should be extremely small. This attitude is manifested when the engineering teacher is used solely as a supplier of one correct structural solution for a particular design. It is submitted that it is academically unsound to use a specialist in this manner. In this situation unless the student is able to be critical of the specialist's advice and have some ability to assess the structural and architectural possibilities himself, the specialist's advice is less effective. The student must be able not only to recognise alternative possible structural solutions which are in rapport with the other design constituents but to discuss intelligently, develop and perhaps to transform, along with the design team, the proferred specialist advice while still leaving large areas of knowledge and skill to the province of the specialist. In the real situation, certain critical structural decisions are and must be made by the design team. If the learning of structural knowledge falls short of a fundamental grasp, the knowledge will be superficial and will not be useable in the student's thinking beyond the situation in which learning has occurred. If it does not contribute to the power of the architect's imagination it will be no more than theoretical in the worst sense - "an impotent collection of particulars". It will therefore be irrelevant for the architect to emulate the engineer by analysing complex structures. It is no excuse to claim that this can stretch the students' mind; the experience of secondary educators in teaching Latin and Greek for this same purpose should be heeded. There is, moreover, sufficient fertile ground where the structure has to be developed along with the other components. That will have more potency for stretching the mind for architectural decision makers.

On the other hand knowledge of only a few elementary scientific theories may avoid gross errors in building - and this is a laudable aim - but it would exclude the architect from creatively interpreting or exploring the potential of architectural form or for adapting himself to the technological advances which he is bound to encounter. To fill the student's notebooks with prescriptions for every conceivable situation is not only impractical but educationally undesirable. It is unnecessary for the architect to match the specialist knowledge of each specialist involved in building but it does mean the student must reach a general level of competence and understanding which will give a well-founded and coherent vision so that the essential unity can be achieved. There is considerable disagreement in architectural schools about the extent and level of knowledge required and the methods by which the architectural student can best attain this knowledge. Even if the decision is made to give a comparatively small amount of structural knowledge there is the dilemma between exercising the student's judgement and imagination in design projects and the requirement that the student has sufficient knowledge and understanding of technical subjects to make reputable design decisions.

From the latter requirement it is necessary to give the student basic theory before participation in a design project. There is usually a design project in the third year, if instruction is not started by the

the first year then sufficient knowledge can only be obtained at the end of the third year. This is unrealistic for the first requirement of reputable design decisions. Two factors emerge.- First, that basic theory must be acquired early and economically in time. Second, a broad survey of structural systems with their general behaviour should be given. Thirdly the inter-relations of structural theories and systems and the other architectural components should be demonstrated. There are strong arguments for some measure of the third category being given before the detailed study of the basic structural theory. That will have the merit of emphasising the integration of the structure in the building. The other question remaining concerns the communication of structural knowledge to architectural students. Those who believe in using mathematics do so because they insist that it is an essential element in the communication, development and learning of the structural idea. This treatment, they argue, gives the only logical, thorough and rigorous knowledge of structures and allows communication between engineer and architect. This type of approach takes advantage of the university department system, where the various primary subjects whether they are physics, languages or mathematics are taught by and to the same standard as the specialist. About 1950, however, some architectural schools were of the opinion that this didactic approach did not stimulate creative application of structural knowledge in the architectural design. Engineers such as Torroja (1967), Nervi (1963), Maillart (1938) and Freyssinet (1954) have all claimed that even engineering design in its fundamental phase is not "born from the calculator". Nervi, Maillart and Freyssinet have never in design "gone beyond the basic arithmetical stage" but they insist that approximate calculations were always made. Whether it is possible to learn, as opposed to design, by approximate calculations rather than by the rigorous mathematical approach is a question which has not been answered. Most architectural authors require the architect to be able to visualise the stress behaviour but as Torroja (1967) says "the designer must make more trials and more elaborate calculations in solving a problem if he is without much previous experience". However, both he and Samuely have shown it is possible to explain the behaviour of complex structures, once the basic knowledge of simple structures is known. Salvadori and Heller (1963) claim that such verbal/graphic explanations do not imply that the structure will be explained and understood in an elementary, incomplete or simplified manner. But it should be remembered that Salvadori (1968) has written a book which treats statics in a mathematical manner. There are critics such as Engel's (1967) of the verbal treatment who take Torroja's (1967) assertion that "in general the artist does not know how to deal with symbols" to mean that any communication should be by drawings and models. This method he claims is particularly suited because of the "predominantly pictorial nature of architects' language and physical-mechanical essence of the subject matter". Authors such as Howard (1966) and Torroja (1967) would like the geometrical aspects of structure to be taught but Torroja is alone when he wishes architects to study the pattern of isostatic lines of principal stress. One other approach, that of Giedion (1949), should be mentioned. Giedion appears to suggest that structural form such as Maillart's bridges have an affinity to the prevailing artistic philosophy - "a new method of construction has found its simultaneous echo in a parallel method in art". This could again raise the question of artistic expression. It might suggest that the structural form could be derived from prevailing or fashionable art theories. But if that were so, the words 'simultaneous' 'parallel' would have been omitted. It is suggested that the essence of Giedion's statement is that every great artist or builder uses his technical knowledge with imagination and perhaps intuition. This is not the same argument that was previously rejected i.e. a mature architect can ignore the rational and technical requirements in order to produce 'art for arts sake'. To stimulate the former attitude is obviously desirable but the educational methods in structural theory which foster its imaginative use rather than stifle it are difficult to find.

2.6 Summary

This second section has been concerned with the structural content and the methods of imparting such content. The review of literature on this subject suggested that there was no unanimity about the content beyond having basic theories of statics. The later discussion on this aspect considered the kind of knowledge required and an adequate minimum level. The content had to contribute towards an imaginative use of the knowledge so that the architect could make a major contribution towards developing a structure in relation to the other functions of the building and in particular to the potential of the structure towards its affinity to architectural space. Such a content means that the teacher must steer a course between a rapid survey of structural systems and teaching analyses of complex structural systems. The desire to stretch the student's mind should not lead the teacher into conveying the latter type which for the time available will not make a significant contribution to the architects' vision of unifying 'delight, firmness and commodity'. On the other hand the availability of consultants should not suggest that the knowledge can be negligible since the architect must have a fundamental grasp of structures to combine intelligently with the specialist. On this point, the danger of using consultants in educational projects was specified.

Closely linked with the problem of content is the difficulty in finding time to impart the structural content so that reputable design decisions can be made and time to allow the student to use imaginatively the acquired knowledge. It was suggested that basic structural theories should be given early and in a short space of time, along with that of a knowledge of the behaviour and variety of structural systems and that the inter-relations of that knowledge and the other architectural components should be given initially before the detailed structural theories.

Inseparable to the structural content are the methods of imparting the knowledge. The review of literature showed that the language could be mathematical, verbal or graphic. The graphic medium could be either models, vector diagrams, geometry or lines of stress. It is contested in this paper that mathematics is the only satisfactory language to use but further work in relation to this and imagination needs to be made. Imaginative creativity has emerged as a main criteria against which all teaching methods must be judged on whether they stifle or foster.

2.7 Conclusions

Apart from those questions, the discussion on this section has suggested that the general objectives for teaching structures should be as follows:-

The student should be in control of generative grammar for :-

(a) nourishing the design process rather than just making the enclosures practicable.

(b) ensuring the safety, economy and practicability during the realisation of design.

Basic principles should be taught so that an intellectual basis is given for :-

(a) conceiving, selecting, adapting, extending, appropriate structural systems or elements for the total design solution.

(b) evaluating the priorities in the relationships (affinity and conflicts) between the various components of the architectural space and function, and the structural component.

(c) asking productive questions of, evaluating advice from and co-operating with the professional specialists involved in building. (To do this the architect must be capable of grasping suggestions on structural forms and elements and communicating the essential needs of such products of the engineer).

Within this general professional objective there are further objectives which can be summarised:-

(a) Development of creative thought within a disciplined field of knowledge.

(b) The evaluations of evidence; finding and transferring factual data; forming hypotheses and conclusions; the manipulation of abstractions.

(c) Communication of ideas and decisions.

(d) Skill in self-education and self-monitoring.

(e) The inculcation of willingness in the student that he continue his study after the tuition has ended.

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ARCHITECTURAL CREATIVITY

Chapter 3

3.1 Introduction

Architectural design is closely concerned with creativity and all teaching methods must be scrutinised for their efficacy in nourishing or inhibiting that quality. The next section examines general creativity for relevance to (a) architectural creativity, and (b) objectives and methods of teaching 'structures'.

The basic difficulty in any analysis of creativity is in the definition - Taylor (1959) lists over 100 definitions. Assuming a definition is agreed there is the possibility that the dissection and categorising of factors which influence creativity may mask its features, but some specification is required to provide a basis for a guide towards the objectives. The two main types of approach to this subject are from the philosopher and the psychologist. Philosophy is concerned with the judgement on creativity and psychology is concerned in how the judgement is arrived at. As teachers are concerned with such judgement, whether good or indifferent, and also with the process of how the students arrive at this judgement, this paper must examine both areas. To do this, it is proposed to consider the constituent elements of creativity i.e. (a) the product created (b) the mental processes (c) the abilities of the person who creates and (d) the cultural environment in which it takes place. The first element will be examined on a philosophical basis and the last two elements will be considered by both methods.

3.2 Creative Product

The quality of the creative product is assessed by the harmony (or inner perfection), effectiveness and uniqueness for its purpose. For this thesis, the product is classified into 3 groups, with the implication that the classifications are more concerned with differences along a spectrum than with rigid categories.

1. The communication of feelings, instincts, perceptions and knowledge.
2. The making of serviceable objects.
3. The development of natural resources.

The effectiveness can be graded by its breadth of application - i.e. to the extent the product transmits and generates in others

1. Growth of their understanding and/or feeling
2. Further creative acts
3. An adjustment of existing significant values.

"The progress of science takes place through a few master architects, or in any case through a number of guiding brains which constantly set all the industrious labourers at work for decades" (Schiller 1954). Although science is specifically mentioned, the statement is equally true of the 'arts'. There is a further measure of creativity in that it must be judged according to the importance of the purpose of the product as well as its harmonious appropriateness for that purpose. The first category is concerned with the development of understanding and sensibility to such a degree of clearness that other people sense or understand where previously they had not, or had only dimly, perceived. This can be done by sensing values, relationships and parallels not evident previously. As a result confusion can be mastered and experience of others can be enriched. The communication is a formal ordering of elements which connect diverse experiences by means of image, symbol or metaphor. Poetry exemplifies this feature of the 'arts' setting up connections, relationships and parallels in order to transform understanding. Science theories too are concerned with setting up connections. The connection between electricity and magnetism, or that of neurophysiology and astronomy Koestler (1964) or

Descartes (1927) linking arithmetic with geometry, are only some examples which lead Bragg (1964) to remark "Important advances usually occur not in discovering new facts but in discovering new ways of thinking about them". Science like art is transmitting new relations and connections of existing data which transform people's insight or inner images of events.

3.3 Arts and Sciences

This first category of the creative product has as its extremes-

a) scientific predictions/explanations of natural behaviour.

b) the product of the 'arts' or 'humanities as generally understood.

The 'sciences' and the 'arts' are grouped together because they share this kind of transmission of concepts of what 'truth' might be. Both are wanting to know and make known their aspect of reality, both are rich in the consequence of their 'truth' and both require Tolstoy's (1950) condition of excellence in art, 'infectiousness', so that the recipient can feed on the insight suggested by the transmission. Both are interpretations of experiences and as a result, both products are the results of imaginative conjectures. Faraday's theory linking magnetism with electricity by imagining lines of stress in what seems open space, or Newton's gravitational theory or Darwin's natural selection theory, involve imagination of a high order. This, as Popper (1959) has argued, means that even the selection and construction of hard facts to form a scientific theory will have subjective values.

That there is a distinction between the arts and sciences is not denied. The arts contain within their product a large amount of subjective values, and the project has to be largely judged by the subjective values of the recipient. A statement by Keats or Shakespeare is universal and yet every listener takes a slightly different meaning from the statement. Einstein's universal communication aims to mean the same to everyone who listens. The scientific laws are largely concerned with objective criteria. No matter what personal interpretation of facts are used in the process of producing the theory, the scientific product - e.g. $e = mc^2$ = has no subjective values. The physical effect of the theory can be regularly reproduced by anyone who carries out the appropriate experiment in the way prescribed.

The subjective values of the artist's product are the personal values of the artist fused with the matter of the product. These values are concerned with such qualities as awe, pity, tenderness, fear, suspense, joy, remorse and intelligence. One aspect of the product containing the artist's personal values is seen when artists comb the works of other artists for ideas. For example, the plots of Shakespeare's 'Twelfth Night', 'Merchant of Venice' and 'Macbeth' can be traced to other sources, but the material was assimilated by Shakespeare to produce the drama bearing his own particular stamp. Two quotations - Ridon (1962) "To fashion..........things into which I have put myself entirely" and Picasso (1956) "a painting is the best hidden image of the man who painted it", indicate the infusion of personal values into the product. That requires an ability foreign to the scientist's method; it requires from the producer the opposite of empathy, not a losing of identity in the contemplation of the product - that is required by the recipient - but the addition of the producer's identity to the product. The equivalent in science - Einstein's "intellectual love of the objects of experience" (1935) - is manifested in the process not in the product. Art on the other hand has it in the process and the product. The individual and unique product of the 'arts' achieves its fulfilment when it weaves with the audience's experiences, sensibilities and intelligence to provide an understanding which is beyond rational explanation or generalisations.

Explanation in this context is the clarification of experiences based on external generalisations or reasoning, whereas understanding is a blend of that reasoning and a sympathetic identification with the object.

In contrast, all the values of the scientist's product are within the object and the scientist has to uncover them. Consequently the scientist remains outside his product. The scientist does not require to have the artist's ability to fuse his feelings with features of his theory. As a result scientific communication aims to dissociate fact from personal opinion and therefore it has to be tested by objective criteria for its validity. This testing by objective criteria has led the scientist to explain the complexity of our experiences in nature by generalised statements rather than by a series of singular statements used by the artist. The objective criteria which tests the validity of the scientific product forces the scientist to predict as well as explain.

Such objectivity is epitomised in the language of mathematics used to formalise scientific communications. It is used because of its unambiguity in communication. That is in contrast to the Arts, where, whatever the language used "it induces emotional correlations by the sound and rhythm of the speech and by stimulating intellectual or emotional association"; Pound (1968). Compare the image of a past decade induced by "bicycle built for two" and the image associated with "tandem". What is implied becomes more important than what is said, and this is relevant to the other arts, where ambiguity may be part of the aims, as with Kandinsky's use of transparent film; Overy (1969). Elusiveness or ambiguity appears to be a necessary condition of the artist's product to allow a personal evaluation by the audience. If the artist's product does not have this ambiguity there is no place for the audience's individual response. The objectivity is, however, in the scientific subject whether it is described in mathematical terms or not, the maths are a symbolic expression of the physical qualities. Galileo, Descartes and Newton originally stated their 'laws' in words (Gillespie 1960) and so fulfil the aim of transmitting the same message to all listeners as well as providing a tool. Such objectivity is particularly applicable to scientific subjects such as physics but the sciences which are directly concerned with human behaviour depart towards a statistical objectivity.

The different characteristics of the products of the arts and sciences are emphasised when light and colour are the subjects of visual art and physics. Both products deal with relationships, science objectively with the energy and matter relationships of light, visual art subjectively within the changing relationship of adjacent colours. Science explains its aspect of reality by specifying certain properties (e.g. wave length and intensity) by quantities, in order to explain why something has happened. Science largely does its measurement with instruments as opposed to the arts which appeal directly to the human eye to arouse varying interpretations. Artists, even those who theorise, like the Pointellists or Kandinsky are concerned with the colour transmitting a mood implying a manipulation of the feelings of the spectator. "White and black are strong colours, but yellow and orange (are) rather pasty"; Calder (1967). "Orange is a man convinced of his own powers". "Black is a silence with no possibilities"; Kandinsky (1968). Black light is not a colour to the physicist, but the artist uses it in his product for its effect on man, i.e. to produce sensation, symbolic meaning, and to influence adjacent colours by making them appear richer.

This description can be contrasted with the scientific description of colour. Science defines the physical quality of light entering the eye in terms of spectral composition i.e. the relative amount of energy present in the different parts of the visible spectrum;Chambers (1950). The artist is concerned with what light reveals in particular circumstances; the scientist explains the composition of light by measurable generalisations. That each influences the other cannot be gainsaid. The French Impressionist school owe much to Newton's description of light. The same distinguishing character could be drawn between the singular pyschological explanation of novelists such as Tolstoy or Dostoyevski and the testable general conclusions of the psychologist.

In both science and art the audience is enriched by becoming capable of more fruitful activity. With scientific theories the audience is enriched by the knowing of new objective criteria, whereas in the 'arts' the audience is enriched by the knowing of new subjective values. The meaning of an 'art' product eludes apprehension in terms of concept, not so in science. As a result, different qualities are required from the audience if the transmission is to be received. The subjective values inherent in the 'arts' product require interpretation from its audience, whereas knowledge and rational thinking are mainly required for scientific communication. This area will be considered later.

Traditional teaching methods have reflected this objective/subjective characteristic. The scientist has taught largely by generalised theories and by the use of mathematics and experiments to prove or disprove. That generally has meant a lecture situation with large groups and problem-solving and error detection with the aid of experiments. The 'arts' teaching situation is based on a much more personal relationship between student and master to the extent of trying to share a common experience. This situation aims at individually learning the differences between affectation and real feeling, showing the abundant possibilities latent in a subject and encouraging the student to be natural to himself.

Because the meaning of the 'arts' product eludes apprehension in terms of concept, it cannot be strictly defined, but can only be discovered. The pattern of learning therefore is to be guided by consideration and discussion of the matter through the values and understanding of the student until he reaches a point at which the subjective values start into their own life. We can co-operate in the process by bringing to his notice all that is already known and familiar to elaborate the experience. This suggests that it should be evoked or awakened rather than expounded. The student must first produce something which the teacher uses as a medium for teaching objectives. That implies that the student's product must spring from his experience and understanding rather than newly learnt knowledge. Among many teaching techniques for these purposes are such methods as allowing the student to imitate and watch the master composing, or in giving prohibited or negative laws for production and later in the student's development allowing him to override these laws. Reynold's strictures on using blue as a focal point in a picture are an example of this; as also is Schonberg's (1968) discussion on consecutive fifths in music when he advised his pupils not to proceed from one fifth to another during the process of learning composition but would allow them to do so if it met the needs of the product. That approach is derived from understanding.rather than from generalised explanations. The artists would prefer not just to give principles or laws but also to teach that "impoverishment comes out of taking the laws too seriously" Klee (1969).

The objectivity of generalised scientific theories would not permit this. However, it should be reiterated that both are concerned with imaginative conjectures and both are wanting to know and to communicate their aspect of reality.

3.4 Serviceable Product

The second category of creative product is that of serviceable objects, namely all these objects from bridges to vases which are to be physically used. The distinction made between the intrinsic objective criteria required by scientific theories and the subjective values brought into the artistic object from the producer may also be relevant for this category.

To check this, we can first examine the product of pure science and that of applied science (technology), where a clear distinction can be seen in the light of the classification made at the beginning. Science, as with the 'arts' - which includes the humanities - is questioning accepted judgements of behaviour in the natural world in order to "replace good theories by better theories". Although this was said Popper (1959) for science, it could apply to the arts if for "better theories" were substituted "different values". It is not essential for technologists to have this particular questioning attitude - C.P.Snow's "New Men" (1959) brings out the difference in behaviour, when he contrasts the engineer's and the physicist's attitudes and behaviour towards governmental authority. In general, technologists accept scientific theories when making their products; they have to control nature rather than predict. There is, however, a freedom allowed in the problem and in the methods of production which approaches the 'artists' freedom especially where the product is to be used by people. This freedom can be seen in the design of a vase, a bridge, a tool or an instrument, where several possible alternatives are available to the designer. This choice brings in subjective values even although it has to be contained within the framework of the technical production and scientific theories. This subjectivity is seen at its best when the product has an elegance as well as efficiency so that the product has an indefinable bloom. As a result the product transmits sensations and arouses feelings. Many, such as Barnes Wallis (1963) believe that the objective efficiency of function automatically brings elegance into the product. Such advocates cite the excellence of the Comet aircraft or the Jaguar Mark X and find that they agree with Baudelaire's dictum "all that is beautiful is the result of reason and calculation". In this paper, it is suggested that elegance is a sub set of efficiency and this can be seen in the design of, for example, helicopters and bridges. If for a bridge by Maillart were substituted an N truss girder bridge, it would be seen that while both were efficient in function, materials and economy, the Maillart product has an additional elegance married to its efficiency. Even when a tool is considered, the best gives a feeling of balance - not to all persons but according to the characteristics of the person using the tool. This quality can be seen in all tools whether they be a golf club or a hammer. Mumford(1934) suggests that the source for this fallacy of equating beauty to efficiency lies in the associating of some artificial objects with "certain kinds of animals and birds (with which) we have an especial sympathy i.e. the aeroplane and the gull". Both objective and subjective values are required for this kind of product.

It is not suggested that the objective criteria intrinsic in the product should be ignored. Rather is it suggested that while those criteria are important they do not completely determine the product. The argument of Wallis (1963) is based on the power of mathematics, but he also states that "there is a flexibility of outlook that mathematics confers on the design". This must involve a choice of alternatives, albeit within the mathematical framework and as such, some subjectivity has been allowed, rather than the rigid belief in the virtue and power of deductive reasoning. This belief "Particularly in its mathematical form" Freyssinet (1954) is "unable to acquire in the smallest part". The view that such mathematical reasoning should determine the design unequivocally and unanswerably is widespread but "it is impossible to allow for every factor" Maillart (1938). The calculations may refine and improve but not initiate. This paper maintains that subjective values are intrinsic in all the products of the technologists other than in the third group of products,ie. development of natural rèsources. This freedom is intrinsic in the problem, even the negative use of subjective values can be felt and where overwhelming ornamentation is used to convey subjective values this generally means, as in late Gothic architecture or in Victorian products, a decline in the development of the product. The assessment of excellence at the transition stage - i.e. judging the balance between harmony and efficiency - must be a matter of personal judgement by the user since subjective values have been built in by the product.

Ruskin's (1853) argument that "ornamentation is the principal part of architecture" is at one extreme, while Corbusier's machine examples in "Towards a New Architecture" (1946) are at the other extreme. It is argued here that both subjective values and objective criteria are in the product and because of the values, the treatment will oscillate between extremes. This is manifested in the extremes of the 19th and 20th century with, at one end, the rationalists school of Paxton, Haussman, Nervi and Fuller, and at the other extreme, the romantic camp of Butterfield, Webb and the later Corbusier.

Where there is little scope in the product for subjective values such as in mechanical or electrical products, the technical efficiency will largely provide for the limited satisfaction of the user. In this type of product, the objectivity is statistical in nature especially when concerned with criteria of economy, safety and production. However even cost benefit analysis, for example, can and should never be entirely free from subjective values; the production of aluminium or the erection of a pylon in an area of natural beauty or the manufacture of scientific instruments to be used and maintained by people, will contain some subjective values unable to be quantified. The range of objectivity/ subjectivity is shown in the scales of measurement used to assess the product. These extend from ratio and interval scales to preference scales involving such items as convenience, comfort and economy. The criterion used by the technologist is at its most objective when it relies on scientific or mathematical theories, but even in this area, modification coefficients have to be used and the technologist is exhorted to 'temper science with judgement'.

Unlike science and more like medicine or politics, technology often has to solve a pressing problem. Not only must it be solved, it often has to be solved with incomplete knowledge while professional judgements assess the possible dangers and limits. This means using theories which are merely 'best fit' or 'lower bound' and as such, subjectivity is within the problem and will partly be judged by the kind of subjectivity used. The problems that technology is trying to solve contain data which may alter with time as people's behaviour and attitude change i.e. subjective values are changing. An immaculate solution for the original data may then turn out to be inadequate and thus the producer must aim for a solution which is a 'loose fit' but which presumably doesn't 'rattle' too much with the changing data. This kind of criterion which is beyond statistics will also ensure that subjective values are inserted in the product. Any product which is to be serviceable to people either allows for freedom of alternative or has to provide for the unforeseen and will therefore contain within itself both subjective and objective values. It can be seen therefore that there must be some subjective values, albeit in varying degrees, in all the technological products of the second category. If the technologists' product contains subjective values as well as the obvious objective criteria, the difference between the vase of a potter - an 'applied artist' - and that of engineering products becomes only one of degree of complexity and intensity rather than of basic principle. It could be argued that the difference lies in the use of technique but the application of technical skill, simple or complex, is not unknown in the arts. Devices such as perspective, study of light and shade or the properties of oil and polymers have a scientific ingredient. The continuum between, for example, the work of a potter and that of a sculptor is another indication that the use of technical skill is not confined to the products of the second category. Technique itself may provide satisfaction but this can apply to the complete range of objects considered in this thesis. Excitement can be generated by the structural ingenuity of the form of the object whether of art, science or technology. It is one of the evaluations of excellence of serviceable objects to observe how the product expresses its technique of production, which is the machine's equivalent to the craftsman's sound workmanship. This aspect, although generally diminished in importance, is similar where the product is concerned with the transmission of values. The technique whether in style of argument, description or in use of media may give an intellectual excitement to the audience. In both categories this excitement will generally appeal only to conoisseurs who may on occasions exaggerate the importance of technique and thereby make an unbalanced judgement.

The prime difference between the arts/science product and the artefacts is that the utility product is to be used as a physical service to man, and that applies whether the product is a tool or an instrument used to produce goods or whether it is a finished product like aeroplanes or furniture. The excellence of its harmonious efficiency therefore arises from the ease with which the object can be used in this fashion and the satisfaction of any of the physical senses used in its function. As a result the harmonious quality will be manifested fully only when the function of the product is eloquently demonstrated during its physical use rather than by the intellectual or sensual contemplation aroused by a work of an artist or scientist. This condition for harmony is verified when one compares a yacht sailing with the wind to its lying stranded on the dockside.

This example brings out other features about the harmonious efficiency of manufactured objects. The first is that if this fulfilled state is only achieved when the product is being used as a service to man, the product must be sensitive to that aspect. Ugliness will arise when the product dominates its human user. The car shows the potential for both these extremes. This suggestion is similar to Nietzsche's (1872) argument about the biological value of beauty: "that which we feel instinctively opposed to us, is according to the longest experience of mankind, felt to be harmful and dangerous".

As the object is to be used, it will have an active relationship with its surroundings of varying intensity according to its relationship with people. The yacht, furniture or spaceship all have this necessity of integrating with their surroundings built into their use. This is in contrast to a painting, sculpture or a book which makes its surroundings either neutral or appear as an acolyte. Kant (1929) says "Art is disinterested". Another feature demonstrated by the yacht is that while the senses and the intellect are used by the audience to appreciate its harmonious efficiency, these emotions will be agreeable. These agreeable emotions range from serenity and humour to awe but will not evoke disturbing emotions such as fear or ugliness. Braque (1959) says "Art disturbs". This agrees with the previous argument on the aims of 'art' as compared with those of the serviceable product. Consequently the emotions aroused by the latter product may be strong but are limited compared to those aroused by Beethoven's music, Keat's poetry or Picasso's paintings. The subjective values inserted into the serviceable product are not so intense, are more concerned with Gill's (1933) definition of beauty: "when a thing is well made, well ordered, the mind is at rest, is satisfied, is pleased". However the differences do not lie between the significance of feelings, perception and knowledge transmitted. This can be done in the first category at the level of amusement as well as serenity or awesome terror. If the product is used as a physical service or with a serviceable object rather than used for contemplation or explanation (even if as a preliminary measure to fruitful action) then there will be alimit to the range of mental satisfaction incurred and will not have the potential to transform the insight of the recipient. Architecture is therefore mainly in the second category with all the implications about judging the excellence and the way in which it is to be taught. Moreover those technical aspects such as engineering cannot be solely taught by objective theories, for it is inherent in the problem that subjective values are inserted when the theories are applied. In other words there is a disagreement with Baudelaire's dictum that "all that is beautiful is the result of reason and calculation".

3.5 Appreciation

To attempt to write comprehensively on the appreciation of creative works is clearly beyond this paper, but certain aspects may be relevant to this study.

To appreciate the unique and harmonious effectiveness of the serviceable product some sensitivity and technical knowledge is required by the user since these qualities are within the product. However intellectually exciting, mere knowledge of the function and how it works is insufficient. This is particularly applicable to the artefacts of 'applied art' but it can be seen in varying degrees in poetry, music, visual art and in reverse emphasis in engineering products. When a new technique or an as yet unaccepted standard of value or a new explanation/ prediction is presented, a difference in the general acceptance of the product can be observed between the first and second categories.

In the first type, there is a personal communication. The uniqueness of the product usually requires the collaboration of knowledgeable and sensitive intermediaries - they may even be critics - so that the transmission can be appreciated by a wider audience. The utilitarian innovator has a more immediate contact with the public particularly when a group of people use the product or are immediately affected by the prominent display of use. In this situation the intermediaries are an overlay and are not so essential. When the utilitarian innovator uses accustomed material in a new solution, the public are easily convinced of its efficiency, such as in the horseless carriages. When new material is used for a new or old situation the gap in the knowledge and sensitivity of the user requires a measure of plausibility in the appearance of the product to promote confidence in the user. This can be seen in (a) the wood grain of a formica panel and (b) the Doric building and the Forth

Railway Bridge. Our sensibilities do not readily accept novel adjustments because our past associations are part of our bank of perception giving our experience an emotional tone. If these deep associations are uprooted it will be at the cost of disturbing our emotions. This sometimes results in a dilemma between the innovator's integrity and the user's confidence. This compromising attitude is scorned by innovators of the first type.

There are however deeper contrasts between the users of the first and second products. The first category supplies a frame of reference by which our experiences in nature can be recognised and understood. It is a superior product if it has a relevance to a wide variety of behaviour. This is obvious in science. Einstein's theory of relativity, extending the predictive ability of Newton's theory to higher speeds and larger masses, is an example of this, as is Darwin's theory of evolution. Literature with its archetypes ranging from Faust to Peter Pan has this same feature of coherent comprehensiveness. This requires personal interpretation and is seen when e.g. over the centuries Shakespeare's characters such as Othello, Shylock, Hamlet and Lear have had different interpretations according to the era's culture. Freudian theories of behaviour are used to realign elements of the drama which were conceived long before Freud and yet the drama is still harmoniously effective. "Literature is news that remains news" Pound (1968). The great creative work speaks clearly eventually to all manner of people of different eras even if at different levels according to the means and culture of the audience. An example of this is seen in a musical criticism Wilson (1972) "each generation of music lovers gets the kind of performance of the Brahms which it appears to need. At one time, sung in English, the music seemed the very essence of Victorianism. Now, from Daniel

Barenboim, we get yet another view of the Requiem which many listeners to-day will surely find much to their taste". That it speaks in such a manner is because of the profound and comprehensive subjective values put in by the producer as well as by the manner of the communication.

There is again a contrast between the arts and the sciences in this area. The science product will achieve its full stature when it is tested against a vast range of objective criteria. The arts product involving human feelings will only be completed when a dialogue which includes a testing mechanism arises between the audience's own subjective values and experience - which has an intellectual component - and that of the product. This demands a creativity from the communicant. For example where subjective values are communicated by symbol, metaphor or image this will require the audience to make its own imaginative comparisons and judgement for the communication to be complete. Sartre (1972) regards the 'artists' product as an analogue. The critical feature of the analogue is that it contains within its superficial aspects profound sense which can only be obtained by a dialogue between the user and the product. This dialogue leads towards the complete fulfilment of the product when it enriches the experiences, perceptions and knowledge of the audience and becomes a personal act of dicovery. "A work of art with that alone which the artist puts into it is but half of itself, it attains its full stature by what time and people make of it". Gabo (1959).

People may have difficulty and consequently appeal to the originators but many artists resist this pressure by claiming as Schonburg (1964) does, that he does not want to reveal the poetic intentions. Rene Giuette (1951) agrees when he states "my works demand more from the spectator than I wish to define". This is in effect saying that the transmission is a frame within which it is essential for the audience themselves to extend or elaborate the transmission with their own experiences and values. The scientific theories are solely concerned with being proved right by the appropriate behaviour in nature - a different kind of interpretation. The serviceable object will also contain subjective values of a narrower range and therefore will demand from the user a similar mental activity but only in the context of being physically of service.

Much more could be said about interpretation but the attributes of the serviceable object mentioned previously have been reinforced and in addition the dilemma of the innovator has been indicated. Before summing up the previous discussions a further aspect of creativity must be mentioned. While the term 'creativity' is used too freely it should not be confined to a high order product. This paper includes 'ingenuity' and extending the range of application of known concepts by restating elements which have never been so ordered. This may not alter concepts intrinsically and therefore is at first glance a lower order of creativity but it does initiate a wider use of an already developed product. Pound (1968) agrees with this kind of extension in the 'arts' when he finds that Literature has been created by (1) inventors of a new process (2) the masters who combined a number of such processes and used them as well or better than the inventors and (3) the diluters who could not do the job quite as well (4) good writers without salient qualities (5) the starters of crazes. If such orders are admitted, uniqueness becomes relative and is measured on subjective scales, therefore the creation of a product new to the designer but not necessarily original can be considered as creativity. The orthodox may be a triumph of originality for a particular person and the conventional may be also with novelty at a particular moment. By considering creativity in this manner we will concern ourselves with raising the general standard to the equivalent of Pound's 'good writers' rather than concentrate on genius if and when it arrives.

The qualities of harmony, effectiveness and uniqueness which were given to distinguish the creative product contain a conflict between the parts if carried to extreme. Efficiency means that it is appropriate to the purpose and could conflict with uniqueness if that is struggled for at all costs. It is in this area that there is a conflict between the uniqueness emphasised by art and science and the efficiency required by applied science. The result is that either element may wrongly become the only goal rather than the fusing throughout the process of the relative uniqueness of the ideas and the competence of the analysis, appraisal and realisation. This does not mean that the difference between creativity and problem-solving becomes blurred but that each is used appropriately.

3.6 Summary of Discussion on the Creative Product

Before going on to discuss the 'process' of creativity, a brief summary of the previous discussion seems necessary. A distinction was made between the 'serviceable product' - in which architecture is classified - and the communication of feelings, perceptions and knowledge - in which the arts and sciences were classified. Both art and science want to know and make known their aspect of reality and require interpretation of experiences, imaginative conjectures and subjective selection and construction of facts to sense values and relations not evident previously but only previously dimly realised. Both products enrich the audience to more fruitful actions. There are differences in the product of science and art, the former is concerned with explanation and has solely objective criteria to satisfy and does so by generalised statements. The latter product gives singular statements for understanding and has the personal values of the artist fused with its matter. Such a product is only fulfilling its function when the experience and values of the audience is used for translating its subjective values.

The traditional teaching methods reflect the difference. Science operates through generalised theories proved and explained by mathematics and experiments, generally in a lecture situation. The art teaching is largely a master and student sharing a common experience with the teacher showing the possibilities latent in the subject, encouraging the subjective values of the student and bringing to his notice all the knowledge, experiences and feeling already in his mind. Therefore in contrast to the lecture, the first action is for the student to produce something from which the experience will be enlarged or awakened.

Architecture, like all other serviceable products, must use these two systems where appropriate since the communicative product is a basis of the serviceable product. This product aims at controlling nature rather than questioning basic knowledge of its behaviour.

It was argued that the beauty of the serviceable object is only manifested fully when the function of the product is eloquently demonstrated during its use rather than in intellectual or sensual contemplation as in the first category. As a consequence to this service it must have an active harmonious relationship with its surroundings. The freedom in providing serviceable objects insists on subjective values being brought in with objective criteria. As a result elegance or the arousing of pleasurable feelings is not automatically generated by efficiency of its function. That calculations may refine and improve or confirm but not initiate ideas is a necessary corollary to this freedom. It was also suggested that the serviceable object, which includes architecture, may be the result of having to solve a pressing problem after incomplete knowledge. Some educational exercise must allow not only an opportunity to judge what knowledge is absolutely essential, but also to assess what and where information can be obtained quickly, as well as cultivating a critical attitude towards the efficiency of the finished products.

3.7 Process

The next three areas - process, person and environment - will be examined for possible educational methods. In the previous section it was argued that there was a freedom intrinsic in the making of a serviceable object which required some subjective values being fused with the objective criteria for the use and control of materials and the behaviour of men.

First let us consider a general description of the creative process. The classical description first given by the mathematician Poincare (1913) and later considered by Wallis (1926) is :-

1. Preparation - preliminary studies, learning knowledge struggling for insight, understanding of concepts.
2. Incubation - only observable behaviour is silence but it can be described as'reculer pour mieux sauter'
3. Illumination - spontaneous appearance of fresh insights accompanied by a certainty, not always valid, but where the actions are conscious in that a hypothesis is formed which transforms the problem into a solution.
4. Verification - appraisal of the hypothesis for its effectiveness.

This description can be accepted with the proviso that the stages interpenetrate e.g. stage 4 can produce insight.

In searching for an educational organisation there is an immediate barrier in stages 2 and 3. Hadamard (1945) and Poincare (1913) for maths, and Koestler (1964) for science, all speak to a spontaneity preceded by a stage where the study seems to be interrupted. The 'arts',particularly music, do not subscribe to this interrupted study. That difference between the process in 'arts' and that in science may be attributable to the internal or external nature of the subject. For this study it is sufficent to note that the scientific process implies thorough knowledge before the spontaneity stage. But accummulated knowledge is insufficient by itself and could lead to the pedant who has an inability to transfer the potential of knowledge, whether of facts or emotion.

An attempt must be made to discover the components of this ability to transfer knowledge for a creative solution assuming that the emergence of new ideas does permit of explanation other than divine inspiration. Therefore specific variables must be known so that the instructional tactics can be chosen.

3.8 Architect's Creative Process

The creative process of the architect is similar to Poincare's description but some amendment and elaboration is required if it is to be useful as a model for architectural education.

Anadaptation of the Kelly grid as described by Bannister (1968) see appendix A was used on design tutuors. From that emerged a possible structure for the process of architectural creativity.

1. Identification of needs and problems. This contains abstract and concrete criteria for judging the harmony and efficiency of the solution and it also starts to isolate the possible conflicts aroused by such specification. Dewey (1910) describes a somewhat similar phase.

2a)Organisation and evaluation of existing knowledge.

2b) Problem structured with hierarchy of criteria and component problems.

c) Inquiry into feasibility of resolving conflicts i.e. value judgements required in setting priorities of value.

3. Production of central unifying hypothesis determining broad course of design. That may require at this stage, and will require at more detailed stages, the production of alternative solutions which synthesise the elements and conflicts into a pattern which satisfies the given criteria.

4. Appraisal of the consequences of the hypothesis leading to two possibilities.

5a) Development of solution to a detailed criteria for performance i.e. repeating the cycle but in detailed form.

b) Redefinition of the weighting of the importance in hierarchy of component problems i.e. (2b)

6. Implementation

It is relevant to note that there is often a fracture in this structure occurring between either stage 1 (identification of problem) and stage 3 (production of central hypothesis) or between stage 3 and stage 6. In this context two contrasting creative engineers of the 19th century can be cited - I.G.Brunel, flamboyant, sceptical and adventurous who clearly saw the problem and solution but lacked the ability to get the work done, and G.Stephenson eho had a quick efficiency and inspired his staff so that the ideas were implemented.

That outline can be used in a broad sense to give direction and unity, and it can also be used for the detailed design.

3.9 Architectural Design

If architectural design is examined, however currently, it is seen that it has certain characteristics, some of which are associated with the scientific and artistic approach, and some with the technological approach. Reference can be made to the preceding pages dealing with the creative product.

In the architectural process - shared by the arts and sciences - certain decisions are made after the statement of needs and aims. These decisions release practical inferences which were latent and often create a new situation. This can set up a sequence of action which sometimes makes possible achievements and objectives not contemplated before but still within the broad aims stated at the beginning. In the light of the later action some of the earlier descisions can take on a new significance and acquire a purpose unknown to the original achievement. These decisions will have an inherent structure which within its form will set up possibilities, demands and limits on the development of the design. This dynamic process is best seen in humanistic studies such as visual art, literature or music but can also be seen in historical criticism and to a lesser extent in the production of scientific theories. In these fields it is not necessary that hitherto unknown facts come to light but that a new role or significance is given which it did not possess until more recent decisions and actions were effected. The emphasis on setting up connections and relationships given previously have their relevance to this part of the process. This is why 'structure' must not be considered only at the end of the design process, otherwise the latent possibilites involving 'structure' are ignored.

Architecture requires however that some of these decisions be based on objective criteria as in applied science. The conclusions reached previously on the qualities of the serviceable object were that subjective values particularly in the initial stages need to be mered with the objective criteria. The architect's problem like others in this field is to combine these two realities of personal involvement and the impersonal rational deductions from cold hard evidence. The process further demands that different methods of dealing with 'facts' must be combined into a unified solution and inevitably there are inescapable conflicts.

It has been argued in the discussion on the Review of Literature (Chapter 2) that optimisation of structure is concerned with limits rather than unique solution. When such products as an oar or a scythe are considered, efficiency and harmony appear to be gained simultaneously with ensuring minimal material. The qualities required for the serviceable object are still appropriate even with such basic requirements. There are much more complex factors and resulting conflicts in architecture and a significant aspect of architecture is the production of a superb new solution to an old problem which has already been solved superbly.

Such varying solutions still satisfy these conditions which the designer has classified as essential which in turn must be identical to society's continuing assessment. This means that the architect has to set up a hierarchy of problems and criteria i.e. a set of priorities. During the design process e.g. at stage 6b, that particular hierarchy may have to be changed and so the solution is not completely circumscribed at the beginning. An educational difficulty is to determine whether there is a justified change in the priorities rather than avoidance of the problem through ignorance or laziness. It is also implicit in this schema that the design process is cyclic in character having loops of feedback. This non linear concept is in contradiction to RIBA Design Morphology (1967) but agrees with Markus (1969) and Hillier et al (1971).

This cyclic type of approach also implies that the intermediate testing of the hypothesis i.e. possible solution - will not always be exhaustive. It is legitimate and necessary to act at certain stages on tentative conclusions. Only at the final solution or in some component decision firmly based on objective values will there be complete testing.

3.10 Problem Solving

Contained within this general process there will be problem-solving situations with a wholly correct answer as opposed to the open ended situations. In this category come decisions regarding some engineering aspects where the problem is stable, and assumptions are not going to be changed in order to resolve conflicts between aims and means. It is necessary therefore to compare the open ended process with the problem-solving process.

This latter process when applied to engineering is:-

1. Locate and define needs
2. Establish criteria for judging proposals
3. Search for information, building up of patterns i.e. organising knowledge
4. Develop model, resolve conflicts
5. Generate alternative solution, predicting consequences
6. Verification, improvement, optimising.
7. Plan how to put proposals into effect.

This is similar to the generalised statement of the creativity process; Guilford (1967) and Gagne (1967) are two of many authors who claim that creativity is problem-solving behaviour.

This paper sees a difference in three areas:-

(a) <u>The definition of the problem</u> - the architect's definition at the beginning can never completely determine the solution. In the artistic process the choice of solution is from an indefinite field.

(b) Search for means to solve the problem - the area of search in a creative process is in an indefinite field allowing a circumscribed freedom to produce solutions as compared with the definite area of search for a problem.

(c) Quality of judgement - the creative process with its dynamic relations of elements insists on deferred and 'value judgements' on combined subjective and objective criteria. As a result there is required in varying degrees from the producer 'value judgements' which add some of the producer's identity to the unique and individual aspects of the problem. Such a product requires as its corollary that the user too brings his 'value judgements' to bear on the use of the product. The quality of judgement requires also the use of imaginative conjectures and different levels of consciousness. A satisfactory result makes the solution much more than the sum of its parts.

Two contrasting types of problem therefore emerge:-

1. Algorithmic In this type the problem has a definite objective and can be solved by a correct sequence of action. The search for the sequence is in a definable but possibly wide area; to uncover the correct sequence, memory, abstract knowledge, experience, trial and error, or the computer can be used and once the correct approach is unmasked there will be an inevitability towards the correct conclusion. This not only contains Polya's (1954) routine problem but also the type of problem where the search is for a 'clue' to link the problem to a familiar problem. This process is akin to analysis.

2. Creative This type of problem is characterised by the three qualities given previously i.e. definition of problem, search for means to solve, and quality of judgement. The process is akin to discovery process which is non linear.

This kind of definition allows the relationship between the problem and the knowledge, experience and skill which the individual brings to the problem to classify whether the solution is creative or not.

The job of education is to reduce the indefinite choice of solution if that is so wide as to overwhelm a student and thus it is argued education has to create some pattern or strategies which will give such students control over their creative powers. Such an objective removes the arbritary or whimsical choices made by inadequate students as well as reducing the timeconsuming trial and error. It also does something more than just recognise that the incubation period is 'mind moving upon silence'.

Strategies such as Decision Theory Approach (Archer 1970), Systems Engineering (Chestnut 1967), Cumulative Strategy (Page 1963), Boundary Searching (Jones 1970) are examples of trying to impose as much as possible of an algorithmic form on the creative situation.

Those who advocate such convergent strategies for all claim that they are increasing the amount of time spent on analysis and evaluation and reducing the effort spent on a synthesis which may turn out to be abortive i.e. more time is spent on the detailed structuring of the problem. Where this gives the average student a pattern to intermittenly regulate his creative process rather than a prescription there would be no argument. But we must recognise that architectural problems are not stable nor solely contain data with precise measurement. It is therefore necessary to specify which factors have objective criteria and which contain subjective, and identify the changes required for compatibility between complex requirements of man and material. This requires some tolerance of ambiguity in the initial structuring of the problem, and the recognition that the strategy is in its most important stages more humanistic than technical.

It has been argued that forming a hierarchy of priorities is the same as structuring the sets of elements of an algorithmic problem. That omits the personal involvement, choice and changing the hierarchy because previous decision releases possibilities previously latent[1]. It has also been recognised that the scales of measurement used can be subjective in character. While the properties of materials are related to ratio and interval scales, the values related to human behaviour can be ordinal and nominal scale. If a distinction is not recognised then a spurious objectivity is given to the solution.

3.11 Logic

The next sections will examine those categories of the thinking process which have generally been accepted as creative. Each of the categories - logic, association of ideas, bisociation and gestalt will be examined for their appropriateness in the architectural/structural design process.

Getzel and Jackson (1962) give logic as a category of creative thinking. Deductive logic can, if properly used, lead on with certainty to the truth for certain types of thought. Its emphasis on proof, clarity and development of criteria for testing hypotheses makes it valuable in the evaluation process of design. Its insistence on proof with stringency and rigour at each step, is at first glance commendable but where deferred judgment and the choice of priorities are required, it will hinder genuine creative abilities. The laws of such disciplined thinking demand that the thinkers persist with a given frame of references and do not shift from one to another. In architectural design sometimes the opposite is demanded and it is more important to realise when and when not to be so disciplined.

The discipline of logic is valuable where it concentrates on the difference between hazy concepts and exact judgement but it tends to deal only with two truth values. True and false decisions are made strictly on a Kierkegaard 'either/or' or Hamlet's 'to be or not to be'. To decide in this manner forces us to support one side against the other, as in legal argument, but while appropriate in some aspects of design could plunge to the pedantic poseur's position in others. That latter position generates the illustrative phrase "on the one hand we cannot but admit and on the other it must be confessed", and lead to Hamlet's indecision. Where subjective values are used to resolve conflicts and doubts, the discipline of logic in considering only two values of reality cannot deal with the excluded middle. That is a serious omission especially when the error may only be a partial truth and require development according to the stated priorities and to actuate the dynamic inter-relationships. Logical induction recognises grades of truth but it rests on the empirical content of the proposition and cannot by itself enlarge the statments out of which it issues.

The careful gathering of facts and the empirical study of the problem is helpful but by itself can be barren and in any case can never be free of bias or preconception. Popper (1968), Medawar (1969) and Koestler (1961) are in conflict with Bacon (1968) and Mills (1972) over this idea that creativity could be made into a science which would rationally generate new ideas. The arguments for the modern philosopher are so strong that no one cares to defend it.

In order to understand a building the logician will focus on an element like a wall or a brick and on the way in which they are joined together. This will help in the detailed building up of the design but omits the heart for it has nothing to say of the process by which the elements entered into the solution. Moreover logic requires the bricks to be identical in all situations as this is important for validity. That is not always so, for just as two identical musical notes will alter in meaning according to the content so will a cantilever structure alter its effect and function according to the space of which it is a part.

Emphasis on such logical discipline has resulted in rationalising after the event. A designer will give logical explanation for a decision which in reality could be arbitrary, or could be intelligible by other than logic i.e. feeling. This confuses the analysis and the appraisal by trying to make the process plausible by logical standards retrospectively and can lead to self deception and loses a necessary rigour in identifying those criteria which can and ought to be satisfied objectively. Teaching methods have also suffered from this emphasis on working back to derive an elegant logical proof and as a result the explanations are completely coloured by this procedure. It ignores the process by which the result was found in the first place. The proof of a proposition becomes equivalent to verifying the proposition but the methods and abilities by which the propositions are obtained - equivalent to struggle for insight - are at least as important as the verification. The teaching situation in 'structures' should be as the learner see it. This will result in the student directing himself to the technical goals rather than arithmetical appraisal of an arbitrary solution. This aspect can be compared with Dewey's (Highet 1965) method of lecturing where he talks as if he were thinking out the problem and reporting the development of the process from the beginning. This does not mean putting the student in a situation where he has to discover the solution. The logical method however tends to make discovery and justification one act, yet even in science and maths they are almost always different processes. The discovery starts with a hypothesis which has an imaginative episode of thought and a critical episode. This is outside logic and requires imagination based on knowledge. While reason may never deceive, it does not always bring in new ideas or conviction or relate to the subjective values. Koestler(1964) claims that original thinkers have a virtual unanimity in emphasising intuitive leaps of imagination suggesting that rational processes, however much they are required to appraise the overwhelming certainty accompanying the flash of insight, have been vastly overestimated. No place has been found in the logical frame for flair, sensitivity, the enrichment of experience or even the 'Fleming luck', where an accident is developed by the discerning and knowledgeable creator, as in the discovery of penicillin.

Formal logic has however other features which are relevant to the creative process. Formal reasoning cannot occur in the absence of language i.e. a set of symbols not necessarily linguistic. Language is required to assess the means of action and to develop thought. That, however, is not peculiar to formal reasoning.

Another aspect which appears most obviously in geometrical situations is a readiness to go 'outside the figure'. This is the ability to reason in terms of the possible when a reasoning structure cannot impose directly on the problem in the form in which it is at first seen. This subordination of reality into the possible is noted by Inhelder & Piaget (1964) as a distinctive feature of logic and can appear as analogies and require simultaneous consideration of hypotheses.

Another feature of logic according to Lanzer & Morris (1968) is the 'systematization of inter-relation'. If by this is meant a reconstruction of the problem by disentangling the relations operating between the various forces in the problem so that the separate factors are identified in priority of relevance and potential and then recombined in terms of a model imposed on the problem, then this comes near to the architect's design process. But this change of character of the approach brings it close to gestalt thinking which will be considered later. It is sufficient at this point to emphasis that the architect's design process can be seen to have interpenetrating styles of thought and cannot be confined solely to logic.

3.12 Association of Ideas

Another category of creative thinking given by Getzel & Jackson (1962) is 'Classical Association' which is the ability to think productively in the working of associative bonds and depends on the number of associations acquired by the individual. The problem is solved by recall and new ideas are intelligent association of older ideas or chance discovery in a succession of blind trials.

The first to formulate this explicitly was Aristotle (1930) "thought processes depend on ideas occurring contiguously". The 17th century philosophers developed this theme with Hobbes (Hampshire 1956) dismissing ideas as being innate, and basing the process on experience. Hartley, Locke, Berkley and Hume led the Association theory to explain cognitive faculties by regarding ideas as atoms and new ideas as additive combinations of these atoms. New ideas, they claim, depended on chance happening of particular contiguous events. This mechanistic view, largely abandoned, is still maintained by Skinner (1969) when he regards creativity as largely a matter of selecting, reshuffling and combining existing facts and skills with the addition that external training with contiguous reinforcement is of value. Where that view regards the rearrangment as revealing unsuspected relationships between facts long known but wrongly believed to be strangers to one another; then it partially comes into focus with our requirements of some aspects of creativity. But that view of creativity does not recognise the necessary dynamic development of changing possibilities in the new combination. That view also does not explain how the individual relationships take the form they do rather than the many forms they could take. If that question is ignored then it will encourage the use of 'trial and error' where that can be a heedless and random procession of blind procedures from which the arid assumption is that forming fertile hypothesis depends on chance. To create consists in not making useless combinations; rather it relies on an ability to estimate the possibility of a fruitful sequence of action as well as the mental sieve which Poincare (1913) describes.

The computer is regarded as a useful tool to replace the traditional use of experience for such estimations and review because of its ability to explore a substantial number of continuation. Newell et al (1957) go further with their belief in the intelligent behaviour of machines which they claim can form static evaluations and integrate these for a total solution. This process is approaching the creative, if the evaluations, both subjective and objective, are dynamic in that they interlock, actuate latent possibilities or significance, and change some of the original conditions of the solution. This concept of dynamic relationship is at the heart of all architectural design and it implies that there is no longer an inevitable sequence or algorithm leading to the solution. While the computer can speedily evaluate stable problems or a vast number of combinations it cannot discover all the latent possibilities in combinations which provide the new situations not envisaged in the original statement. Many situations in design occur where unsuspected application of elements can be seen quite differently, extended beyond the original requirement of that element.

An example of this can be seen in Torroja's (1958) description of the development of the design of the Madrid Racecourse stadium. Compression supports normally required for a promenade were eliminated in favour of a combination with one compression support and the back support of a cantilever whereby a tensile member was sufficient. The computer cannot evolve new screening concepts because it separates the screening function from the generation of new ideas(whereas it is often out of the interaction of specific ideas and screening techniques that the material change for the new solution emerges.) In this context, there is a radical difference between the computer and the designer in that there ought to be a tolerance of deferred judgement sometimes amounting to ambiguity - the keeping of options open - and in the ability to readjust the priorities of the problem, which is a matter of interpretation.

This is not to argue that the computer will not have a strong impact on design. At present it can be seen successfully operating in verification of proposals as for example verifying the proposed space layout of a building against the given hierarchy of the individual efficiencies of the various functions. Examples of such functions are circulation of the occupants and illumination if these functions are basically matters of efficiency and economy. If illumination involves the sophisticated use of light contrasts or the use of an inner courtyard, the performance specifications cannot be confined to quantifiable diagrams which will be models for firmness and commodity only. There is an analogy here between the artist's use of light and colour and the scientist's description and use of light and colour described previously. The computer presupposes a logical process. Where there is subjectivity involved, as in all serviceable objects, the computer will be confined to either checking that the efficiency is within the performance specification, or given a specific item 'a' then quantity 'b' will result from its use. It is argued therefore that both the computer and some interpretations of the 'Classical Association' theory do not encourage the concept of dynamic relation of elements when forming a solution. This ability requires that familiar elements are seen for all their latent potential so that when two or more elements are juxtaposed a new meaning or action can be made and other elements which have a link usually beyond the literal definition of the elements are harmoniously combined to form an efficient solution. This sensitivity is similar to the ability to illuminate difficulties by relevant analogy - any problem or object seen for the first time may suggest an idea of something resembling it. It should be noted that this action is made not because it is new but that it helps to solve the problem.

3.13 Bisociation

Koestler takes up this aspect that ideas have connotations beyond their literal definitions in his Bisociative Theory in the "Act of Creation" (1961). That theory regards it essential to find the unifying link between two ideas which are to be connected from habitually incompatible frames of references. Any concept can be collected in a matrix of associations with other concepts. The creative or problem-solving skill is in searching for a matrix containing two ideas which have an efficient and harmonious association, but were apparently unconnected at first glance. To combine these unconnected ideas, Association suggests a blind try, Skinner suggests a gradual cumulative process, Koestler suggests a sudden fusion of concepts normally thought incompatible but having associative contents. Koestler recognises that dynamic development in relationships is required but, as with either the Marxist development of inherent contradictions, or with the logical approach, the process still considers only two facets and therefore there is an inherent restraint for design.

One aspect that bears examination is that by definition, a Koestler matrix can be formed by analogous qualities and by its relationship transformed into something unique. The use of analogy combined with 'the mental sieve' can break the preformed pattern which on the one hand gives us frames of reference but at the other pole leads to habit.

3.14 Gestalt

The problem of sensing the latent potential in familiar elements is treated by the Gestalt school in a particular way. Gestalt theory suggests that the essential structure of the problem should be separated from the inessential variables. Originally applied only to perception of spatial shapes it was expanded to the formation of abstract generic concepts, since as Bruner (1957) suggests "all perceptual experience is necessarily the result of categorization". The notion that a problem situation must be structured as a whole rather than split into its components belongs to the Gestalt philosophy based on the work of Kohler (1966), Wertheimer (1961) and Koffka (1935). The problem is solved by finding (a) inner structural relations within the situation as a whole and arranging its parts accordingly; (b) grouping, segregating and centring structures (i.e. sub-structures of the whole), (c) isolating the essential gaps or trouble regions in the structure; (d) treating operations in terms of their structural place, role and dynamic meaning and (e) realizing changes involved and occurring in operations and structures. Wertheimer (1961) claims that by reorganising the essential elements of a problem into a coherent structure there will often be a change in the goals and in the questions related to these goals thus bringing it into line with the design process.

Where the Gestalt theory emphasises the abilities to see the nature of the intrinsic interdependence of the sub-structures and this relationship to the whole, and also seeing the structured whole when developing the component parts, then this too is in focus with the architect's creative process in design.

The Gestalt theory postulates that the final solution in its entirety comes in an 'eureka' flash of insight. That must include the condition that the designer's repertory contains all the requisite skills but it contains educational dangers which will be discussed in the section on 'Intuition'.

There are claims that this flash of insight is not central to the Gestalt theory. Koestler (1964) points out that Kohler admits that insight is a matter of approximation and may be achieved in several steps i.e. more or less 'sensible' hypotheses which imply 'good errors' but also imply that the solution is just one step before full knowledge. This process rather than the 'eureka' flash has a higher educational potential and is in line with the architect's process of design so discussed. The assumptions of Gestalt have extended it beyond the faculty of perception into other fields where it has doubtful validity as the ultimate of all creative processes. Moreover it could not be linked directly with new objective experiments and was regarded by many as rather woolly compared with the pragmatic experiments of the Behaviourists.

3.15 Psychological Theories

When discussing the process of creativity, personality characteristics of the producer cannot be ignored because of the considerable influence on the whole process. The aim of education towards developing creative abilities must be the same as the aim for developing cognitive abilities where personality characteristics are also involved.

The works of the philosopher and the psychologist, such as Koestler (1964), Ghiselin (1952), Mackinnon (1968) and Roe (1963) reflect the close interaction between process and personality. In this overlapping area both disciplines collate biographical material of people who are considered by their peers to be outstanding in producing a 'creative product'. This approach circumvents the problem of defining creativity by trying to measure what society accepts as exhibiting creativity. Some facts emerge from these studies e.g. the extent to which creative people conform or do not conform to a personality type, or a type of thinking skills or strategies. Some doubts may arise on this method.

In the reports by Mackinnon (1968) and Roe (1963) the results could have been influenced by a halo of self justification or rationalising effect on the self-rating of the personality and the process. While the process can in fact be readily checked in this area, the time lag between the production of the product and the investigation of the process could be considerable. Mackinnon's (1968) own structures on his conclusion i.e. that those mature characteristics thus identified may not be the same as they were when they were students are apposite to this study of personality characteristics if they are to be applied to educational techniques. With this in mind, it does seem helpful nonetheless to note that in Hall & Mackinnon (1968) investigation of architectural creativity, intuition and perception have the most significant correlation of the personal characteristics.

Case studies by psychologists on the general area of creativity have given some relevant personality characteristics. Until Freud, creativity was linked with madness. The Midsummer Night Dream has 'the lunatic, the lover and the poet are of imagination all compact.' Freud (1950) regarded creativity as "a continuation and substitute for the play of childhood." He also claims that the source of artistic creativity is in the inner conflicts in the artist which are resolved in his art. The Freudian view is, therefore, that creativity is a means of reducing disturbing tension within oneself and is derived from the preconscious which gives the mind a freedom to gather, compare and rearrange ideas to form a harmonious and unique whole. The Gestalt contribution to resolving the conflict to harmony requires a mind which is continually and unceasingly observant of the disharmony arising, for example, from imposing or following a preconceived pattern, is sensitive to the relevant differences between what is aware of a new set of relevant differences and similarities of pattern which give rise to the new structure.

A fresh impetus to further investigation was given by Guilford's paper (1950) on Creativity. Her approach was mainly experimental, either by structuring a situation and comparing results or by measuring creative potential. If the psychologist can achieve a large degree of precision to predict future creativity, this will be of value to screening entrants to a course. The difficulty with these tests is that creativity cannot be readily anchored to a specification.which will allow scientific measurement. Some investigators like the Maitland-Graves (1971) tests for identifying artists from non-artists suffer from a definition of creativity which is not yet generally acknowledged. The difficulty of using scientific methods is largely overcome when psychologists measure originality. This can be objective and although those who are original are not necessarily creative it is a reasonable premise that those who are creative must be original. Torrance (1962) has collected the findings of various investigators which can be summarised as follows:-

1. Willingness to risk: absence of serious threat to self
2. Self awareness: in touch with one's feelings
3. Self differentiation: self as different from others
4. Openness to other ideas and confidence in one's own perception of reality or ideas
5. Balance in interpersonal relationships

All items are relevant but the items 1,2,3 and 4 are of immediate value for erecting educational techniques. Other personality factors likely to modify the student's experience have been given by various investigators summarised by Freeman et al (1968). Such factors as femininity of interest, humour, scepticism, results of serious childhood illness or dominant mother, low general anxiety, stable extroverts and concern about personal adequacy, do not appear to have an immediate practical value.

When the investigators discuss abilities as opposed to personality characteristics some direct value towards a choice of educational methods arise. Qualities relating to originality such as fluency, flexibility, elaboration, tolerance of ambiguity, and intelligence appear desirable however difficult it is to initiate, discern or reward such abilities. The recognition that a tolerance of ambiguity is desirable has led to educational techniques such as 'brainstorming'. This paper in the light of its discussion on the process argues that this technique is of only marginal value, since it omits a screening or filtering ability. This tolerance of ambiguity or deferred judgement mentioned previously must nonetheless be developed in some of the educational tactics.

The relation of intelligence and creativity has occupied some investigators notably Getzel and Jackson (1962) and Terman and Oden (1959), who both distinguish between the two. Terman and Oden (1959) assessed in

1925 the top 1% of the Californian school system by intelligence tests and eventually tested the same subjects in 1959. They claim that intelligence tests were regarded as inadequate for creativity. Recent studies by Freeman (1972) however confirm other claims that intelligence and creativity are not independent. The correlation is high but not absolute. For instance an I.Q. above 135 does not guarantee high creativity. It would appear that intelligence and creativity are on overlapping scales. Intelligence deals with sustained abstract thought but the tests devised to measure this, concern themselves with rapid and error free solutions. These tests as with creative tests have led to educational methods which increase the student's response for these tests and thus becomes a rather circular affair. In other words creativity is defined as the tests understand it. Hudson (1966) begs less questions than the creative intelligence difference when he contrasts the convergent thinker with the divergent thinker. If the differeence can be shown to go beyond cognitive style and reflect deep variations in personality, it will be necessary to organise educational experiences for this. If, however, these processes are to be regarded not as distinct faculties of the mind but as mades of thinking, each person will be capable more or less of achieving both processes and education will have to consider them together, and bearing in mind the previous discussion on art and science, it would appear that the latter course is more fruitful. This brings in the additional ability of being able to change from open and subjective to objective and restricted styles of thought at appropriate times in the process.

Further Guilford (1959) has attempted to place the special abilities required for creativity into a general structure of the intellect and among the appropriate factors are Transformations and Implications. One of the results of Guilford's work is the use of tests to attempt fine discrimination, which encourages a process of fragmentation into more factors of less importance. The antagonism towards the splitting of the intellect is best stated by Wordsworth when he said "who can point as with a wand and say this portion of the river of may mind came from yon fountain". It is submitted that it is necessary to identify the factors in the same way that engineers idealise a heterogeneous material so that the material's behaviour can be predicted within reasonable limits. This is in parallel when the scientist explains complex natural phenomena by relatively simple generalisations. The danger is that an analysis of this nature may not be carried out to exhaustion or that the immediate cause and motive will be considered as the chief significance in the generation and development of creativity or that the essence is lost in the process. We may as D'Arcy Thomson (1917) pointed out "come in touch with 'ratio cognoscendi' though the true 'ratio efficiendi' is still enwrapped in many mysteries." It is not supposed that man's behaviour can be explained solely by mechanisms or by teleology: to 'see that it is good' requires another plane of explanation. Neither a bridge, a building nor a violin can achieve harmony simply as an instance of physical laws. Intelligence must be intimate with feeling, feeling with sensibility and sensibility with knowledge and language (whether semantic, figural or symbolic).

Such amplitude of mind and reason Wordsworth (1959) describes as imagination. The education system therefore must be dedicated to refining feeling to become intelligible and perceptive and therefore increase the power of the student to 'make subtler the power of pertinent connectives and foster a conscious responsibility without dividing the intellect from the feeling'.

3.16 Summary of the 'Process and Person' Section

An approximate pattern of the architect's design process was developed from an adaptation of Kelly's Grid Analysis given to architectural staff. From that pattern it was noted particularly that some decisions released inferences which often created new situations or gave an altered significance to previous decisions or to what was thought to be relatively minor conditions of the brief of the building. This humanistic approach confirms that structures must not be considered only at the end of the design. This approach also gives rise to difficulties for the 'structures' teacher, in that he has to judge whether or not the student is justified in changing his conditions or priorities. It was noted that deferred judgement is required and that this is contrary to the technical approach in general. The 'structures' teacher or consultant therefore must recognise the possible validity of that kind of judgement.

This section of the thesis also dealt with the differences between problem-solving and creativity since many regard creativity as a particular type of problem. This paper discussed this view and concluded that there are basic differences in three areas, viz:- The definition of the problem; the search for the means to solve; and the quality of judgement. Teaching methods in structures must allow the students not only to exercise in conventional problems but also to operate in those three areas.

Four types of thinking strategies were considered namely logic; association of ideas; bisociation; and Gestalt. It was argued that while some qualities of logic (such as rigorous proof, clarity, development of criteria from which to judge results, use of analogies, identification of priorities of the elements of the problem, and a reconstruction of the problem to disentangle relations within the problem) were of use in the architectural/structural process, there were other qualities which were not. In particular logic makes discovery and justification one act in the process and this, it was argued is the opposite of a large part of architectural design. The process of logic ignores the imaginative or intuitive leap which is thought to be of basic importance in the architectural/structural design. Moreover, total reliance on logical methods tends to force one to consider only two facets and excludes the 'good' or partial errors on which development should be attempted. Teaching methods in structures suffer from the desire to make the explanation of phenomena elegantly logical. That results in a rather retrospective plausibility which covers up the messy but vital process in searching for a possible solution.

The theory of Association of Ideas appears to be in accord with the design process because it requires the intelligent association of different elements. However, all interpretations of that theory are by no means agreeable. For example there is the mechanistic view of numerous blind trials which does not recognise the required dynamism nor the necessary screening of possible relations and combinations. To create, one must foresee the possibilities of a fruitful sequence of combinations. The place of the computer in this context of solving problems was briefly considered.

It was felt that while Koestler's Bisociation theory of creativity recognises the dynamic process of connections between the forces in the problem, it too was concerned with two facets only. The Gestalt theory offers some help in forming strategies for creativity in structures. For example, the suggestions for regrouping elements in terms of the structural whole, consequent possibility of changing goal, and seeing the structured whole when developing the component parts are congenial to the architectural/structural design process. There are, however, two interpretations of part of that theory, one states that solutions can be arrived at by a flash of insight, the other claims that it is more likely to be by a series of approximations and development of 'good' errors. While the latter gives a sounder base for developing an educational method further examination of this aspect is required and will take place in the next section.

On examining the psychological approach to creativity it was argued that there are two types. The first consists of case studies of various personalities deemed creative by a consensus of opinion, the second is an attempt to predict by tests the creative potential of individuals. Some personality factos appear to give a possible foundation on which to construct educational methods but in general it was argued that the necessary reliability or precision with which to confidently build a teaching method has not been achieved. The danger of fragmenting the qualities of the mind was discussed but on balance it was felt it was legitimate to use the approach of idealising the qualities so that some analysis would be used.

3.17 Refernces

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SOME TEACHING METHODS ADAPTED TO THE CONCLUSIONS OF CHAPTERS 2 AND 3

Chapter 4

4.1 Introduction

This section examines the concepts, imagination and intuition which have persistently emerged from the previous section.

The first part will try to define the terms within the context of this thesis and see if any general principles can be applied to teaching methods. The second part is concerned with four teaching tactics for structures which have been developed to utilise some of these principles.

The view of imagination has varied from Kant (1929) - "remodelling experience following principles which have a seat in reason" to St.John of the Cross (1946) - "in order to go where one knows not, one must go by a way we know not". In view of previous discussion, a cursory description which might reflect in some teaching methods must be made.

4.2 Imagaination

Instinct, which is completely identified with self-satisfaction rather then with understanding, is omitted. So also is the activity described as 'in imagination', since one can imagine, as in a day dream but to do so 'without imagination' in the sense that is relevant to this study. For example, one can, in a Walter Mitty fashion, imagine onself as a music conductor or an athletic hero, this activity though controlled is not distinguised by originality nor does it have "a seat in reason".

The relevant activity is that which treats the data "with imagination". A brief schema of the process would have to be concerned with the action upon sensory or intellectual data by sensibility, knowledge, cognitive faculties, reproductive imagination and a 'control' system. This control system has to establish a "manifold" (Kant 1929) or a "matrix of associations" (Koestler 1961). The product at this stage, if combined with problem-solving techniques, can be creative in terms of the effectiveness originally defined.

If however the arrangement of material is acted upon by a productive imagination and a 'control' mechanism, concepts or hypotheses can be formed in two ways - intuitive or combining. Then somes appraisal and verification. Once conceptual ideas have been formed, 'fancy' - largely an intellectual reorganisation - can operate to slightly change the product.

Such a sparse schema combines the ideas of many philosophers and references are given at the end of this section. Some definition, however cursory, is still required of the terms used in the above.

'Sensibility' as used is a mode of perceiving, ordering and valuing knowledge and is activated partly by objective judgements and partly by subjective criteria which although inherited can be disciplined and modified partly by education, contemporaries, and the family.

'Knowledge' must be dfined to contain experience which gives data for reason to state definitive principles.

'Reproductive imagination' is that as defined by Kant (1929). It produces the sensible relationships in this apprenticeship period from observation, analysis, comparison, analogy and a controlled "suppose that.........". This type of imagination is akin to reflection and speculation on possibilities but is concerned with previous knowledge, and intimately related to reason. The product of the rapid interaction between these elements requires a 'control' or screening system. This should be a ruthless evaluation involving choice, rejection and filtering. This process is of a cybernetic nature, a regulative process modifying and adjusting by examining the consequences of the project. The manifold or the matrix is as Kant (1929) and Koestler (1961) describe, but it is noted that the sensible, if unusual, relationships are compatible with cognitive laws where the criteria is objective, but are not determined by them. The imagination, as with the activity of thought, is an activity of unification which connects not separated facts but "chiefly the relations of things, either their relations to each other, or to the observer" (Coleridge 1929). As stated, there are two paths open, the second and more significant process uses productive imagination. This is largely Kant's thesis (1929) and it is taken that this faculty has an iconoclastic quality of shifting the emphasis or destroying the previous system of explanations, understanding, assumptions or likenesses "to create a second mature out of material supplied to it by actual nature". This can be seen at its highest with Einstein's relativity theory embracing Newtonian theories in a wider generalisation and by a different framework. At this level, imagination becomes "reason in her most exalted mood" Wordsworth (1959). This link with reason is emphasised by Kant (1929) - "we use imagination to remodel experience following principles which have a seat in reason". This productive imagination has as extremes:-

(a) Sensation evoking vivid impressions of sight, touch and movement.

(b) Feeling or evoking or suggesting emotions similar to the 'arts' values given previously.

(c) Practical and rational, concerned with the choice of fundamental characteristics which become a substitute for the omitted rest but give a clearness in explanation of complex natural experiences.

All extrmmes are concerned with clarity and organisation. It is one of the many difficulties facing teachers when they have to be able to distinguish between the genuine expression and facile effusive fluency. As with reproductive imagination, productive imagination is still compatible with cognitive laws where relevant and therefore requires the same controls based on reason and knowledge. Where explanation is the goal rather than understanding, the product becomes a substitute, if the imagination is not appraised by reason and knowledge like astrology.

The two kinds of productive imagination, intuitive and combining, agree with the results of tests given to staff (see appendix). The former offers a comprehension rich in consequences which must be developed from the whole to the detail. This is the kind of imagination which Goethe (1961) claimed that Shakespeare must have used in developing the character of Hamlet. The other subdivision is initially concerned with a part of the whole and proceeds to what is a vaguely preconceived unity.

4.3 Intuition

In previous discussion the faculty of intuiting has emerged as one of the basic elements of the creative process for example Einstein (1938) claims "They (scientific laws) can only be reached by intuition based upon something like an intellectual love". Koestler (1959) and Hadamard (1954) cite many examples which argue for a fringe conscious mechanism as a primary function in the creative process. Architects like Philip Johnson (1955), engineers like Maillart (1938) and Freyssinet (1954) all subscribe to this process in forming a hypothesis. This ability is not limited to architects and engineers, but according to Jung (1923) physicians, inventors and judges are only a few who also make use of this faculty. Intuition has been the object of scrutiny from great minds such as Plato, Aristotle, Locke, Bergson, Spinoza, Jung and Whitehead.

It appears that there are several forms of intuition. There is religious intuition which is an immediate knowledge of the spiritual world. There is moral intuition which is immediate knowledge of right or wrong - i.e. the conscience. None of these are directly applicable although both have an immediacy and a certainty contained in their composition. In both, too, the knowledge is more of a belief than verifiable knowledge and depends greatly on revelation.

Intuition in the intellectual sense appears to have two main streams - the fallible and infallible. Descartes (1970) and Aristotle (1930) argue that some knowledge cannot be proved but is known to be so by intuition. For example, the statement that parallel lines cannot meet. There is no question of error it is claimed, because the opposite is impossible. Liebnitz (1966) includes this element in his method when he argues that one should analyse the problem into simple ideas till one comes to the 'primitive' where there is no question of error. It is noted that this kind of intuition is not only acquired by experience but is known innately as *a priori* knowledge. The arguments for this kind of intellectual intuition where it is suggested that some knowledge is infallible have not been generally accepted.

Aaron (1971) is only one of many who illustrate that there are grave objections from mathematics and overcome the question of proving 'primitives' by forming it as an axiom or definitive. The requirement is that even if we know with certainty, universally accepted proof must be given where objective criteria is the main burden of acceptability. Where intuition is regarded as a substitute for knowledge, or has not a universally accepted proof, it is plainly unacceptable no matter how convincingly the credibility of the product.

This infallible kind of intuition, therefore, is not the medium of framing a hypothesis. The qualities of such a faculty of hypothesising appear to have some similarities with the Gestalt method of problem solving. There is Spinoza's (1951) view of intuition as an apparent "immediate recognition of the meaning of particulars in relation to the whole". There is also the view that intuition is the ability to distinguish essential features and to ignore the irrelevant elements which it treats as peripheral. This has obvious similarities with Wertheimer's (1961) arguments that "the functional and structural meaning of an item first seen from an atomistic point of view may well be very different". If this similarity is conceded, then Wertheimer's methods of teaching would be appropriate. Briefly, these consist of developing the students thinking strategies so that the problem is changed in the direction of structural improvements. This involves (a) dealing with gaps, trouble regions, etc.; (b) finding inner structural relations within the situation as a whole and arranging its parts accordingly; (c) grouping, segregating and centring structures (i.e. substructures of the whole); (d) treating operations in terms of their structural place, role and dynamic meaning; and (e) realising changes involved and occurring in operations and structure.

Wertheimer (1961) illustrates this technique when he describes a method of teaching areas. In the appendix, this system is contrasted with the programme instruction on the same subject. A further quality of this kind of intuition is seen in the ability to make rapid judgement and synthesis, particularly in unconsciously arranging data according to the immediate needs of the situation. There is the concomitant feeling that the object discovers itself, or, that like Goethe (1970), the feeling of being an unconscious instrument rather than the agent. This is dangerous if universally applied without recourse to rigorous appraisal or to situations which are unsuitable.

This kind of intuition is not a substitute for reason where that should apply but should occur when existing ideas and concepts have to be broken and new ideas and concepts are derived from accumulated experience deeply reasoned and pondered upon. "It is not in opposition to reason" Whitehead (1959) but is beyond the edge of rational thought while dependent on reason to articulate, develop and appraise its harmonious effectiveness. This kind of intuition therefore is not the primitive perception of Russell's definition but "mental working at higher levels" Whitehead (1959) and requires "prolonged reflection".

Such a view, if left at this juncture, would be dangerous, if the other characteristics of this kind of intuition were not stated. There are possible undesirable resultants from this power, both related to each other. These are an inability to apply or explain the intuitive result and an ability to be in a self-deceiving certainty of the rightness of the intuition. These require further elaboration. Concerning the first undesirable characteristic, it is seen that in the other types of intuition there is an immediate knowledge which is not the equivalent of a power to act. Religious intuition does not give the power to work miracles neither does moral intuition give the power to do right or wrong irrespective of the conviction of the recipient. Similarly, intellectual intuition does not guarantee the power to apply the knowledge intuited. One of Jung's (1929) psychological types is a "seeker after possibilities who loses interest as soon as the possibilities have become actualities". The power of implementing the hypothesis requires another ability which requires to be developed along with the intuitive ability. In education this gives rise to the situation where the teacher is unable to discriminate between the inarticulate producer and the wise fool. The first reveals his grasp of his subject by the development of the work and his conclusions but has little ability to reconstruct all the influences on his conclusion. The latter is full of appropriate words and analysis but no matching ability to use or develop the ideas to a detailed conclusion.

The other dangerous outcome of intuitive thinking is the utter certainty and satisfaction which is generated by intuition. Such self deception about the infallibility of the intuitive leap can only be erased by rigorous appraisal against either objective criteria, is relevant, or subjective values to determine the reliability and variety of the intuitive hypothesis. If such examination is not done, the product is unlikely to go beyond the unique stage. The harmony and efficiency will be omitted to result in the bizarre and the cranky. Reason or sensibility will confirm, or confute, develop and control the product of intuition. This requires a language, ambiguous or non-ambiguous, which communicates. This involves describing and in order to describe one is forced to analyse. This second approach must be used even if the inarticulate producer is disinclined to reconstruct, analyse and describe. Such a request could help the architects collaboration with specialists.

Once the hypothesis is made, no matter in what field, the product stands on its own, irrespective of its antecedents and must be tested for its validity and reliability, so that it will become universally accepted. The education then must not only instill the fact that these are two separate episodes of thought but that both must operate on the principle that the intuitive hypothesis is fallible.

The method of testing must be fertile so that it leads to new methods of selection by elimination, rather than a final justification. A discrimination is required according to Whitehead (1959) between what is really intuited and what is more or less fallaciously deduced from the intuition. As a result, the aim should be to make the harmonious whole, yet more harmonious by a polishing process.

There is, therefore, in brief, two types of intellectual intuition. First, the infallible a priori "primitives" and second the fallible conclusion which depends on reasoned knowledge as a necessary prerequisite but is beyond rational deduction or induction and produces a self-convincing aspect of truth which must be realised and tested.

There is considerable danger for the development of the average student if uncontrolled encouragement of the intuitive process is given to him. There is certainly no clear distinguishing action between the interestingly wrong leap or partial truth by the inarticulate designer and an ignorant construction or misleading judgement proceeding from blundering to uncontrolled imagination or unappraised intuition. It would be a relatively simple matter to confine some students to algorithms or problem-solving methods which rely on painstakingly moving from analysis to logical conclusions provided the problem was overwhelmingly subject to objective criteria or there were complete information and knowledge about every aspect of the problem. It has been suggested in this paper that architecture is not wholly a problem-solving situation. Therefore the student must not be confined to this situation. The process of using intuition should be identical to the empirical or trial and error strategy. As it is important to recognise that in this latter strategy the results require to be appraised for error and that the hypothesis contain subjective values, so it is with the intuitive strategy. Both systems have the expectation of fallibility and therefore require rigorous justification. It is therefore essential that when both methods are used in education the student not only learns from his mistakes but to expect and consciously search for them. This can only be done on knowledge gained previously.

If this intuitive behaviour is to be encouraged in certain circumstances what teaching specifics are compatible? Psychology cannot as yet explain the personality variable influencing this behaviour at least in terms of what the teacher requires. This leaves prescriptions such as thorough familiarity with the knowledge involved. Pasternak (1959) claims that "the most striking dicoveries are made when the artist is so full of his subject that it gives him no time to think". It is difficult in the learning situation to reach that situation. In architectural engineering the intuition would have to be used only with such structures as simply supported columns and beams which the student has had experience in daily life rather than the complex structures of which he is learning at University.

The operator for this dangerous but rapid judgement and synthesis requires room to manoeuvre in the problem which is therefore not a rigid problem. If this is combined with self direction and freedom to make mistakes, the project type study becomes relevant. However it is difficult to convince staff or students to regard mistakes as potential truths requiring development, polishing and selection. Therefore it would be essential to create a situation where the staff are seen to make guesses. The staff cannot opt out of this process. This faculty of making intelligent guesses and analysing the result could also be linked to the practice of estimating how much information is required before a decision can be reached and a balancing of the risks involved in coming to a decision at any particular juncture. The antithesis of the trial and error process occurs when formal proofs or rational reconstructions are made of a solution. Unlike reason, intuition cannot communicate its derivations and in order to provide an elegant method of reaching a conclusion, a rational reconstruction of the grouping and fumbling processes is given by the teacher. This elegant proof is, in fact, a logical skeleton of the procedure for testing rather than for discovery. Wertheimer (1961) has several instances of this in "Productive Thinking". Popper (1959) points out the difference between this rational reconstruction and the process of stumbling on a hypothesis. Koestler (1964) has also shown how great scientists have irrationally groped forward to solution. The somewhat glamorous formal proofs or reconstruction of how decisions one arrived at should, at times, be substantiated by the teachers working through a problem for the first time in front of the class. A formidable proposal but this procedure was highly regarded by students of Dewey (Highet 1965).

Freedom of manoeuvre, freedom to make guesses or mistakes are all elements of play. This kind of play is best seen in artists where it is a form of experimentation. This allows the artist to have intimate contact with his chosen material (words, clay, paint, sounds or whatever) so that not only can relationships be tested but collaborative contact with the unexpected can be obtained. Such a contact will allow the necessary kind of empathy and relates strongly to associations and connections of elements both mentioned previously. Such 'play' has the paradoxical nature that links freedom and experiment with a disciplined restraint by rules derived from the tension and conflicts of the various parts of the solution. This is the same kind of discipline that occurs in science, where the selection of certain key facts or the technique of development impose restraints as well as inject a vitality and direction. In technology this can be seen when the requirements of the chosen material take over the structure of the form.

Bruner (1960) is one of the few in education who has dared to give prescriptions. He suggests the teaching of the specific knowledge must make clear its context in the broader fundamental structure of knowledge. Comparison of intuitive thinking in other fields of knowledge such as physics, mathematics and history, all of which, let it be noted, follow the intuitive leap with a rigorous analysis. Mackinnon (1961) has a related suggestion when he requires the teacher "to search for common principles, in terms of which facts from quite different domains of knowledge can be related."

Bruner goes on further to suggest the use of general heuristic rules such as analogy, symmetry, examination of limiting conditions, and visualising the solution without falling into the proverbial affliction of the centipede.

Medawar (1969) in arguing for the importance of intuition in scientific method, considers the faculty of analogy - i.e. "a real or apparent structural similarity between two or more schemes of ideas regardless of what the ideas are about" - as part of the creative imagination. Koestler in 'Act of Creation' (1961) is making the same point when he compares the structure of a witticism with the forming of a hypothesis for an ingenious solution.

The difficulty is to have a curriculum which allows such opportunities for intuitive thought, while the student is still learning the basic knowledge with which to make a rigorous analysis.

4.4 Technical Project

From the conclusions of the other previous sections there have emerged some features which teaching methods for structures should possess. Features such as searching in a wide field for a solution to a problem which cannot be defined completely at the start, evaluating and changing priorities, communicating ideas and asking productive questions of specialists. The accepted teaching method which encourages divergent ways of finding and using facts so that it contributes to the architect's imagination is the project method. This is the accepted media for developing design abilities because it allows the student to organise, direct and monitor a large part of his studying as well as harness his motivation. Such a project is regarded as part learning, part examination. Design projects encourage the student to combine knowledge acquired from the specialist staff. It seems desirable, therefore, to use the design project as a vehicle for learning specialist subjects such as structures, especially when that knowledge will be directly transferred to the design. The design project is not however, unanimously regarded as suitable as the sole vehicle for acquiring knowledge of structures. It has been found that the student is so much concerned with getting results in terms of design that he takes unkindly to continually being diverted from his main object in order to learn a package of complex specialist knowledge. Programmed learning which is to be discussed later could provide a device where students could at various times during the design process study a particular detail of a specialist subject. If the teaching of a specialism is to be given solely through the design project, the teacher would be repeating the same material to many small groups in a short space of time. This undoubtedly would reduce the teacher's efficiency and motivation. Another objection to using the design project as the sole vehicle for the total learning of structures is that the student would be inclined to use the specialist staff to provide an answer rather than have the necessary dialogue which demands previous knowledge. Such digression to learn very specialised knowledge is desirable during design but it could be regarded as unreasonable to demand that the student stop and start his design process to the extent of learning basic technical material. Moreover some designs may ask only for the most elementary structural knowledge and therefore it is possible that some students would not obtain the necessary minimum knowledge.

While the design project and the acquisition of basic theories are only part of the teaching strategy for students another tactic is required. It is suggested that a technical project should be given after the acquisition of a certain amount of general knowledge in structures and other technical subjects. The kind of project which would have the chracteristic of the design project but emphasise the dynamic connection between various technical knowledge. Such a scheme was started by the author in 1962 as part of the curriculum for structures and eventually was used for all technical subjects. The arrangements have been modified as a result of the experience gained and from 1970-73, the arrangements have been as follows:- The subjects are chosen by the students provided the subjects are of a technical nature connected with architecture and are such that the student has not had previous instruction nor can the problem posed be solved from one interview with the appropriate specialist. A section of the project must be of a practical nature such as the construction of a full scale solution or a working apparatus to test the data. This latter condition eliminates some of the more obtuse subjects. The subjects can be vetoed by the staff if the subjects are considered to be too generalised or too complex for the available six weeks duration. Strong efforts are made to preserve the freedom of choice since one of the conclusions of the section on creativity was that to identify the problem or need where others had failed to do so was part of the creative process. Some of the subjects chosen have been:-

(a) construction and development of a water analogue to show wind effects in architectural projects.

(b) pneumatic structures

(c) geometry in structural systems

(d) housing for 'Disaster Areas'

(e) Ferrocement

(f) lessons for housing construction from the construction of prefabricated ships

(g) effect of vibrations on cathedrals

4.5 Organisation

The projects are done by groups of students varying in number between 2 and 5. Experience has shown a marked diminution in the success of the projects if the numbers are larger or smaller. Interim meetings at regular intervals take place with the supervisor to define feasible units of work and it is suggested that staff's advice need not necessarily be acted upon but that justification must be made in the final report and in the oral presentation. Unlikely though it may appear this has happened on several occasions with profitable results for both staff and student. In addition there are seminars made up of one member from each group where he discusses the planning strategy of his group for the following week along with a brief report on past work. The attendance of the seminars is on a rotating basis to ensure that all members of the group attend at least one meeting. As well as developing communication skills such meetings encourage productive criticism from the students and the temporarily coalition of several groups to search for common knowledge. Such interim meetings can also correct insufficient preliminary studies; this generally occurs when more exotic problems are tackled. The staff have to restrain themselves from constantly giving their own ideas, as it is believed in this case to be detrimental to the student's development; there is a close analogy here with school children's homework. Explicitly correcting mistakes should be avoided until the completion unless they are very dangerous. Information should only be given at the specific request of the student and confirmed specifically to the questions asked without elaboration. This behaviour is not easy for the teacher but if the student's responsibility for his own learning is to be nurtured then the role of the teacher is similar to that in the group discussion.

4.6 Inter-disciplinary Projects

In 1970/71 a further development was tried when 5 inter-disciplinary groups from 2nd year architecture, 3rd year civil engineering and 3rd year building courses. A group consisted of two members from each discipline. Among the subjects chosen were 'Building on ground liable to movement' and 'Staining of building materials'. All members of staff from these departments felt there were benefits from such a programme, but there were great difficulties in providing sufficient and synchronised time in each curriculum. This teaching device should be continued since it has advantages compared with combined courses for these disciplines. In the inter-disciplinary project each profession is developing its strengths while contributing to the total solution and allowing opportunities for appreciating the varying views of the other professions. Where there is a common course e.g. for architects and engineers, one group is not being stretched in its own particular area of study. The technical project overcomes this.

4.7 Format

The completed project consists of :-

1. Written report with construction of solution
   or apparatus.
2. Demonstration and/or exhibition to remainder
   of class.
3. Short report in any media, other than written,
   to the remainder of the class and the answering
   of questions by the class and staff other than
   their own supervisor.

Written report must contain:-

1. A clear statement of objectives and criteria
   for assessment

2. The solution with relevant evidence and its authority.
3. Alternatives considered and reasons for rejection
4. What could have been achieved in retrospect.
5. Suggestions for furthering or improving the project.

The short report generally contains visual explanations. All members of the group must take part in the oral section and the report is taped so that the students can evaluate their own performance. Some reports, chosen at random, are made on close circuit television for the same purpose. General critiques on the short presentations are made by architects in practice as well as by other professionals accustomed to explaining technical briefs to laymen.

4.8 Project Assessment

Methods of asessing projects vary from the single assessor to a jury of external and/or internal specialists and with or without students. It is not the purpose of this study to test the values of such variations beyond giving one observation. When the assessment is made by a jury of technical staff there is generally agreement on the rank order but not agreement on the absolute marks value, as a result most of the marks are usually within 55% to 65%. The other difficulty is the perennial one of individual assessment in group work. Unless under extreme circumstances which can be identified during the interim meetings or in the final oral presentation, all members of one group obtain equal marks for the technical project. In 1971 the project was linked to conventional examinations by asking the group to provide three questions which when answered would measure adequately the learning achieved. The staff can then choose or adapt such questions for the examination.

For the technical project each student is given a guide to the assessment (see appendix). Briefly there are 4 divisions of criteria - (a) choice of topic (b) solution (c) method of achieving solution and (d) presentation of results. The students and staff together set up any special criteria by which the particular project can be evaluated; this is not necessarily done at the beginning. Up to the present a proportion of the student's performance specifications has been more severe than that of the staff. It is essential that the staff do not give interim assessments once the topic and the criteria are agreed, but of course, the staff have to assess the finished production. Efforts have been made to encourage the students to assess their own and other projects so that they can develop their self monitoring abilities but this has not been as successful as anticipated.

4.9 Conclusion

Some of the desirable qualities deduced from previous chapters are encouraged by the use of such technical projects. Qualities such as the following :- 1. The ability to identify a problem or need which others had not thought existed. This in turn emboldens the student to search for a hypothesis and unusual connection between areas of technical knowledge. An example of this was the suggestion that the staining of the cladding of an office building was due to the combination of the wind flow and a chemical in the mortar. 2. An understanding of the specialists' goals. Many projects entail correspondence and interviews with such specialists as chemists, physicists, salesmen, etc., employed by commercial firms, for example Turner Newall & Co. (asbestos), went to generous lengths to provide information to the students. Objectively measuring any change of attitude is difficult but interviewing and corresponding with such specialists outside the University has revealed the differences in professional attitude, values and aims of the various specialists. This has given the student more confidence in his own particular abilities and values while recognising their limitations in relation to the specific objectives of the specialist.

Another example of the specialists' goals occurred when the project entailed interviewing salesmen in a firm providing mastic joints for windows. This forced the student to ask questions which not only allows him to differentiate between fact and propoganda but directed the student to find out the performance from the material. This in turn has led on numerous occasions, discovering 'no-man's land'where both the architectural profession and commerce are waiting for each other to specify their requirements. Some artificial materials can now be made to a specification, which is a reversal of the craftsman's approach which was to use the material for its intrinsic qualities. 3. The ability to search for facts in a wider area than the conventional, evaluate the authority, essentialness, and the significance of those facts. The technical project can excite the germinal power to develop the acquired facts for a use peculiar to the individual but appropriate for the solution. It has on two occasions led the student to query some of the recommendations of codes of practice and this is felt to be a healthy inquiry. The project appears to activate experiences of the student outside his academic knowledge in the search for solutions. This ability was first noticed when a model was built to demonstrate visually the variations in stresses in a portal frame. The use of apparently unrelated resources within the student obtained from such experiences as hobbies enables him to widen with confidence his area of search. As he has to describe his project to the class this will encourage others to widen their future area of search for a solution.

4. Self-directive learning - the freedom of choice means that in many cases the staff may only have a peripheral knowledge of the subject chosen. This allows the student to observe the staff's attitudes,

assumptions, values and thinking strategies in an area where the staff is not the complete repository of knowledge. This may appear to be a heavy argument against the project, but it allows the more basic abilities rather than the giving of information to be seen by the student. This can on occasions be better than a rational reconstruction of the creative process and is compatible with the conclusions given in the section on 'Intuition'. The self-direction of the students' learning is also in accord with the conclusions of the previous section. Weaker students are however more quickly exposed in their deficiencies and therefore the staff have to provide for them smaller components of study within which the student can organise himself. The benefit of such a project appears to be with the strong groups who can extend themselves to their own limits rather than those of the staff who are considering the class as a whole. Some of the 2nd year groups have attended post-graduate courses at Building Research Stations as part of their project and on their own iniative. An important part of this kind of learning is the feedback obtained by the student and the review mechanism he himself has for checking the success of his learning. If the class is organised in groups, the individual has to defend his judgement and opinions to his peers and to the staff. This involves the student personally and so a higher level of learning is obtained than mere acceptance of authority's declaration of truth. 5. The last quality in the project which concurs with the conclusions reached about creativity is the freedom to make and develop from mistakes. This arises from the principle that until the final oral presentation, the staff correct only the more blatant errors.

The disadvantages, apart from the difficulty in individual assessment where more objective tests are required, are mainly administrative. The wide range of ideas for projects stretches the department resources.

The essential outside aid depends on the goodwill of people outwith the university. Up to the present, valuable assistance has been received but usually cannot be repeated. Material required for the project can often not be readily made available. Time is required to search for and obtain such items. This does not always fit in with the tight schedule of the project. Preliminary meetings a month before the project starts gives some help with this aspect.

4.10 Structural Models

The next three teaching tactics have been used in most architectural schools but adaptations in the light of the preceding discussion have been made and tested on all of them.

The first of these three adaptations was on the design and construction of structural models to withstand specified loads. Following the criticism of the accepted technique of the Bauhaus programme on architectural models the external loads were considerably heavier in relation to the dead weight of the material so that some structural realism was simulated. It is vital that all models should be tested to destruction or alternatively that individual elements should be broken so that the behaviour of the structures is seen and explained. Three typical programmes were -

1. Build a structure in the material described below which will safely carry a circular load of 40 M force (9 lbs) and 210mm (6¾") diameter at a height approximately 600mm (2 ft) above a clear space of 500mm x 250mm (18" x 9").

   The model must stand up to 'normal' loads found in a lecture room - i.e. touching, draught and shaking of table while carrying the load. The model will be tested to destruction unless it is of sufficient architectural merit. The structure must be rigid, economical in cost, and construction, and have a high strength/weight ratio. State the approximate weight of the material used.

Materials for the Structure

1. Gypsum; 2. String; 3. Cartridge paper or thin cardboard; 4. Balsa wood ($\frac{1}{4}$" x $\frac{1}{8}$" strips maximum size).

Choose one or two materials (of two chosen, string or paper is a compulsory material).

2. Construct a structure of any height, width or length, made from balsa wood and thread. No two rigid members must touch. The rigid members must essentially be straight and they may be connected indirectly with thread. The completed structure must be stable as well as pleasing to the eye.

3. Construct a support for three or more weights ranging from 2 lbs to 6 lbs suspended anywhere from 65mm (25 ins) to 1 metre above ground level. Total minimum weight to be supported is 15 lbs.

Material for the structure is to be limited to the following:-

(i) Blasa wood, maximum size 3.2mm x 3.2mm.

If two members are glued together to form a larger cross-section the maximum dimension of 3.2mm should not be exceeded. Thread may be used.

(ii)Gypsum with thread.

The model will be tested to destruction.

This allows abstract laws to be seen but more important it allows intuitive hypothesis followed by rigorous confirmation. It allows the student to bring in subjective values in the choice of his solution and can allow facts to contribute towards the imagination.

4.11 Case Studies

The next method adapted was the case study of a building. Before the learning of structural theories and immediately after group lectures by the specialist staff who showed the relevance and dynamic relationship of their subjects to architecture, the class was divided into groups of 8/10 students each supervised by a member of the technical staff. The programme is given in the appendix, and in its final form was the amalgam of the opinions of all the technical staff. The initial framework and co-ordination was done by the author. The building chosen was a church since this incorporates relative simplicity of structure and other technical aspects with a high degree of artistic and emotional content. In brief the objectives were that the student, with prompts, should first identify the various technical systems and second, discover the reasons for the choice of these systems in terms of material, physical and mental satisfaction of the user and thirdly the influence on the general form of the building and the inter-relations of the technical determinants of the architecture. All students were asked questions by all the technical staff and then each staff leader directed the students to study a particular aspect of the building. The communications of the final report had to be mainly by graphics and oral description to the remainder of the class. One condition was regarded as crucial: value judgements by the student had to be excluded. Midway through the programme the students discussed the building with the minister and the architect who showed them the prototype and further developments of the architectural ideas. Such case studies, not necessarily on whole buildings, could be given with advantage to all classes of students since above all it demonstrates the inter-relations of all the technical system in whole and in detail. In complex systems there is the inclination to over-simplify or idealise the pattern by which the parts are fitted together. This has its place in the initial understanding but if too much stress is laid on over elaborate abstract classification then the reality and practicability are lost in the students' design. The elements of the building are important but it is the evolving system as a whole which should matter most.

4.12 Use of Consultants

The last method to be adapted was the teaching method involving the students' use of consultants' advice for the design project. The discussion in the Review of Literature suggested that 'structures' was a basic ordering device and a fertile source of architectural ideas. To be so it is necessary to develop a structural system or element in coherence with the other architectural components. This entails evaluating priorities, conflicts and affinities. For all but the most simple of structural systems or elements the student requires specialist advice in such a manner that it encourages the asking of productive questions in a dialogue situation.

The conventional requirement for the structures sections in a design project is that the student adequately explains his final structural intention by drawings which show the suggested structural layout indicating the various loads and nominal sizes of the principal structural members. The drawings are accompanied by calculations or a qualitative appreciation of the stability in strength of the structures. Further work showing that the structural proposals are physically realisable, particularly showing typical connections, details and the sequence of construction is often asked. As a result of the previous section it is suggested that some rational reconstruction of the design process should be required. Even if intuition cannot describe its antecedents it has been argued that rigorous confirmation and polishing is required. As a result it is felt that the following should be required from the design project.

How and why was the structure modified during the process? To demonstrate this a three dimensional 1/500 scale model or drawing should show the major changes along with a statement giving the priorities in relation to such basic items as the architectural function, space and circulation. The basis for choosing the 'structures' should be presented emphasising which qualities influenced other components and vice versa. This implies that alternatives were considered and the basis for choosing and rejecting the system, particularly the influences on design should be given. The other requirement should be that the student should indicate where there might be maintenance difficulties or disfigurements, cracks, staining or deformation, their consequences and how they were overcome and to what extent.

The possible methods of obtaining consultant advice are from consulting engineers in practice, staff or engineering students. Each system has had at least two trials and the advantages and disadvantages of each are now given.

Where the consultants in practice were senior partners there was the advantage of obtaining experienced advice in addition to the latest thoughts on the economics of the system. The disadvantages were of two kinds - administrative and academic - there were administrative difficulties of synchronising a time convenient to consultants and students and in obtaining sufficient numbers of consultants. The Architectural Association have a sound scheme based on using such consultants but even with the London availability, a large number of consultants are required to keep the ratio of 1.15 for consultants/ students. More important than the administrative difficulties is that when a senior engineer is consulted the student tends to be discouraged from maintaining a dialogue among equals and as a result does not use the structure as a generator but as an exotic substitute for design. In 1968 and 1969 newly qualified consulting engineers were used. It was felt that this allowed a good training for such an engineer, allowed a more profitable dialogue to take place and still have the advantage of up to date economic experience. This worked well and on occasion too well because the juniors involved the seniors to the detriment of other necessary office work. The synchronising of time could still be difficult when emergencies arose in the office. This system relied on the goodwill of a number of offices which was readily given so long as it did not interfere too much with the office work and this it did occasionally.

In 1970, 71 and 72, final year engineering students were used even although their theoretical and practical knowledge was at first considered to be less than necessary for some design projects. The final arrangements which tried to overcome some of the deficiencies were as follows:- Four 3rd year engineering students helped one architectural student. It was important that the engineers obtained academic credit for their work so each had to make a written report. Some of the structures were more complex than could be dealt with by the average student so a hierarchy of responsibility was laid down using the consultants office as a model. Four of the best students were used as consultants by the engineers for complex questions, and if they were unable to give suggestions they went to two members of staff so that only the more complex problems went up the seniority tree. The original students were still responsible for discussing the scheme with the architect. Part of the report had to be concerned with minutes of the various meetings. The advantages were mainly in the education of both sets of students rather than in the finished product. The collaborative dialogue could take place where no experience gap will inhibit. Such disadvantages were that the architects tended to leave all calculation to the engineer who was in any case happier to provide only calculation. This disadvantage could easily be erased. There were certain difficulties in matching curriculum time especially if the architect wanted instant help. The main disadvantage was that the average engineering student was not au fait with the latest or most economic structural system.

The most used method of consultation in design projects is by the staff who can, amongst other things, ensure that the objectives are carried out. As a result of the discussion it is felt for the architectural/engineering tutors to demonstrate the kind of dialogue which takes place. This should not be a carefully rehearsed drama but the real searching for and testing of ideas. Those ideas should be realistically shown in front of and with the student on his own design. Tossing ideas about, most of which will be rejected, is a necessary tactic in design project. This tactic should be done before external consultants are used.

Four teaching tactics have been described, all of which have some of the qualities thought desirable in the creativity process. There is still a considerable problem in teaching basic material and none of the methods given in this chapter are suitable. The next chapter will consider one method for such learning.

4.13 References

All the references used in this chapter are included in the references for Chapter 3 (section 3.17).

PROGRAMMED LEARNING OF STRUCTURAL KNOWLEDGE Chapter 5

5.1 Introduction

This section deals with the hypothesis that programmed learning (to be written as P.L. for brevity) is appropriate and practicable to teach basic structural theories to architectural students. It is sufficient to describe P.L. as a process for the systematic design of learning sequences. The characteristics of P.L. have been described in texts including Carmichael (1968-1972). The programmes used are the author's programmes, which were produced for the R.I.B.A., who for that purpose granted a Research Fellowship in 1967. The chapter will be divided into sections dealing with review and discussion of literature on the subject, the appropriateness of P.L. for teaching structural knowledge to architectural students and the results of tests on possible formats for such a course.

5.2 Review of Literature

There is abundant evidence that programmed instruction is effective in primary and secondary schools, Hartley (1966) and Leedham (1967). Industry and Armed Services have also used this technique and found it efficient for their particular learning objectives (Bajpaie & Leedham 1970). Cavanagh and Jones (1967) however, reported that in 1967 only eight British universities were using programmed learning mainly in the fields of mathematics, science, medicine, engineering and education; the writer has constructed and used programmed learning material as part of the instruction in 1966. By 1969 Leith (1969) had reported that there was programmed learning in 19 universities and there were research centres in 12 universities.

All the studies reported better examination results and with the exception of Harden Dunn et al (1969) the programmed instruction occupied less than the equivalent lecture and tutorial system. Glynn (1965), Hoare & Inglis (1965) reported that the lower ability students gained most, but Croxton & Martin (1965) and Hogg (1966) reported that some of those students lost their motive for learning the subject. All the studies with the exception of Hartley (1968) preferred P.L. to lectures. Mills & Martin (1968) claimed that P.L. was only economical for large numbers since it took some time to prepare and to administer.

A table showing the type of pacing and whether P.L. was used to augment or replace lectures is contained within the appendix.

Enthusiasts for programming insist that a well validated programme will achieve its objectives independent of other instruction. Reports of work in universities by Harden Dunn et al (1969) and Attiyeh, Lumsden et al (1969) confirm this. The alternative view is that P.L. should be used in a framework of lectures and tutorials etc. That view is given for educational fields outside universities by Deterline (1962) and Austwick (1964). There is therefore a conflict between those insisting that P.L. should be used as the sole tactic and those who wish to use it as a component in a system. It should be noted that where the technique was successful as the sole tactic, the subjects were medicine and economics, which are relatively self-contained. Architectural science may not be amenable to such a compartmental approach if the arguments of Chapters 1 and 2 are heeded where transfer and synthesis of knowledge are of primary concern.

5.3 Programmed Learning and Seminars

A technique recognised as increasing the transferability of acquired knowledge is that of the seminar. This is regarded as an efficient tool for refining, qualifying and elaborating acquired knowledge. It would appear logical to combine P.L. and seminars since the merits of both would appear to be complementary. However two reports appear to contradict. A report (to be published) by O'Brien and Jackson suggests that seminars should be used for efficiency in attaining their objectives which include teaching the essential professional skill of working within groups, as well as the merits mentioned above. The opposite view is that of Stones (1969) on the use in a university of P.L. combined with seminars. All groups had a programme but some had seminars and others did not. The seminars were unstructured and were intended to put the programme into a general educational context and to go in greater depth with questions raised by the programme. Stones observed two main elements in the seminar (a) concentration on the minutiae of programme and (b) far ranging discussions. All students worked through the programme in their own time and took responsibility for further reading for which they were issued a book list. Stones found no significant difference in attitude or learning between those students who had seminars with the programme and those who did not have seminars. He admits that there may be learning from small group discussions which neither the post test nor the attitude scale can measure, and this is an important proviso. He also claims that while the students accepted the programme without seminars they do not necessarily prefer a teaching system without seminars. It would appear however that the use of seminars by Stones in this test had more limited objectives than the conventional use of seminars.

5.4 Programmed Learning and the Student

While the educational merits of an instructional technique can be checked against the learning objectives and the transferability of the knowledge, the resources of the student is as important a constituent in the learning process. Eraut (1969) has defined any learning system as human and material resources enabling students with one set of characteristics (input) to emerge with another set of characteristics (output) together with the relationships between these resources and the interaction of students with these resources. This brings in another parameter in testing a potential serviceable system - that of the student's intellectual ability and personality, both of which strongly influence learning and possibly the choice of individual teaching methods. It should also be possible to investigate the attitude of students towards Programmed Learning. The ultimate aim of any teaching system would be to provide for individual approach in learning.

5.5. Programmed Learning and Computers

It has been claimed by Stolorow (1969) that computer assisted instruction - C.A.I. - has this individual approach. As C.A.I. is based on the 'branching' type of programmed instruction, and with the unique abilities of the computer, C.A.I. can extend and integrate the qualities of programmed learning so that it is equipped for personal instruction. The use of programmed learning at the moment, whether branching or linear, accommodates all individual difference in learning patterns within one text. C.A.I. presents a branching programme simultaneously to a group of students - 16 in number. On evaluating a group of responses the complete programme decides what material can be presented next so that eventually each student may be working on a completely different set of instruction material. In addition a realistic and complex problem can be set with the students making decisions on given variables in the problem. These decisions cause changes in the original values which must then be revaluated for subsequent decisions. Such a technique is relevant to the design process but evidence has not been found that C.A.I. is being used in architectural schools although there are examples in other fields. Dunn & Holroyd (1968) quote 21 authors on the various uses of C.A.I.; a typical use of C.A.I. is made by Hamer & Romiszowski (1969) who ran an individualised crash course in mathematics with a programmed machine supported by tutorials and controlled by a computer managed diagnostic /

prescription system. The computer programme marked the diagnostic test, classified errors and produced an individual study prescription for every student. In the majority of reports on C.A.I. there are the claims that the computer with its large store and flexibility of modes of presentation can accommodate individual differences, is more adaptive in technique, grades the process of students, acts as a decision maker of learning strategies and provides an analysis of its own teaching material after the teacher has decided on teaching and evaluation strategies. Such a cornucopia may well astound and excite but unfortunately at the moment the high cost of the equipment cannot justify its use in teaching the subject under observation.

Several questions have arisen from this review. It is seen that P.L. could be effective but there is considerable difference in the objectives of the subjects reviewed and the teaching of structures. It remains to be seen whether P.L. is appropriate for the latter subject and as the number of students under test will be about 30-40, the question of whether programmed learning is appropriate only for large numbers might be answered. The use of programmed learning and seminars will not be examined since one of the reports concerned architectural education. Another question which will not be examined is the use of C.A.I., but the related question of whether students' abilities or personalities are compatible with P.L. will be examined. There was also a report that some students lost their motive for learning and this must be investigated. A question arose whether P.L. should be the sole tactic, previous arguments have indicated that this cannot be so in this context of transferring the knowledge to design.

Two main features of architectural education can be identified as (a) learning of scientific and technical knowledge and (b) the synthesising of that knowledge for an architectural solution.

The potential of programmed learning appears to be appropriate for the learning of scientific and technical knowledge required by an architect.

The first feature is scientific in nature and therefore is concerned with generalised theories, but already some thought to the transfer of such knowledge to design must be given in the presentation of the content. The basic aim is to give the student a vocabulary of structural behaviour which is in accord with the objectives stated in chapter two.

5.6 Appropriateness of Programmed Learning

To test the appropriateness of P.L. in this context the following will be done:-

1. A comparison in terms of acquisition of knowledge and transfer of knowledge will be made on the examination results of students who have received P.L. and those who have not.
2. An examination of the students' attitude towards P.L. and a test on whether the students' abilities or personalities can be matched with teaching methods.
3. An examination of the teacher's role if P.L. is used.
4. An examination of possible formats for such a P.L. course. This will contain two tests, the first on audio tape version and the second on the use of mathematics or visual methods to communicate the theories. This part will end with a comparison between texts based on the gestalt theories and behaviourists theories.

The programmed text used was made by the author and consisted of 155 foolscap pages and the version used in the experiment was constructed after 5 drafts had been made and given to 400 architectural students from Heriot Watt University, University of Virginia and California State Polytechnic.

Details of the modifications in the programme texts are given in section 5.14. The immediate objectives of the programme were that the students were able to -

(1) Describe the manner in which bending deflection buckling and eccentric loads can best be resisted by economical and efficient forms or arrangement of structural systems, of timber, steel or brick.

(2) Given a structural failure caused by bending, deflection, buckling or combined bending and axial load, the student is able to suggest how it could have been avoided.

(3) Dimension structural members subjected to the above forces.

(4) Form adequate design decisions involving the behaviour of those structural elements and systems and discriminate between varying possible structural forms. This under conditions where there is not one correct and finally revealed solution but several different solutions all equally satisfying the architectural conditions.

These objectives can be listed in terms of Bloom's (1956) categories:-

1.12 Knowledge of specific facts
1.21 Knowledge of conventions
1.23 Knowledge of classifications and categories
1.25 Knowledge of methodology
1.31 Knowledge of principles and generalisations
1.32 Knowledge of theories and structures
2.10 Translation
2.20 Interpretation

2.30 Extrapolation

3.00 Application

The prerequisite knowledge required is gained in the department and was not obtained from secondary education. The examination questions were of conventional examination standard and examples are given in the appendix.

5.7 Test Results

The 1st year examination results are as follows (P.L. was used from 1968 to 1970). For better comparison the raw marks were standardised to a mean of 50% and a deviation of 10%

	1965/6	1966/7	1967/8	1968/9	1969/70	1970/1
No. of students	38	40	39	32	34	36
Raw average mark	59	60	59	65	66	57
Raw standard Dev.	11.9	10.4	10.1	12.3	12.4	10.5

The standardised marks of these classes were then statistically compared using Pearson's correlation coefficients (Fisher 1946) The results are summarised as follows:-

Conventional Teaching -

	non P.L.			P.L.	
Years	1965/6	1966/7	1967/8	1968/9	1969/70
1965/6 non P.L.					
1966/7 non P.L.	.N.S. (+1.0)				
1967/8 non P.L.	N.S. (-0.47)	N.S. (+1.47)			
1968/9 - P.L. -	S.D. (+6.35)	S.D. (+5.53)	S.D. (+7.0)		
1969/70 P.L. -	S.D. (+7.85)	S.D. (+6.85)	S.D. (+8.32)	N.S. (+1.32)	

N.S. represents no significant difference

S.D. represents significant difference at 95% level, the positive sign indicates results are significantly better.

These results seem satisfactory in that the P.L. results were significantly better than previous years and also correlated with each other. In addition the conventional teachingexamination correlated with each other. A further check was made when in 1968/69 the P.L. results were compared with the results in examination in 'construction', building science and the conventional teaching of structures previous to the P.L. sessions. The results are summarised:-

	Construction	Building Science	1st Year Structure
P.L.	S.D. (+2.19)	S.D. (+2.0)	S.D. (+2.53)
Construction		N.S. (-1.64)	N.S. (-0.58)
Building Science			N.S. (+0.85)

N.S. represents no significant difference

S.D. represents significant difference at 95% level, the positive sign indicates results are significantly better.

This too gave results which indicated that P.L. gave significantly better results than in the other subjects including another structures examination given by conventional teaching previous to Programmed Learning sessions. It is also seen that there is no significant difference between the examinations of building science, construction and structures.

The above results indicated that P.L. was a satisfactory teaching tactic for architectural students learning the basic structural theories if the results of conventional examination are the criteria. It has been previously indicated that this is not the entire criteria but part of the criteria will be concerned with initial basic knowledge. Whether this acquired knowledge can be readily transferred will be examined later.

5.7 Programmed Learning and Theoretical Content

The next part is a general discussion on the use of programmed material for learning theoretical content such as structural theories. There have been objections that the aims of P.L. are limited. To plan a learning sequence in a complex discipline is a matter of specifying and putting in purposeful sequence the relevant capabilities within the discipline. Capabilities which appear early in the sequence and which cannot be omitted, such as knowledge of concepts and principles, will have local objectives. This does not mean that they are limited but are realistic within the sequence. For example learning about the collapse mechanisms of structures has a limited objective before it is applied to a design problem.

There is a disagreement about the use of P.L. for content principles. It is agreed that because the basic theory has sprung from generalisations and analogies derived from animal experiments, there is a tendency to regard the rat in Skinner's box as a paradigm of man. It is claimed that the use of language, abstract and symbolic thought, the forming of ideals and the imaginative hypothesis are abilities unique to humans, therefore the limitations of the human mind must be significantly different from those of the rat or dog.

The behaviourists argue there is a substantial body of research on humans to justify their theories particularly with certain contingencies of reinforcement such as operant conditioning, and that animal experiments merely show helpful similarities and provide useful hypothesis. If the hypothesis is verified then the source of the hypothesis is irrelevant.

Opponents of the behaviourist school also argue that by insisting that the output of gained knowledge is mainly the result of the input stimulus, we are ignoring the possibility and relative importance of transitional thought processes or predispositions to behave in a certain way. Its present lack of conciseness in behavioural terms ought not to mean a total evasion of its value in educational terms.

The importance of such transitional thought processes has been part of the perennial debate between the importance in education of (a) environment or external circumstances and (b) hereditary or innate character, capacity or inclination.

The stimulus/response theory is a development of empiricists such as Hume (1971), who deny the value of innate intermediary processes of the mind. A contrary view is taken by those philosophers who believe that there are faculties of the mind which determine the organisation of knowledge, and although Leibnitz (1966) assumed that the principles involved could be made conscious, most of that school thought they were as inexpressible as the principles which determine visual preception. This argument is contained in Chomsky (1967) criticism of Skinner's learning theory when applied to the learning of language. Chomsky postulates that there is such a mental phenomenon mediating between the input and the resulting behaviour of speaking and writing. This he argues cannot be explained on the stimulus/response model and therefore any theories of learning based on this model can only be applied to human learning in a superficial way. This mediating process may be radically different for other cognitive processes, but it is unlikely.

It will be prudent to closely observe this controversy in learning languages. Analogies have always been drawn between the technical fundamentals required for architectural design and the grammar of language required for the essay. Such a description is more than merely metaphorical. There are basic similarities between creativity in architecture and in language, both are concerned with communication and value judgement. Those who communicate well in both media have the ability to perceive original and exciting relationships between hitherto unconnected knowledge.

5.8 Conclusion

The comparison of the structures examination results of two classes who acquired knowledge by Programmed Learning to three classes who received a conventional course has shown that P.L. is significantly better in achieving examination results. The comparison, after standardisation of marks, between P.L. structures, non P.L. structures, construction and building science confirm the superiority of P.L. in this context. This assumes that the five examinations are similar and valid for testing such knowledge and that such knowledge is required for architectural studies. All the marks were standardised which according to Ebel (1965) allows such comparison to be made. Every effort was made to have all the examinations similar in quality and comparisons were made with the accepted examination in the subject both in U.K. and in U.S.A. The subject content was basic and a discussion followed on the merits of using P.L. for all such theoretical content. Doubt arose whether Programmed Learning was appropriate for the transferring of theoretical knowledge to the design and the next section will examine this.

5.9 Programmed Learning and Transfer

While P.L. is satisfactory for acquiring basic structural knowledge, the previous sections have indicated that as much importance should be given to the transfer of that knowledge to the design. Any structural knowledge however considerable, must not remain inert, it requires to be used alongside the other architectural subjects. While it helps to learn the initial principles of the subject, it should not be kept in separate compartments no matter how well furnished.

To examine whether the acquisition of structural knowledge is the only requirement for transfer, comparisons were made of the structural examination marks and design assessment of three classes, two of which learnt by P.L., the other by conventional teaching. Statistical comparisons were made for correlation and for significant differences (Fisher 1946). The following are the results:-

Correlation Matrix

Programmed Year A 1969/72

	Structure 1	Design 2	Design 3	Design 4
Structure 1	1	0.415	0.421	0.224
Design 2		1	-0.22	-0.473
Design 3			1	0.487
Design 4				1

Programmed Year B 1971/73

	Structure 1	Design 2	Design 3	Design 4
Structure 1	1	0.379	0.638	nil
Design 2		1	0.738	nil
Design 3			1	nil

Non Programmed Year C 1968/71

	Structure 1	Design 2	Design 3	Design 4
Structure 1	1	0.15	0.223	0.19
Design 2		1	0.610	0.467
Design 3			1	0.281
Design 4				1

There appears to be a correlation between the structures and design assessment of Class B. Further statistical work given in the appendix indicates that although the correlation showed that those who had a high achievement in Structures 1, also did so in Design 3 and similarly with the weaker students, there was no significant difference in the achievement level of Class B compared with the other two. Such a result could be explained by a different kind of student in Class B. It is noted that in Class B 70% had Higher Mathematics or equivalent, compared with 50% for Class A and C and this can explain the correlation.

5.10 Discussion on Transfer

Skinner (1969) and Gagne (1966) argue that in learning the knowledge for transfer, the type of instruction must be adopted for the purpose. Gagne emphasises the need for broadening the knowledge under which ideas can be discriminating. Skinner suggests that knowledge should be transmitted in a form which can be easily transferred to another situation. Realising that more positive direction is required he suggests that we provide highly reinforcing contingencies and instances some possibilities which occasionally lose all explanatory force because of the wide range of examples. He also suggests that teachers arrange instructional contingencies for originality and teach students to arrange environments "which maximise the probability of original response", such as arbitrarily rearranging words. It is suggested that this is based on a limited conception of creativity. Skinner goes on to state that the student should state the propositions in several different ways and that the student is in full possession of the "contribution of earlier thinking." There must be however some scepticism when he claims that "there is no danger that teaching facts will overload the student's mind."

These statements, some of which beg the question, are not entirely helpful and his arguments are not helped when he attacks the conventional teaching system with loaded statements such as "by assigning more than one student can possibly read with care, we avoid any danger of too rigid a repertoire".

Skinner's main contention is that programmed instruction will develop self reliance and self management in the student, as well as being a powerful tool in the thorough learning of organised knowledge: and this can <u>lead</u> to creativity

He advises us to trace creativity to the manipulative variables but when he claims that one of the most important of these is quantity of ideas, there must be considerable argument.

There is another doubt about P.L. and creative attitudes. There may be residual effects of P.L. which may inhibit creative competence. Characteristics such as channelled responses might lead to regimental conformity of thought which could constrict creative competence.

Gagne (1969) provides evidence that the general effect of learning concepts and principles frees the individual from control by specific stimuli so that he is able to transfer his knowledge in any situation.

Gagne argues that to establish or arouse the learning of such topics the properties of stimulus/response must always be present in the mode of instruction. This buttresses the claim that programmed learning can directly and efficiently teach such topics even those concerned with creativity. Koestler (1961) is in opposition to this view. He believes there is a strong element of regimentation which is anaethma to creativity. Skinner denies the accusation of regimentation since (a) the reinforcement used is positive and not aversive, and (b) "that teaching well existing knowledge will give freedom and self reliance to the individual". The latter statement, perhaps seems again to beg the question. The behaviourists go further and claim that it is the present educational practice of rigid syllabi and examinations which are sternly regimental, and which is forgotten in the argument.

Research reports can be quoted much in the same way as quotations from the Scriptures were in theological disputes. Torrance (1965), reported that highly creative children expressed a strong dislike for programmed learning. Stolorow (1964) on the other hand, found significant correlations between originality scores and scores from his programmed instruction on mathematics, logic and statistics. Torrance reports that Stolorow's programme emphasised a hypothesising approach that builds specific but multiple associations to a stimulus and this seems a highly important emphasis.

It may be that this is yet another example of Russell's scathing observation that "all the animals that have been carefully observed have behaved so as to confirm the philosophy in what the observer believed before the observation began". Russell goes shatteringly further than this when he accuses the studied animals of displaying the national characteristics of the observer - American rats rush about with an incredible display of hustle and pep, while German rats sit still and at least evolve the situation out of their inner consciousness". In an uncharacteristic chauvinistic vein he does not reveal the predilections of British rats.

Reluctant to believe that this demolishes the concept of testing but only points out the danger, the technique of programmed learning will be checked for any qualities which may hinder the development of creative competence in the design process. It could be added that other techniques for transmitting knowledge should also suffer the same test.

One of the undesirable residual qualities in programmed learning may be that it gives too much 'Svengali' power to the teacher if the programmed learning fulfils its objectives so efficiently as it claims. Not only educationalists but churchmen and parents have always recognised their limited and uncertain power to make the child the image of the instructor or to create complete conditions within which men think.

There may be a Luddite feeling to smash the machine, a more rational result is to have an inquiry into the objectives of the particular educational system. This has been the general and welcome reaction by those who have used the technique not only because the technique demands it, but also as a result of the increased achievement by the students. The use of programmes moreover depends on a sequence of steps of reasoning within a limited area of knowledge with each step being voluntarily questioned so that it is impossible for the core of the mind to be possessed in anything like the manner which characterises political trials or medieval witch-hunts.

5.10 Programmed Learning and Creativity

As there are schools of architecture there must be a conviction that creativity can be taught. A number of research studies in other fields agree with this contention. Studies such as Maltzman et al (1959), Guilford (1962), Parnes et al (1963) and Torrance (1964) suggest some positive results can be obtained. The discussion on the teaching methods of 'science' and 'art' indicate that different methods were used for each branch of learning. It has been claimed by some that programmed material is successful in teaching creativity e.g. Covington & Crutchfield (1965). This seems surprising in view of its dominant characteristic of meticulously guided control of students' thought processes by carefully regulated steps all leading to the same conclusion, and a high degree of pre-structuring of material. This seems to be inconsistent with the requirements of creativity. Any teaching device used in architectural design must be able to respond and evaluate the hypothesis put forward by the student. The ability to tolerate ambiguity and lack of closure while progressing to the architectural solution is not compatible with the idea of programmed learning. Skinner (1959) agrees mainly because of his mechanistic approach to creativity, and also because he believes "that original thought cannot be taught by its very definition".

Some authors do contend that programmed learning can teach creativity but when claims such as Landa's (1969) are examined it is only the platitudes of self administration and self pacing of learning which are regarded as suitable. Covington and Crotchfield (1965) claim success with programmed material for "Productive thinking", but they are careful to state that they are teaching directly higher order cognitive processes related to creative thinking. Such cognitive skills thought to be fundamental to architectural creative problems were developed by Moore & Gay (1967) and Wehrli (1968) but the procedure has a circular argument. The skills are tested by component tests rather in the nature of psychological tests and the programme develops the abilities for these tests.

5.11 Conclusions on Programmed Learning and Creativity

Planning for learning is a matter for specifying and organising the sequence for various capabilities within a subject and among the subjects of a discipline. Programmed learning appears to be a reasonable device for learning the initial concepts provided there are no residual qualities hindering creative competence, this can be reduced by using teaching methods similar to those described in the previous chapter.

The main conflict between advocates of programmed learning and their opponents is around the importance of internal thought processes. At one extreme is Skinner who dismisses this as of no consequence, the other is Chomsky who is opposed to the idea that instruction is merely a question of input and output.

The chain of connection is too long and complex to be ignored by any educational technique. In the centre of the range is Gagne who claims that the initial learning must be based on stimulus/response but once these principles ahve been learnt the learner is free from stimuli and can transfer to any situation.

For such a creative discipline as architecture it would be folly to limit instruction solely to P.L. A pragmatic approach appears reasonable. Where there is a firm transmission of knowledge required there is justification for using P.L.; but rather than limit the content to bald information, a broadening in terms of Bruner's suggestions require to be incorporated in the material. This implies a recognition of mediating processes. Even when that broadening of the content is made, the integration with the adjacent instruction is vital.

5.12 Students' Attitudes

The suitability of the technique must also be gauged against the attitude of the students towards the programme. While marketing procedures cannot directly be applied to education, it seemed to be of advantage to get the general feeling of the student for what has been described as an inhuman technique. An examination test (1) was given each after soon after the completion of the Programme. That was followed immediately by a questionnaire. Nine months later, test No.2 on the same material was given to the same students before continuing their course on structures. A questionnaire was given after each test. The same questionnaire was given to the succeeding year. The questionnaire had 50 questions and was composed by W. Dunn, M.Ed. (Department of Education Glasgow University). The questionnaire was divided into 5 basic type questions, (i) attitude towards programmes in general, (ii) comparison of programmes with traditional teaching, (iii) whether programme was challenging or not, (iv) the advantage of self-pacing and (v) the knowledge of results.

A comparison was made using all students and a further comparison was made between the weak and strong students' attitudes. The following are the results:-

Attitude towards the P.L.	For P.L.	Against P.L.	Undecided
1968 Test 1 March	60%	25%	15%
Test 2 November	56%	29%	15%
1969 Test 3	59%	26%	15%
1969 Top 7 and Bottom 7 students	80%	20%	-

Attitude towards specific characteristics of P.L.

Characteristics	For P.L.	Against P.L.	Undecided
Self-pacing	70	20	10
Knowledge of results	56	31	11
Programmes are challenging	70	15	13

The Attitudes towards the programmes in general is about 60% favourable and 15% undecided and that after a nine month period of reflection. It is seen also that 80% of the strong and weak students thought P.L. was worthwhile. When compared with traditional instruction, programmed learning is seen generally at its best when the classes of students involved are very large, in this test the maximum number in the classes was 42, which is not considered as very large. It must be pointed out that the attitude questionnaire requires the student to compare P.L. with other teaching technique and an essential part of his design instruction is on an individual or small group basis and the result must be considered in this context.

The questionnaire had 5 types of questions, one of which was concerned with self-pacing - 70% of the students liked this quality but it was found that this quality can trap the disorganised student, it is suggested that some control such as criterion tests at specified intervals should be arranged.

The weak students found it was easier to keep up with the class when using programmes. They felt they got more individual help from programmes although they get a better explanation of mistakes from a human teacher. The strong students felt they got more individual help from a human teacher and think that programmes should be used only along with a teacher and not by themselves.

This is an uneconomical arrangment, while the programme itself would have to be purged of irritating arithmetical errors, the results still indicate that this is another reason why it should not be used as the sole tactic. The student needs to be shown the relevance of what he is about to learn and what he has learnt by P.L.

The general conclusion from both the examination results and the attitude questionnaire is that for certain limited areas in the structural curriculum - similar to those tested here - it is worthwhile, but that the integration of P.L. with the other systems is as important as the tactic.

From the results it was concluded that it might be possible to identify those students who find P.L. satisfying and successful and further discussion on this takes place in the next section.

5.13 Matching Abilities with Teaching Methods

In the discussion of the previous section and in chapter 3 there arose the possibility of allocating a particular teaching system to individual students. This next part is an effort to identify certain kinds of students so that a particular type of learning can or should not be given to them. There have been some attempts to identify specific characteristics of entrants to architectural departments. Abercrombie (1969) concluded there was no evidence to support these pre-entrant tests but Freeman et al (1969) concluded there was. Kelly's Grid Tests (Bannister and Mair 1968) carried out on staff, indicated some crude divisions of student qualities such as rational, intuitive, good at analysis, good at synthesis etc. (see appendix). This was regarded as insufficient to identify students for the above purpose. Suchett-Kaye (1972) surveying the test results for personality factors and programme learning concluded that I.Q. tests were poor predictors of performance. To deal adequately with such problems of how abilities affect the learning performance requires some theoretical framework of such abilities and Guilford (1967) provides a comprehensive foundation. It was surmised for this thesis that if I.Q. and convergent/divergent tests were carried out and related to the results of the students' programmed work and design work, there might be a sufficient guide to allocating particular learning methods. A survey of possible tests was carried out using the assistance of Professor L. Hudson and M.Parlett, Ph.D., Department of Educational Sciences, Edinburgh University, and B.Simeonoff, Ph.D., Department of Psychology, Edinburgh University. It was decided that the following tests be used - I.Q. test, A.H.5 which is divided into verbal, numerical and diagrammatic and two tests on verbal convergent/divergent tests. While those tests were carried out it was noticed that there was no convergent/ divergent tests using graphics.

Pearson (Fisher 1946) correlation tests were carried out with the following results on the 1st year students of 1970/71.

Correlation Matrix

	Structures	I.Q. Test			Convergent/Divergent	
	Exam	Numerical & Verbal	Diagrammatic	Total	Objects	Words
	A	B	C	D	E	F
A	1	-0.358	-0.057	-0.296	-0.2	+0.097
B		1	0.415	0.930	0.037	0.204
C			1	0.720	0.173	0.337
D				1	0.098	0.292
E					1	0.188
F						1

There was thus no correlation between the structure examination related to programmed learning and any other test, and no relationship between I.Q. tests and Convergent/Divergent tests.

Another test was carried out for the 2nd year students of 1970/71 - the results were similar.

	Structures	I.Q. Test			Convergent/Divergent	
	Exam	Numerical & Verbal	Diagrammatic	Total	Objects	Words
	A	B	C	D	E	F
A	1	-0.068	0.103	0.016	0.125	0.316
B		1	0.696	0.905	0.513	-0.038
C			1	0.933	0.242	0.098
D				1	0.398	0.034
E					1	0.120
F						1

Further tests were carried out with art students offering similar results. After developing the tests for visual convergent/divergent abilities and considering the results of the tests it was concluded that the distinction between convergent and divergent is largely temperamental rather than intellectual and therefore it would be inappropriate to continue further.

5.14 Role of the Teacher

The questionnaire has brought up the question of the teacher's role when Programmed Learning is used. There is also concern from the teacher on a possible deterioration of his status if he is to be used only as a test administrator. Before discussing this point it is emphasised that the arguments and the tests have indicated that Programmed Learning should not be the sole teaching tactic.

If the teacher's role is regarded as solely the handing on of existing knowledge, it is possible that a denigration of the teacher will occur. However important this existing knowledge is, it is only a part of the activity of teaching or learning. Such goals as guiding student self development, establishing and nurturing professional attitudes and values, and stimulating the student to learn and to use his learning with imagination and precision, are regarded as a sine qua non in any educational system. Under this strategy P.L. reinforces the teacher's role as a manager of learning conditions. At this level the teacher defines the range of students resonsibilities and freedom in the study and application of knowledge. It is prudent for the teacher to consider if he can help his own talents and time by using any efficient external apparatus whether it is limited to books or extended to the whole range of audio-visual aids. This involves a type of system analysis using the techniques which have been traditional in good education practice and which are mandatory in P.L. - defining learning objectives, analysing the learning structure of the subject matter, selecting and planning the range and route to these objectives, generating performance criteria and measures, isolating and analysing difficulties by feedback and testing of communication.

Such a list is not comprensive but generally it can be seen that the teacher interacts with the student, the material, and the organisation of learning so that the individual can develop himself. Programmed Learning is efficient for student learning and allows the teacher more time for the higher levels of his duties where his teaching talents will have the greatest influence.

5.15 Format

Detailed investigation on the type of written programme has been given in previous reports Carmichael (1972). Part of the report suggested that control of pacing was required even although 70% of the tested students appreciated this characteristic. Some of the weaker students however procrastinate, and judging by the examination results derive little benefit from a cursory glance at the programme. If the student does so he would be better advised to spend the short time on reading textbooks. Some control of the pacing can be made by substantial and frequent criteria at stated intervals which give timely warning to both student and staff. This was tested in 1970/71 and gave adequate examination success and also was satisfactory from the timing aspect.

The principle of small steps has not invariably been found efficient and has led to fragmentation with a consequent loss of coherence and increase of study time. Sections of the initial draft based on a 90% of the students passing 80% of the tests - which is the kind of claim made by many programmes - was found by 6 small groups of the students as having boring sequences. Moreover, it was felt that by gearing the reasoning down to the weakest student there was an unjustifiable increase in study time. Larger steps were used but not with approval by all the class. When a skip linear technique was used, only 8 students used it. It is argued that the feedback will correct the error but the teacher on his own initiative must try to balance the issued. Fragmentation is also dangerous for the programmed material as it can have problems which involve a number of manipulations of theories or in the explanations of complex fundamental structural behaviour. Some students complained that while they answered correctly all the frames they could not see the wood for the trees. Frequent overviews, either by lectures, closed circuit television or contained within the programme helped considerably, but progressive prompts or the principle of mathetics will increase the reading matter and this does not appear justifiable.

The time taken by the students to complete the programme was as follows:-

Subject	Time	Standard Deviation
Theory of Flexural Resistance	11.75 hours	3.72
Deflection	5.75 hours	2
Columns and Walls	13.00 hours	3.5

However the preparation time is considerable. There have been 5 drafts for each of the above subjects as follows:-

Draft No.A given to 2 students + 2 lectures (Engineer & Architect)
Draft No.B given to 6 students
Draft No.C given to 10 students of 1st year and 2nd year
Draft No.D given to 45 students of 1st year and 2nd year
Draft No.E (with exception of brick wall) given to 32 students of 1st year - 1969
A 6th Draft of the programme on Deflection was given to 30 students at the Architectural School of the University of Virginia in 1969.

The system allows for modifications and another four major alterations were made. This is expensive in staff and secretarial time and therefore in conjunction with J.Cowan, M.Sc., a comparison of a written programme and an audio tape/slide programme based on the Deflection programme was used on 2nd year students in 1972.

3 versions were used on 2nd Year students of architecture.

(a) Text - in its final, well validated form.

(b) An audio tape/tutorial version of the above, made so that the parts which the student might well wish to retain for revision purposes were on a printed handout, with the remainder on tape.

(c) A re-ordered version, structured around the objectives list and presented, group paced on tape with overhead projected diagrams.

An immediate post-test was given and results compared with post-tests on a similar programme, taken in text by all groups on a different topic, and on a lecture/tutorial period of instruction on a third topic. Results were as follows:-

Average Scores

Treatment on Deflection	No. in group		Scores	
		Deflection (a)	BM (written) (b)	Shear (lecture) (c)
Audio Tape/OHP	7	51.9	61	67.3
Audio Tape/Tutorial	10	51.8	46.7	57.1
Written P.L.	11	46.6	50.3	55.8

These results implied different group abilities and when an "Analysis of Variance", Fisher (1946) was made on the average marks for each group it showed that the Audio Tape/OHP group were significantly better than the other two groups. The results were as follows:-

		Subjects	
Teaching Methods	Deflection	Moment of Resistance	Shear
Audio Tape/OHP	67.1	61	62.3
Audio Tape/Tutorial	51.8	48	50.1
Written P.L.	55.7	50.3	52.8

The conclusion drawn was that because of one group of students being significantly better than the other, the effectiveness of all methods were somewhat similar. If, however, the average times for each method were taken it is seen that the audio tape with either the overhead projector or with tutorial sheets is more effective in cost of time. The average times were - Audio Tape/OHP - 1.5 hours; Audio Tape/tutorial - 1.8 hours; Written P.L. text - 2.5 hours.

The final conclusion is therefore that there is little difference in results but substantial difference in students' time and ease in amending the text. Tape/slide whether by group paced tape/overhead projector or by individual tape presentation should be preferred to text programme for this subject.

5.16 The Use of Mathematics to Explain Structural Theories

In the discussion in section 2 there was conflicting opinion on whether mathematics was the only language to use to explain structural theories. It was also argued in section 3 that mathematics could only refine and confirm but is unable to initiate. Intuition on the other hand can initiate but cannot refine or confirm. If however, visual means could explain the theories as well as mathematics, then the visual acuity of architects would allow them to appreciate complex structures and perhaps develop an intuitive approach as well.

Accordingly a text was set up with the 2nd year of 27 architectural students for a learning sequence for statistically indeterminate structures (continuous beams and portals). 10 members were chosen at random from the 27 students, 19 of whom had Higher Mathematics or equivalent, This group was given a lecture course in matrix algebra, stiffness and flexibility theories in structural analysis. This course was given by tape/slide programme learning. The student with this knowledge was able to set out and explain equations of equilibrium for continuous beams and form stiffness equations for structural analysis. This was followed up by tape/slide programmes for interpreting computer 'print-outs' to determine the distribution of moments from the data provided by their structural analysis. Each student then used a given computer programme on similar principles to determine the distribution of moments for portal frames which included 3 span 2 storey buildings (see appendix). The non-maths group used a programmed text (see appendix) to learn about the distribution of bending moments of the identical structural system as the other group. This learning was based on visualising then sketching the deformation of such systems assisted and checked by balsa wood models, in addition to a knowledge of statics involving some arithmetic. Both groups had the same amount of time to learn their subject and in the conventional examination all students answered the same questions on the distribution of moments. The results were also compared with their design assessment.

The marks for the structure examination were standardised and compared with the following results:-

<u>Non maths group</u> mean 77.65% Standard deviation 12.81

<u>Maths group</u> mean 64% Standard deviation 17.18

The standard error (S.E.) was calculated and if the difference of the means (D.M.) is twice that error then according to Fisher (1946) there is a significant difference. The non maths group were significantly better than the maths group i.e. D.M. was 13.65 and S.E. was 6.25.

It was thought possible that this significance could be carried over to the design project and accordingly these results were analysed with the following results:-

<u>Cross Correlation Coefficient Matrix</u>

<u>Non Maths Group</u>	Structure	Design of 2nd Year	Design of 3rd Year
Structure	1	-0.39	-0.208
Design 2nd Year	0	1	0.677
Design 3rd Year	0	0	1
<u>Maths Group</u>			
Structure	1	0.192	0.208
Design 2nd Year	0	1	0.561
Design 3rd Year	0	0	1

No relation was noticed

5.17 Gestalt and Behaviourism

To complete this section on the format of the programme, a brief examination will be made of two different approaches for the structure of the programme. Programming sprang from the theories of the behaviourist school who insist that their learning principles should be applied. The Gestalt approach is in direct contrast to those principles but the question arises on whether programmed texts or tapes can be adapted to include both systems.

Two texts dealing with the learning of calculating areas were considered. The Gestalt approach was that set out in Chapter one and appendix 4 of 'Productive Thinking' by M. Wertheimer (1968) and the Behaviourist text was by R. Harris (1969). Both systems try to get the student to work by himself. The main difference lay in the kind of examples given at the end of the lesson. The Gestalt school gave a number of differing problems but not a great many of each - 'A few interestingly different problems'. The behaviourist school gave an abundance of examples; and in contrast to the Gestalt, meticulously detailed all teaching points and gave a large number of prompts. One draft programme used was of this nature and the students' attitude and results indicated a boredom with such detailed exposition. As there is also a limited time in the curriculum for this kind of exercise, the conclusion was that the programmed instruction content should be more in the nature of Gestalt's technique and by using a skip technique, the weaker students can be diverted to a number of examples on the behaviourist technique. The skip technique provides additional material for those students who do not understand some of the teaching points.

5.18 Remedial or Initial Learning

Assuming that in the planning of a course, a topic is learnt by programmed instruction, there are two questions which have to be answered

(a) is P.L. to be used as remedial instruction or for presenting information new to the student and (b) will P.L. be a commercial programme in existence or will the teacher construct his own programme?

The first question largely depends on the teacher's assessment of the relative merits of P.L. and the other means available such as lectures or selected reading.

For the answer to the second question it is generally urged that teachers should not construct their own programmes because of the tedious time involved. This report suggests, contrary to general belief, that teachers should try to construct small sections either by themselves or with an expert and which can be used for remedial work. The suggestion is given not only because the teacher's general teaching ability can be further developed, but because their own individual approach to the subject can be used and is therefore consistent with the remainder of the course and lastly because at the moment and for the immediate future the commercial programmes available for architectural students are remarkably few.

Briefly this thesis has been concerned with methods for teaching structures to architects. The first two chapters discussed the fundamental considerations and objectives for such methods. The last two chapters reported and discussed the results of some experiments in the use of specific teaching methods (most of which were new developments) which were compatible with those considerations.

5.19 References

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Appendix

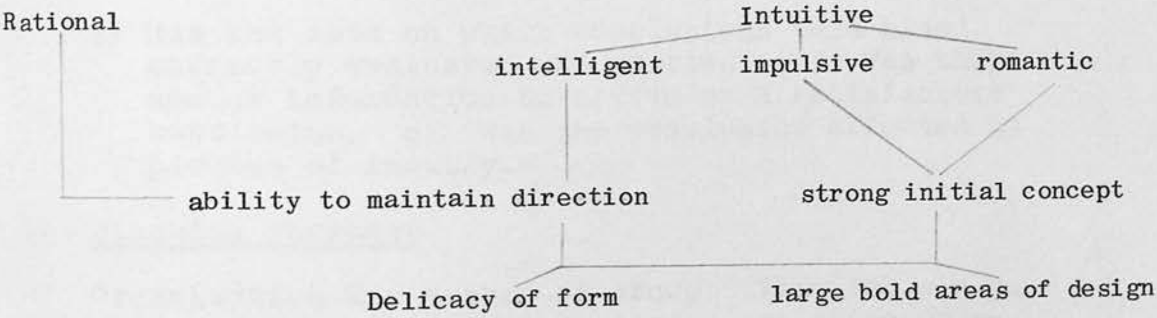
Kelly's Grid (Bannister & Mair 1968) refer to pages 57 and 133

A questionnaire based on Kelly's Grid was given to 5 design tutors concerning 160 students, (some of whom were undergraduates at University of Liverpool). It was thought that this would elucidate the criteria of design assessment used by the staff, help to define architectural creativity and provide variables that would distinguish students so that particular teaching methods could be allocated.

The results helped only the second aim. The interpretation of the results are given under three headings viz. Design Approach; Principal abilities: and Components of Design Principles.

Design Approval

The staff divided the students in the following arrangement



Principal Abilities

Intelligence: Aesthetic skills: manipulative skills
Knowledge (abstract & practical)

Variation in Components of Design Principles

Components	Unteachable Aberrant +	Ideal	Unteachable Aberrant -
Identification of Problems	over concerned with details	Precise	Insensitive
Hierarchy of Problems	Irrational (analytical)	Rational (Balanced)	Irrational Intuitive
Redefinition of priorities Evaluation	Compulsive rigid	Willing Options kept open	Unwilling Unable to decide
Choice of solution	Preference for standard	Balanced	Preference for novel
Analysis/Synthesis	synthesis	Analysis based synthesis	complex analysis
Harmonious relations in space and technical factors	Technical function dormant	Inter-dependent	Space factor dormant.

6.2 GUIDE TO ASSESSMENT OF PROJECTS

A. How was the project achieved. i.e. - the mode of approach.

---

1. Data collecting procedures

   a) Economy of means - directness. b) How valid were the sources. c) Was information readily available from textbooks. d) Were the fundamentals adequately learnt and used.

2. Cognitive skills

   How to handle facts analysis
   synthesis

   e) Was the data on which conclusions were based correctly evaluated and queried. f) Was there enough information to arrive at a satisfactory conclusion. g) Was the conclusion affected by process of inquiry.

3. Planning Strategy

   Organisation and method of group. Planning - e.g. - co-operation, iniative, attitude, prejudice, preconceptions, and myths.

(45 Marks)

B. Solution

---

1. Is the conclusion mainly the result of the group's own judgement rather than a catalogue of facts.
2. What could have been achieved. Part or non achievement.
3. Did the project justify the academic time made available.
4. Generalisations and hypothesis - Assumptions.

(25 Marks)

C. Presentation

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1. Effectiveness of communication. Factual content : method : elegance : ideas.
2. Documentation of data sources.

(15 Marks)

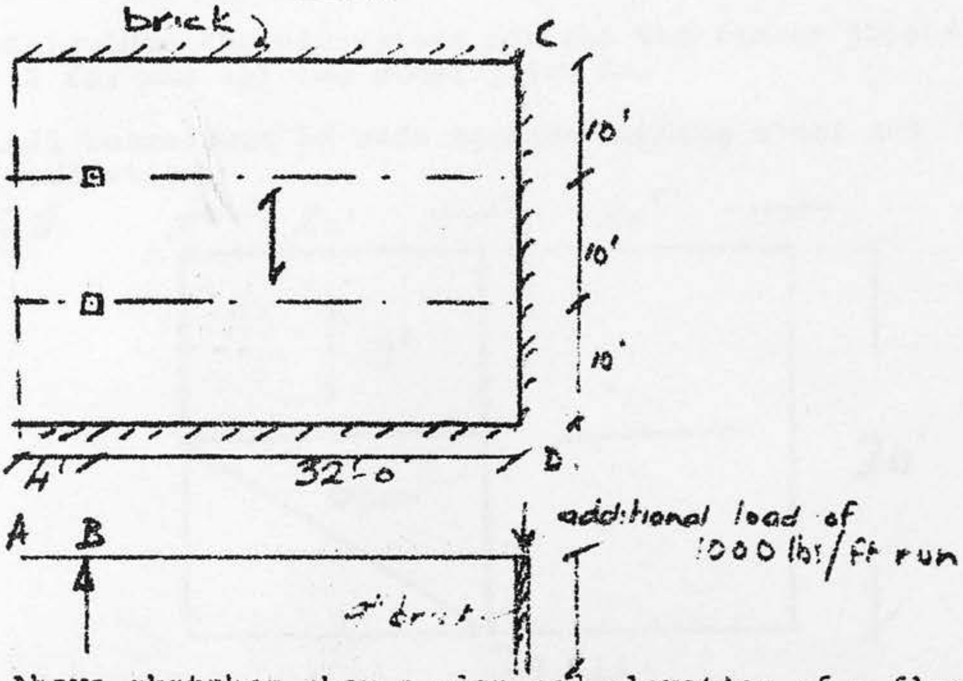
D. Choice of Topics

(15 Marks)

SUBJECT	AUTHORS	Selected Aspects of programmed instruction common to these reports mentioned in this review.			
		Replaced Lectures or Tutorials	Augment lectures	Type of Pacing	Type of integration with other tactics
Structural Engineering	Mill & Martin 1968	*			
"	Croxton & Martin, 1965	*		Self + tests	Compulsory problems.
"	Croxton & Martin, 1967	*		Controlled	
Architecture	O'Brien & Jackson to be published	*		Self	Seminars.
Economics	Attiyeh, Lumsden et al 1969	*		Self	None.
Medicine	Harden, Dunn et al, 1969	*		Self	None
"	Owen Hall et al 1965		*	Controlled	Lectures
Chemistry	Glyn 1965		*	Self	
"	Hoar & Inglis 1965		*	Self	
"	Gunstone 1966		*	Controlled	Lectures
"	Hogg 1966		*	Self	Lectures & tutorials
Electrical Engineering	Hewlett 1969	*			Laboratory work; reading.
Mathematics	Stroud 1969		*	Controlled	Lectures & tutorial
"	Hartley, 1967		*		Lectures & tutorial.
"	Hartley, 1968		*	Controlled	Compulsory tests.

6.4. Exam Questions

Question 1: 1967/68



Above sketches show a plan and elevation of a floor. Group II Timber joists at 1.6 ft. centres span 10'-0 between steel beams which span between a 9" brick wall and a column 32 ft. apart. The beam continues to cantilever a further 4 ft. Total inclusive load on the floor is 100 lbs/ft. run. Assume the self weight of the steel beam is 0.05 tons/ft. run.

Required

1. Calculate safe economical dimensions for the timber joists.
2. Calculate safe economical dimensions for the steel beams against bending and shear only.
3. Explain but do not calculate, why the tip of the cantilever section (A) will not deflect the same amount as a beam fixed at B. and cantilevering out 4 ft. even although the load and span are identical.

Question 2: 1968/69

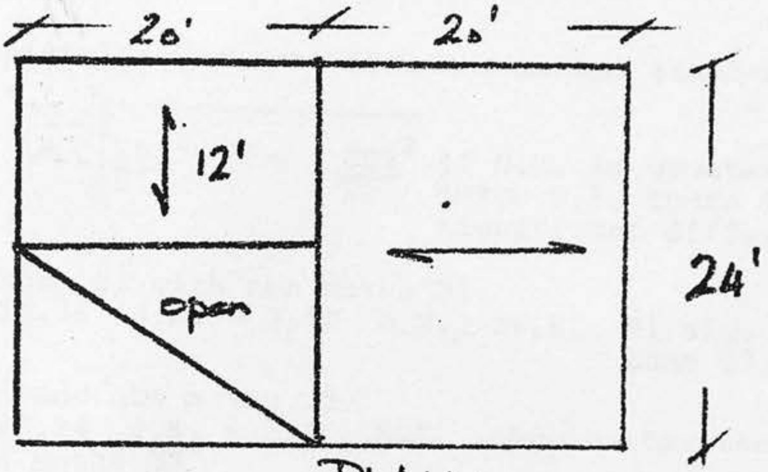
The maximum load which a column can support is largely dependent on the column's ability to resist buckling. Which factors influence buckling and in what manner do they influence the amount of load supported by column?

Question 3: 1969/70

The following sketch shows the plan of a floor supporting an inclusive load of 80lbs. per sq. ft.

Calculate the dimensions for (a) the timber joists spanning 12 ft. and (b) the steel joist AB.

All beams must be safe against bending shear and deflection.



PLAN ·

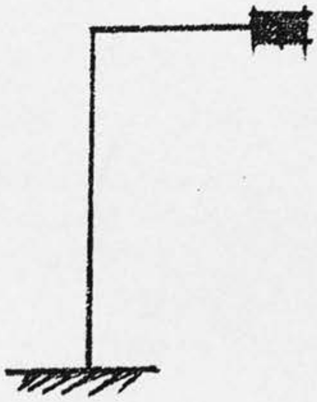
Question 4: 1968/69

The structural support of a load applied at the tip of a cantilever which is supported on a column can be several kinds.

(a) Sketch 4 basic structural systems which relieve the foundation and the solumn section of providing a resistant moment.

(b) Indicate the type of forces in each part of the structural system including the foundation.

(c) Illustrate the use in actual buildings of each one of those 5 basic systems.



6.5. Comparison of maths group with non maths group

Non maths		Design 3	Design 2	Structures 1
	mean	58.29	60.41	77.65
	S.D.	8.10	8.65	12.81
Maths				
	mean	60.60	69.90	64.00
	S.D.	7.10	7.96	17.18

Test: Calculate difference between mean and standard error where

$$S.E. = \sqrt{\frac{SD1^2}{N1} + \frac{SD2^2}{N2}}$$

if D.M. is greater than twice S.E. there is a significant difference

Non maths group S1 with non maths D3
D.M. = 19.36 S.E. = 3.68 D.M.> 2S.E. S1 sig. better than D3.

Non maths S1 and non maths D2
D.M. = 17.24 S.E. = 3.75 S.1. sig. better than D2.

Maths S1 and Maths D3
D.M. = 3.40 S.E. = 5.88 no sig. difference

Maths S1 Maths D2
D. M. = 5.9 S.E. = 5.99 no sig. difference

Non maths S1 Maths S1
D.M. = 13.65 S.E. = 6.25 non maths S1 sig. better than maths S1

Non maths D3 Maths D3
D.M. = 2.3 S.E. = 2.98 no sig. difference

Non maths D2 Maths D2
D.M. = 9.49 S.E. = 3.28 Maths D2 sig. higher than non maths D2

6.6. Building Appraisal

OBJECTIVES

1. Analyse and describe the building in terms of its various technical components by -

    (a) identifying in isolation the various technical sections:

    (b) finding the reasons why the particular component was used in this context, broadly dividing the answers into (i) physical comfort, (ii) materials:

    (c) finding out the inter-relations between the individual technical components as well as the influence of some of the technical determinants on the building envelope and space:

    (d) listing and discuss possible alternatives to these components and the probable change in the building.

The technical components should be -

1. Materials
    - a) External weathering and fixings;
    - b) Internal methods by which interior finishes are married together.
2. Structure
3. Lighting
4. Heating and Services
5. Acoustics

COMMUNICATION OF REPORT

1. Mainly by graphics or models to bring out the 3-dimensional aspect.

2. All value judgments, either aesthetic or functional, of the building either as a whole or in parts, must be excluded.

3. A short verbal description - illustrated by models and drawings - by one member of the group.

GENERAL COMMENTS

For the purpose of initial learning the various technical components have to be isolated for examination. However, the design process integrates these components into a whole until and therefore after identifying and understanding the behaviour of the separate components, the inter-relationships and consequences between those components, must also be understood.

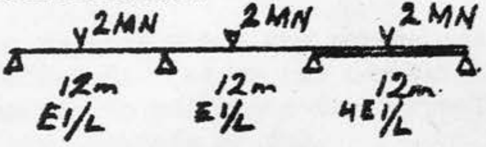
6.7 Mathematics group compared with non mathematics group

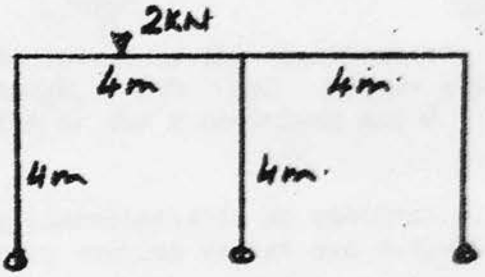
Two programmes were given with the same objective that students should be able to appreciate the behaviour of continuous beams and multi-storey frames.

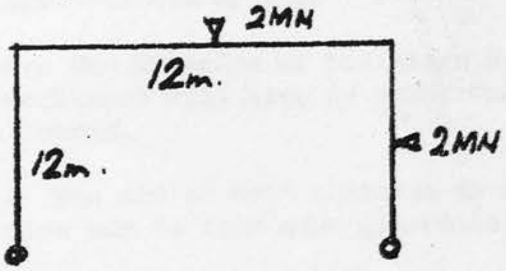
A summary of the mathematical programme is :-

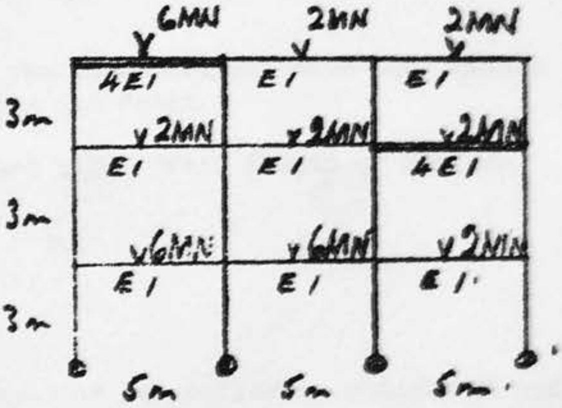
Day 1	Matrix algebra with test Main features of stiffness analysis and flexibility analysis of structural frames.
Day 2	Group formulation of problem for computer solution Derivation of stiffness equations.
Day 3	Comparison of stiffness and flexibility methods of analysis of indeterminate structures.
Day 4	Formulation of data sheets and card punching.
Day 5	Analysis of computer printouts.

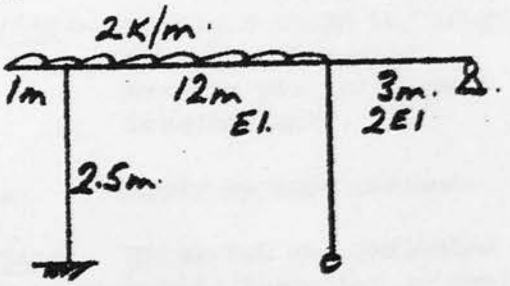
The following is a sample of some of the indeterminate structures:-









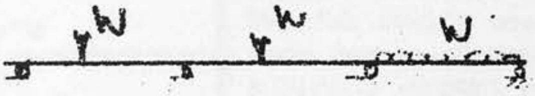


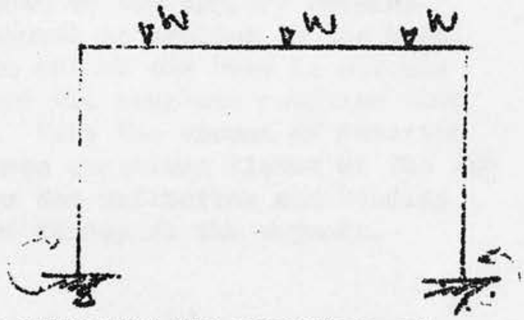
The following are extracts from the non mathematical programme which was concerned with sketching the deformation of the frames and using statical methods for calculating bending movements.

Sample pages (pl, 8 & 13) of non maths instruction on indeterminate frame behaviour

Introduction: The structural systems you have considered so far has been simply supported e.g. beam and cantilevers and the bending moments can be solved by applying the 3 basic equations of equilibrium M = 0 : Vertical forces + 0: Horizontal forces = 0. Generally there is only one or two unknowns and therefore with 3 equations at your disposal these unknowns can be calculated.

Modern materials - steel and concrete - are capable of having strong joints so we can have such systems as -





These systems which are continuous cannot be solved by the equations of equilibrium. If we use our existing knowledge, V=0 M=0 H=0 we shall be unable to calculate the 3 reactions of (a) or the 2 reactions and 2 reactive moments of (b).

Because the majority of buildings have this characteristic of continuity, the architect will have to understand how such systems resist and deflect when loaded.

Aim:- The aim of this exercise is for you to experiment with some simple examples and to form some generalisations and rules.

Material:- Obtain 2 No.24 in. length and 1 No. 36 in length of approx. $\frac{1}{4}$" x $\frac{1}{4}$" balsa wood.
Drawing pin for support
Drawing paper.

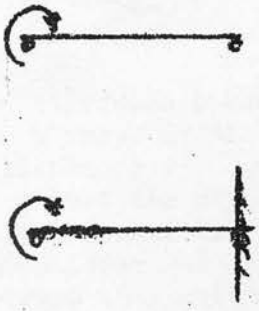
Load:- Apply by hand pressure

Required:- To sketch the deflected shapes of the following structural system it is important to learn how to feel the structural deformations. Since this takes practice, trace the first seven experiments then sketch the remaining, check by tracing the balsa wood model under load. The remaining experiments can be sketched first then checked from the experiment.

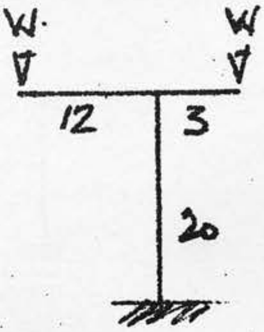
(a) Sketch the deformed shapes and mark the fibres which are in tension and which are in compression.
(b) Some of the sections have tension at bottom and compression at the top - others vice versa - How does this relate to the bending moment diagram?
(c) Mark these section which are not curved (contraflexure points).
(d) How do these contraflexure points (C.P.) relate to the amount of bending moment?
(e) Can you find two general rules about the position of those contraflexure points?
(f) Sketch the shape of the bending moment diagram for all the examples

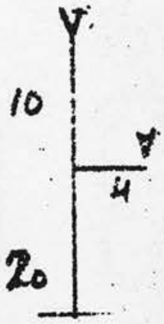
For the next series of tests

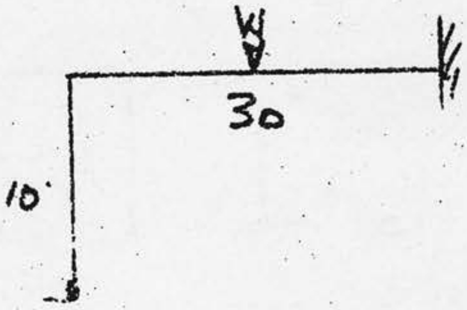
1. Sketch the deflected shape, the bending moment diagram and the position of maximum tension and compressive stresses.
2. Draw the direction of the reactive moments at all supports and mark the contraflexure points.
3. Propose a rule about the movement of the contraflexure points in relation to the rotation of the beam at the supports.
4. Which of the joint distortions sketched below are possible?

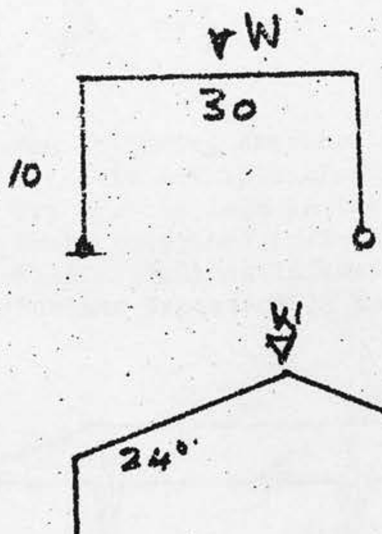


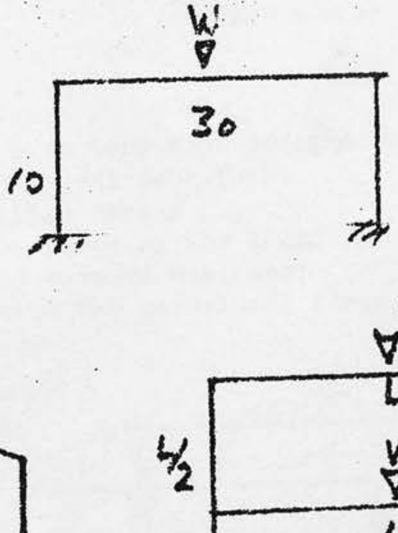
In this example experiment with different degrees of fixity at the right hand support while applying a bending moment at the left hand support.
Complete fixity is when the beam at the support remains horizontal whatever load or moment is applied to the beam. Partial fixity occurs when the end of the beam is allowed some degree of rotation but not the complete rotation that a hinged support would allow. Vary the amount of rotation and in addition to the 1st three questions listed at the top of the page note the effect on the deflection and bending moment relative to the type of fixity at the support.

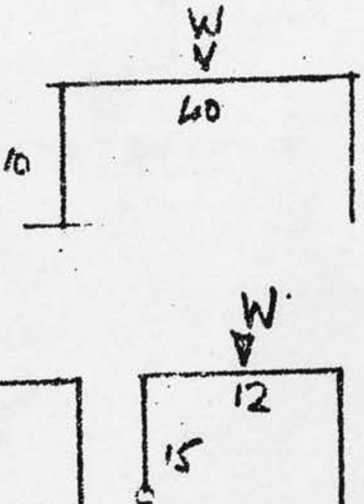


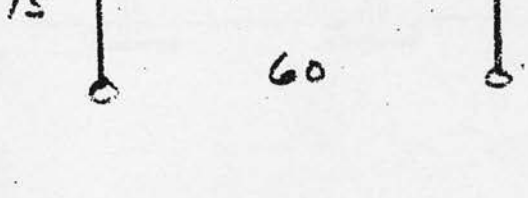


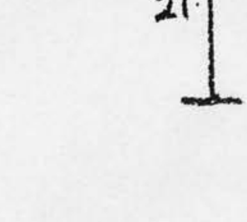


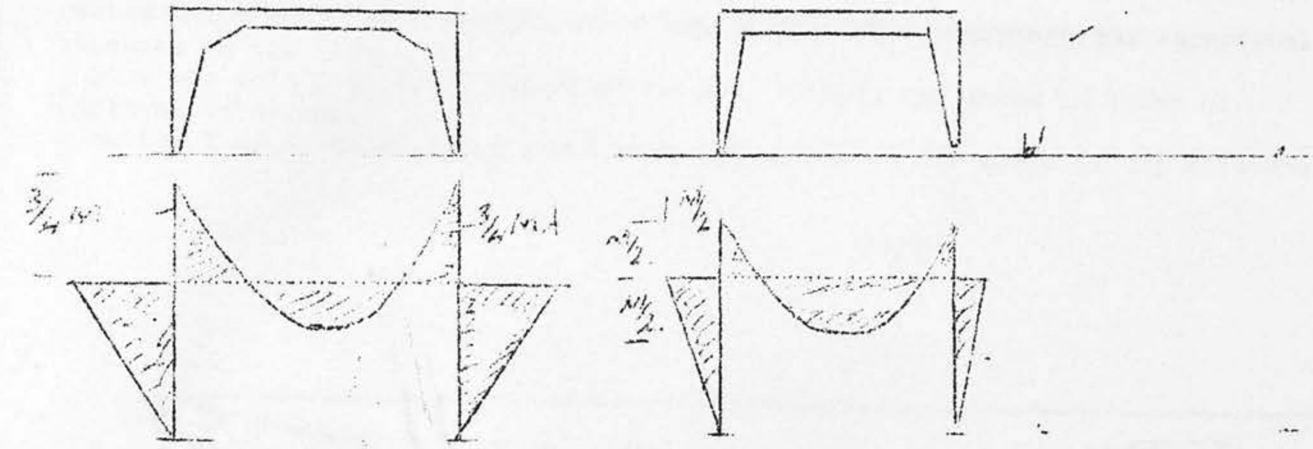








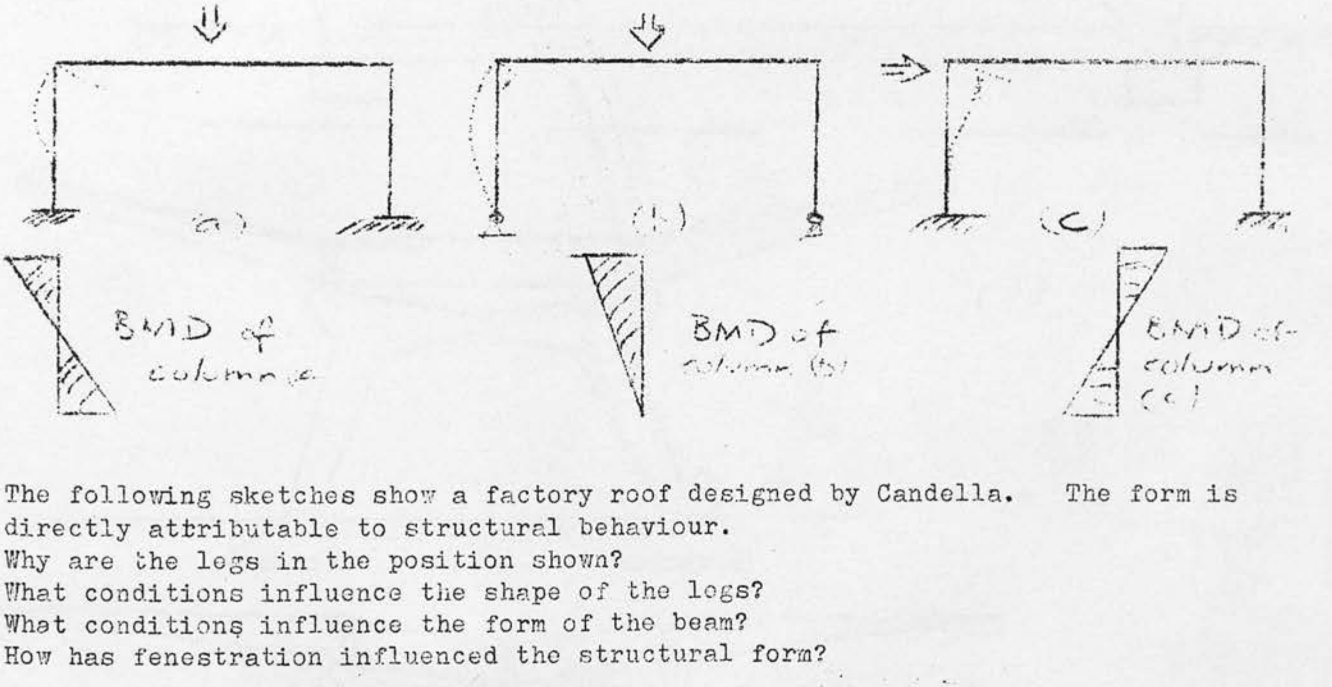




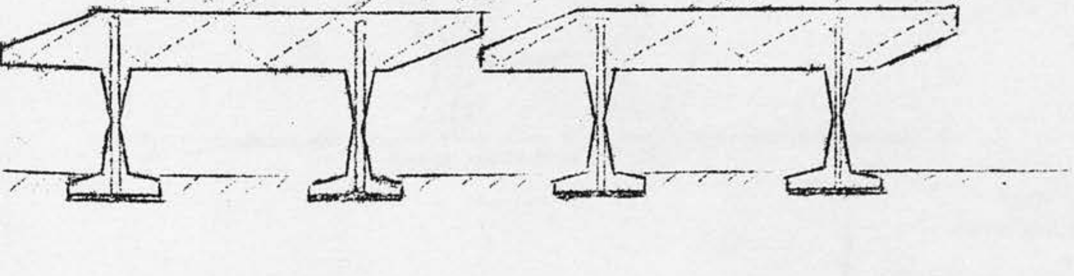
NB $M = wL^2/8$

The stiffness depends on the moment of inertia of the section around the joint, the E value of the material and the length of the adjacent members (compare deflection) .

Note that the structural form of the frame column is not a direct result of the calculations, the calulations depend on the shape of the coulmn, beam and joint. The stiffer and less flexible the columns the more bending moment they attract because they prevent the joint rotating. As the stiffness of the joint increases so the bending moment in the beam is relieved. The converse applies if the columns are supple, the bending moment in the beam becomes closer in magnitude to a simply supported beam. The shape of the column is also affected by the joint at the base e.g.

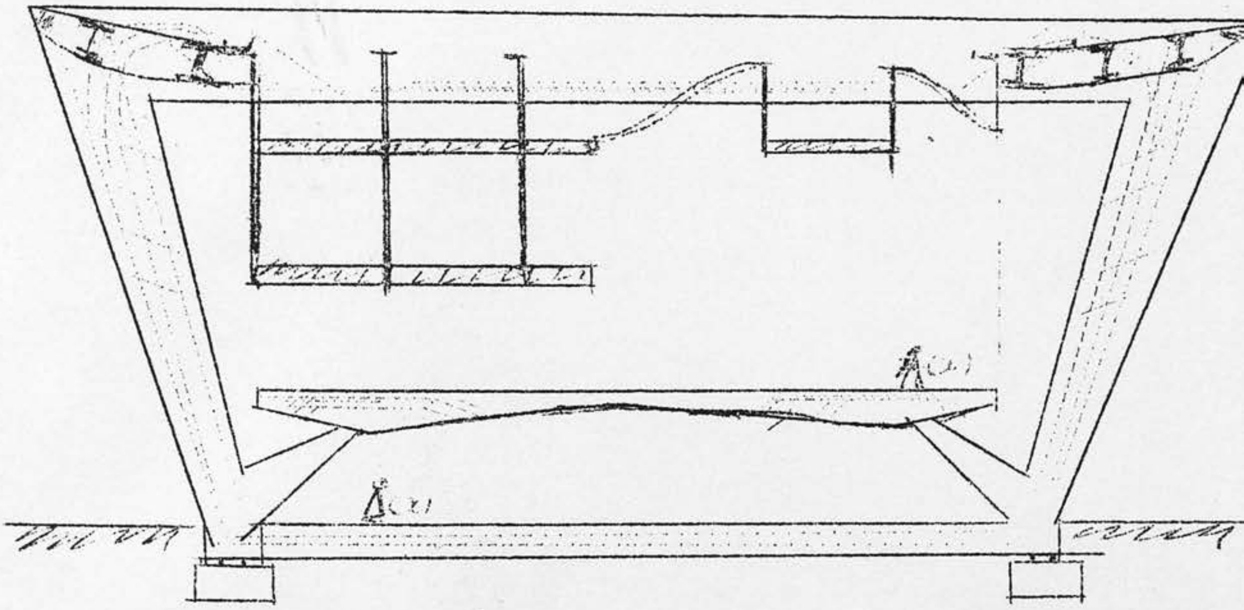


The following sketches show a factory roof designed by Candella. The form is directly attributable to structural behaviour.
Why are the legs in the position shown?
What conditions influence the shape of the legs?
What conditions influence the form of the beam?
How has fenestration influenced the structural form?

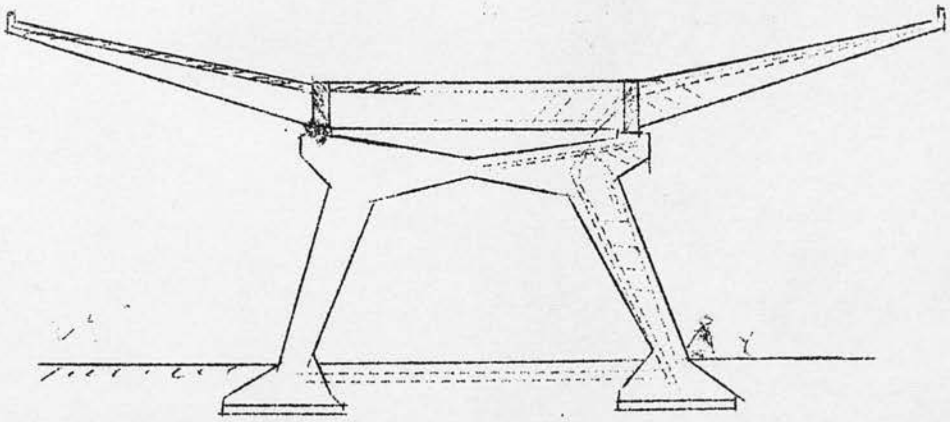


Sketches below show (a) a section of an exhibition hall. Explain the structural influences on the form.
(b) show two solutions for an aircraft hanger; compare the forms in terms of structural behaviour.
The sketch X of a human being gives some indication of the scale of the strcture.

(A)



(b)



(b)