THE CATHOLIC UNIVERSITY OF AMERICA

PLASTICS IN ARCHITECTURE

A DISSERTATION
SUBMITTED TO THE FACULTY OF THE SCHOOL OF ENGINEERING
AND ARCHITECTURE OF THE CATHOLIC UNIVERSITY OF AMERICA
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR
THE DEGREE DOCTOR OF ARCHITECTURE

BY

ERFAN SAMY
M.A. IN ARCH.

THE CATHOLIC UNIVERSITY OF AMERICA PRESS
WASHINGTON, D. C.
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1- Plastic materials
2-

This dissertation was conducted under the direction of Thomas H. Locraft, Ph.D., as Major Professor, and was approved by Henry P. Ward, Ph.D., Jean S. Mendousse, Ph. D., Sc. D., and Edward J. Scullen, M.C.E., as Readers.

In Memory of
MY FATHER AND MOTHER

PREFACE

Although the development of modern plastics was started almost a century ago, plastics did not play any special part in architecture because (a) for development, they belonged mainly to the chemical field, and for application, to the electrical field; (b) the materials for which some of them were developed as substitutes, such as rubber, ivory, horn, silk, etc., are not primarily architectural; and (c) in the experimental stage, they were high in price, and made in small quantities not intended for marketing on a large scale.

The phenomenal recent growth of the plastics industry reflects the fact that research has developed new types--which two world wars have tested under severe conditions and proved suitable; that new outlets have been found for an increasing output of plastics; that some of the patent-rights expired; and that economic conditions and increasing mechanization fostered the development of new materials for new fields.

Architecture still depends upon a great amount of hand-labor and craftsmanship, and offers opportunity for further use of plastics. And now the architect finds himself confronted with a new challenge: a large group of new materials threatens not only to have as revolutionary effects as steel and concrete had on stone architecture, but even to change his own position as architect.

The main purposes of this dissertation, therefore, are: to study the characteristics of plastics, showing advantages, and suggesting remedies for disadvantages; to demonstrate with designs and drawings, where possible, the applications of plastics and their effects; and to discuss some of the related considerations, esthetic and other. This study is based on fundamental information, collected from chemical, technical, and general literature, after translating it, so to speak, into architectural language, in order that the study may be <u>from the architect's point of view</u>, which is essentially different from the points of view of chemists, engineers, or industrialists.

Comparisons with traditional materials, such as steel, concrete, glass, etc., are pursued for a better understanding of the new materials as well as for a re-evaluation of the traditional in the light of the new.

To architects, this dissertation provides the basis for understanding a new group of materials; and to scientists and industrialists who direct their attention to the production of plastics <u>for architectural uses</u>, it presents the architect's point of view to guide them in lines of development in this field.

Special gratitude is here acknowledged as due to Dr. Thomas H. Locraft, Head of the Department of Architecture, under whose guidance this dissertation was made, to Dr. H. P. Ward of the Department of Chemistry, to Dr. J. S. Mendousse and Mr. E. J. Scullen, of the Department of Civil Engineering, for their helpful suggestions while this dissertation was in preparation, and to Mr. Frank A. Biberstein, Professor of Civil Engineering, and to all who helped in any way. I also wish to thank Mrs. Katherine Wickey for her careful and helpful editing.

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INTRODUCTION

It is fundamental in principle that materials have great influence on the design, construction and final shapes of buildings; that every material has its own characteristics; and that a simple substitution of one material for another cannot be considered satisfactory even if such a substitution "works." [1]

Before using plastics, therefore, it is necessary that all the significant properties and involved factors be studied. And until the study of plastics becomes an integral part of his training, the architect will have several courses to pursue.

I. To rely on available general information and specific data in books and magazines. And in so doing he will soon discover the several facts that follow.

A. There is sufficient literature for a lifetime of reading, and more is constantly added, making it difficult to catch up with the latest developments in the field. He will note that these books and magazines differ appreciably--especially the earlier ones--sometimes to the point of contradiction.

B. Due to the lack of standardization of the types of plastics, and to the varieties possible of each type, characteristics vary from country to country, from company to company, and even from book to book! Standardization, though, seems unlikely since, unlike metals, plastics offer scope for improvement in properties so that,

> instead of a small number of basic resins compounded in different ways for different applications it is probable that resins will be formulated specifically for the application in mind. In other words the chemist will have to produce what the Americans call "tailored molecules."[1]

C. Popular magazines, with their over-enthusiasm, created a distorted picture of a Plastic Age to come, and showed plastics as the wonder materials capable of solving any problem

D. Manufacturers and advertising writers--those geniuses of phraseology--often misrepresent facts, distort pictures, and forget about disadvantages, until every product becomes "wonderful," "sensational," "amazing!"

II. To acquire all the first-hand experience with plastics that he can get. An ounce of practice is worth a ton of precept, it is said. He should familiarize himself with the properties of the different types, and more important, with their limitations, for plastics, like all other materials, have their own properties, and their applications should be in accordance with them. Regarding them as mere substitutes for other materials is what has tended to give them a bad name.

The architect should also reject the association of plastics with small gadgets and articles of hard, highly polished surfaces which are usually fragile because of the exaggerated thinness of the material used.

III. To consult the industrial engineer regarding the type or types of plastics suitable for a specific job, and also the chemical engineer who will "tailor" the molecules to meet specific requirements.

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[1] E. F. MacTaggart and H. H. Chambers, Plastics and Building (London: Sir Isaac Pitman & Sons, Ltd., 1951), p. 142.

Plastics for Structural Uses

If plastics have not yet been utilized in structural applications (only semi-structural, such as panels, roofing materials, and other elements that support only themselves), it is almost certain that they will be in the near future. There are several facts to indicate it.

I. Plastics were formerly limited to small articles and electrical equipment because of the technical difficulties, the need for a large number of machines and accurate laboratory controls to produce large units--all suitable only for big concerns with vast economic resources. Now, after about a century of progress, many such concerns in the U.S. and abroad have directed their activities to the study, development and mass-production of plastics materials.

II. Mass production is necessary in order to bring the prices down and to make the products comparable to other traditional ones, and acceptable to the public. Before such an undertaking can be realized, a complete understanding by the public as well as by engineers and manufacturers of the behavior of these new materials is necessary. Lack of complete knowledge in many cases was the reason for seeing many a plastic fail in certain applications, but plastics have now been studied and tested, and the necessary data made available. Once the behavior of a material is known, the limitations can be either remedied, or allowed for in the design. "A structural member is said to have failed when it ceases to function properly in the use for which it was intended."[2]

III. Because of the fast progress and the successive discoveries made in the field of plastics, many big companies were hesitating to go into mass production because any new type that proves better can outstrip the other types and ruin the economy of their manufacturers. There are now several types (combinations of types, or combinations with other traditional materials) that prove adequate for load-carrying.

IV. The air force and army are extremely interested in plastics applications, and in fact many of the studies and inventions were originally made for the development of war equipment, and only afterwards did they find their way into civilian uses.

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[2] G. Murphy, Properties of Engineering Materials (Scranton, Pa.: International Textbook Co., 1939), p. 31.

PART I

CHARACTERISTICS OF PLASTICS

Only those properties of plastics that concern the architect will be discussed here, in order to form a general idea of the subject; an idea similar to a layout which is basic to the development of a large project, but which remains subject to detailed study, and to modification when the details are worked out afterwards.

A complete description of plastics, type by type, will not (and cannot) be attempted, for several reasons.

1. Each plastic would require a whole book to itself for an adequate description of its characteristics, manufacturing methods, applications, etc., and there are enough books dealing with all these subjects.

2. There are many plastics materials as compared to the traditional structural ones, and more are constantly being developed--which is one of the main reasons why architects and engineers have not used plastics long before. They are accustomed to the standardized, uniform qualities of steel, concrete, glass and the other materials, and the great variety of plastics confuses them. It even confuses the industry,[1] and sometimes prevents manufacturers from going into mass production.

3. It would not be of great importance to the architect to go into all the chemical, industrial and technical details, since plastics will reach him in a finished state, ready for use and assembly on the site, and he is not concerned with such subjects as raw materials, plasticizers, fillers, etc. A general knowledge of these matters, however, will help him form a clearer picture of the whole field of plastics.

To avoid repetition, and for better demonstration, applications of the materials are given along with the description of their

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[1] B. H. Weil and V. J. Anhorn, Plastic Horizons (Lancaster, Pa.: The Jacques Cattell Press, 1944), p. 136.

properties, even though Part II is devoted to applications. And unless necessary, no actual, specific products on the market are described or evaluated.

In this connection, several points must be borne in mind:

1. These are the characteristics of some of the commercially-known plastics, as they are today--in their infancy.

2. Research and time will remove their shortcomings, improve their qualities, and develop new types, or combinations, that will be more suitable for architectural use.

3. Plastics will be rarely used in their pure form, but in connection with other materials, as we will see later.

CHAPTER ONE

PHYSICAL PROPERTIES

Specific Gravity

Specific gravities of plastics now available range from 0.92 (polyethylene) and 1.05 (ethyl cellulose, polyvinyl acetals, polystyrene, etc.) to a maximum of 2.09 (molded, mineral-filled phenol formaldehyde) and 2.3 (polytetrafluoroethylene).[1]

Compared with steel's 7.8 or reinforced concrete's 2.5, this great lightness is one of plastics' main advantages. In aircraft, for example, even at comparatively higher costs, plastics result in a big saving.[2] And in architecture, they would similarly negate their higher costs by the savings in handling, transportation and ease of erection.

> The bulk and weight of the material still play important roles in assessing the overall cost of building.[3]

Light weight also means less dead loads on a structure--a further saving in the sizes of structural members, whether plastics are part of the structure or used only in the partitions and external skin. For example:

> polystyrene blocks are designed to carry only their own weight, but their weight is only one-fifth of that of glass. This lightness facilitates easy erection; it also reduces cost of transport and danger of breakage in transit.[4]

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[1] See Table 1.

[2] Weil & Anhorn, op. cit., p. 135; and Modern Plastics Encyclopedia and Engineers' Handbook (16th ed.; New York: Plastics Catalogue Corp., 1951), p. 159.

[3] J. B. Singer, Plastics in Building (London: The Architectural Press, 1952), p. 7.

[4] Ibid., p. 92.

It is also due to these light weights that Barron says: "Weight for weight, cellulose and silk are stronger than steel"[5]--which will be discussed later.

Color

It is not as advantageous as it seems at first sight that plastics have a "complete color range" and "unlimited color possibilities."[6] Having no characteristic colors of their own, plastics were subjected to all the treatments (and maltreatments) possible, and were thus secured no position in the world of materials and colors.

In the earlier period, phenolic resins were limited to browns and black, but when urea-formaldehyde resins were found to be glass-like, and when in rapid succession the other types of plastics appeared, the novelty of bright--the brightest possible!--colors began, along with that of transparency. (Perhaps this was not only for the novelty, but also to draw the attention to plastics and to differentiate them from the traditional materials.) Then "pastel" shades became fashionalbe, and the novelty of bright colors wore out--but not completely, though:

> "Corroplast" sheets are produced in a variety of colours, including dark chocolate brown . . . and pastel stove enamelled blue, pink, green, French grey, white and cream. This wide choice of colour makes it possible to give new life and vigour to town buildings, in contrast to the dull monotomes of the traditional roof coverings.[7]

Another approach to the problem of color (and to avoid sales resistance) was to imitate other materials; amber, marble, ebony,

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[5] H. Barron, Modern Plastics (London : Chapman & Hall, Ltd., 1949), p. 87.

[6] See Table 1.

[7] Singer, *op. cit.*, p. 55.

horn, stone, and the like, as some trade names indicate: "Amberlite," "Marblette," "Plexiglas," "Rockite," etc. In fact many plastics were originally developed to substitute for unavailable materials. And this is still going on:

> [A] wallet made of 20-gauge vinyl embossed to resemble leather grains, . . . lined with 4-gauge vinyl embossed to look like satin . . . made in calf, ostrich, alligator, and other finishes.[8]

and:

> "Vinyl Plants are True to Life"
>
> Interior decorators, following the current trend to 'bring the outdoors in,' are now using plastic plants and foliage in many hotels and stores because of the advantages which they offer over natural flora. As attractive as natural leaves, the plastic reproductions require no care except an occasional wiping, will last virtually forever, and are highly fire-resistant.[9]

We may fear that plastics may come to be cast into transparent Corinthian capitals, or that real flowers be incorporated into plastics wall panels as an improvement over wall-papers!

Another problem arises from the fact that colors have to be chosen from the "unlimited possibilities;" namely, such specialists as the

> nation's foremost home-color consultant and interior designer, color stylist of more than 65,000 homes,[10]

and the color consultant who claims that

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[8] Advertisement, Modern Plastics, XXVIII, 7 (March, 1951), 77.

[9] Ibid., XXVIII, 10 (June, 1951), 94. Imitation seems to be the normal procedure adopted throughout history. Materials gave way one to the other, but forms lingered behind until the characteristics and limitations of the newly-adopted materials became better understood, and were then expressed in the architecture. Egyptians started by transferring reeds forms to stone; Greeks imitated wood with marble (and never changed); Romans followed Greek forms, but with concrete, and so on down to the nineteenth and early twentieth centuries' steel architecture with Renaissance façades. It seems that since unfamiliar ideas (objects, materials, etc.) are not readily accepted (pending examination and evaluation), an imitation that looks like a thing is accepted by association as being like it--or even pass unnoticed.

[10] Avertisement, The Saturday Evening Post, CCXXV, 18 (November 1, 1952), 127.

> for instance, the general wall color of a bank interior may be chosen to influence clients toward feeling either that the bank welcomes small accounts or that it prefers the patronage of the exceptionally well-to-do,[11]

and who describes colors as "edible," "repellent," "hospitable," "soothing," "exciting" and "depressing";[12]

The theories of color are long and complicated, and involve art, philosophy, psychology, and even fashion and taste. But to the architect, plastics pose no new problems; he has always dealt with colors, whether in selecting natural materials or in designing interiors and furniture.

Nor does transparency in connection with color pose new problems, except that the characteristics of the new materials will have some influence on the results, as we shall see later.[13]

Surface, Texture, and Finish

An important fact about plastics is that they lack a surface texture of their own to distinguish them from other materials (which is also the case of all the materials that are "plastic" in the traditional sense, such as clay, cement, glass, and even steel and bronze). While manufacturers were experimenting with colors, they were therefore also trying to force textures upon plastics products: mottled effects, wavy lines, and imitations of wood-grain, leather, and the like. Others are contented to groove the large sheets with regular rectangular patterns to simulate ordinary tile joints. (This recalls the way linoleum was first treated, and the

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[11] J. E. Garnsey, "Color in Architecture," in T. Hamlin (ed.), Forms and Functions of 20th Century Architecture (New York: Columbia University Press, 1952), II, 269. (I think that, once inside the bank, it would be easier to enquire at the information desk!)

[12] Ibid., fig. 327 facing p. 270.

[13] See "Stained-glass Windows," p. 18 of this study.

way large mirrors were grooved in rectangles and fitted together with rosettes to simulate the method of setting small mirrors.) But somehow it is almost always possible to distinguish materials even when under disguise, because their natures force themselves through the applications, and the maltreatments then look just what they are: illogical, ugly, and undesirable.

> There is nothing ugly in art except that which is without character, that is to say, that which offers no outer or inner truth.
> Whatever is false, whatever is artificial, whatever seeks to be pretty rather than expressive, whatever is capricious and affected, whatever smiles without motive, bends or struts without cause, is mannered without reason; all that is only a parade of beauty and grace; all, in short that lies, is ugliness in art.[14]

A second distinctive feature is that, due to manufacturing techniques, and to the light weight and the shatter-proof quality which facilitates transportation and handling, plastics come in large units when prefabricated, and in continuous lengths when in film or sheet form. When used in architecture, joints lines will be reduced to a minimum, if not entirely eliminated. Thus, tile patterns and brick bonds that have always accompanied (not to say haunted) architecture since the dawn of history can now be dispensed with (fig. 1).

The third feature, also a product of technical skill and accuracy, is the uniformity of color, thickness, dimensions and finish, which resultsin a structural and visual perfection. [2]

Textures of new and interesting effects automatically result when plastics are mixed with the fillers and other materials that are used to modify or improve their qualities, in which cases the architect will have on hand materials with pre-determined colors and textures, and the matter of choice is eliminated, and the case becomes similar to that of traditional materials.

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[14] Auguste Rodin, Art, trans. Mrs. Romilly Fedden, from the French of Paul Gsell (Boston: Small, Maynard & Co., 1912), pp. 46-47.

Metal inserts and reinforcement in transparent plastics can also be of great esthetic values if well treated so as to serve both strength and beauty requirements, and not either one alone (fig. 2). For to fulfill strength requirements alone (as in reinforcing concrete) is too mechanical, utilitirian and materialistic; and to be merely decorative is illogical and trivial.

The architect should not lose sight of this point, for so often does the scientific habit inhibit the artistic.

CHAPTER TWO

OPTICAL PROPERTIES

Transparency

Except for the phenolic resins and a few other types, all plastics are transparent in their pure form.[1] However, in many cases they have to be filled or used in connection with other materials to modify their properties--and that renders them opaque. Urea-formaldehyde resin, for example, was first introduced in the United States as a "synthetic organic glass" ("Aldur"), but then it had to be filled with wood flour to overcome its tendency to crack.[2] Cellulose nitrate was also used in airplanes as a glass substitute (to save weight), and was reinforced with a fine wire mesh which did not reduce the transparency of the sheet appreciably--but it turned brown in sunlight, tended to shrink and craze with age,[3] and therefore had to be given up.

In great contrast to these early trials are the acrylic resins--developed in Germany and transferred to the United States in 1931[4] ("known for a very long time [1843] although the commercial application is of very recent date"[5])--of which the most outstanding is methyl methacrylate whose light transmission is "superior to

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[1] See Table 2.

[2] Weil & Anhorn, op. cit., p. 38.

[3] J. Stockley, Science Remakes our World (rev. ed.; New York: Ives Washburn, Publisher, 1946), p. 42.

[4] Weil & Anhorn, op. cit., p. 35.

[5] Barron, op. cit., pp. 565-566.

anything else known at the present time."[6]

Glass does not allow all the light to pass through, and the thicker the glass the less the passage of light; thus it is difficult to see any object through glass which is more than six inches thick. On the other hand, articles seen through slabs of methyl methacrylate three feet thick are as clear as if no obstacle were intervening.[7] Its transparency to white light is over 95 per cent[8] and to ultra-violet light 60 per cent, where glass becomes opaque.[9]

Its major use is in aircraft (transparent bomber noses), and bullet-proof "glass" for military vehicles, since thick sections of it are "as resistant to shock as armour plate,"[10] and when they do break, "large pieces are formed without cutting edges."[11]

It is also dimensionally stable, will not discolor or craze, and has better insulating properties than glass.[12]

For windows, then, and for walls--transparent and translucent--acrylic resins seem to be superior to glass, not only for hospitals and sanatoriums, but also for homes and apartments. And they present no problems in design or application; they would be treated like glass, except for a little more space for expansion since their coefficients are higher.

Acrylic resins have two main disadvantages, which, however, can be remedied:

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[6] _Ibid._, p. 574.

[7] _Ibid._, p. 577.

[8] See Table 2.

[9] Barron, _op. cit._, p. 585.

[10] _Ibid._, p. 577.

[11] _Ibid._

[12] See Table 3.

1. Their soft surfaces, which scratch easily, can be easily restored by polishing with special compositions (such as "Plexipol", "Rhodopol"[13]), or by coating with a film ("about one ten-thousandth of an inch thick"[14]) of glass.

2. They have low softening points which may impose some restrictions upon applications, but not in ordinary cases, however, and besides, heat-resisting types have been developed.[15]

These low softening points were made use of, by Frank Lloyd Wright, to form a transparent dome of acrylic sheets softened

> with a revolving bank of infra-red lamps until pliable, then draping them against a female mold to cool.[16]

(This dome, however, is not used structurally, and is mounted in steel H-channels.[17] And the new dome suggested for the Guggenheim Museum in New York did not meet the city's requirements for a roof "with a $1\frac{1}{2}$-hour fire-resistant rating."[18])

Singer suggests as an application, a translucent panel wall that would

> filter out the hot infra-red rays and allow only the purifying ultra-violet rays to pass, or, in reverse, allow only the infra-red to enter the room. This could be carried even further by replacing the panels at certain times of the year. . . . These theoretical considerations cannot, however, materialize at present, due partly to our still imperfect knowledge of this subject and the uneconomical aspects of the

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[13] J. Delorme, "Conditions imposées aux Matières Plastiques en vue de la Construction," in P. Burelle *et al.*, *L'Extension des Matières Plastiques dans le Bâtiment* (Toulouse: Les Editions Amphora, 1949), p. 28.

[14] H. R. Fleck, *Plastics, Scientific and Technological* (Brooklyn, New York: Chemical Publishing Co., Inc., 1945), p. 167.

[15] Barron, *op. cit.*, p. 588.

[16] *Modern Plastics*, XXVIII, 9 (May, 1951), 77.

[17] *Ibid.*

[18] *Architectural Forum* (April, 1952), p. 141.

enterprise, although other possibilities, e.g. light-diffusing panels, are feasible[19]--
but not very desirable.[20]

A possible application for transparent, thermoplastic sheets, and a more practical one, is in *"stained-glass" windows*. Figures 3 to 6 are designs for windows (which can be equally used for panels and partitions), which demonstrate how new characteristics and techniques can result in designs different from those of conventional stained glass.

These windows would be composed of two large sheets (or smaller ones welded together) of a transparent plastic, between which would be incorporated pigments, colored plastics films, small pebbles, air bubbles, or any other suitable matter, together with metal strips (which may also act as reinforcement). All these would be arranged in their positions, heated with a battery of infra-red lamps, and rendered one solid unit.

Such windows would have the following advantages:

1. They would free the designer from the limitations of the conventional technique. Colors can overlap and flow from one area into another without having to be guided by the metal strips. They can change tone or intensity at will, and the introduction of pebbles or air bubbles would create new visual experiences.[21]

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[19] Singer, *op. cit.*, p. 155.

[20] I fear that if such walls become possible, roofs will follow, and then it would not be so healthy for the house as a whole. Houses and apartments shrink in size, and families are pressed into smaller and smaller living space, every time a new idea or invention makes it possible. Folding partitions, for example, together with couches which can be turned into beds at night, give the family smaller space under a false impression of spaciousness. ("Flexibility"!) These ultra-violet roofs can be reason for more pressure since only health requirements now prevent home-builders from designing interior rooms.

[21] Speaking of new visual experiences, transparency can also be effectively used to produce such designs as that shown in fig. 7, in which opaque elements are supported on transparent ones.

2. The design would be protected inside the plastics sheets, the external surfaces of which would be left clear and smooth for easy periodic cleaning, and polishing when necessary.

3. It would be easier to construct and erect these windows, compared to the tiresome, inexact, and slow process of soldering lead sections and assembling small pieces of colored glass.

Refractive Index

Transparent plastics have higher refractive indices than most of those of the different types of glass and other transparent materials.[22] To this characteristic is attributed the phenomenon of "piping" or "tubing" light around bends by internal reflection (fig. 8).

> This action is so effective that rods of methyl mathacrylate plastic, even when tied into complex knots, will transmit light perfectly. An object or picture at one end is clearly visible at the other.[23]

Light emerges only (a) at sharp corners or bends (fig. 8), (b) where the surface is frosted, or (c) where a reflective or refractive surface is introduced into the path of the light rays, and (d) it will "leak" where there are scratches or irregularities on the surface of the plastic.

This phenomenon has been made use of in edge-lighted panels with concealed light sources, such as in display, exit and elevator signs, and in instrument panels.[24]

The floor lamp (fig. 10) makes use of this "piping" phenom-

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[22] See Table 2.

[23] Barron, op. cit., pp. 586-587.

[24] It is always noticed that light is never evenly distributed on the letters of these signs. This is because the letters are etched to the same depth, whereas, for a uniform distribution of light, they should be either of increasing depths in order to receive equal amounts of light, or the sign itself be made of a diminishing thickness (fig. 9).

enon. Light would travel unseen through the long flexible plastics rods and emerge at the curved end-piece. The flexible rods can be bent in a goose-neck fashion so that light may be directed at will; and the end-pieces are so shaped as to act as lenses in concentrating light at near distances, for reading, and in spreading it over large areas at long distances, for general lighting.

The lamp can be used free-standing or combined with furniture. The sturdy base, containing the light source, can be used as a support for a table (fig. 11).

Figure 12 is another design for a ceiling lighting fixture also making use of internal reflection. When the screw at the bottom of the fixture is turned, the mechanism, composed of the reflector and the pivoted plastics blades, moves, and directs the light rays inwards or outwards by internal reflection in the blades, thus concentrating light or distributing it.

It has been suggested that a huge light source be placed in the basement of a building, along with the other equipment, and that light be "piped" to the rooms much as heat is piped.[25] But this means that that light source would have to be turned on all the time so that the occupants of the building may be able to use it any time at will--a big waste of energy. A more effective and economic solution is that a plastics wall be made so as to be

1) load-bearing, if possible,
2) finished, requiring no surfacing material,
3) translucent, with a light source of its own concealed underneath it, and
4) decorative:
    a) painted with translucent or transparent paint,

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[25] Weil & Anhorn, op. cit., p. 147.

b) with sculptured pieces of plastics applied to it, or

c) with incorporated designs such as those described for "stained-glass" windows.

It is along such lines that plastics can be advantageously used, performing several functions simultaneously.

CHAPTER THREE

THERMAL PROPERTIES

The effect of heat on plastics materials is a long and controversial subject, and constitutes the main limitation on their use in architecture, especially the structural ones.

In relation to heat, plastics materials can be classified into two main divisions: thermoplastic and thermosetting[1]--depending upon the type of polymerization (i.e. the linking-up of monomeric units into long chains). If it is in one or two dimensions, the material is thermoplastic; and if it is in three dimensions or with crosslinks between the different chains, the material is thermosetting.[2]

Thermoplastics soften with heat and harden when cooled, and the cycle is capable of infinite repetition. They can be softened every time heat is applied. In contrast, thermosetting materials soften only once, when they are molded or shaped the first time, and are permanently hardened and cannot be melted or softened again.

The great popularity of thermoplastics is due to their particular characteristic (thermoplasticity) which enables mistakes to be rectified, and which saves material by making it possible to melt and re-use scraps and damaged pieces; and in manufacturing, it permits welding and cementing pieces together. Thermoplastics also "soften at temperatures low enough for easy manipulation, but high

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[1] See Table 3.

[2] Harron, _op. cit._, pp. 88-90.

enough to maintain rigidity at working temperatures."[3]

Thermosetting plastics include the phenolic resins, the urea- and melamine-formaldehyde resins, and the alkyd (glyptal) resins. The advantages of using thermosetting plastics are that they withstand higher temperatures than thermoplastics, and that there are many applications in which no possibility of softening should be present once the article is put in its final form.

In connection with wood, phenolics and formaldehyde resins play important parts in gluing, bonding and lamination, due to their compatibility with wood, and due to their resistance to solvents and weather extremes.

Thermosetting resins char when over-heated but do not melt or burn like thermoplastics, and are therefore suitable for construction work, and are less hazardous than wood itself.

Also, while passing through the plastic stage, thermosetting materials can be dissolved in many solvents, and emulsions can thus be made. This property is made use of in preparing lacquers and impregnating materials which can later be brought to their final stage at normal temperatures with or without the help of accelerators and hardeners.[4]

"Elastomers" are sometimes distinguished as a third type of rubber-like plastics, combining some of the properties of the two other groups. An elastomer is actually any flexible or elastic material.

> In a more limited sense, this term is used with reference to plastics that are chemically different from natural and synthetic rubbers, although they may have many of the physical

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[3] _Ibid._, p. 23.

[4] Singer, _op. cit._, p. 12.

properties of the latter.[5]

Inflammability

Versatile plastics present a complete variety of reactions to fire.[6] On one extreme, cellulose nitrate is *highly inflammable* "because of its close relation to guncotton."[7] The billiard balls for which it was originally invented, exploded sometimes, when they came near a flame, with a loud report that caused a Colorado pool-room operator to complain because it made the customers all pull out their guns![8] Because of this high inflammability, the pioneer of plastics that once boasted of about 25,000 applications,[9] is hardly ever used nowadays. It has been replaced by cellulose acetate and the other cellulose plastics which do not support fire (but which sometimes do not quite match some of its excellent properties[10]).

On the other extreme, there are some thermosetting plastics, such as urea- and phenol-formaldehyde, which may char when overheated, but do not burn, and are actually used for fire-proofing other materials, *including wood*, such as in transportation, where

> partout, le feu est une crainte constante, d'autant plus que le bois est, jusqu'ici, le matériau le plus employé. Son remplacement ou, pour mieux dire, son conditionnement à l'aide des résines synthétiques, permet de réduire considérablement les risques d'incendie ou, tout au moins, la propagation des flammes qui a occasionné et provoque encore de si terribles catastrophes.[11]

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[5] T. A. Dickinson, *Plastics Dictionary* (New York: Pitman Publ. Corp., 1948), p. 92.

[6] See Table 3.

[7] Stockley, *op. cit.*, p. 37.

[8] *Ibid.*, n. 1, p. 37.

[9] H. H. Bunzell and S. Misenson, *Everyday with Chemistry* (New York: Grosset & Dunlap, 1937), p. 57.

[10] Burelle *et al.*, *op. cit.*, pp. 246-247.

[11] R. Michon, "L'Aménagement des Moyens de Transport," in Burelle *et al.*, *op. cit.*, p. 197.

And there are also some new wallboards, in which the proportion of raw materials is 90 per cent sawdust and 10 per cent cresol-formaldehyde resin, the main advantages of which are "the possibility of covering large areas, good insulating properties, and a fire resistance better than that of wood, due to the resin content."[12]

Also, there are plastics that, by virtue of the chlorine content in their chemical composition, are self-extinguishing, such as polyvinyl chloride (depending upon the plasticizer used), polyvinyl chloride-acetate, and polyvinylidene chloride.

The rest of the plastics burn slowly but present no fire hazard. The acrylic resin, for example,

> burns slowly when exposed to a naked flame, but is not readily ignited; it can be easily extinguished, but its fire-resisting property is inferior to glass. It conforms, however, to by-laws, and is not regarded as more combustible than wood.[13]

There are many remedies for inflammability (as will be seen later), and there is no cause for concern, from that point, over the use of plastics in architecture and non-bearing elements, as they may be applied"without elaborate precautions."[14]

It is actually within the problem of heat distortion[15]--the softening and melting of plastics at low temperatures (which may not be a serious limitation in the field of domestic and personal articles)--that the possibilities of plastics are "almost boundless."[16] This is the main reason why plastics in their pure form can only be

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[12] Singer, op. cit., p. 108.

[13] Ibid., p. 58.

[14] J. Delmonte, Plastics in Engineering (2d. ed., "Machine Design Series"; Cleveland, Ohio: Penton Publ. Co., 1942), p. 184.

[15] See Table 3.

[16] MacTaggart & Chambers, op. cit., p. 156.

used to a very limited extent in architecture, and even less so in engineering.

Some plastics cannot even stand to the boiling point of water, and others have to be used most carefully:

> The maximum temperature the [laminated] sheets can withstand is 120° C. and when used for table tops care must be taken not to place on them hot irons or cooking utensils which may leave marks that cannot be removed.[17]
>
> The [polyvinyl-chloride floor] tiles do not support combustion, but owing to their thermo-plastic nature they should not be laid in proximity to heat sources, which may cause curling of the edges.[18]
>
> The low melting-point (115° C.) [of polythene tubes, developed for cold water plumbing installation] imposes a limitation in the use of polythene pipes to liquids below the temperature of 65° C. (149° F.),[19]

and so on.

Other effects of heat include the lowering of the tensile strength, excessive cold flow, loss of plasticizer (with resulting embrittlement, shrinkage, crazing and loss of finish and color), while other plastics undergo "a fundamental change in structure at the transition point."[20]

Remedies for Inflammability and Heat Distortion

> Indeed a great deal of the research work which is continuously being carried out in laboratories throughout the world is directed to improving stability under hot conditions,[21]

and there is already available a very large number of patents for eliminating or decreasing the inflammability of plastics, as also

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[17] Singer, op. cit., p. 105.

[18] Ibid., p. 119.

[19] Ibid., p. 130.

[20] Fleck, op. cit., p. 136.

[21] MacTaggart & Chambers, op. cit., p. 133.

to increase their resistance to heat. These patents can be divided into several groups, which include the following:

1. The incorporation of non-inflammable materials, or the treatment with chemical compounds that contain chlorine, borax, phosphates, and the like.
2. The curing, or thermal treatment of plastics, such as the following French patent:

   > On élève le point de ramollissement par un traitement thermique: 8 heures à 80°, puis 24 heures à 85°, enfin 72 heures à 90°.[22]

3. The use of plasticizers. Tri-cresyl phosphate, for example, will "eliminate the fire hazard of the plastics which support combustion."[23]
4. The use of fillers, which are "not cheapening or adulterating agents, but definite integral ingredients which are necessary to obtain certain specific properties."[24]

   > The maximum working temperature of phenol-formaldehyde is about 300° F. [149° C.]. The use of fillers allows the temperature to be raised to 500° F. [260° C.] with asbestos, to 600° F. [318° C.] with fibre-glass, and to 1000° F. [538° C.] with mica splittings,[25]

   and these are the fillers usually used for heat resistance. (Other fillers, such as wood flour, macerated fabrics, cotton flock or linters, kaolin, china-clay, slate powder, and the like, are used to ameliorate other properties.[26])

The disadvantage of some fillers is that, at the same

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[22] BF 780.289 (1935), Dynamit, A. G.; see Burelle *et al.*, *op. cit.*, p. 242.

[23] Delmonte, *op. cit.*, p. 184.

[24] Fleck, *op. cit.*, p. 175.

[25] Singer, *op. cit.*, p. 15.

[26] Fleck, *op. cit.*, pp. 175ff.

time, they affect some of the other properties of plastics--a point to be carefully studied before using fillers.

Two new basic changes, which have not yet had enough time for study and development, are expected to revolutionize the whole field of plastics. One is to replace the carbon atom in the plastics material with silicon which is closely related to carbon; and the other is to replace the hydrogen with fluorine.

> Naturally, the chemistry of the whole subject is very complicated and so far it may be said that the surface has hardly been more than scratched. Nevertheless, a number of extremely useful materials have been produced on a commercial and semi-commercial scale. They comprise heat-resisting resins which under non-oxidizing conditions can withstand temperatures of up to 932°F. (500°C.) and find particular application in insulating varnishes for electric motors, low-temperature oils, and high-temperature rubbery masses. . . . It would be rash to predict the lines which further development are likely to take, but since the number of compounds which can be made is practically limitless, it will be readily understood that the future, although obscure, is full of interest.[27]

All of these above techniques concern the chemists who do the research laboratory work and "tailor" the molecules.

The manufacturers' approach to the problem is of necessity different. One solution is to simply avoid heat concentrations by incorporating aluminum foil or other sheet metals between the face layer and the core of the composite sheets used for table tops and veneering panels: "cigarette-proof" sheets.

> The foil conducts the heat of burning cigarettes away, and thus prevents damage to the material.[28]

And in products where plastics are only used as bonding agents, such as phenolic resins in plywood, or vinyl resins in floor tiles, the rate of inflammability becomes that of the other materials rather than that of the plastics. Several types of the sandwich and

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[27] MacTaggart & Chambers, op. cit., pp. 133-134.

[28] Singer, op. cit., p. 100.

laminated panels that are now produced are non-inflammable.[29] (But they are still used for partitions only, even though they are advertised as "structural"--an example of the advertisers' liberal use of words.[30])

Load-bearing plastics members will have to be fire-proofed like steel, in which case the only advantages gained by using them would be light weight and the ease of erection; all the other advantages would be cut off by the fire-proofing materials.

Perhaps in low buildings, where the building codes permit the use of exposed steel, the advantages of plastics can be fully utilized, but there is a note of warning from Graf, about concrete construction, which may equally well apply to our case:

> City building departments are prone to allow only just what is provided for in the code--regardless of the merit of any proposed new type of construction.[31]

Linear Expansion

Plastics usually have higher coefficients of linear expansion than traditional materials, and only a few of them are comparable to steel's $1.1 \times 10^{-5}/ ^{\circ}C.$ and wood's $0.6 \times 10^{-5}/ ^{\circ}C.$[32] The expansion and contraction under the change of temperature cannot therefore be neglected in the case of units rigidly connected to traditional materials. They can cause high internal stresses which may cause the falling apart of the structure.

When taken into consideration and allowed for in the design,

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[29] See "Arboneld Panels," ibid., p. 53; and "Plimberite Panels," ibid., pp. 107-108.

[30] See "Plastic-Fiber Structural Panel," Architectural Forum (April, 1952), p. 228; and "Plastic Building Panels," ibid. (March, 1952), p. 218.

[31] Don Graf, Don Graf Data Sheets (2d ed.; New York: Reinhold Publ. Corp., 1949), p. 136.

[32] See Table 3.

however, the amount of expansion is ordinarily a small amount. For example, for a difference in temperature of 65° C. (120° F.), a phenolic-resin panel, four feet wide, would require a maximum expansion space of

$$4' \times 65^\circ \times 7.5 \times 10^{-5} \times 12'' = 0.235''$$

assuming the coefficient to be constant throughout. An acrylic sheet for a window 20 feet wide (or a window molded in one piece), would require

$$20' \times 65^\circ \times 9.0 \times 10^{-5} \times 12'' = 1.4''$$

and for a polystyrene sheet

$$20' \times 65^\circ \times 7.0 \times 10^{-5} \times 12'' = 1.1''$$

A glass window of the same size and under similar conditions expands

$$20' \times 65^\circ \times 0.8 \times 10^{-5} \times 12'' = 0.12''$$

In other cases, the flexibility and stretchability of the materials used, such as in veneering and flooring, and in pipes and ducts, can neutralize the effects of expansion and contraction. Polythene, with the highest coefficient (16 to 18 x 10^{-5}/ C.), is a very flexible material and can stretch 200 per cent, so that it can be safely used for pipes and plumbing installations.

On a percentage basis, the change in length of plastics materials would be a maximum of

$$100 \times 65^\circ \times 18 \times 10^{-5} = 1.2\ \%$$

and a minimum of

$$100 \times 65^\circ \times 1.0 \times 10^{-5} = 0.65\ \%$$

and this minimum is the same as that of most traditional materials.

Thermal Conductivity

Where temperatures are below distortion or melting points, plastics have better insulating properties than stones, bricks, cement, glass, and most materials used in architecture, including wood in some cases.[33] [3] And when designed specifically for insulation (and in fact "many products are manufactured as insulating materials"[34]), the coefficients of thermal conductivity can be lowered further by incorporating air space, expanded plastics, glass fibers, and the like. For example, the British insulating material "Isoflex", made of "corrugated sheets of cellulose acetate stuck together in alternate directions so as to give a composite structure,"[35] has a coefficient of 0.00011 C.G.S. units, comparable to that of granulated cork (0.00010). Resin-bonded glass fibers have a coefficient of 0.000079 C.G.S. units (0.23 B.T.U. units[36])--much better than vermiculite's 0.000091 or asbestos' 0.000100.[37]

In other applications, such as sprays, veneering sheets, or waterproofing membranes, the thinness of the applied film or coat used allows the heat to be transferred to the material underneath, with no resulting concentration of heat to distort the plastics or set them on fire (as in "cigarette-proof" table tops, for example).

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[33] See Table 3.

[34] Singer, op. cit., p. 17.

[35] Barron, op. cit., p. 376.

[36] Singer, op. cit., p. 17.

[37] See Table 4.

CHAPTER FOUR

STRUCTURAL PROPERTIES

Tensile Strength

Compared to steel's 60,000 p.s.i., the tensile strengths of plastics in their pure form fall far short. Cellulose nitrate which was "one of the strongest artificial materials"[1] has a tensile strength of 10,000 p.s.i. Polyvinyl acetals reach 12,000 and urea formaldehyde 13,000, and the strongest plastic now-available is the fabric-base phenolic resin of 18,000 p.s.i.[2]

But it would be erroneous to conclude that plastics are weak and therefore unsuitable for structural uses, for there are several ways in which these lower tensile strengths can be interpreted so that plastics can structurally compare, and even excel, steel in tension:

1. On a comparative weight basis, due to the low specific gravities of plastics, as we have seen,[3] it can be stated that weight for weight, many plastics are stronger than steel. A comparison of strength-weight ratios,[4] of steel and some of the plastics clearly shows this fact. This means that for the same weight, higher strengths can be obtained with plastics, or that in order to develop a certain strength, a saving in weight can result. (This also applies to flexural strength.) But the difference is not so great, however,

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[1] Bunzell & Nisenson, op. cit., p. 57.

[2] See Table 5.

[3] See "Specific Gravity," p. 9 of this study.

[4] See Table 6.

and when compared with prices, the substitution usually proves uneconomic, except perhaps in the cases of resin-bonded wood panels and other laminated materials which attain an "extremely high ratio of strength to weight."[5]

2. What is more striking that Table 6 shows is the phenomenal strength of glass fibers and other filaments.

While the ultimate tensile strength of bulk glass is about 10,000 p.s.i., it varies <u>inversely</u> with the area, so that commercially available fibers of 0.0002 to 0.00025 inches in diameter have from 250,000 to 500,000 p.s.i. tensile strength,[6] and "in several tests, strengths of 3,500,000 p.s.i. have been reported on fibers 0.00005 inches in diameter."[7]

And even though plastics fibers do not reach such high values, yet they develop 20,000 p.s.i. (soya-bean fibers[8]), 30,000 p.s.i. ("Saran;" polyvinylidene chloride) and 60,000 p.s.i. (nylon, which drops to 43,000 when wet[9]). Knowing that since all these are "brittle" materials, i.e. they have no elastic limit like steel's[10] or that their elastic limits are high up on the scale, the working stresses can be greatly increased beyond steel's 20,000 p.s.i. These synthetic fibers were primarily developed for textiles to be used in furnishing and upholstery, but their high strengths attract the attention and give rise to a new field of application: reinforced

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[5] Barron, op. cit., p. 282.

[6] H. G. Engel, C. B. Hemming, and H. R. Merriman, Structural Plastics (New York: McGraw-Hill Book Co., Inc., 1950), fig. 3.4, p. 53, borrowed from F. O. Anderegg, "Strength of Glass Fiber," Ind. Eng. Chem., 31, 290 (1939).

[7] Murphy, op. cit., p. 334.

[8] Fleck, op. cit., p. 226.

[9] Barron, op. cit., p. 634.

[10] Under normal conditions, glass fibers obey Hooke's law from zero to ultimate stress. See Engel, Hemming & Merriman, op. cit., p. 53.

plastics, especially glass-fiber reinforced polyesters.[11]

The field is fairly new and not well explored yet, but there are available such products as car bodies molded of single pieces which required no heat or pressure to mold, and which are "stronger than metal ones."[12] In the field of architecture there are chairs,[13] translucent "structural" panels such as "Resolite"[14] and "Kerr"[15] panels, and other corrugated sheets for roofing, and also pipes that stand up to 220° C. and whose tensile strength "which reaches 50,000 lb. per sq. in., is equal to that of stainless steel."[16]

Glass fibers and polyester resins also have good insulating properties (like other plastics), and can be applied for external uses.

Silicones will play an important part in this field because they act as a bridge between glass and plastics, with "the silicon end of the molecule sticking tight to the glass while the other end cleaves to the plastic."[17] (It was reported that the materials, glass fibers and polyester resins, in some applications, did not stay stuck together and sometimes tended to separate.[18])

3. A theory (the "lockerstellen" theory) puts forward the argument that

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[11] "Polyester" resins are "complex reaction products of polybasic organic acids (acids containing more than one -COOH group) and polyhydric alcohols (alcohols containing more than one -OH group)." (Weil & Anhorn, op. cit., p. 45.) "Typical of the so-called 'unsaturated polyester' plastics are combinations of styrene and allyl resins." (Dickinson, op. cit., p. 225.)

[12] Time, LIX, 7 (February 18, 1952), 98.

[13] Advertisement, Modern Plastics, XXVIII, 10 (June, 1951), 26.

[14] Architectural Forum (March, 1952), p. 218.

[15] Ibid. (April, 1952), p. 228.

[16] Singer, op. cit., p. 134.

[17] Time, LX, 13 (September 29, 1952), 70.

[18] Ibid.

> the full theoretical strength of hardened phenol-formaldehyde resins (4000 kg/mm^2) [5,700,000 p.s.i.] is not attained (in practice 8 kg/mm^2) [11,370 p.s.i.] owing to the presence of flaws in the molecular structure of the resin.[19]

While the architect is waiting for the chemist to solve the problem, he can make sketches and preliminary studies in order to be ready when such resins become available.

4. A method has been developed by Hordern-Richmond, Ltd., to produce a compressed wood, "Hydulignum," of a 45,700 p.s.i. tensile strength. The wood veneers, bonded with a thermoplastic resin, are pressed from the sides as well as from the top and bottom.[20] It is used for airplane propellers, but perhaps will become a building material if its price balances its high strength.

It must be noticed that the difference in temperature has an effect on the ultimate and working stresses of all plastics materials, especially the thermoplastics. Allowance for this fact must be made in the factor of safety.

Compressive Strength

Compressive strengths of plastics[21] are adequate for structural uses, especially those of the thermosetting resins, such as the phenolic, the urea-and the melamine-formaldehydes.

Attention must be drawn, however, to one important thing about compression: it is always accompanied with buckling which would have otherwise permitted the use of smaller cross-sections and slenderer columns. This means that a strong material is wasted when used in compression, since it is not safe to exceed a certain slenderness ratio. This will be more wasteful in the case of plas-

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[19] Fleck, op. cit., p. 171.

[20] Singer, op. cit., p. 53; and Fleck, op. cit., pp. 241-242.

[21] See Table 5.

tics where partitions are only one or two inches in thickness. It may be found necessary, therefore, to suspend whole floors from girders or trusses overhead (fig. 14), rather than to support them on columns as usual, in order to avoid the whole problem and to make economic building possible at all.

Flexural Strength

As in the case of tension, plastics are also stronger than steel in flexure--on a comparative basis--, and further strength can also be gained in several ways:

1. In designing a stronger member by increasing its cross-section (as when adding cover plates to beams, for example, or when choosing beams with larger flanges), weight in the case of plastics is less than the corresponding weight in steel.

2.
> The flexural strength and rigidity [of boards and panels] are greatly improved by the use of a ribbed or honeycombed core, and the development of synthetic resins should contribute to the progress and utilization of low-density materials combined with plastics.[22]

3. In steel construction, there could not have been a worse place to make a connection than where it is (or rather <u>has to be</u>) done nowadays: at the support--where shear and negative moment are maximum. Connections that would reduce the sizes of members by avoiding these points of high stress concentrations cannot be achieved with rolled sections. But with plastics, such connections (figs. 18, 31, 32, 33) are quite in accordance with the nature and forming techniques of plastics.[23]

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[22] Singer, op. cit., pp. 154-155.

[23] The comparison with steel, here and in the above two cases, can be misleading, because plastics sections have not yet been standardized. And there is also a possibility that there will be no such sections. Steel I-beams, channels and all the other shapes are rolled, and rolling is not natural to plastics materials. (See also n. 32, p. 40 of this study.)

4. Since plastics structural members will more likely fail on the tension side,[24] the natural and obvious thing to do is to reinforce them. The few experiments that were done with metal sheets as reinforcing materials gave good results and showed that the principle can be carried further in various new applications.[25]

Further strength should be gained by using glass fibers which are three times lighter than steel, and with plastics filaments, seven times lighter.

In the case of plastics filaments, however, the full strength cannot be secured until the elongation of the filaments takes place. And since that elongation is sometimes as high as 40 per cent (soyabean fibers[26]) and even 700 per cent (nylon[27]), the bonding resin fractures long before the filaments start to act. This immediately suggests prestressing, in similar manners that concrete is prestressed with steel.

The field of prestressing cannot be discussed here.[28] Only a few remarks can be made:

1. Under factory control, it would be easier to prestress plastics than concrete. Light weight would make shipping to site easy if the members are not too large.

2. Large members can be precast or laminated in standardized sections which can be assembled and prestressed on the site. One method of prestressing these sections would be vertically, under their own weight. A narrow platform P (fig. 13) would be suspended from

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[24] Compare stresses in Table 5.

[25] Singer, op. cit., pp. 152-153.

[26] Fleck, op. cit., p. 226.

[27] Barron, op. cit., p. 633.

[28] See A. E. Kommendant, Prestressed Concrete Structures (New York: McGraw-Hill Book Co., 1952); an excellent and up-to-date book.

the prestressing cords, and the precast sections S placed on the platform, one after the other--held in position between the two columns C--until the pre-tensioning force is reached. The platform would then be supported from below to prevent further strain while the rest of the sections are placed. (Or if the total weight of all the sections is not sufficient, extra loads would be placed on the platform to produce the necessary force.) The "grouting" would then be carried out, and after it sets and hardens, the girders would be raised to their final positions in the building (and, perhaps, instead of erecting a special structure for the operation, the prestressing might be performed on the actual supports of the building), and the floors suspended--three or four to a girder. For such a large building as that in figure 14, the girders would be more economical if made as deep as a floor is high, in order not to disturb the module of the façade, and in order that the space inside them may be used for storage, for mechanical equipment, or even as living space just like the other floors. It will be noticed that prestressing with steel would be of no avail, because when steel wires are pre-tensioned to their allowable limit, the elongation (i.e. strain) is of a very small magnitude, and when the external force is removed and the wires contract to their original lengths (or almost their original lengths), a very small stress is exerted on the plastics members because they have lower moduli of elasticity.[29] A numerical example will show this more clearly:

The steel wires are pre-tensioned to 40,000 p.s.i., say.

$$\text{Strain} = \frac{\text{Stress}}{\text{Young's Modulus}}$$

$$= \frac{40{,}000}{30{,}000{,}000}$$

$$= 0.00134$$

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[29] See Table 5.

After the external force is removed, the steel wires return to their original lengths, and exert a compressive stress on the plastics member:

$$\text{Stress} = \text{Strain} \times \text{Young's Modulus}$$
$$= 0.00134 \times 600{,}000$$
$$= 804 \text{ p.s.i.},$$

which is of no appreciable value compared to plastics' compressive strengths.

3. Prestressing has one more advantage in that it is a reversal of the stresses which a structural member is designed to carry, and it is therefore a check on the actual strength of that member. If it is successfully prestressed, it is safe to use in a structure.

Elasticity

Deflection is inversely proportional to Young's Modulus of elasticity,[30] so that when the moduli are low, materials deflect appreciably when subjected to flexural stresses. This, however, is not a reason to conclude that such materials are "therefore, undesirable," as some have,[31] for there are several ways in which excessive deflection can be treated, or used to advantage:

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[30] Deflection may be expressed, for instance, as the integral

$$\int_{L_1}^{L_2} \frac{M\,m\,dx}{E\,I}$$

where M = the moment due to the actual loads, at any point on the beam, at a distance x from the end;
m = a similar moment, produced, at the distance x, by a unit load applied at the point where the deflection is computed;
E = Young's modulus of elasticity;
I = the moment of inertia of the cross-section of the beam at the distance x; and
L_1L_2 = a part of the beam (whose total length is L) for which the values of M and m (in terms of x) are given functions.

[31] Engel, Hemming & Merriman, op. cit., p. 24.

1. The obvious and direct solution is to increase the depths of structural members, and even though such increase would be excessive,[32] it can produce designs that are quite satisfactory--structurally and esthetically (figs. 15, 16).

2. Plastics beams, which will not be rolled like steel, but cast or laminated, can have variable cross-sections--the depths being increased only where necessary (fig. 17).

3. In tall buildings, the whole structural problem can be re-phrased. As the loads and stresses increase, proceeding from the top floor downwards, the *number* of columns, rather than their *sizes*, is increased (fig. 18). Aside from avoiding deflection, this design has other advantages. All floor slabs, beams, columns, window lights and spandrels are standardized, thus eliminating the conventional, gradual increase in cross-sections which results in members that are all different and requiring individual analysis, design and detailing. This standardization lends itself to mass production, facilitates manufacturing, detailing and assembly. Furthermore, all are clearly expressed in the building, with no pretension or attempt at "design" or "art" for their own sake.

4. In some cases, deflection does not have any harmful effects on the buildings, nor interfere with their functions. Instead of wasting effort and material on attempts at preventing beams and spandrels from deflecting, the fact should be *accepted* and used to

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[32] Steel's modulus of elasticity (30,000,000 p.s.i.) is from 6.70 to 20.0 times those of phenolic resins, for example, and 50.0 times that of acrylics. To increase the value of I in the above equation (n.30, p. 39) by the same ratio means that the breadth and depth of a section should be increased from 1.61 to 2.65 times.

This is another reason why it was said that comparisons with steel can be misleading (n. 23, p. 36), and assembled, precast sections were suggested (pp. 37-38) because while they are deep enough to meet flexural and deflection requirements, they are also hollow so that pipes and ducts can be run through them, and it may be possible to make them so deep as to accommodate whole floors.

advantage in design (figs. 19, 20).[33] Again, such buildings would be quite expressive of their materials and their characteristics, and would look natural and "relaxed." (The shape of the roof of the stadium in figure 20, with its excessive sag, can be suitably adapted to auditoriums and other buildings in which acoustics is an important factor.)

5. Low moduli of elasticity mean <u>resiliency</u>: and just as there are

> miscellaneous engineering designs which require these low moduli of elasticity for the load-deforming characteristics imparted to the structural member,[34]

there are also many uses in architecture for resilient materials that have the ability to absorb shock stresses, stretch when subjected to tension, and contract under pressure. Floor coverings, waterproofing membranes, caulking materials and expansion joints are to name but a few.

"Vinyon," a vinyl plastic that was used for making transparent belts, suspenders and wrist watch straps, some ten years ago, is a flexible material and has a "lazy return, gradually resuming

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[33] Any similarity between these designs and some of those executed in reinforced concrete, in some countries, only shows the insignificance of the shapes of the concrete ones. Whereas the sag of the plastics frames is due to the actual deflection of the materials used, it has no meaning in concrete, and proves that it was done simply for "design" effects.

Concrete is "plastic" in a sense, but it is quite different from real plastics, both in behavior and methods of execution: 1. Concrete is poured on wood forms, and any unusual shape means extra and excessive labor, while plastics are cast, extruded or laminated into sections which span the whole length with single pieces and which are spot welded or glued together. No forms are required: only temporary supports until the structure is erected. 2. Concrete becomes hard and stone-like after setting, with no trace of elasticity and plasticity left, while plastics remain pliable and flexible, and their low moduli of elasticity cause them to sag. 3. Any deflection in a concrete member results in cracks, and can cause the failure of the member, while deflections in plastics members can be excessive without any harmful effects, as the materials are apt to "give."

[34] Delmonte, <u>op. cit.</u>, p. 172.

its original size and shape."[35] This "lazy return" suggests an interesting application: a door without hinges or unsightly closers. The whole partition (figs. 21, 22), not necessarily transparent, would be made of one sheet, and the door formed by simply cutting along the top and one of the two sides. The other "hinged" side would be defined with a mullion, running from floor to ceiling, which would also serve to strengthen the whole partition. (The cut which defines the top of the door may have to be extended a few inches beyond the mullion in order to prevent any tear that may result from fatigue after long usage.)

The same principle can be applied to windows, "hinged" from one side or from the top.

As they are "brittle" materials, i.e. have no elastic limits, plastics, when overstressed, give no indication before they "snap off short like a carrot."[36] And naturally there is also a certain amount of creep superimposed on Hooke's law,[37] which occurs when plastics are permanently stressed.

> Vinyls and acrylics are particularly subject to it, but urea and phenolic resins are not greatly affected.[38]

But it is for such reasons that there are factors of safety.

These are purely engineering considerations, and the architect only recognizes these facts and allows for them in his designs. The reason for reviewing them all, as for all other properties, is to form a basic understanding of the whole subject; for when it comes

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[35] Stockley, <u>op. cit.</u>, p. 56.

[36] C. A. Redfarn, <u>A Guide to Plastics</u> (London: Published for "British Plastics" by Iliffe & Sons, Ltd., 1951), p. 97.

[37] Fleck, <u>op. cit.</u>, pp. 149-150.

[38] Singer, <u>op. cit.</u>, p. 15. Vinyls are in general flexible materials, and are not likely to become load-bearing; and if acrylics creep, they would not be different from glass which creeps "under a very low stress." (Murphy, <u>op. cit.</u>, p. 334.)

to individual cases, the facts will have to be scrutinized and worked out in detail. Due to the lack of ductility, for example,

> points of stress concentration, such as holes and notches, initiate cracks which lead to early failure. For this reason the designer of plastic components must avoid sharp corners and other stress raisers.[39]

Allowance for this factor can be easily noticed in all drawings and sketches presented in this study.

Two more purely engineering problems, of no great importance to the architect, may be mentioned here:

1. The modulus of elasticity "is not the same in compression as in tension,"[40] which throws the neutral axis off the center of a cross-section and complicates the calculations, especially when a reinforcing material is involved.

2. The value of the modulus can be varied "depending on the moulding pressure during the process of manufacture."[41]

Impact Strength

This property is of more importance to industrial engineers and machine designers.

For architectural purposes, plastics in general have high impact strength which can be further improved with fillers of fibrous origin, such as cotton fibers, macerated fabrics and the like. Phenolic molding powders, for example, have an exceptional range of high mechanical power, and, with suitable fillers, impact strength becomes "of a very high order in relation to other materials."[42] Cellulose acetate is characterized by "great toughness and impact

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[39] Engel, Hemming & Merriman, op. cit., p. 73.

[40] Singer, op. cit., p. 13.

[41] Ibid.

[42] Barron, op. cit., p. 156.

strength;"[43] ethyl cellulose is "extremely flexible, has great toughness, . . . and has the outstanding property of maintaining its strength and flexibility at very low temperatures,"[44] and is therefore used in safety glass. We have seen that acrylic resins in thick sections are as resistant as armor plate, and when they do break, large pieces are formed without cutting edges.[45] Polystyrene, differing from most other plastics, becomes tougher as the temperature is reduced,[46] and vinyl elastomers exhibit similar behavior.[47]

If early plastics gave the impression that they were brittle and fragile, it was because they were either improperly designed and molded, their thinness was exaggerated to save material and reduce price, or because they sometimes actually became brittle after periods of time due to the loss of volatile plasticizers. All these can be remedied with proper design. And price will be discussed later.[48]

Outstanding examples of shock-resisting materials include telephones, vacuum-cleaner parts, washing-machine parts, etc., and all the semi-structurally products on the market, such as "Duralux,"[49] "Corrulux,"[50] and "Holoplast"[51] panels are shatterproof and possess high impact strength.

Surface Hardness

Lack of surface hardness of many plastics materials imposes

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[43] Ibid., p. 369.

[44] Ibid., p. 400.

[45] See p. 16 of this study.

[46] Fleck, op. cit., p. 147.

[47] Ibid., p. 163.

[48] See pp.59-62 of this study.

[49] Architectural Forum (January, 1952), p. 200.

[50] Ibid.

[51] Singer, op. cit., pp. 81-82.

some limitations on their uses, for no organic material has yet been developed that can withstand abrasion like glass. But it is a serious drawback only when transparency is a factor in the application. Thus, with methacrylates,

> optical clarity is very exceptional . . . but unfortunately the surfaces are somewhat soft in comparison to glass and . . . are prone to damage by air-borne dust and abrasive materials.[52]

And it is also a drawback, but not as serious, where the materials are subjected to excessive abrasion, such as in floors and table tops, because scratches are not as easily noticed as they are on transparent materials, and therefore do not mar opaque, decorated surfaces--especially when the decoration is an integral part of the material and not only "skin-deep."

Otherwise, the resistance that plastics have for abrasion is sufficient for all practical purposes. They are not more prone to damage than the traditional finishing materials that are ordinarily used in buildings.

Of the materials that have good properties in this respect are the urea-formaldehyde resins which are "very hard, resist abrasion and scratching,"[53] nylon, which has "exceptionally good resistance to abrasion,"[54] and melamine resins.[55]

Of the transparent materials, a series of tests showed that

> cellulose acetate had the greatest resistance to abrasive action, followed by Vinylite sheeting, methyl methacrylate sheeting, and poly-styrene sheeting, in that order.[56]

Still, there are several remedies and protective treatments

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[52] Fleck, op. cit., p. 167.

[53] Barron, op. cit., p. 225.

[54] *Ibid.*, p. 634.

[55] Fleck, op. cit., p. 211.

[56] *Ibid.*, p. 169.

for the materials with insufficient resistance:

I. Regulating the amount of plasticizer:

> Reduction in plasticizer content will increase hardness appreciably for cellulose derivatives.[57]

II. Regulating the time of curing:

> The hardness of cast phenolics are [sic] controlled by regulating the length of time they are maintained at an elevated temperature during the final curing operation.[58]

III.

> Improvements in methods of controlling polymer-forming reactions might be expected to help towards a solution of this problem [of lack of surface hardness].[59]

IV. Coating with various materials with hard surfaces and resistance to abrasion. The argument for coating materials is that while they provide protection from abrasion, at the same time, they also remedy weathering effects, moisture absorption, and, (if good conductors), static electricity.

A. Coating with glass. This has been applied to methacrylates in cases where clarity and optical qualities are of the greatest importance. A film of about one ten-thousandth of an inch is sufficient for protection,[60] and is thin enough neither to interfere with the optical properties nor to cause any difficulty due to dimensional changes.

B. Coating with metals[61]--which renders plastics good

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[57] Delmonte, op. cit., p. 174.

[58] Ibid.

[59] MacTaggart & Chambers, op. cit., p. 143.

[60] Fleck, op. cit., p. 167; also p. 17 of this study.

[61] This method may be of limited use, since, aside from hiding the materials behind them, metals themselves need to be protected from weathering and rusting, and one way of achieving such protection is to coat them with plastics! For more details on coating with metals, see D. W. Brown, Handbook of Engineering Plastics (London: George Newnes Ltd., 1943), Ch. X, pp. 137-151.

conductors of heat and electricity. This can be done in several ways:

1. The sticking on of a metal sheet, either during the manufacturing of the plastics product, or applying it later (and plastics adhere firmly to metals[62]).

2. Metal sprays--a technique that is limited to metals with low melting points, (as for example, tin, aluminum, zinc and lead[63]) because otherwise the plastics can melt or be scorched or damaged.

3. The chemical depositing of a layer of silver in a similar manner to that in which mirrors are made, after which any metal capable of electro-deposition can be plated on to it.[64]

C. Coating weak plastics with others of harder surfaces, such as melamine and urea formaldehydes, alkyd resins and silicones. Those latter, "bridging the gap between completely organic and inorganic products,"[65] have possibilities in rendering plastics resistant to many of the corrosive and destructive factors. Phenolic varnishes also can be used provided heat can be applied to the product, because it is necessary to cure the varnishes to cause them to harden and solidify.

V. Polishing with the special compositions and varnishes that have been developed:

> On pourra en tenir compte, quoique la possibilité de repolir facilement ces surfaces [des matières trans-

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[62] See also "Gluing," pp. 71-74 of this study.

[63] Brown, op. cit., p. 144.

[64] MacTaggart & Chambers, op. cit., p. 136.

[65] Barron, op. cit., p. 670.

> parentes] avec des compositions spéciales (Plexipol, Rhodopol) permette de réduire cet inconvénient,[66]

which is similar to waxing floors,[67] and which seems to be a practical and convenient method that is quite applicable to buildings.

VI. Finally, there is the advice not to stress transparency unnecessarily, because, as said before, insignificant scratches show easier on transparent surfaces and detract from their beauty, while on opaque surfaces or even translucent ones, the effect of scratches would be minimized or even go completely unnoticed. Translucent panels also admit light and ultra-violet rays, and have all the properties of the transparent ones--except transparency itself.

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[66] J. Delorme, "Conditions imposées aux Matières Plastiques en vue de la Construction," in Burelle _et al._, _op. cit._, p. 28.

[67] Vinyl tiles are often advertised as being capable of giving life-long service without needing any waxing, but any flooring material will succumb to wear after a period of time, and waxing and polishing will be found necessary.

CHAPTER FIVE

DURABILITY OF PLASTICS

This factor, durability, which could be equally called permanency, or weathering properties, is actually a group of physical and chemical properties, and not just one. The point is to determine how long plastics can last, when used in buildings, and to what extent they can endure the several corrosive factors that attack them, try to change their nature, and cause them to disintegrate or deteriorate. [4] Among these factors there are sunlight, ultra-violet light, cold and freezing, water obsorption and water penetration, atmospheric pollution, aging, dimensional stability, etc. Some of them affect the used of plastics in exteriors only, while others apply to both exteriors and interiors.

In Tables 7 and 8 are grouped the properties that belong to this section, and from them it can be seen that, with the exception of a few cases--in which some materials undergo slight changes due to one factor or another--none of these factors seem to have an effect that is appreciable enough to be worth elaborate precaution or special treatment. Some materials even improve with age.

The effect of sunlight and ultra-violet light[1] is mainly a discoloring or fading of colors, which is a common property of all organic pigments and coloring materials. But on metallic powders and inorganic compounds, there is naturally no effect. And since transparent materials transmit most of these rays, the effect on them, if any, is no more than a slight yellowing.

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[1] See Table 7.

Of the few materials that are appreciably affected, there is cellulose nitrate which used to turn deep yellow or even brown when used in safety glass. (Cellulose nitrate, however, is not a suitable material for building purposes due to its high inflammability.)

Another material is polyethylene, of the excellent chemical properties. But, again, it is not a building material. It is mainly used as waterproofing membranes and flexible tubing for water and chemicals, under the protection of other materials.

The detrimental effect of sunlight and ultra-violet light on polystyrene is unfortunate because it is otherwise an excellent and beautiful material, and this handicap confines its uses to interiors only.

Water absorption[2] is practically nil in the case of polystyrene, polyvinyl chloride, polyethylene and polytetrafluoroethylene; and is of a very small magnitude in the case of most other plastics. The only material that absorbs a great amount of water is casein, and casein has several other disadvantages (such as weak resistance to chemicals, and poor molding properties) that limit its use to the manufacture of small, non-exacting articles, paints and glues.

The amounts of water absorbed are insignificant:

> Si l'on suppose un film protecteur homogène en plastique de 0,2 mm d'épaisseur, la quantité d'eau qui pourra diffuser à travers cet écran ne dépassera pas 0,25 mmg par mètre carré et par heure pour la matière la plus perméable, soit 6 mmg par jour.
>
> On peut donc dire qu'en ce qui concerne le bâtiment, une telle protection est efficace pour toutes les matières.[3]

But it is the effect of water absorption that calls for attention. In the case of some materials, even though that effect is a "slight

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[2] See Table 7.

[3] J. Delorme, "Conditions imposées aux Matières Plastiques en vue de la Construction," in Burelle *et al.*, *op. cit.*, pp. 19, 21.

swelling," it is sufficient to cause them to warp (hence the not-quite satisfactory performance of some vinyl tiles when used in bathrooms and kitchens, whether it is due to the swelling of the tiles themselves or to that of the glues used--one reason why tiles should not be used at all[4]), or to produce enough dimensional tolerances[5] that can create internal stresses and disjoint rigidly-assembled members--just as thermal expansion and contraction can do.

Also water can always penetrate a crack or a joint--a possibility that seems to call for measures that are contradictory to those required to overcome the effects of swelling; namely, allowing for the movement of the various units by non-rigid assembly.

To meet these contradicting requirements, the solution is (a) that the number of joints in the exterior of a building be reduced to a minimum, (b) that allowance be made still for dimensional changes, where windows and doors are set, and (c) that the gaps be packed with a soft, compressible material such as polyvinyl chloride or one of its rubber-like derivatives with resistance to prolonged flexing, resistance to sunlight, corrosion, moisture and oxidation, and that does not swell in the presence of oils and solvents.[6] A suitable synthetic rubber (foamed, if necessary), or a silicone material, can also perform the same function (figs. 31 to 33).

The surface quality of a material also has an effect on the amount of water absorbed. Tests carried out on molded urea-formaldehyde showed that

> surfaces which have been sanded absorbed considerably more water than those still polished from the mould. Consequently, rough-surfaced mouldings will tend to have a more reduced surface resistivity than polished mouldings, owing to greater moisture content.[7]

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[4] See also "Flooring," pp. 70-71 of this study.

[5] Delmonte, op. cit., p. 195.

[6] See Barron, op. cit., pp. 519-522.

[7] Fleck, op. cit., p. 185.

Unless materials are water-resistant, therefore, they should either be polished or coated with other materials of good resistance. (It should be noted that the "reduced surface resistivity" is advantageous, in some respects, from the point of view of architecture.[8])

A porous material has its advantages too. By absorbing water and allowing it to dry over a period of time, it prevents moisture from running down and spoiling the surface appearance, especially that of transparent materials. But this is the same case as with glass: a periodic cleaning would be sufficient for maintenance in proper condition.

Dimensional stability "compares favourably with that of traditional materials,"[9] and does not present a new problem as long as tolerances due to water absorption and thermal changes are accounted for by avoiding rigidly joining two materials that would behave differently due to unequal dimensional changes. When cellulose-acetate sheets, for example, were reinforced with a wire mesh, "the acetate shrank away from the wire layer and could not be regarded as satisfactory."[10]

Atmospheric pollution, combined with rain water, has, as is well-known, detrimental effects on traditional building materials. But on plastics, most of which are chemically inert,[11] there is no effect. In fact, some plastics are used for the protection of metals (steel structures, cars, airplanes, etc.), and are envisaged as impregnating materials for concrete to improve its resistance.[12]

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[8] See "Electrical Properties," pp. 57-58 of this study.

[9] Singer, op. cit., p. 16.

[10] Ibid., p. 56.

[11] See Table 8.

[12] See "Impregnating Concrete," pp. 69-70 of this study.

Resistance to abrasion by the action of wind and air-borne dust may also be included here. However, abrasion has been dealt with;[13] and by stretching the meaning of durability, most other properties of plastics would be included!

It should be noted that the necessary combinations of properties that made a material durable cannot always be found in every type of plastics material; and therefore only a limited number of them can be used externally. Of these latter, there are the phenolic resins, in connection with woods and laminates; acrylic resins, except for surface softness;[14] the rubber-like polyvinyl alcohol and polyvinyl butyral, of modern safety glass, which seem to be "almost immune to ageing;"[15] cellulose acetate, despite its slight shrinkage with age; silicone plastics; glass-reinforced polyester resins; and several other materials. Even those with shortcomings can be used externally, if well treated according to their particular behavior and individual natures (a) by adding fillers and stable plasticizers--and the patent literature is full of formulas and chemical treatments for these purposes--, (b) by painting and protecting with various materials, including some of the plastics (alkyd and glyptal resins) that are exclusively used in this field,[16] and (c) by chemically producing related compounds with improved properties, such as cellulose nitrate which, being highly inflammable, was substituted with cellulose acetate. (Then the acetate was found to undergo a slight change in dimensions with age due to slow losses of plas-

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[13] See "Surface Hardness," pp. 44-48 of this study.

[14] "Perspex" has withstood well the test of time and has shown good weather resistance and dimensional stability throughout the many years of its use. (Singer, op. cit., p. 58.)

[15] Barron, op. cit., p. 604.

[16] Ibid., p. 641.

ticizers,[17] it was in turn improved upon by the copolymer cellulose acetate-butyrate which has "greatly superior moisture resistance, improved dimensional stability, excellent weather resistivity, and high impact strength."[18])

If some of the articles and products on the market do not possess the properties that would make them durable, it is because they are not intended for such purposes. But when they are, manufacturers formulate them so as to meet the requirements of durability, and many such products (panels, roofing materials, etc.) that are now available are quite resistant and suitable for exterior applications. Window frames made from the cellulosic plastic that was developed in post-war Germany are said to be "for all practical purposes everlasting, waterproof, and never need painting."[19]

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[17] Ibid., p. 382.

[18] Weil & Anhorn, op. cit., p. 43.

[19] Architectural Forum (January, 1952), pp. 86, 90.

CHAPTER SIX

CHEMICAL AND ELECTRICAL PROPERTIES

Chemical Properties

The whole field of plastics is basically chemical, and all research work, discoveries and inventions in it are made by chemists. What interests the architect specifically is whether plastics in their finished state--the way he will be using them--will have, on the whole, good resistance to acids, alkalis and solvents.[1]

Outstanding in its resistance is polyethylene which is used extensively in factories "in chlorine-cell rooms and nitric acid plants;"[2] and polystyrene has an extreme resistance "even to hydrofluoric acid, which dissolves glass."[3] Urea-formaldehyde resins are

> resistant to oxidation, to oil, grease, weak alkalis, weak acids, alcohol and other solvents . . . and are consequently popular for domestic uses [in plates, cups, etc.].[4]

On the other hand, there are casein plastics, the application of which

> has been limited by poor resistance to water, acids and alkalies, so that they are used chiefly for the manufacture of such nonexacting articles as buttons, beads, buckles, jewelry [etc.].[5]

If the architect happens to be designing a laboratory or a chemical factory, he will need more specific information (obtainable from the chemist), but otherwise, in all usual types of buildings, plastics have good resistance to the different types of liquids

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[1] See Table 8.

[2] Singer, op. cit., p. 125.

[3] Stockley, op. cit., p. 46.

[4] Barron, op. cit., p. 225.

[5] Weil & Anhorn, op. cit., p. 15.

commonly encountered.

The architect is, therefore, not concerned with the study of raw materials, their properties and availability; the types of plasticizers and their effects; and the chemical intermediates and their properties. Nor is he concerned with testing plastics to determine the percentage of free ammonia, for example, or the pH value of an aqueous extract. He will use solvents and glues; he will cement and spot-weld plastics parts; but he will not go deeply into their chemistry or the theories of adhesion and the "polar" and "non-polar" materials. Whenever there is an available plastics material with specific properties, it is his job to know how to use it, and whenever he requires another with other properties, he will consult the chemist. For, as Hudnut said, "not invention, but the use made of invention is the measure of an architect."[6] [5]

Atomic Resistance

> Une information, non contrôlée, avait signalé que, lors des essais de Bikini, les pneumatiques de camions, en caoutchouc synthétique, avaient été retrouvés intacts alors que tous les autres matériaux avoisinants avaient été détériorés, ou détruits.
>
> Il se peut que les plastiques offrent une bonne protection aux radiations proprement dites (rayons gamma et neutrons) surtout s'ils sont chargés avec des masses à base de plomb plus difficilement fissionables.[7]

If this be the case, it may have great effect on the need for plastics in architecture as well as in other fields, and it would not be the first time that war, or the preparation for war, gave an impetus to research, invention and the increase of output of plastics materials.

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[6] J. Hudnut, "Le Corbusier and the New Architecture," in Le Corbusier, ed. S. Papadaki (New York: The MacMillan Co., 1948), p. 11.

[7] J. Delorme, "Conditions imposées aux Matières Plastiques en vue de la Construction," in Burelle et al., op. cit., p. 35.

Electrical Properties

Here is an interesting case to show how an advantage in one field can mean exactly the opposite in another. The fact that about 43 per cent of the entire production of plastics is used in electrical and affiliated products (while the much publicized novelties and toys account for only 2 per cent[8]) clearly proves the excellent electrical insulating characteristics that these synthetic materials possess. Polystyrene has amazingly excellent resistance--"a sheet one-thousandth of an inch in thickness being able to resist up to 3000 volts."[9]

But it is exactly this excellent insulating power that causes the accumulation of static electricity on the surfaces of plastics, and leads to their subsequent dusty appearance, caused by the atmospheric particles which they attract--

> indications que les maîtresses de maison ne méprisent pas.[10]

Wiping with a cloth only makes things worse; and wiping with a damp one is only a temporary solution because soon after the surfaces dry, they begin to pick up new charges when air currents sweep across them. The answer is to incorporate a good conductor in the material, either in the composition itself, by adding mineral powders, or on the surface in the form of a coating material which can be either metallic in origin, a varnish, a wax, or one of the plastics which do not accumulate such charges. Of these latter, there are the aminoplastics, cellulose acetate, casein and polyvinyl chloride.[11]

Mention should be made here of the application in which even

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[8] Redfarn, *op. cit.*, p. 102, after R. G. Chollier in the *A.S.T.M. Bulletin*, 1948, 152, 81.

[9] Stockley, *op. cit.*, p. 47.

[10] J. Delorme, "Conditions imposées aux Matières Plastiques en vue de la Construction," in Burelle *et al.*, *op. cit.*, p. 53.

[11] *Ibid.*

a "disadvantage" can be put to profitable use:

> While the affinity which many plastic materials have for dust drives their fabricators to absinthe (and currently to antistatic chemicals), one company has capitalized ingeniously on the natural electromagnetism of certain resins and waxes. Goodyear has shredded polyethylene sheets into a porous mass and encased the filaments in a wire cage to make a highly efficient air filter for heating and cooling systems. . . . The plastic filter picks up an electrostatic charge when hit by an air stream which attracts and retains fine dust, soot and pollen particles which are suspended in the air. Another feature of the new filter: it can be cleaned easily by a rinse in clear water and may be used countless times without loosing its effectiveness.[12]

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[12] *Architectural Forum* (March, 1952), p. 210.

CHAPTER SEVEN

OTHER GENERAL CONSIDERATIONS

Price

Comparisons, as they are usually made--by weight, volume or surface area--show that plastics have higher prices than traditional materials. Therefore, the advantages gained in weight and strength, by using plastics, can thus seem to be easily negated. And early attempts to make plastics furniture prove it. They "could not compete in price with other already established materials."[1]

In the field of architecture, such comparisons are insignificant and unjustified, in view of the following factors:

1. Until plastics are mass-produced in such large quantitiss as other materials are, there is no way of comparing prices. The increase in demand, due to broader understanding of plastics and their characteristics, results in substantial decreases in price.

> An illustration is the fact that in 1936 the chemical, melamine, was valued at about £10 per lb. Inside of twelve months the scale of production had grown so that the price had dropped to the order of 3/- per lb.[2]

The broad understanding of plastics is still lacking in many cases, and

> there is a circle of cause and effect in such matters which is difficult to break. Because there is no cheap material on the market there is no firm demand for it, and because there is no firm demand there is no supply, for such [low] prices can only be attained with large-scale production.[3]

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[1] Singer, op. cit., p. 138.

[2] Barron, op. cit., p. 240.

[3] J. E. Gordon, "The Future of Plastics in Engineering," abridged lecture, Engineering (London), 174, 4533 (December 12, 1952), 770.

There are signs, however, that this circle is being slowly broken. Ten years ago, the verdict was that

> there will probably be no great flood of plastics on the post-war market. . . . Neither are revolutionary price cuts at all likely, but a gradual reduction in prices seems probable.[4]

And recently, news came from post-war Germany about a cellulosic plastic:

> Finished articles made from it retail for less than half the corresponding cost of a wooden article. All normal household articles have been made from it--from water closet seats to brush backs, and even furniture. Window frames made of it are for practical purposes everlasting, waterproof and never need painting. They cost less than half the price of steel windows.[5]

2. All the functions that a plastics component performs should be included in the comparison. For example, a partition made of plastics panels, will be insulating and decorative, will "pipe" light, need no painting or surfacing,[6] and if suspended from a beam above, will require very small mullions (or none at all). All these factors, plus the cost of transportation, the ease and speed of erection, and the elimination of many labor-consuming tasks, should be included in the cost of the corresponding partition of a traditional material. Actually, comparisons would almost have to be based on the total cost of a building.

3. Prices, even if for some plastics they stay higher, can be justified by plastics' "good quality and high utilitarian and decorative values;"[7] thus, acrylic resins for windows because they admit ultra-violet rays and because of their shatterproof qualities; vinyl membranes for the floors and walls because they are resilient,

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[4] Weil & Anhorn, op. cit., p. 153.

[5] Architectural Forum (January, 1952), pp. 86f.

[6] If occasional varnishing and polishing be required, the cost of re-plastering or re-painting a traditional wall should also be taken into consideration.

[7] Singer, op. cit., p. 9.

water-proof, easy to clean, and are insect- and termite-proof; and so on.

> The automobile and aircraft industries owe much to the plastics industry. In marine engineering plastics are gradually supplementing--and in some cases ousting--metals, by virtue of their lightness, durability and ease of manufacture.[8]

And if plastics are atomic-radiation resistant, it will be reason enough for their adoption--regardless of cost.

4. Higher prices have to be accepted in some cases where there are no other choices, for,

> no matter how good a substitute may be, it is useless if not available . . . preferably of domestic and not foreign origin.[9]

And this is the reason some of the plastics were originally developed: to replace natural rubber, silk, ivory and other unobtainable materials. All efforts are made, while formulating these synthetic substitutes in the laboratories, to make them better and cheaper, but that does not always guarantee that prices can be brought down, so as to be lower than, or even equal to, those of the materials replaced.

5. While prices are high, plastics can be used in small amounts--sprays, films and impregnating materials--in which cases they would only contribute to the properties of the other materials. A thin coat of a silicone resin, which is very expensive, can be applied to weather-proof other materials and plastics that cannot be used externally. A spray on a plywwod panel can render it water-proof, and so on.

Such applications must be carefully studied first, because a spray can billow or blister when there is an excessive amount of

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[8] Fleck, op. cit., p. 3.

[9] H. Bennett, Substitutes (New York: Chemical Publishing Co., 1943), p. 6.

moisture; and a thin film cannot be expected to stay perfectly flat unless well-glued to a backing material, and so on.

6. And then there is the "noble regardlessness of expense" which Schuyler considers to be "of the essence of the architecture, and an integral part of its effectiveness,"[10] and which a survey of history reveals to be always the case. For to produce Architecture is not merely to fulfill the utilitarian functional requirements of a building. What happened in the twentieth century is that the Machine brought about a functionalism and an efficiency of unprecedented degree, and the industrialists and merchants began to demand similar properties in their buildings. Most of the tall office buildings, stripped to their bare minimum essentials, are actually efficient and utilitarian huge pieces of machinery rather than works of architecture.

> Between the two poles of an architecture purely lyrical and one which is utilitarian, all types of hybrids can be found: architecture in which the lyricism dominates, yet where utility plays a certain part (such as palaces and luxurious residences). And according as the useful is more present or more absent, so these constructions relate to one or other type.
>
> Lean kine of architecture. Lyric architecture slumbers, not because our epoch lacks great "plasticians," but because the demand is, so to speak, nil. All that is needed to be a Rembrandt or Stravinsky is genius, a bit of pencil and some paper: but no one can be an Ictinos at such small cost. Our age is first and foremost utilitarian: it has reduced its architects to the rôle of specialists. These wretches, lacking the demand for art, succeed in finding some pasture for their art by introducing it into their houses, utilitarian edifices. Somewhat as a sardine-vending poet might publish his verses on his tins.[11]

Patents

These are man-made obstacles placed in the field of plastics. Patent rights, necessary as they are to protect inventors

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[10] M. Schuyler, American Architecture (New York: Harper & Brothers, 1892), p. 119.

[11] Amédée Ozenfant, Foundations of Modern Art, trans. John Rodker (New York: Dover Publications, Inc., 1952), p. 137.

and manufacturers from having their ideas plagiarized, their efforts wasted, and their compensations denied, more often become stumbling blocks that only succeed in retarding progress and the use of new discoveries. The production of casein plastics, for example, was started immediately in Germany and France, after Spittler, the German chemist, discovered the reaction of formaldehyde on casein, "but development in the United States was delayed until after the original patents expired."[12] The case of phenolic resins is similar. Baekeland was granted the master patents in 1908, and only after they expired in 1926 was there a "considerable expansion in the number of concerns interested."[13]

Cellulose nitrate plastics, too, had to struggle for their existence, in this case because Japan was the sole producer of camphor (which is still the best plasticizer for these materials), and it was not until synthetic camphor could be produced in the laboratory that the situation was eased. (And cellulose acetate was also discovered, however, and took over most of the applications of cellulose nitrate, owing to its low inflammability.)

The reason that there are so many vinyls nowadays is perhaps because many patents expired or became void after the war (especially since vinyls are closely related to the chemistry of synthetic rubber, and much research was done in that field by many countries to remedy the shortage of natural rubber which is concentrated in small areas of the world).

Trade Names

The types of plastics themselves are numerous and confusing

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[12] [Eclipse Moulded Products Co.], So You're Going to Use Plastics! (Milwaukee, 1944), p. 4.

[13] Barron, op. cit., p. 110.

enough, due to the unlimited varieties and combinations possible, and when the same material becomes known by several trade names, nothing is achieved except making the confusion more thorough and the acceptance of plastics in architecture extremely slow.

> The phenol-formaldehyde resins are sold under many trade names such as Bakelite, of the Bakelite Corp., and Durez, of the General Plastics Corp., and many in turn are marketed under other trade names by the molders. Makalot, of the Makalot Corp., Colasta, of the Colasta Corp., Reynolite, of the Cutler-Hammer, Inc., Indur, of the Reilly Tar & Chemical Corp., are names for molded products, powders, and laminating powders.[14]

Cast phenolic resins are also known as Bakelite Cast Resinoid, Baker Cast Resin, Catalin, Catavar, Catabond, Gemstone, Marblette, Opalon, Prystal, and many others.[15]

Manufacturers also, for some unknown reason, tend to advertise their products without reference to the type of material. They give only trade names, data (usually incomplete, in order not to mention the disadvantages, and supplemented with such description as "amazing," "exciting," etc.), and instructions for proper applications.

Laboratory tests and methods of identification are basically chemical, and therefore lie outside the field of architecture and beyond the architect's purview. The architect also cannot rely blindly on the optimistic promises of advertisements, and the result is a slow acceptance of plastics, which neither helps production nor increases the manufacturers' sales.

The remedy to this situation is left to the manufacturers and advertisers to figure out.

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[14] G. Brady, Materials Handbook (4th ed.; New York: McGraw-Hill Book Co., 1940), p. 549.

[15] See "List of Trade Names."

PART II

AVAILABLE FORMS OF PLASTICS AND THEIR APPLICATIONS

CHAPTER ONE

APPLICATIONS OF LIQUID PLASTICS

When plastics are prepared, and while they are still hot, they are in a molten state. The forming of finished shapes and products is preferably carried out directly to save unnecessary extra labor. However, chemical concerns do not themselves manufacture articles. They market plastics in liquid or powdered form ("According to whether a liquid or solid resin is required, so the cooking of the resin . . . is stopped at an earlier or later stage."[1]), for use by other manufacturers.

Powders are mostly used for all methods of molding, but since molding techniques require high temperatures and heavy and expensive equipment that are unsuitable for site work, they will therefore be scarcely encountered by the architect or builder.

Liquids, on the other hand, even though they are intended for similar purposes, can have different applications in their liquid form in architecture, such as casting, impregnating other materials, gluing, and such other applications as we are going to see:

Casting

Liquid resins can be cast into permanent forms usable for all purposes, but naturally the casting process is necessarily different from pouring concrete because of all the different properties, working techniques, and the other involved factors that they do not have in common. Resins are too fluid and do not have the consistency of concrete, and therefore (a) they would not remain in the forms unless

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[1] Barron, op. cit., p. 124.

well-protected and surroundéd on all sides, nor would it be possible to cast them on an inclination; (b) they would seep through the joints of the forms; and (c) they would adhere firmly to the wood unless it be treated with wax or oil, or coated with another plastic that would stay liquid, such as some silicones, while the cast resin hardens.

While these factors seem to require extra care and labor, and limit the use of cast resins, there are several advantages, nevertheless, that can be gained: (a) due to the fluidity of the resins, they would fill the molds completely, and surround the metallic inserts, if any, without leaving air pockets or requiring vibrating: air bubbles would rise to the surface by themselves, and if they do not explode, they can be simply scraped off like foam; (b) they would perhaps harden (polymerize) slower than the initial set of concrete, but would reach their final set much faster, and the shattering can be removed after a day or two, especially as the hardening can be accelerated by heating, or curing, with portable heating units,[2] or by the addition of weak acids to the liquid resins before casting (while alkalis can retard the process if necessary); (c) they would take smooth, exactly horizontal levels that would form perfect grounds on which the flooring materials can be directly, easily and perfectly laid. If transparent, cast members can be inspected for flaws, and other defects, and would be remedied by drilling to where the flaw occurs and casting more resin to fill up the cavity.

Individual cast objects and architectural items, such as door furniture and bathroom fixtures, would be better and more conveniently cast in the factory. (One method for producing heavy sheets and plates is to cast them between two plates of glass separated by the desired thickness. The syrup is poured, the air bubbles allowed to escape, and then the molds are heated to cure the plastics material.

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[2] See "High-frequency Heating," pp. 88-89 of this study.

This method saves polishing and cutting, and can also produce sheets of irregular shapes or variable thicknesses for use in such applications as the edge-lighted signs of fig. 9, for example.)

On the site, casting structural members is one possibility, and to avoid the difficulties described above, resulting from the use of the usual wooden forms, the casting should be done in prefabricated hollow, U-shaped forms. These would be seamless, running the whole length of the member from support to support, and stiff enough to support themselves plus the weight of the resin until it sets and becomes capable of carrying the loads for which it is designed. They can also be structurally shaped in cross-section (fig. 35), depending on whether metallic reinforcement is used or not; and in length (fig. 17), to obtain the most economic members--such shapes as are unattainable with steel or concrete except at excessive work and high cost. Further economy and utility would be achieved if these forms are the fireproofing material itself that is required by all building codes. They can even be made of concrete applied with a gun on expanded metal or wire mesh.[3]

Impregnating Concrete

This application of cast resins is in connection with conventional reinforced concrete. Knowing that the strength of concrete depends to some extent on the water-cement ratio, because when the water evaporates it leaves behind it pores which reduce the effective cross-section of members, impregnating concrete with a liquid, set-

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[3] "Building twice" is the main disadvantage of concrete construction: all slabs, beams, columns, etc., have to be built with timber first, before the concrete can be poured. And in the case of steel, it is even building thrice, since all structural members have to be protected with concrete. With cast plastics, the forms would be part of the construction, first acting as forms for the casting, and secondly, fireproofing the structure.

ting resin would then mechanically fill the pores and transfer the concrete into a solid material. (It might even be found necessary to increase the water-cement ratio, even though it would temporarily produce weaker concrete, in order to permit the viscous liquids to penetrate the mass.)

The advantages of this application, or rather treatment, are several. Aside from increasing the strength of concrete, it would also increase its resistance to atmospheric pollution, due to the excellent chemical resistance of plastics.

> L'incorporation de résines au béton, notamment de résines phénoliques, permet d'améliorer sa résistance aux atmosphères corrosives et dans ce cas, cette application peut être intéressante pour les constructions d'usines de produits chimiques ou de bâtiments situés dans des atmosphère agressives.[4]

The resin would also provide a subfloor compatible with the glues with which the plastics flooring materials may be fixed, or with the next application.

Flooring

An economic method of "laying" floors would be to cast another layer of resin after the first one would have impregnated and sealed the concrete floor slab. This second layer would then remain on the surface, take a smooth, horizontal level and become the finished floor itself, thus eliminating all the work that is usually required for laying floors.

One concept that must be given up is that floors have to be covered with tiles. Tiles were necessitated by the fact that the materials used, whether stone, cement, clay, wood blocks, or the like, had to be made in small pieces due to the natures of these materials, their weights, the possibility of breakage in transportation, the

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[4] J. Delorme, "Matériaux de Construction «Plastiques»," in Burelle et al., op. cit., p. 66.

manufacturing techniques, and such other factors. Some manufacturers of plastics did not stop to consider these points and blindly followed the tradition and produced plastics tiles, while others, aware of the facts but unable to break away from convention, manufactured sheets with applied tile designs and patterns! None of these products was found satisfactory. Due to the exaggerated thinness of these materials--necessitated by their comparatively higher prices--tile edges lift, and sheets billow and dimple when they come in contact with moisture. Also the gluing methods seem to be still unsatisfactory. They also require that the subfloor be well screeded and leveled before they are applied, in order to obtain a floor that is as regular as possible--which is not an easy task to perform since on a shiny surface any irregularity can be easily detected.

By simply pouring the resin, mixed with abrasion-resistant fillers, all other processes would be eliminated. And the floors would neither blister nor have edges to lift, for the resin would be as tenaciously bonded to the impregnated concrete as a glaze to a ceramic vase.

Gluing

It is the glues and their characteristics, rather than the chemical theories of adhesion, that are of significance to the architect. The general and important facts that he should know are: (a) that "glued joints with a thick glue-line are almost invariably weaker than those with a thin glue-line;"[5] (b) that roughening surfaces before gluing them together cleans them and facilitates contact between materials and glues, but adhesion itself is due to "specific attractions between the adhesive and the surfaces joined, and not, as formerly believed, to a simple mechanical interlocking between

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[5] MacTaggart & Chambers, *op. cit.*, pp. 92-93.

the adhesive and the adherent surface;"[6] and (c) that an important contribution of some plastics glues, such as casein and soya-bean, is their ability to join any two kinds of materials, whether metallic ("non-polar") or non-metallic ("polar").[7]

All the necessary data for specific uses should be obtained from the manufacturers, because the types of glues are innumerable.[8] And although most of them are intended for industrial uses, many are cold-setting and applicable to site work. Hardeners (or accelerators) may be required, as in the case of casting resins. Phenolic resins, for instance, can be either mixed with the resin, and "the useful life of the mixture is 2 hours at 60°C., ½ hour at 80°C.,"[9] or the glue is applied to one surface, the hardener to the other, and then the two surfaces brought together.

Gluing cannot be effective unless the coefficients of expansion of glues and materials (especially when two different materials are being joined together) are very similar. Otherwise, stresses will develop, and cracks will result. Where it is not possible to achieve such similarity, flexible adhesives should be used: they stretch to some extent and compensate for the difference in expansion and contraction. Examples of flexible adhesives are the vinyl acetal resins, used in safety glass, which have "considerable flexibility, combined with transparency and great strength,"[10] and synthetic rubber adhesives (though synthetic rubbers are usually excluded from the

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[6] Fleck, op. cit., p. 228.

[7] Ibid.

[8] For descriptions of some types, see Engel, Hemming & Merriman, op. cit., pp. 212-230; and Fleck, op. cit., pp. 230-240.

[9] Barron, op. cit., p. 149.

[10] Stockley, op. cit., p. 143.

definition of plastics even though they have considerable resemblance to plastics and are often used in connection with them; which can bond porous materials, and "can even bond plastics to masonry."[11]

The advantages of synthetic glues over the traditional ones of vegetable or animal origins, are that they do not deteriorate in humid weather and are not attacked by fungi or insects. And over usual methods of joinery, the advantages are several:

1. Glues eliminate screws, rivets, and nails, which are objectionable not only on esthetic grounds but also in construction--especially in the cases of materials which are weak in shear, and to which stress concentrations inevitably result in wasteful applications.

2. As said before, glues will bond all kinds of materials, metallic and non-metallic, solid and porous. New developments are announced almost daily--like the plastic bonding agents which unite metals with a bond stronger than welding or riveting, or which join rubber, synthetic rubbers, wood, plastics, or leather to metal or to each other, with a bond stronger than the materials themselves.[12]

3. By eliminating the holes of bolts and rivets, and by filling the joints and gaps (with the employment of mixtures loaded with wood flour, plaster of paris, mica, silica, ground Bakelite, or other powders which reduce shrinkage[13]), glues give additional resistance to corrosion by preventing water penetration and electrolysis. As to the resistance of the glues themselves,

> tests carried out in U.S.A. to investigate the strength of adhesives when subjected to moisture penetration, proved that the decay of wood occurs before the failure of synthetic resins in the glued joint.[14]

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[11] Singer, <u>op. cit.</u>, p. 46.

[12] Weil & Anhorn, <u>op. cit.</u>, p. 151.

[13] Barron, <u>op. cit.</u>, p. 229.

[14] Singer, <u>op. cit.</u>, p. 41.

Their wide use in aircraft is ample proof of their ability to withstand severed conditions.

4. The ease and speed with which a joint can be formed (which is almost instantaneous when the glue is applied to one surface, the hardener to the other, and then the two surfaces brought together), should be a great asset to construction--just as nailing and "balloon construction" were to the old methods that were used

> to rob a stick of timber of all its strength and durability, by cutting it full of mortices, tenons and auger holds, and then supposing it to be stronger than a far lighter stick differently applied.[15]

Finally, it must be remembered that glues form a very small part of the total cost of construction. If their prices be comparatively higher, this should not be considered a serious hindrance to their application, with a view to the advantages just mentioned.

Painting and Coating

From all that has been written on the subject, it seems that the varieties of coating materials are limitless, and that all possible types and properties can be formulated: "straight" resins, water-dispersed phenolics, or oil-soluble plastics. Some types, such as the alkyd resins, are "used exclusively for enamels, lacquers, paints, inks, and finishes of all types."[16]

In methods of application, articles can be sprayed, dipped, roller-coated or painted with an ordinary brush; and in drying, some require baking while others are air-drying. Air-drying may be due to the evaporation of solvent (which can be accomplished in a matter of seconds), the oxidation of the resin and oil vehicle, or the polymerization of plastic; and drying time can vary from hours to seconds.

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[15] S. Giedion, *Space, Time and Architecture* (Cambridge, Mass.: The Harvard University Press, 1949), p. 285.

[16] Weil & Anhorn, *op. cit.*, p. 45.

The properties of the applied coats naturally depend upon the material used, but, in general, what characterizes modern paints are the excellent adhesion, color retention, quick drying (which makes them less prone to pick up dust and less liable to damage), and the high degree of uniformity that is difficult to achieve with natural resins.[17]

The choice of a finish, therefore, depends upon the properties of the materials, the surfaces to be coated, the kind of surface required (hard or resilient, shiny or matt, resistance to specific chemicals, etc.), the method of application that suits the situation best, the cost, and the way the finish relates to the other adjoining surfaces--finished or natural--in a building.

Many of the plastics products may be designed and formulated so as to contain within themselves the properties that coating materials have to offer, but the main reason for coating is that it is sometimes more economic and practical to do so, and where permanency is an important factor, as it is almost always the case in architecture, it is better to have a protective cover, which may be renewed--if it can only withstand for limited periods of time--while the material behind it remains intact.

Spraying

Even though spraying is included in the previous section on painting and coating, it deserves special consideration here. Only with the Machine Age did spraying come into use, because of the impossibility of covering large surfaces without the equipment and the fast-drying paints that are the products of modern chemical research. As may be expected, spraying started in the factory where the speed and uniformity necessary for mass production, require such a tech-

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[17] Fleck, op. cit., p. 196.

nique. Later, it found its way to architecture, but only to a very limited extent, because in architecture, painting provides better control over materials and permits the covering of only those areas which are to be painted, without touching any of the adjoining surfaces, and without filling the whole space with solvent vapors, some of which are poisonous or dangerous.

With plastics, spraying seems destined to play a more important role, because it is the means by which plastics may be used sparingly--thus making use of their properties and at the same time keeping cost at a minimum. It can furnish thinner films than a brush can; it is faster; and requires no special skill.

Vinyl sprays were the first to find application in buildings (as waterproofing membranes for roofs) after they were tested and used in "moth-balling" warships and airplanes after the war. Sprayed on roofs, they form a film that can be sprayed onto almost any surface,

> can be bent, hammered, scratched and stretched into various shapes and still remains watertight, . . . [and that] will not crack at 40° below [-40°C.], nor will it get tacky at temperatures as high as 200° above [93°C.].[18]
>
> Navy tests have indicated that it will last for 30 years . . . [and it is] only 15% more expensive than the usual tar and gravel finish.[19]

Blowing

Even though many plastics materials can be blown, yet very little use has been made of this interesting forming technique. At the present time it is limited to the manufacture of small objects

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[18] Architectural Forum (January, 1952), p. 133.

[19] Ibid. (June, 1951), pp. 156f. "Almost any surface," however, does not mean that it can be sprayed on masonry in order to seal it or waterproof it, as some manufacturers claim. The trapped air in a porous material is certain to expand and contract according to the variations in temperature, and will inevitably cause the film to blister. Sealing a porous material becomes feasible only if the plastic penetrates the material and fills its pores (as for example in impregnating concrete, see pp. 69-70).

from a viscous liquid or from a heated and softened material, and does not attempt more than the manufacture of toys, vases or bowls (made by cutting the bubble in half). One day it will be possible to blow bubbles large enough to be used as domes or whole structures.

It is well known that what hinders the progress of reinforced concrete shell construction is the excessive amount of labor required for the wooden forms on which the shell is cast. The cost of it often exceeds that of the structure itself, and makes it prohibitive, especially in countries where labor is high.

To blow a large shell out of a plastics material would simply require placing the viscous resin in a saucer-like shell built on the ground, and blowing a strong current of compressed air from underneath. The bubble would then rise and expand until it uses up all the resin and at the same time fills the "saucer" (fig. 23). The pressure inside is maintained until polymerization takes place and the shell hardens, and then it is gradually decreased to atmospheric. Doors and all other openings can then be cut, and the rest of the construction and finishing work carried out as usual. There is nothing fantastic or impractical about such an undertaking. It is quite feasible. Only the details need to be worked out: viscosity of the resin, the pressure required, and such other considerations.

The advantages are numerous:

1. No forms would be required. Even the "saucer" would stay in place and serve as foundation.

2. The resulting structure would be smooth and perfect, with no need for finishing except remedying the blemishes that may occur.

3. A great amount of labor and material--and hence expense--would be saved.

4. Taking the time factor into consideration, such structures would be realized in a matter of <u>hours</u>, instead of months and years,

as is usual in the building industry of all eras.

And there are disadvantages to the process of blowing, of course, but they are few and can be overcome:

1. The first few attempts may be expensive, due to the possible waste in material until the technique is mastered, but on the other hand there is the great saving in labor and time mentioned above.

2. The possible collapse of the shell while being blown, and the danger and damage resulting therefrom; but this can be met by not allowing anybody to be near the site during the operation (and none are required to be there at the time anyway since the compressed air can be conducted from a great distance).

Another precaution, and an improvement over the technique, is to blow the air into a rubber bag immersed in the resin. The resin in such a case would be adhering only to the bag and not subjected to pressure. The bag would be convenient also in determining the exact required size of the shell, and would be peeled off afterwards. Still allowing for the unforeseen, blowing should be used only in new developments, away from cities and inhabited regions. And for a group of buildings (figs. 24, 25), the shells should be executed before the other structures.

3. Liability to damage by fire is met by fireproofing around the shell to the necessary height; and to abrasion and weathering by coating with a protective material. It should be noted that the structure does not have to be transparent all over. Parts of it may be covered with traditional materials.

Dipping

One method of forming hollow shapes is to have a form made and then dipped in a liquid resin, and when the coat dries, it is peeled off. (This is how rubber gloves, for instance, are made.)

CHAPTER TWO

FORMING TECHNIQUES OF RIGID PLASTICS

All the possible and practical uses of liquid plastics, described in the last chapter, form only a small percent of the total usages. The majority of products are of the rigid types, which are manufactured by a variety of techniques (depending upon the articles to be produced, the characteristics of the materials, and many other factors). The different techniques often become associated with particular types of materials, and these do not leave the factory until they pass through all the intermediate stages and become either finsihed articles or semi-manufactured products such as sheets, rods, tubes, and special sections. In such cases, the architect's interest is restricted to plastics as they reach him, and he is not concerned with any of the intermediate stages they pass through--unless he decides to cooperate with the chemists and industrialists in shaping these articles and products in the factory, as said before in [5].

The forming technique, therefore, will be briefly reviewed here, but only in order to give a clear picture of the factors involved, and the influences they have on the shaping of plastics.[1]

Molding is the chief method used. The idea of it is to shape articles by subjecting the molding materials to heat and pressure. This can be accomplished in several ways, as we are going to see, differing in detail, but all having these two basic factors.

Compression molding is the "oldest method and was used in the

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[1] For more details, there is sufficient technical literature on these subjects, that can be consulted if necessary.

pioneering work of Dr. Baekeland."[2] It consists of pressing the molding material, whether it be in powder or granular form, between a positive and a negative mold, with the simultaneous application of heat. The process involves (a) the accurate weighing of the amounts of molding material that would suffice to make the objects, with an allowance for flash formation,[3] (b) placing it in the negative mold, (c) applying the pressure through the positive mold--both molds being heated--until the material melts, flows and fills the space between the two molds, (d) allowing time for the molded piece to cool sufficiently enough to retain its acquired shape, and finally (e) ejecting it from the negative mold.

Low pressure molding came as a result of the desire to eliminate or reduce the high pressure required for molding (especially large pieces), and the heavy and expensive machines that make the technique uneconomic and unsuitable for small enterprises.

> Spurred on by the needs of war and the availability of new raw materials as well as a better knowledge of resin making, resin chemists began to develop modifications of older resins which could be used at lower pressures, such as 800, 700, or even 500 psi [as compared to the former pressures of 3000 psi in some cases].[4]

Cold molding differs from compression molding in that an initial shaping of the molding powder is affected, and then heat is applied to cure the molded piece. It is a method that is especially suitable for laminating curved shapes. It has the advantage of permitting the different layers of laminates to slide over one another, so that after the molding process is complete, they would have no tendency to warp or create internal stresses.

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[2] Singer, op. cit., p. 21

[3] Sometimes the molding powder is pressed and pre-formed into tablets, in order to make it easier to handle, and to divide the labor so that measuring and molding would be done independently.

[4] Engel, Hemming & Merriman, op. cit., p. 109.

These molding techniques (compression, low-pressure and cold molding) are applicable to all kinds of plastics, but are more suitable for thermosetting rather than thermoplastic materials, because, with the latter, time is lost in waiting for them to cool before they can be released, while the former can be released while hot without danger of their losing their shapes. And it is important to regulate the amounts and duration of heat and pressure according to the properties of the material used. Plasticized polyvinyl chloride paste, for example, requires very little pressure,[5] while silicone molding powders require high temperatures to mold and a long time to cure, which make them too costly at present.[6]

The regulation of temperature is also of great importance because "strength, as well as many other physical and electrical characteristics of molded plastics are markedly dependent upon material flow during molding."[7]

The sizes of articles produced range from bottlecaps and small methacrylate lenses,[8] to "the large plastic-plywood fuselages of 'plastic' planes."[9]

In <u>transfer molding</u>, the measured amount of molding material is heated in a separate chamber before it is forced by a plunger into the mold. The reasons for this additional step are (a) to make the process suitable for thermosetting resins, materials with large amounts of fillers, and materials with poor flow properties, (b) to provide room for the amount of molding material which, before heating and pressing, occupies more space than it does after, (c) to permit

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[5] Barron, <u>op. cit.</u>, pp. 512-513.

[6] <u>Ibid.</u>, p. 677.

[7] Delmonte, <u>op. cit.</u>, p. 164.

[8] Barron, <u>op. cit.</u>, p. 582.

[9] Weil & Anhorn, <u>op. cit.</u>, pp. 20-21.

the molding of solid objects such as handles and knobs which would not be otherwise easy to heat and soften evenly, and (d) to mold parts which contain metallic inserts (screws, plugs, wires, washers, etc.), which cannot be easily pressed between positive and negative dies without disturbing them, or which cannot be molded at all, due to their awkward shapes.

Injection molding consists of feeding a powdered or granulated thermoplastic material into a heated cylinder, at one end of which a plunger forces the softened material forward, through a nozzle at the other end, into a tightly-locked mold.[10] The molded article is given enough time to cool before it is released, and to speed up production, several molds are used, so that while one is in operation, the others have sufficient time to cool.

> Moldings, 3 ft. by 4 ft. in dimensions have been made by injection [at the rate of 3 to 4 every minute]. Even such articles as bath tubs are visualized as being feasible by this method,[11]

but it is clear that the pressures required in such cases may be hundreds or several thousands of tons, and that the technique is more suitable for articles of smaller sizes.

Injection is associated with polystyrene and cellulose acetate--the two materials that are commonly formed by this technique--, but many other thermoplastics can be injected, including cellulose aceto-butyrate, methacrylates, nylon (which is confined to thin sections, however[12]), and many other materials.

Jet molding differs from injection in one respect: only the nozzle of the cylinder is maintained at an elevated temperature, which makes it suitable for injecting thermosetting resins. For in

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[10] Fleck, op. cit., p. 262.

[11] Barron, op. cit., p. 389.

[12] See "Injection Moulding of Nylon," ibid., pp. 637-638.

injection, if the amount of thermoplastic powder fed to the cylinder is not accurately measured, the excess material may stay in the cylinder till the next stroke of the plunger, but if a thermosetting resin is used, it will harden and obstruct the operation. By heating only the nozzle, therefore, the molding material remains in its initial form, and is heated only on its way to the mold.

Requirements for good molding

Not any conceivable shape for an article can be executed by one or other of the molding techniques, for the requirements of good molding impose certain limitations on the shapes of objects. The architect has to assimilate these requirements, and train his eyes to see "plastics" in order to be able to produce designs that are compatible with the materials and with all the factors involved--the same as a sculptor would think in terms of the material which he works, and that a sculptural idea expressed in bronze, say, looks different from the same idea expressed in stone.

Molding, then, requires that the sides of an object taper towards the edges, or lean slightly outwards, so that the object may be easy to release from the mold. No undercuts are possible. Sharp corners and abrupt changes in thickness should be avoided because they set up uneven stresses which may eventually lead to the development of cracks; molded objects should therefore have the corners finished "with as big a radius as is possible."[13] Holes and screwthreads can be made with the aid of collapsible cores, or can be machined afterwards, but in either case, these affect strength, and should be strengthened by slightly increasing the thickness around them, as if a washer were added. The suitable thickness depends upon many factors, and has to be de-

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[13] MacTaggart & Chambers, op. cit., p. 161.

termined by experiment: extra thick walls make curing difficult, and very thin sections will always warp. Metal inserts are possible, but if they complicate the process, transfer molding should be used. The parting lines of the molds show on the finished pieces, more or less obviously, and unless polishing and buffing are used, these lines should be strategically placed so as not to mar the appearance. Similarly, the position of the marks left by the pins that eject the molded pieces and release them from their molds should be studied and likewise conveniently located.[14]

Extrusion is similar to injection except that instead of injecting into tightly-locked molds, the material is forced out of a special nozzle that is given the shape desired for the cross-section of the extruded material. (Sometimes the plunger of the press is substituted with a spiral that revolves at constant speed and exerts a uniform, continuous pressure.)

By this method, indefinite lengths of rods, tubes and strips of all possible cross-sections, as well as fibers and cords, can be produced--all depending upon the shape of the nozzle. Also if the plastics material is forced through a slit instead, films and sheets are the result.

Extrusion can also be used as a means for coating and insulating cables and electric wires. By passing them through the nozzle while the plastics material (usually a vinyl in these cases, owing to its flexibility) is being extruded, a protective coat is formed around them.

Extrusion is mainly associated with vinyl plastics and polyethylene, which are produced in flexible, stretchable sheets and strips; also with Saran (polyvinylidene chloride), nylon and cellulose acetate, for the production of synthetic fibers for the textile

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[14] See "Design Tips" in [Eclipse Moulded Products Co.], op. cit., pp. 22-23.

industries;[15] and with casein plastics which are extruded on account of the difficulty of molding these horny materials. Rods and tubes can be sliced afterwards to produce buttons and rings; and sheets can be stamped to produce inexpensive articles (but all these products are limited to inexacting tasks, due to casein's poor resistance to chemicals, and to its capacity for absorbing large amounts of water.[16])

Calendering is a method borrowed from the glass industry. By passing the plastics material, in a softened state, between two cylindrical rollers, it is rolled out into sheets of indefinite length, the thicknesses of which are determined by the space between the cylinders. If the cylinders have embossed designs or textures on them, they are accurately reproduced on the sheets; and if papers, woven fabrics, or other plastics sheets be passed between the rollers, along with the molten material, they will be coated with it.

Calendering and extrusion are the two methods most commonly used for the production of sheets, but there are several other methods possible.

One of them is to press an amount of the material between two hot, stainless-steel plates, and squeeze it down to the required thickness.[17] (The size of the sheet is limited to the size of the plates.) The technique is rather expensive, but it may be necessary to fall back upon (a) if the flow qualities of the material are poor; (b) in order to produce sheets with variable thickness (by tilting one of the steel plates), or special shapes; (c) to press together different elements such as those of the "stained-glass" windows and

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[15] The woven fabrics need not be all synthetic. The fibers can be mixed with cotton, wool, silk, etc., and it depends upon the ratio of synthetic fibers whether they are used for decorative effects (in small amounts, up to about 5 per cent) or for the improvement of the strength, wear resistance and washability of the textile.

[16] Weil & Anhorn, op. cit., p. 15; also see Tables 7 and 8.

[17] Barron, op. cit., p. 660.

decorative panels (figs. 3 to 6); or (d) for any such other reason that justifies the use of the technique.

Another method, previously used, was to saw sheets from cast blocks, similar to sawing wood veneers from a log, but it was found to be a wasteful and expensive method, much as it is in wood, and was modified later when it was realized that sheets could be more easily sliced from a block that is not fully hardened.[18] Waste is thus eliminated, and the method becomes less expensive, but the sheets are still limited in size, and recourse to this method should be had, not for the production of regular sheets, but only for sheets with special shapes (such as those required for the design in fig. 4), and special uses (such as stamping chairs out of single pieces with appropriate outlines). Also if the block is cast of layers of different colors, sliced sheets of variegated designs can be obtained that can be used in flooring, furniture and other uses.

There are also the methods of forming that do not start with molding materials, but which use sheets and veneers made by any of the other techniques described.

Infra-red lamps and negative molds are used together to heat sheets and make them sag and assume the curvature of the negative mold. Segments of domes and shells can thus be prepared, to be glued or welded together afterwards,[19] and it is this making of shells and domes, "which is so difficult and unsatisfactory in metals,"[20] (and even more so in concrete) that plastics will surely have a wide and important field of application in architecture.

The steam autoclave is more or less a large press which uses sheets and laminates for the production of curved shapes, which a

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[18] Ibid., p. 263.

[19] See also p. 17 of this study.

[20] J. E. Gordon, "The Future of Plastics in Engineering," abridged lecture, Engineering (London), 174, 4533 (Dec. 12, 1952), 710.

flat press cannot do. It was used during the war for the formation of radomes for radar equipment, boats and other laminated constructions, and can be used in architecture for the production of molded windows (figs. 31 to 34), bath tubs, and items of such nature. The initial cost of the mold may be very high, but the autoclave can be economically operated wher a large number of items are made.[21]

When the laminates are large, or of complicated, curved shapes, the <u>rubber bag (or balloon) technique</u> is adopted. The impregnated veneers, or the assembled parts, are placed inside a rubber bag, and the pressure inside is reduced to nil by drawing the air out. The bag assumes the shape of the body inside and at the same time transfers to it the atmospheric pressure of between 14 and 15 lb./sq. inch.[22] (The converse method for internal surfaces is to inflate the bag inside the hollow parts.)

This method is more economic than the autoclave because it eliminates the need for a mold, but it is limited to materials that can be molded at temperatures lower than those that affect rubber, and also limited to pressures not higher than one atmosphere.

<u>High-frequency heating</u> is only a method of applying heat, but it is very instrumental in the molding and welding of plastics.

> When a homogeneous dielectric is placed in a uniform field of high frequency, the material becomes uniformy hot through the mass.[23]

And according to the frequency and the intensity of the field, a temperature of 150-180°C. can be attained in a few seconds.[24] This opened up new possibilities and permitted the execution of tasks that were until then impossible. Its chief use is in laminating ply-

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[21] Engel, Hemming & Merriman, <u>op. cit.</u>, p. 111.

[22] Fleck, <u>op. cit.</u>, p. 239.

[23] Barron, <u>op. cit.</u>, p. 680.

[24] <u>Ibid.</u>, p. 683.

CHAPTER THREE

USES OF PLASTICS SHEETS

At first sight, sheets seem to be of very limited practical uses. One usually associates them with such uses as wrapping packages, perishable goods and food items. But the uses of films and sheets[1] are quite numerous, and even if they were not, more would need to be devised, because due to the high pound-per-pound comparative prices of plastics materials, solid sections are not economic, and their uses should be avoided as much as possible.

Starting with thin sheets, and proceeding to heavier materials, we find applications as follows:

1. Facing and wall-lining, whether the sheets be of pure plastics or combined with other materials, is one usage which, however, has several points that must be taken into consideration when it comes to specific applications: (a) the imperviousness of the sheets, when bonded to a porous wall, will cause them to blister or billow, either due to moisture in the wall, or to the wall "breathing"--the same as would happen to sprayed plastics (see n. 19, p. 76); and (b) irregularities in walls, such as the lines between boards, or brick joints, or the like, will be reproduced on the surfaces of the sheets, and the careful elimination of these irregularities would be a laborious task, besides being a finishing job in itself! In such cases, the sheets would be better stretched from floor to ceiling on strips firmly attached to the wall, and raised a fraction of an

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[1] "Foil" is material less than 1/1000 of an inch in thickness, and "film" is of up to 15/1000.

inch above the level of the wall. (The space can be padded with a heat- or sound-insulating material.) In this way, the sheets would not be in contact with the wall, and the irregularities remain in the background.

It would be more convenient, however, to have the sheets bonded in the factory to an inexpensive backing material, to insure perfection and a stronger bond. (And it will be noticed that in such cases the sheets lose their identity and become integral parts of rigid panels or laminated boards.)

2. Corrugated sheets have the added resistance to flexure, and also give a variety to design. They can serve, better than flat sheets, as wall-lining materials, and also for skylighting jobs.

Another field of application for corrugated sheets is in heat insulation. Cellulose-acetate sheets have been assembled, at alternating right angles, to thicknesses from one to four inches, to produce an insulating material with a value (0.32 B.T.U.) that compares favorably with other insulating materials.[2] Its other advantages include resistance to corrosion and insects, imperviousness to moisture, and extreme lightness in weight.

3. Waterproofing membranes (and also the chemical insulation of walls, floors and ducts) of polyethylene, for instance, are made more feasible and easy than in finishing work, by the non-exacting nature of this application, The sheets can be laid directly over the wooden boarding or concrete slab, and protected under a finishing material. The subfloor has to be smoothed as much as is practicable, but the elasticity of the material can be relied upon to compensate for the irregularities and small projections; and the stretchability for the expansion and contraction of both membrane and structure.

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[2] See pp. 30-31 of this study; also Table 4.

4. To flooring applies what was said about wall-lining,[3] except that floors, in this respect, are in a better position than walls, since it is possible to impregnate them with liquid resins, and since they are easier to render smooth and level planes upon which flooring sheets can be laid.

5. Tiles of all makes and properties, intended for flooring, wall covering, and other uses, have been manufactured, and while they have some good possibilities, tiles have been shown to be obsolete.[4] Their use should be strongly discouraged.

6. Heavy sheets and plates can be used for glazing. This, however, is one of the applications in which comparative price is a decisive factor. A simple substitution for glass can be justified only if the shatterproof qualities of the plastics sheets, their light weight (as in aircraft), and their admission of ultra-violet light, are of special significance in the application.

To economize on large windows, it may be possible to mold them, together with their frames, with single pieces of transparent material (figs. 31 to 34). In such cases, both the strength of the frame, and the curvature of the sheets, add to the strength of the window without increasing the thickness of the sheet.

7. Furniture is also a field of application in which simple substitution should be avoided, especially since wood, the chief material used, is cheap and easy enough to manipulate. The only way plastics can compete with wood is by surpassing in the characteristics wood does not possess. Plastics sheets can be softened and re-shaped so that a chair or a table, for example, can be made out of one molded piece, thus saving a great amount of work and craftsmanship; and

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[3] See pp. 90-91 of this study.

[4] See pp. 70-71 of this study.

several pieces can be easily welded together to form continuous surfaces and rigidly-constructed pieces of furniture. Sheets are available in a wide range of colors, and do not require painting or finishing. Also they will not splinter or crack; and, used outdoors, they do not become hot in the sun, because they transmit light.

8. Lighting fixtures, molded or assembled, combine versatility with workability, and have interesting optical properties, as was shown,[5] that can be made use of.

9. With heavier sheets, one inch or more in thickness, we now come to structural applications: sheets for roofing and infilling between beams and frames.

Moduli of elasticity are low,[6] and in order to form floors and roof decks, it will be found impractical to use sheets because they will not only be required to support dead and live loads, but also to be stiff enough not to deflect appreciably. Materials other than plastics can perform better in this respect.

In cases where function permits, therefore, sheets should be allowed to assume their natural and "relaxed" positions (figs. 16, 19), and the same applies to continuous covering sheets (fig. 29).

The reverse position is also possible with sheets that are heavier and stiffer, and that can assume and retain arched shapes when push-fitted into place (fig. 30). Their flexibility would also permit them to curve slightly more, or less, with changes of temperature; and their strength would permit them to carry roofing materials and a live load.

10. Domes and shells, unless blown,[7] can be molded in segments and welded in situ, and this method is apt to be more readily adopted since it does not involve any of the risks of the blowing technique.

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[5] See Chapter Two, Part I of this study.

[6] See Table 5.

[7] See 76-78 of this study.

CHAPTER FOUR

USES OF EXTRUDED PLASTICS

Starting with thin, small sections, and proceeding to heavier and stronger ones, we find that there is a wide scope for extruded sections. As with sheets, applications based on the mere substitution of materials cannot compete with traditional materials on a price basis; besides which, there is no sense in substituting unless there are advantages to be gained in quality, performance, or versatility.

1. Strips and moldings.--Even though butt jointing, with a little extra care, is possible and quite satisfactory, it will be found necessary sometimes to use fillets, covering strips, and such other extruded sections. Aside from the merely decorative uses and trimming--to be discouraged as being trivial--, fillets will be necessary to construct free connections for panels and sheets. Expansion space must be provided for the changes in dimensions, and fillets and strips are necessary to cover the gaps.

In fact, there are strips on the market for a wide variety of uses: finishing, trimming, furniture, construction, and many other uses. There is even transparent weather-stripping for use around glass doors to reduce drafts and dust and eliminate the whirring noise caused by air passing.[1]

2. Window and door frames of plastics have the advantages of combining the working techniques for wood (cutting, sawing, nailing, filing, etc.) with those for steel (welding, heating and bending), besides being resistant to extremes of weather and moisture, and never

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[1] Architectural Forum (January, 1952), p. 200.

needing painting. The prices of the newly-derived articles compete favorably with traditional materials.[2]

3. Window slats and blinds of plastics have the advantages of being light in weight, translucent, admitting light without the loss of privacy, washable with soap and water, and possessing more durable qualities than the average window shades or Venetian blinds.[3]

A type of blind can be made with tubes, painted around half their circumference with a reflecting foil on the inside, and with an opaque paint on the outside. The other half of the tube is left transparent. All the tubes that form the blind would be geared to a mechanism. By turning them around, a variety of lighting phases can be attained. Light can thus be direct or indirect, reflected on the ceiling, or cut out completely--according to the angle of the sun and the position of the tubes.

4. Tubes for plumbing (and gas pipes) facilitate handling and manipulation. Cost of installation is less than that of lead or steel pipes; and the flexibility of some tubes allows them to be bent without cutting or using special bends.[4] Also the danger of explosion in freezing weather is eliminated, due to the stretchability of the pipes.

Care should be exercised in the choice of tubes for hot water on account of the low softening points of some materials. But there are several types that can withstand heat and pressure. "Glasweld" pipes, for instance, made of polyester resin reinforced with glass cloth, can withstand an internal pressure of 150 lb. per sq. in. with a temperature of 425° F. (218° C.), and 450 lb. per sq. in. at 320° F. (160° C.). Their tensile strength of 50,000 lb. per sq. in. compares

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[2] See p. 60 of this study.

[3] Singer, op. cit., p. 141.

[4] Ibid., p. 130.

with stainless steel pipes, while their specific gravity is only 1.8 as against 7.8 for steel.[5]

Sales of non-corrosive plastics pipes have increased 3,000 per cent since 1948:

> Already widely used by mining, chemical and oil companies to carry corrosive fluids, plastic pipe is generally easier to install and cheaper to maintain than corresponding metal pipe. Sales, which reached $15 million last year, are expected to hit $250 million by 1960.[6]

5. In furniture, there is scope for the use of tubes and rods, but molded and laminated plastics stand better chances than extruded sections. The competition from traditional materials is big, and one has to weigh the arguments for and against, with respect to properties and price.

6. Façades of buildings can make use of plastics pipes similar to the glass tubes used for the Johnson Wax Company by Frank Lloyd Wright. In this application, plastics have several advantages over glass, for they are shatterproof, admit ultra-violet light, can be bent around corners, are continuous and eliminate a large amount of joinery, and also can be welded, cut and sawed with wood-working tools.

7. Boards have been extruded in continuous lengths for siding and furniture making, and this application is similar to that of sheets.

8. There is no reason why structural columns cannot be extruded. Many plastics have compressive strengths that are high enough for structural purposes.[7]

The shapes of these structural members will necessarily be different from other materials. Steel shapes are rolled and there-

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[5] *Ibid.*, pp. 133-134.

[6] *Time*, LXII, 1 (July 6, 1953), 77.

[7] See Table 5.

fore have to be open; and wood is sawed from logs, and therefore has to be solid and rectangular; but plastics are extruded in this case, and therefore may be open or box-like, solid or hollow (to eliminate the unnecessary material around the neutral axis of the shape), and the cross-section can be circular, square or any desired shape. It is better, however, that they be so shaped (fig. 26) that the effective area would increase with the increase of stresses--the stresses being proportional to the distance from the neutral axis, and maximum at the extremeties.

If the cross-section is too large to extrude in one piece, smaller sections can be assembled (glued, or welded with high-frequency heating) to provide the required area for the shape.[8]

These structural members can be used directly as columns, or can, better still, be heated and bent into continuous grid-like formations (fig. 27) that would accomodate molded windows in their cells. They can also be bent at right angles, with the columns turning and changing into beams (fig. 28). In this case, it is noticed that the area of the column is increased from floor to floor, not by increasing the section itself--which would require special columns for each floor--but by assembling the sections side by side. The beams can be strengthened, if necessary, with added spandrels that would act as cover plates.

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[8] The similarity to the flutes of classic columns indicates that while in the case of extruded columns they are the direct outcome of the method of production, they are only decorative in their classic counterpart--which gives support to the theory that classic columns in stone and marble are imitations of earlier ones made of reeds and stalks.

CHAPTER FIVE

RIGID PLASTICS, PANELS, AND THEIR USES

Several reasons require that plastics be used in connection with other materials. The proper combinations of characteristics may not be found in the homogeneous material in its pure form. Another is that a heavy object or structural member, requires large amounts of material, and is therefore uneconomic.

Besides adding fillers to molding compounds, in order to improve their properties (by reducing inflammability, increasing resistance to abrasion, giving body or color to a transparent material, and so on), one can also combine plastics with other cheaper materials: wood, paper, fabric, glass fibers (with their very high tensile strength), or such other materials as are found suitable:

Laminates

Laminates, in general, consist of layers of paper or fabric, impregnated with a liquid, thermosetting resin, or of glass-fiber mats and polyester resins, and cured under low heat and pressure to become solid units.

Their properties vary greatly according to the materials used, but, in general, they have good thermal insulation and fire resistance (especially the phenolic-base and the polyester-glass ones), good machining qualities, high strength-weight ratios, and when corrugated can be used for roofing, having qualities superior to corrugated iron.[1]

The choice of materials and adhesives depends upon the uses

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[1] Singer, op. cit., p. 54.

for which the laminates are intended, and the properties necessary for such uses. Usually all the plies of the laminate are of the same material, but since all the properties cannot always be found in one plastic, a laminate may be composed of different layers of materials, each of which performs a different function. For example, in a "Formica" laminate,

> a multi-layer of Kraft paper impregnated with phenol-formaldehyde resin forms the core of the laminate. The intermediate layer consists of a pigmented opaque sheet [to give color] impregnated with urea resin [because it has unlimited color possibilities while phenolic resins are limited to dark shades]. The layer is covered with a melamine abrasion resistant sheet. A translucent paper is impregnated with melamine and becomes transparent [to show the color underneath it] on application of heat and pressure. Sometimes an aluminum foil or core is incorporated into the laminate [to conduct and radiate heat].[2]

A laminate is usually a fraction of an inch in thickness, and is intended for use as a veneering, wall-lining or table-top material, i.e., it must be fixed to a backing material--unless it is thick and strong enough to support itself, because otherwise it will not remain flat. [6]

Impregnated and Compressed Woods

Since wood "suffers from several disadvantages owing to the fact that it is natural and not man-made and man-controlled,"[3] solid wood is sliced into veneers which are thoroughly impregnated with a resin, and then cured under heat and pressure, to produce solid sections whose structural strength and resistance to temperature changes, shrinkage and swelling are improved according to the percentage of resin used. The articles made of these woods "are regarded as superior to their metal equivalents in their properties."[4]

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[2] *Ibid.*, p. 95, my italics.

[3] Fleck, *op. cit.*, p. 241.

[4] Singer, *op. cit.*, p. 52.

One of these woods is "Hy-du-lignum," which is

> impregnated with vinyl formal resin and compressed into a dense board. It is used for aircraft propellers. The specific gravity is 1.3., tensile strength 45,000 psi, and compressive strength 21,000 psi.[5]

In these cases, its high price is justified on account of the high strength-weight ratio required for aircraft.

Another technique was found,[6] which eliminates the wasteful process of slicing wood into veneers. Solid wood is thoroughly dehydrated, and a solution of methylol urea is forced into its fibers. The reaction with the natural acids in the wood converts it into a resin.

> This process opened up great possibilities of substituting hardwood by softwood, where greater strength, dimensional stability, durability, density and wearing strength of wood were required. Flame resistance, tensile and compressive strength, and resistance to the action of most chemical agents, were also increased.[7]

Such woods would find uses, in particular, in small prefabricated houses and temporary, demountable shelters that would be moved from one place to another, because strength, combined with lightness, is of more importance in such cases than in ordinary houses or other types of buildings.

Plywood

Plywood actually dates back to antiquity:

> L'emploi de colle pour assembler des pièces de bois remonte à la plus haute antiquité. En effet, un bas-relief égyptien qu'on situe au règne de Thothmès III (environ 1.500 ans avant J.-C.), décrit sans hésitation possible le travail du bois et son collage. Un coffre en cèdre collé a été retrouvé dans le tombeau de Tut-Ankh-Ammon.[8]

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[5] Brady (1951), op. cit., p. 569.

[6] "Arboneld" by E. I. du Pont de Nemours & Co., Inc., U.S.A.

[7] Singer, op. cit., p. 53.

[8] P. Burelle and M. Fournier, "Les Matières Plastiques dans l'Ameublement," in Burelle et al., op. cit., p. 148.

However, since the adhesives used--albumin, casein, animal or fish glue--made it subject to deterioration and attack by insects and bacteria, modern, resin-bonded plywood that "even if unpainted, will withstand severed weathering for a very long time,"[9] can be considered a totally different material.

The resin used is usually phenol-formaldehyde which is "as durable as the wood itself."[10]

The uses of plywood in architecture and furniture, and its characteristics are too well-known to need any discussion here.[11] A new development in this field, however, is the bonding of phenolic resin laminated paper onto plywood, which has the advantage of making the material water resistant so that it can be used in house construction, and also of utilizing softwood veneers on the outside since they are protected by the laminated paper--making the manufacture of panels more economic.[12]

Laminated Wood

Wood can also be laminated, in which case the grains in the consecutive layers remain parallel, and not at alternating right angles as in plywood.

For certain applications, these laminates have more versatile qualities than plywood. They can be given curved shapes (before bonding, to eliminate the tendency of the different layers to slide over one another); they can be tapered to suit special applications and to meet stress requirements, with a great saving in material and weight,[13] and also to reduce waste in wood to a minimum by incorpo-

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[9] MacTaggart & Chambers, op. cit., p. 116.

[10] Engel, Hemming & Merriman, op. cit., p. 163.

[11] For a summary of plywood properties, see MacTaggart & Chambers, op. cit., pp. 110-111.

[12] Singer, op. cit., p. 48.

[13] Ibid., p. 49.

rating a certain amount of wood containing knots and other defects.[14]

> Another advantage [of lamination] is the end-to-end scarf jointing which enables great length to be obtained.[15]

Sandwiches and Panels

Sandwich constructions and panels are composite structures, made of several materials, each of which performs a special task. The difference between a sandwich and a panel is not very distinct, but, in general, the components of a sandwich are merely assembled together in a frame while those of a panel are all glued together to make one solid unit. In applications, however, there are less distinctions between them; they are used in the same ways, and will here be discussed together and referred to as "panels."

A panel is usually composed of a core between two skins, protected with sheets of a surfacing material, and all mounted in a frame that holds all the components in position.

The core forms the body and the insulating part of the panel. Therefore, softwood, corrugated paper, or glass-fiber mats are all suitable materials. The panel may also be hollow, with only the skin held on a rectangular or honeycombed frame, and for better heat and sound insulation, the core can be filled with granulated cork, foamed rubber, glass wool or such other insulating materials.

The skin, the strength-giving element, can be (a) metallic, such as aluminum, stainless steel, or lightweight alloys, since the strength-weight ratio is an important factor in the design of these panels;[16] (b) of a fibrous material, such as high-strength paper, plywood, resin-bonded fabrics, or asbestos (for its resistance to

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[14] Ibid.

[15] Ibid.

[16] Engel, Hemming & Merriman, op. cit., pp. 160-161.

flame-spread); or (c) a plastics material reinforced with nylon, other fibers, or a polyester resin with glass fibers. The more commonly-used synthetic resins for impregnating and laminating these fabrics are polyester resins, allyl-compound copolymers, phenol-formaldehyde resins, melamine-formaldehyde resins, and certain cresol resins. In fact, within broad limits, any combination of resin and fabric can be used to produce a plastic-laminate skin for sandwich construction.[17]

The surfacing material, both protective and decorative, is of an abrasion-resistant plastic such as urea and melamine formaldehyde, with a decorative film underneath it, and perhaps an aluminum foil if the skin is not metallic.[18] If a panel is used for flooring, and a resiliency more than that of wood is required, linoleum or vinyl sheets can be bonded onto the skin.[19] In many cases, since laminated sheets are intended for use as veneering materials, they are preferably bonded onto the panels at the time of manufacture instead of gluing them later, thus saving extra work and ensuring good adhesion. It is necessary that the same kind of facing material and the same kind of skin be used on both sides of panels to prevent warping due to unequal expansion. In the cases where only one side of the panel is exposed, this requirement may be wasteful because the surfacing materials are of special qualities, are executed with more care, and are therefore expensive. But this will not be the usual case, because panels are self-supporting and can serve as partitions and external walls, with both sides exposed.

The frame, usually metallic but sometimes wooden, holds the elements together if they are only assembled to form a sandwich, and

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[17] Ibid., p. 161.

[18] See "Laminates," pp. 98-99 of this study.

[19] Engel, Hemming & Merriman, op. cit., p. 164.

can be dispensed with if all the elements are pressure-bonded. Its edges can be either square or so shaped as to permit assembly with the mullions that are specially designed to be used with them.

The thicknesses of panels vary from a fraction of an inch to several inches. The thick ones are stiff enough to be used "as partitions or light infilling floors between beams spaced at regular intervals,"[20] but they should not be subjected to appreciable loads, for they will buckle or fail under shear. The problem of a truly structural panel remains unsolved, for panels that would be strong enough to be load-bearing would also at the same time be uneconomic and impractical. This leaves one possibility, and that is the use of panels as stressed skins for beams and cantilevers, so that a floor slab (fig. 36) would itself be a large panel, constructed along a principle similar to that of the single panels of which it is composed.

Advantages and Disadvantages of Panels

Aside from the properties which are determined by the type or types of plastics, together with the other materials used, the properties of panels can be summarized as follows:

1. Easier and faster erection are the results of simply inserting the panels into their positions without need for any further work of any kind, as compared with laying bricks or nailing boards, plastering or painting, and all the other time- and labor-consuming operations. The light weight of a panel allows it to be four feet in width; a convenient size for one man to carry single-handed. (Compare this to the weight and method of laying which determine the size of a brick; a convenient size for one hand.) This reduction of the amount of labor is not a small factor when we consider that the brick-

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[20] Singer, op. cit., p. 90.

layer in some States earns more than does the architect.[21]

The care and accuracy required in such cases, however, so that every unit will fit exactly in its position, may prove more money- and time-consuming than expected. The same situation is well-known in the case of traditional materials, especially steel, where a "simple," straightforward, exposed structure is more expensive than the usual methods of construction. The solution is to have as many as possible of these elements and units assembled under factory conditions to minimize site work. (But this, at the same time, would have other effects on architecture and on the architect himself, as said before in [5]).

2. The sizes of these units will be determined in the factory, and until a large variety of them becomes available, any size other than those prefabricated will have to be made to "special order" and therefore at extra cost. This, and the large sizes of the units, where three or four of them suffice to constitute the side of a room, instead of the thousands of bricks or the hundreds of wood pieces, will impose a rigid modular system on plans and even more so on elevations. Whether this can be considered as an advantage or a disadvantage, whether regularity becomes orderliness or monotony, depends upon the architect and upon the way he will handle the situation and make use of the module.

3. Healthier environments will result from the ease of cleaning (since plastics have smooth surfaces that are unaffected by water) and the very small number of joints (which can be further reduced or completely eliminated by scarf jointing or with gap-filling cements). And if translucent or transparent, plastics also admit germ-killing ultra-violet rays. This is (as said before), pro-

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[21] See "Gropius Appraises Today's Architect;" condensation of a statement by Dr. Walter Gropius, Architectural Forum (May, 1952), pp. 111ff.

vided that transparency and translucency are not used only in the creation of tight, windowless interiors.[22]

4. Better sound and heat insulation than most other building materials, including brick.

> Some of these laminated sandwich materials an inch or so in thickness are equivalent in insulating value to several inches of brickwork.[23]

This is because of the variety of insulating materials with which the cores can be filled, and because the insulating properties can be determined and adjusted in the factory according to requirement.

5. Color is an integral part of all these products, and cannot be changed, therefore, except with applied, opaque paints which would destroy many of the surface attributes. This is a disadvantage only to a very limited extent, because the "impossibility of changing colour schemes"--for which reason it was questioned whether laminated materials "will ever come into general use for houses"[24]--is not actually a problem. For except in offices, ocean liners, bars, restaurants, and the like, color schemes are changed only when a place is remodelled because it *needs* remodelling, and not simply for the sake of changing its "colour scheme." Also it will be noted that the new colors are applied only to those elements to which color was applied in the first place. No one would take off floors tiles, for example, or demolish a brick wall and rebuild it simply to change a color scheme! It should also be noted that the reason for paint is primarily to *protect* and *hide* surfaces, and that the question of choosing a color arises *after* there is need for paint.

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[22] See n. 20, p. 18 of this study.

[23] MacTaggart & Chambers, *op. cit.*, p. 103.

[24] *Ibid.*

NOTES

1. At least not by the standards of our day; for very often in historical periods were such substitutions made, and forms expressive of one material transferred to another, and it seems that the architects of the past did not see any objection to such maltreatments--or were not even conscious of them except when these substitutions failed and structures collapsed--but otherwise, the limitations of the different materials were close enough to one another, and broad enough to permit such substitutions.

Perhaps this attitude can be justified if we consider that forms crystallized and became so symbolic and meaningful to them that they would not consider abandoning them for the sake of expressing a new material. This can also explain why we insist upon the functional and expressive uses of materials: there are no such crystallized symbols in our architecture. Instead, the functional uses of materials in our architecture expresses the advanced theoretical understanding of materials and their behavior; and the economic uses of them express the economic conditions under which they were erected, and the speed and efficiency of design and construction.

2. Perfection, a main requisite for beauty,[1] is a quality that artists and artisans have always tried to achieve in their work, and all historical examples indicate such an attitude. In no case did they leave tool marks on their work, except perhaps on rough work and utilitarian structures which were understood to be rough and of no high architectural or artistic value. In temples, for example, in localities where marble was not available, the Greeks covered rough stone with powdered-marble stucco to achieve a perfection similar to that of real marble, even when it meant the com-

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[1] Cf. Summa Theol., Pt. 1, Q. 39, Art. 8.

plete disregard of the nature and expression of materials. Even the Gothic builders--whose execution was rough and crude, and materials poor and scarce--veneered rubble walls with stone slabs.

But since perfection was always the product of hard physical work, labor mistakenly became the measure of perfection, and hence of beauty itself.

Hamlin states that

> the marks of hammer or chisel often increase the richness of the expression which the stone makes, because they recall to the observer the patient labor which shaped the rough mass into the carefully finished block.[2]

And a similar opinion is expressed by Fleck:

> We have progressed considerably from the horn drinking cup to the urea-formaldehyde resin cup, although it is sometimes questionable whether the result is as aesthetically elegant as that of the craftsman who laboured long and lovingly to produce his masterpiece.[3]

This remains to be the common attitude even in our own day; when the Machine and power tools made perfection easy to attain, only then did the intimidated artists deliberately leave tool marks on their works of sculpture, and hand labor had to be stopped at the point beyond which it could be mistaken for machine (hence "cheap") art. Similarly, mass-produced architectural ornaments were left out of buildings because they were "cheap" and of no "artistic value," and it will be noticed that ornaments were never considered so before the Machine Age when they were mass-produced by hand by laborers and craftsmen who "laboured long and lovingly."

Only now, after the Machine had taken on itself the beastly and inhuman labor (and such a "human" deed at that!), and separated labor from perfection, can perfection be enjoyed independently, especially in such architectural items as wall panels, slabs, window

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[2] Hamlin, op. cit., II, 461.

[3] Fleck, op. cit., p. 2.

plate glass or plastics, etc., not as having (nor intended to have) "artistic value" in themselves, but as contributing to the work of art which is the building as a whole.

If it be argued that the beastly and inhuman labor is not seen, and that the objects are admired for their perfection alone, then the more reason why they should be admired now for that same--if not more--perfection, with the Machine behind the scenes. For the perfection now achieved by machinery is gained without the human suffering and indignity which was always the price paid for it in older times.

3. To some people, plastics furniture and table-tops look "cold," and plastics-covered interiors produce an "inhuman" atmosphere. But this is a misconception. Actually plastics are as warm to the touch as wood, if not warmer. That feeling of coldness comes from long associating polished surfaces with metals, marble and glazed tiles, which have high coefficients of thermal conductivity (just as transparency was associated with glass, and transparent plastics looked fragile when they are actually quite shatterproof, the impact strength of methyl methacrylate being ten times that of glass of equal thickness[4]). Also, traditional, polished materials are generally used where the atmosphere is cold, such as lobbies, swimming pools, bathrooms, and the like.

It is true that synthetic-fiber clothes feel cold, but that has a different reason. Synthetic fibers do not absorb moisture, and textiles extruded in continuous filaments do not have the fuzz that materials made of short staples have. The feeling of warmth comes from the insulating layers of air on the surface of the textiles. (And it will be remembered that when "brushed-nylon" sweaters

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[4] Barron, op. cit., p. 577.

were made a few years ago, with the aim of producing such an effect, they were found so highly inflammable that the government had to warn the people of their danger.)

4. It seems that man always tries to make his buildings durable and lasting--everlasting, if possible--and his reasons are either spiritual (to leave behind him monuments with which he and his deeds may be remembered long after him), or materialistic (to get all the service he can out of his buildings which are by no means easy or cheap to erect or to own). But whether his buildings do live up to his expectations, or have to succumb sooner or later to the aggressive and corrosive elements, including the vandalism of other men, he cannot foretell. Nor can he determine the durability of his materials. He can carry out indicative tests, and he can notice that certain materials are stronger and last longer than others; then he can build--within the physical limitations of his surroundings, the availability of materials, labor, time, etc.--and leave his buildings to their fate.

On the other hand we can argue that since the only building materials used to be stone, brick and wood, man in all ages had to use them, whether they satisfied his desires or not, and whether he was thinking of permanence or not. The Greek builders, for example, had no choice but to use marble for their temples. It was a durable material and therefore it lasted. Also, they had no other choice but to use timber for the roofs, and therefore not a single temple today has a roof left. And in Egypt, the sudden emergence of a fully-matured stone architecture indicates that it must have been preceeded by centuries of building activity, but that this earlier building activity must have been with perishable materials--wood, bricks and reeds--because none of it remained while its stamp on the stone architecture that followed can be easily noticed. It is not possible to tell whether the shift to stone was due to a sudden decision to attempt to defy time, or was due to other reasons, and that it only happened that the material chosen was the abundant, durable stone.

In the twentieth century, we have taken to concrete and steel (or perhaps, due to some reasons, we had to); but we do not know how long they will last. Concrete will possibly endure for centuries, but steel gives every indication that it will not: it has to be protected from weathering and corrosion to make it last as long as possible (but who will keep doing that?).

The case of plastics is not different. They are materials of definite serviceable properties. They can be used, and they can be protected, but they also have to take their chances.

5. This seems a big step along the line of development--with the ever-increasing number of specialists[5] that are claiming a greater and greater share of the architect's role. But the architect is in no danger of losing his position, for he stands on firm grounds. He is the link between the various groups that cooperate to execute a building, and he is the organizer of all the complex procedures involved.

There was a time when he collaborated with artists and craftsmen in the actual building of a structure, executing from small and rough studies, making his decisions on the spot, and solving his problems as they arose during execution.

But that was long ago. He ceased to be that "master builder" when artists detached themselves and went to work independently, and when craftsmen deserted him for the factory (and there lost their identity in the over-specialization), and architecture ceased to be

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[5] Structural engineers, electricians, air-conditioners, interior decorators, color consultants, economists, psychologists, etc.

the "mother of all arts."

The new economic conditions forced upon the architect a new kind of architecture: "paper architecture" in which a building is drawn, and all the operations described--complete to the smallest detail--before the actual execution is undertaken; and where a building becomes more of a financial project than anything else. Had the builders of temples or cathedrals thought along similar lines, they would have never left behind them a trace!

It is this economic factor, <u>and not the machine</u>, that is the real cause of all this change. The machine is only a tool; an advanced, complicated and expensive tool that we would not have had recourse to had it not been shown us that it was capable of achieving more economical results, or of performing tasks otherwise impossible. The reason craftsmen went to the factory is that they get more pay there; and the artist also became industrialized, because he gets royalties whenever his design is duplicated (at the time when the architect, as is well known, is rewarded by reducing his compensations when he invents easier and more economic solutions).

The reason for mass-production is not the machine itself, but the fact that it (the machine) cannot be made to function economically except in producing large quantities. And the more building components are turned over to the machine, the less the architect's scope and role become.

If conditions continue in this direction, (and there are many indications that they will, with plastics being a big stop), the end of the architect will not be far!--the architect <u>as we know him today</u>, that is to say.

To remain the master builder (of a new type) he will have to have sufficient understanding of these new materials and products, and learn how to use them; or, better still, join the old group in the factory, and collaborate with them, as he used to do, in the production of building components and finished products. It is true that "not invention, but the use made of invention, is the measure of an architect," but he certainly invents solutions and achieves esthetic triumphs which can hardly be at their best without his participation in their shaping during manufacture.

Another solution to the problem of industrialization is, not to manufacture the finished product, but its elements only: sheets, plates, rods, strips, glues, etc., so that the solution of an architectural problem would remain an artistic creation and not merely the jointing together of parts, or, to go to the extreme, the unfolding of completely prefabricated houses shipped to the site in single packages.

6. There is no doubt that such treatments are functional and economic, but whether they are expressive remains a subject for discussion. The only difficulty is that a laminate can be easily mistaken for a panel, for it is only a difference in thickness and a variety of the materials that are laminated. The broad and jointless surfaces, decorated or plain, would, however, indicate plastics, and, in a sense, there is no difference between a laminate and a panel in application, for when a laminate is backed with a frame, it becomes a panel in effect.

TABLES

The following tables were compiled from several sources, including the books listed in the bibliography.

Where necessary, values were converted from one system to another in order to standardize all the units of measure used. And the ranges of properties indicate variations due to the different compositions and grades possible to each material, or the effects of temperature, humidity, aging, or other influential factors.

TABLE 1

PHYSICAL PROPERTIES

Material	Color Possibilities	Odor and Taste	Specific Gravity from	to
Acrylic and methacrylic	unlimited	none	1.16	1.20
Casein	unlimited	none	1.34	1.35
Cellulose acetate	unlimited	very slight	1.27	1.63
propionate	unlimited	none	1.16	1.21
acetate butyrate	unlimited	none to slight	1.14	1.25
nitrate	unlimited	slight camphor	1.35	1.60
Ethyl cellulose	unlimited	none to aldehyde	1.05	1.25
Phenol formaldehyde,				
molded, filled with wood flour	dark colors	none to phenolic	1.25	1.52
mineral powder	dark colors	none to phenolic	1.59	2.09
macerated fabric	dark colors	none to phenolic	1.36	1.47
laminated, paper or fabric base	dark colors	none to phenolic	1.30	1.40
cast, unfilled	limited	none to phenolic	1.20	1.70
Phenolic furfural, filled	limited	none	1.30	2.00
Polyvinyl acetals, unfilled	unlimited	none	1.05	1.25
acetate	unlimited	none	1.19	
chloride-acetate	unlimited	none	1.30	1.60
plasticized	unlimited	varies	1.20	1.70
Polystyrene	unlimited	none	0.90	1.07
-butadiene	unlimited	none	1.05	
Urea formaldehyde	pastel	none	1.45	1.55
Melamine formaldehyde, filled	unlimited	none	1.42	1.86
Vinylidene chloride	unlimited	slight	1.68	1.75
Polyethylene	limited	very slight	0.91	0.94
Polytetrafluoroethylene	limited	none	2.10	2.30
Polyamides (nylon)	unlimited	none	1.09	1.15
Silicone rubber	white and tans	none	1.10	2.10
Aluminum			2.60	2.77
Bricks and stones			1.90	3.40
Concrete			2.40	
Glass			2.50	2.75
Steel			7.78	
Woods		slight	0.36	1.00

TABLE 2

OPTICAL PROPERTIES

Material	Clarity			Refractive index n_D		Light Transmission per cent	
	trans-parent	trans-lucent	opaque	from	to	from	to
Acrylic and methacrylic	x	. . .	. . .	1.48	1.51	90	95
Casein	. . .	x	. . .	. . .	. . .	. . .	. . .
Cellulose acetate	x	. . .	. . .	1.47	1.51	85	92
propionate	x	. . .	. . .	1.47	1.48	. . .	. . .
acetate butyrate	x	. . .	. . .	1.47	1.49	. . .	. . .
nitrate	x	. . .	. . .	1.46	1.58	90	
Ethyl cellulose	x	. . .	. . .	1.47		91	
Phenol formaldehyde							
molded, filled with wood flour	. . .	. . .	x	. . .	. . .	. . .	. . .
mineral powder	. . .	. . .	x	. . .	. . .	. . .	. . .
macerated fabric	. . .	. . .	x	. . .	. . .	. . .	. . .
laminated, paper or fabric base	. . .	. . .	x	. . .	. . .	. . .	. . .
cast, unfilled	x	. . .	. . .	1.50	1.70	85	
Phenolic furfural, filled	. . .	. . .	x	. . .	. . .	. . .	. . .
Polyvinyl acetals, unfilled	x	. . .	. . .	1.46	1.50	. . .	. . .
acetate	x	. . .	. . .	1.46		. . .	. . .
chloride acetate	x	. . .	. . .	1.52	1.53	. . .	. . .
plasticized	x	. . .	. . .	1.54		. . .	. . .
Polystyrene	x	. . .	. . .	1.59		. . .	. . .
-butadiene	x	. . .	. . .	1.58		. . .	. . .
Urea formaldehyde	. . .	x	. . .	1.54	1.60	89	
Melamine formaldehyde	. . .	x	. . .	1.60		. . .	. . .
Vinylidene chloride	. . .	x	. . .	1.60	1.63	. . .	. . .
Polyethylene	. . .	x	. . .	1.51	1.52	. . .	. . .
Polytetrafluoroethylene	. . .	x	. . .	1.30	1.40	. . .	. . .
Polyamides (nylon)	x	. . .	. . .	1.53		. . .	. . .
Silicone rubber	. . .	. . .	x	. . .	. . .	. . .	. . .
Aluminum	. . .	. . .	x	. . .	. . .	. . .	. . .
Bricks and stones	. . .	. . .	x	. . .	. . .	. . .	. . .
Concrete	. . .	. . .	x	. . .	. . .	. . .	. . .
Glass	x	. . .	. . .	1.49	1.77*	88	91
Steel	. . .	. . .	x	. . .	. . .	. . .	. . .
Woods	. . .	. . .	x	. . .	. . .	. . .	. . .

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*1.52 for ordinary, soda-lime-silica window glass

TABLE 3

THERMAL PROPERTIES

Material	Type: thermo-plastic	Type: thermo-setting	Burning Rate	Heat Distortion °C from	Heat Distortion °C to	Softening Point °C from	Softening Point °C to	Maximum Operating Temperature °C from	Maximum Operating Temperature °C to
Acrylic and methacrylic.	x		slow	50	85	66	123	49	71
Casein	x		very slow		149	94		. . . .	
Cellulose acetate.	x		slow	41	100	60	130	60	82
propionate	x		slow	54	72	. . . . .		. . . .	
acetate butyrate	x		slow	47	102	60	127	60	96
nitrate.	x		very slow	43	66	60	90	60	
Ethyl cellulose.	x		slow	45	93	93	140	60	82
Phenol formaldehyde									
molded, filled with wood flour . . .		x	very slow	115	140	none		175	
mineral powder		x	none	115	160	none		232	
macerated fabric		x	almost none	115	160	none		121	177
laminated, paper or fabric base. . .		x	very slow	160		none		100	177
cast, unfilled		x	very slow	35	122	none		71	
Phenolic furfural, filled.		x	very slow	132	146	chars 290		138	
Polyvinyl acetals, unfilled.	x		slow	47	100	47	200	. . . .	
acetate.	x		slow	40	50	65	175	. . . .	
chloride acetate	x		none	52	69	60	65	. . . .	
plasticized	x		varies	77	121	. . . .		66	
Polystyrene.	x		slow	70	90	88	121	65	75
-butadiene.	x		medium	52	64	. . . .		. . . .	
Urea formaldehyde.		x	very slow	127	138	none		71	96
Melamine formaldehyde, filled.		x	almost none	130	141	none		150	200
Vinylidene chloride.	x		none	66	82	116	160	130	
Polyethylene	x		slow	40		115		82	
Polytetrafluoroethylene.	x		none	132		. . . .		. . . .	
Polyamides (nylon)	x		none, melts	160		135		. . . .	
Silicone rubber.			slow	200		315		. . . .	
Aluminum			none	. . . .		melts 657		. . . .	
Bricks and stones.			none	. . . .		. . . .		. . . .	
Concrete			none	. . . .		. . . .		. . . .	
Glass.			none	. . . .		500	1540	. . . .	
Steel.			none	. . . .		melts1500		. . . .	
Woods.			slow	. . . .		. . . .		. . . .	

TABLE 3--Continued

	Thermal Conductivity				Thermal Expansion 10^{-5}/°C	
	Gram cal/sq cm/sec/°C per 1 cm of thickness x 10^{-4}		BTU/sq ft/hr/°F per 1 in of thickness		from	to
Acrylic and methacrylic.	1.0	10.0	o.29	2.90	8.0	9.0
Casein	. . . .		. . . .		4.1	8.0
Cellulose acetate.	4.5	8.7	1.31	2.54	5.0	16.0
propionate	5.5		1.60		13.0	16.0
acetate butyrate	4.0	8.0	1.16	2.33	11.0	17.0
nitrate.	3.1	5.5	0.90	1.60	6.5	16.0
Ethyl cellulose.	3.8	6.3	1.11	1.83	10.0	14.0
Phenol formaldehyde						
molded, filled with wood flour . . .	4.0	12.0	1.16	3.50	3.0	7.5
mineral powder .	8.0	20.0	2.33	5.82	1.5	4.0
macerated fabric	3.0	7.0	0.87	2.04	1.0	6.0
laminated, paper or fabric base. . .	5.0	8.0	1.45	2.33	1.7	3.0
cast, unfilled	3.0	7.0	0.87	2.04	4.0	15.0
Phenolic furfural, filled.	3.5	20.0	1.02	5.82	2.0	7.0
Polyvinyl acetals, unfilled.	3.4	4.4	0.99	1.28	7.8	22.3
acetate.	3.8		1.11		6.5	8.6
chloride acetate	3.5	4.1	1.02	1.19	6.9	7.0
plasticized	3.9	4.0	1.14	1.16	7.0	25.0
Polystyrene.	1.9	3.2	0.55	0.93	6.0	8.0
-butadiene.	. . . .		. . . .		. . . .	
Urea formaldehyde.	7.1		2.06		2.5	3.0
Melamine formaldehyde, filled.	. . . .		. . . .		1.8	4.5
Vinylidene chloride.	2.2	3.0	0.64	0.87	15.8	
Polyethylene	8.0		2.34		16.0	18.0
Polytetrafluoroethylene.	6.0		1.74		10.0	
Polyamides (nylon)	5.2	5.8	1.51	1.69	10.0	18.0
Silicone rubber.	4.6	9.9	1.34	2.87	. . . .	
Aluminum	4800.0	5200.0	1400.00	1508.00	2.3	2.54
Bricks and stones.	4.16	43.0	1.21	12.50	0.2	1.17
Concrete	20.6		6.1		1.08	
Glass.	15.0	19.0	4.37	5.53	0.78	1.10
Steel.	1125.0		328.0		1.10	
Woods.	1.34	6.0	0.39	1.74	0.30	0.90

TABLE 4

THERMAL CONDUCTIVITY OF SOME INSULATING MATERIALS

Material	Coefficient of Thermal Conductivity	
	Gram cal/sq cm/sec/°C per 1 cm of thickness x 10^{-4}	BTU/sq ft/hr/°F per 1 in of thickness
"Isoflex"	1.10	0.32
Granulated Cork	1.00	0.29
Wood fiber board	1.30	0.38
Asbestos sheets	1.00	0.29
Vermiculite	0.91	0.263
Pine	3.28	0.958
Wood pulp	1.34	0.39
Ground cork	1.06	0.31
Brick	13.80	4.00
Dry brick	4.16	1.21
Clay tile	2.06	0.60

TABLE 5

STRUCTURAL PROPERTIES

Material	Modulus of Elasticity p.s.i.x10^5		Tensile Strength p.s.i.x10^3		Elongation per cent		Compressive Strength p.s.i.x 10^3	
	from	to	from	to	from	to	from	to
Acrylic and methacrylic	4.0	6.0	4.0	10.0	1.0	15.0	10.0	15.0
Casein	5.1	5.7	7.5	10.0	2.5		27.0	53.0
Cellulose acetate	0.6	4.0	4.0	11.0	7.5	25.0	4.0	30.0
propionate	. . . .		2.0	6.5	. . . .		1.0	4.0
acetate butyrate	0.6	3.5	2.4	7.5	13.0	82.0	7.2	22.5
nitrate	1.5	4.0	5.0	12.0		35.0	20.0	30.0
Ethyl cellulose	1.7	5.0	2.0	12.0	2.0	40.0	10.0	20.0
Phenol formaldehyde								
molded, filled with wood flour	8.0	15.0	4.0	11.0	0.6		16.0	36.0
mineral powder	10.0	45.0	3.5	10.0	0.6		10.0	40.0
macerated fabric	7.0	12.0	5.0	8.0	0.7		20.0	32.0
laminated, paper or fabric base	3.5	30.0	8.0	18.0	. . . .		20.0	44.0
cast, unfilled	1.3	18.0	3.0	12.0	1.0		13.0	33.0
Phenolic furfural, filled	7.0	45.0	5.0	11.0	. . . .		24.0	40.0
Polyvinyl acetals, unfilled	3.5	4.0	2.0	12.0	4.0	450.0	. . . .	
acetate	. . . .		1.5	5.0	. . . .		. . . .	
chloride acetate	3.5	4.1	6.0	10.0	. . . .		11.0	
plasticized	. . . .		8.0	10.0		550.0	10.0	12.0
Polystyrene	12.0	15.0	3.0	10.0	0.5	5.0	11.0	17.0
-butadiene	. . . .		6.2			10.0	. . . .	
Urea formaldehyde	12.0	16.0	5.5	13.0		1.0	24.0	35.0
Melamine formaldehyde, filled	12.0	16.0	3.5	7.0		0.5	30.0	31.0
Vinylidene chloride	0.2	2.0	3.0	7.0	10.0	40.0	7.5	8.5
Polyethylene	0.2		1.3	2.3	400.0		11.6	16.5
Polytetrafluoroethylene	0.6		1.8		110.0		0.7	
Polyamides (nylon)	2.6	4.0	7.0	11.0	50.0	300.0	7.0	15.0
Silicone rubber	. . . .		0.3	0.7	75.0	300.0	. . . .	
Aluminum	95.0	103.0	9.0	35.0	30.0	60.0	15.0	
Bricks and stones	15.0	145.0	0.3	2.3	. . . .		1.0	30.0
Concrete	20.0	55.0	0.3	0.4		0.002	2.0	5.0
Glass	70.0	114.0	4.5	17.0	. . . .		36.0	180.0
Steel	300.0		45.0	67.0	15.0	27.0	60.0	150.0
Woods, along fibers	2.8	18.0	5.0	18.0	. . . .		0.4	9.0

TABLE 5--Continued

	Shear Strength psi x 10^3		Flexural Strength psi x 10^3		Impact Strength			
					Ft lb to break ½" x ½" bar		(Izod) ft lb per in of notch	
	from	to	from	to	from	to	from	to
Acrylic and methacrylic	8.2	11.5	10.0	15.0	0.02	0.50	0.4	
Casein	. . . .		10.0	18.0	1.00		. . . .	
Cellulose acetate	6.0	10.0	5.0	16.0	0.60	1.60	0.4	3.5
propionate	. . . .		4.8	10.0	. . . .		1.0	11.0
acetate butyrate	3.7	6.0	5.5	12.0	1.30	3.30	0.6	3.2
nitrate	. . . .		6.0	15.0	0.25	1.00	1.0	4.0
Ethyl cellulose	7.5		9.0	10.0	0.60	1.80	. . . .	
Phenol formaldehyde								
molded, filled with wood flour	11.8		8.0	15.0	0.10	0.28	0.2	0.4
mineral powder	6.7	9.0	8.0	20.0	0.11	0.36	0.2	1.5
macerated fabric	11.0	13.0	10.0	13.0	0.40	2.40	0.4	4.8
laminated, paper or fabric base	4.5	11.8	13.0	30.0	0.30	8.00	. . . .	
cast, unfilled	8.5		10.0	17.7	0.10	1.50	0.2	1.2
Phenolic furfural, filled	. . . .		8.0	22.0	0.08	3.00	. . . .	
Polyvinyl acetals, unfilled	. . . .		. . . .		. . . .		0.4	1.2
acetate	. . . .		10.0	13.0	. . . .		. . . .	
chloride acetate	10.0		7.5	13.0	0.30	0.60	0.3	0.5
plasticized	. . . .		12.0	17.0	. . . .		. . . .	
Polystyrene	6.2		14.0	19.0	0.20	0.50	0.2	1.0
-butadiene	. . . .		. . . .		. . . .		0.2	
Urea formaldehyde	13.0		10.0		0.14	0.16	0.2	
Melamine formaldehyde, filled	. . . .		7.5	16.5	. . . .		0.2	1.0
Vinylidene chloride	. . . .		15.0	17.0	. . . .		0.5	8.0
Polyethylene	. . . .		14.0	18.0	. . . .		. . . .	
Polytetrafluroethylene	. . . .		. . . .		. . . .		2.5	4.5
Polyamides (nylon)	. . . .		5.7	15.0	. . . .		0.6	
Silicone rubber	. . . .		. . . .		. . . .		. . . .	
Aluminum	12.0		. . . .		. . . .		. . . .	
Bricks and stones	0.3	6.5	0.2	3.0	. . . .		. . . .	
Concrete	3.0		1.0		. . . .		. . . .	
Glass	. . . .		11.0	18.4	. . . .		. . . .	
Steel	42.0	65.0	48.0	65.0	. . . .		. . . .	
Woods	0.06	3.9*	0.7	1.7	. . . .		. . . .	

*Across fibers

TABLE 6

SOME COMPARATIVE STRENGTH-WEIGHT RATIOS

Material	Tensile Strength psi x 10^3		Specific Gravity		Comparative Strength-Weight Ratio	
	from	to	from	to	from	to
Acrylic resins.	4.0	10.0	1.16	1.20	3.3	8.6
Cellulose acetate	3.0	11.0	1.27	1.63	1.8	8.7
Ethyl cellulose	2.0	12.0	1.05	1.25	1.6	11.4
Phenolic resins						
molded, filled with wood flour. . . .	4.0	11.0	1.25	1.52	2.6	8.8
mineral powder. .	3.5	10.0	1.59	2.09	1.7	6.3
macerated fabric.	5.0	8.0	1.36	1.47	3.4	5.9
laminated, paper or fabric base . . .	7.0	18.0	1.30	1.40	5.0	13.8
cast, unfilled.	3.0	12,0	1.20	1.70	1.8	10.0
Polyvinyl chloride acetate.	0.8	9.0	1.34	1.37	0.6	6.7
Polystyrene	3.0	10.0	1.05	1.07	2.8	9.5
Urea formaldehyde	5.5	13.0	1.45	1.50	3.7	9.0
Polyvinylidene chloride filaments	30.0	60.0	1.68	1.86	15.1	35.6
Polyamide filaments	50.0	60.0	1.09	1.14	43.8	55.0
Steel		60.0		7.80		7.7
Aluminum.		35.0	2.60	2.70	13.0	13.4
"Compreg"	43.0	54.0	1.22	1.37	44.3	31.4
Birch, against fibers		30.0		1.20		25.0
"Hydulignum".		45.0		1.31		34.4
Plate Glass	6.5	30.0	2.50	2.60	2.5	14.0
Glass filaments, 0.0002 to 0.00025" diam.	250.0	500.0	2.50	2.60	96.0	200.0
0.00005" diam.		3500.0	2.50	2.60	1340.0	1400.0

TABLE 7

DURABILITY OF PLASTICS

Material	Effect of Sunlight and Ultraviolet Light	Effect of Aging at Room Temperature
Acrylic and methacrylic	very slight	none
Casein	slight fading	hardens
Cellulose acetate	slight yellowing	slight shrinkage
propionate	none	none
acetate butyrate	slight	slight
nitrate	yellows	hardens
Ethyl cellulose	very slight	none-slight
Phenol formaldehyde		
molded, filled with wood flour	light colors fade	none
mineral powder	light colors fade	none
macerated fabric	light colors fade	none*
laminated, paper or fabric base	light colors fade	none*
cast, unfilled	light colors fade	hardens**
Phenolic furfural, filled	light colors fade	hardens**
Polyvinyl acetals, unfilled	slight	slight
acetate	slight to none	none
chloride acetate	darkens	none-slight
plasticized	slight fading	none
Polystyrene	yellow stains	none
-butadiene	none to slight	none-slight
Urea formaldehyde	none	hardens
Melamine formaldehyde, filled	none	hardens
Vinylidene chloride	darkens slightly	becomes stronger
Polyethylene	darkens, degrades	slight-none
Polytetrafluoroethylene	none	none
Polyamides (nylon)	slight discoloring	none
Silicone rubber	none	none

*Mechanical and electrical properties improved **Insulation value reduced

TABLE 7--Continued

	Effect of Hot Water	Effect of Cold Water	Water Absorption per cent 24 hrs immersion at 25 C	
			from	to
Acrylic and methacrylic.	softens	none	0.3	0.5
Casein	softens	softens	7.0	14.0
Cellulose acetate.	softens	swells	1.0	6.5
propionate	slight	none	1.2	1.7
acetate butyrate	. . . .	. . . .	0.8	2.2
nitrate.	softens	slight	0.6	4.0
Ethyl cellulose.	none	none	0.7	2.0
Phenol formaldehyde				
molded, filled with wood flour . . .	insulation value reduced	insulation value reduced	0.2	0.7
mineral powder .			0.01	0.3
macerated fabric			0.5	2.5
laminated, paper or fabric base. . .			0.3	9.0
cast, unfilled			0.01	0.6
Phenolic furfural, filled.			0.01	1.4
Polyvinyl acetals, unfilled.	. . . .	slight	0.6	5.0
acetate.	softens	softens	2.0	
chloride acetate	softens	none	0.05	0.15
plasticized	slight	none	0.1	0.6
Polystyrene.	none	none	0.00	0.06
-butadiene.	slight	none	. . . .	
Urea formaldehyde.	. . . .	. . . .	0.75	3.0
Melamine formaldehyde	none	none	0.07	0.6
Vinylidene chloride.	slight	slight	0.1	
Polyethylene	slight-none	slight	0.00	0.01
Polytetrafluoroethylene.	none	none	0.00	
Polyamides (nylon)	slight-none	slight-none	0.4	2.0
Silicone rubber.	slight	slight	0.5	5.0

TABLE 8

CHEMICAL PROPERTIES

Material	Chemical Resistance to: Weak Acids	Strong Acids	Weak Alkalis	Strong Alkalis
Acrylic and methacrylic	excellent	excellent	excellent	excellent
Casein	good	poor	softens	poor
Cellulose acetate	fair	poor	fair	poor
propionate	good	fair*	fair	poor
acetate butyrate	fair	poor	fair	poor
nitrate	fair-good	fair*	good	poor
Ethyl cellulose	fair-good	poor	good	good
Phenol formaldehyde				
molded, filled with wood flour	good	good*	good	poor
mineral powder	good	good*	good	poor
macerated fabric	good	good*	good	poor
laminated, paper or fabric base	good	good*	good	poor
cast, unfilled	good	good*	good	poor
Phenolic furfural, filled	good	good*	good	poor
Polyvinyl acetals, unfilled	poor	poor	excellent	good
acetate	good	poor	good	poor
chloride acetate	excellent	excellent	excellent	excellent
plasticized	excellent	excellent	excellent	excellent
Polystyrene	excellent	good	excellent	excellent
-butadiene	excellent	excellent	excellent	good
Urea formaldehyde	good	poor	varies	poor
Melamine formaldehyde, filled	excellent	fair	excellent	excellent
Vinylidene chloride	excellent	excellent	excellent	good**
Polyethylene	excellent	excellent	excellent	excellent
Polytetrafluoroethylene	excellent	excellent	excellent	excellent
Polyamides (nylon)	excellent	poor	excellent	excellent
Silicone rubber	good	fair	good	poor

*Except oxidizing acids **Except ammonia

TABLE 8--Continued

	Chemical Resistance to:			
	Alcohols	Mineral Oils	Animal Oils	Vegetable Oils
Acrylic and methacrylic.	poor	excellent	excellent	excellent
Casein	good	good	good	good
Cellulose acetate.	soluble	good	good	good
propionate	soluble	excellent	excellent	excellent
acetate butyrate	poor	good	good	good
nitrate.	soluble	good	good	good
Ethyl cellulose.	fair	fair-good	poor	poor-fair
Phenol formaldehyde				
molded, filled with wood flour . . .	good	excellent	excellent	excellent
mineral powder .	good	excellent	excellent	excellent
macerated fabric	good	excellent	excellent	excellent
laminated, paper or fabric base. . .	good	excellent	excellent	excellent
cast, unfilled	good	excellent	excellent	excellent
Phenolic furfural, filled.	good	excellent	excellent	excellent
Polyvinyl acetals, unfilled.	fair	excellent	excellent	excellent
acetate.	soluble	excellent	excellent	excellent
chloride acetate	excellent	excellent	excellent	excellent
plasticized	varies	varies	varies	varies
Polystyrene.	excellent	excellent	varies	varies
-butadiene.	excellent	excellent	excellent	excellent
Urea formaldehyde.	excellent	excellent	excellent	excellent
Melamine formaldehyde, filled.	excellent	excellent	excellent	excellent
Vinylidene chloride.	excellent	excellent	excellent	excellent
Polyethylene	excellent	excellent	excellent	excellent
Polytetrafluoroethylene.	excellent	excellent	excellent	excellent
Polyamides (nylon)	varies	excellent	excellent	excellent
Silicone rubber.	good	good-poor	good	good

TABLE 9

AVAILABLE FORMS OF PLASTICS

Material	Cast	Film	Impregnating Varnish	Laminates	Lacquer	Powder Or Granule	Rods	Sheets	Tubes
Acrylic and methacrylic	x	...	x	...	x	x	x	x	x
Casein	...	...	...	...	...	...	x	x	x
Cellulose acetate	...	x	...	...	...	x	x	x	x
propionate	...	...	...	...	...	x	...	...	...
acetate butyrate	...	...	...	...	...	x	...	x	...
nitrate	...	x	...	x	x	...	x	x	x
Ethyl cellulose	...	x	x	...	x	x	x	x	x
Phenol formaldehyde									
molded, filled with wood flour	...	...	...	...	...	x	x	x	x
mineral powder	...	...	...	...	...	x	x	x	x
macerated fabric	...	...	...	...	...	x	x	x	x
laminated, paper or fabric base	...	...	...	x	...	...	...	x	x
cast, unfilled	x	...	...	...	...	...	x	x	x
Phenolic furfural, filled	x	...	x	...	x	x	...	...	...
Polyvinyl acetals, unfilled	...	x	x	...	x	x	...	x	...
acetate	...	...	x	...	x	x	...	...	...
chloride acetate	...	x	x	x	x	x	x	x	x
plasticized	x	x	x	x	x	x	x	x	x
Polystyrene	...	x	x	x	x	x	x	x	x
-butadiene	...	...	...	...	...	x	...	...	...
Urea formaldehyde	...	...	x	x	...	x	...	...	...
Melamine formaldehyde, filled	...	...	x	x	x	x	...	...	...
Vinylidene chloride	...	x	...	...	...	x	x	x	x
Polyethylene	...	x	...	...	...	...	...	x	x
Polytetrafluoroethylene	...	...	...	...	...	...	...	x	x
Polyamides (nylon)	...	x	x	...	...	x	...	x	x
Silicone rubber	...	...	...	x	...	...	x	x	x

LIST OF TRADE NAMES

Plastics Trade Names, Descriptions, and Manufacturers

Acelon B	Cellulose acetate lampshades	M. & B. Products Ltd., U.K.
Acousti-Pad	Perforated sheets backed with sound-absorbing material	Burgess Products Ltd., U.K.
Acrilex	Clear acrylic sheeting	Acryvin Corp. of America, U.S.A.
Acrolite	A dark-colored resin made by the action of phenol on glycol	. . . .
Acryloid	Acrylic resin, solutions for coatings, finishing for leather, textiles, and papers	Rohm & Haas Co., U.S.A.
Adaptosol	Cellulose acetate sealing solution; non-inflammable	The London Capsule Co., U.K.
Aero-Brand Ester Gum	Resin-glycerol for lacquers and enamels	American Cyanamid Co., U.S.A.
Aero Jablex	Expanded polyvinyl chloride for sound and thermal insulation	Moulded Components (Jablo) Ltd., U.K.
Aeroflex	Polyethylene extrusions	Anchor Plastics Co., Inc., U.S.A.
Aerolite	A water-soluble urea-formaldehyde adhesive	Aero Research Ltd., U.K.
Aeroplastic	Paper-base phenolic laminate for high shock resistance and high tensile strength	Aeroplastic Ltd., U.K.
Afcovyl	Polyvinyl chloride plastics	Alais, Froges et Camargue, France
Akalit	Casein material in sheets, rods and tubes	Akalit Kunsthornwerke, Austria
Akco	A phenolic resin for quick-drying varnishes and enamels	American Cyanamid Co., U.S.A.
Albertol	Oil-soluble phenolic resins for use in paints	Albert Products Ltd., U.K.
Aldur	Urea-formaldehyde plastics	Aldur Corp., U.K.
Algonite	Masonite faced with decorative wood veneers	U.S. Plywood Corp., U.S.A.

Alkathene	Polyethylene molding powder and extruded forms	I.C.I. Ltd., U.K.
Alresates	Maleic resins for varnishes and enamels	Albert Prods., Ltd., U.K.
Alsynite	Corrugated sheets, glass-fiber reinforced plastics	Alsynite Co. of America, U.S.A.
Altro	Aluminum oxide bonded with polyvinyl chloride, for non-slip treads	Welwyn Plastics Ltd., U.K.
Alvar	Polyvinyl acetal powder for lacquers and adhesives	Shawinigan Chemicals Ltd., Canada
Amarith	Cellulose nitrate sheets, rods and tubes	Celanese Corp. of America, U.S.A.
Amberlac	Air-drying phthalic alkyd resins for coating and finishing	Rohm & Haas Co., U.S.A.
Amberlite	A phenol-formaldehyde adhesive	Rohm & Haas Co., U.S.A.
Amberol	A series of modified phenolic resins, for varnishes and printing inks	Rohm & Haas Co., U.S.A.
Amer-Glo	Cellulose acetate and cellulose nitrate metal-surfaced sheets, for toilet ware	Celanese Corp. of America, U.S.A.
Ameroid	Casein plastics	American Plastics Corp., U.S.A.
Amron	Vinylite coating materials	The U.S. Stoneware Co., U.S.A.
Antisol	Cellulose acetate sheets	Gevaert Co. of America Inc., U.S.A.
Aralac	Translucent, white, silky casein fibers	Aralac Inc., U.S.A.
Araldite	Synthetic adhesive for bonding metals	Ciba Ltd., Switzerland, and Aero Research Ltd., U.K.
Arboneld	An impregnating chemical for solid timber	E. I. du Pont de Nemours & Co., U.S.A.
Arcolite	Phenolic door knobs and handles	Applied Resins Corp., U.S.A.
Ardux	Resorcinol-formaldehyde	Aero Research Ltd., U.K.
Armourbex	Cellulose acetate reinforced with wire	BX Plastics, Ltd., U.K.

Arochem	Modified phenolic and maleic paints and varnishes	Strook & Wittenberg Corp., U.S.A.
Arofene	An oil-soluble phenolic resin for paints and varnishes	Strook & Wittenberg Corp., U.S.A.
Artoco	Laminated, synthetic-resin bonded paper for walls and table tops	Ioco Ltd., U.K.
Asbes-Tech	A laminated material with asbestos core	Technical Plywood, U.S.A.
Astralon	A polyvinyl chloride and methyl methacrylate sheets for glazing	(of German origin)
Astrolite R-250	Polyester casting resin	Associated Plastics Labs., U.S.A.
Bakelite	Phenol-formaldehyde resins, molding materials, lacquers, etc.	Bakelite Corp., U.S.A., and Bakelite, Ltd., U.K.
Bakelite C.A.	Cellulose acetate	. . . .
Beautywood	Phenolic laminates with photographic reproduction of wood grain (!) for wall panels (see also Luxwood)	. . . .
Beckamine	Urea-formaldehyde resins for high bake finishes	Beck, Koller & Co. Ltd., U.K., and Reichhold Chemicals Inc., U.S.A.
Beckosol	Oil-modified alkyd resins for use in paints	Beck, Koller & Co. Ltd., U.K.
Beetle	Urea- and melamine-formaldehyde resins for lacquers, enamels, and molding compounds	Beetle Prods. Co. Ltd., U.K., and American Cyanamid Co. U.S.A.
Beutafilm	Printed vinyl film	Hartford Textile Corp., U.S.A.
Bexoid	Cellulose-acetate sheets, rods and tubes	BX Plastics Ltd., U.K.
Bexone F	Polyvinyl acetal	BX Plastics Ltd., U.K.
Bois Glacé	Catalin-coated wood for desk tops	Catalin Corp., U.S.A.
Boltaflex	Calendered vinyl sheeting	Bolta Prods. Inc., U.S.A.
Bondwood	A casein glue	Franklin Co., U.S.A.

Boscoprene	A cement for bonding plastics to asbestos, plaster and concrete	B.B. Chemicals Ltd., U.K.
Bostic	A cement for bonding plastics to asbestos, plaster and concrete	B. B. Chemicals Ltd., U.K.
Breethees	Vinyl film which permits moisture vapor evaporation	Rand Rubber Co., U.S.A.
Butacite	Polyvinyl butyral for safety-glass interlayer	E. I. du Pont de Nemours & Co., Inc., U.S.A.
Butvar	Polyvinyl butyral for safety-glass interlayer	Shawinigan Prods. Corp., U.S.A.
BX Copolymer	Polyvinyl chloride acetate	BX Plastics Ltd., U.K.
BX Distrene	Polystyrene	BX Plastics Ltd., U.K.
BX Lactoid	Casein materials	BX Plastics Ltd., U.K.
BX Xylonite	Cellulose nitrate sheets, rods and tubes	BX Plastics Ltd., U.K.
Carbo Mold	Phenolic repair cement	Carboline Co., U.S.A.
Catabond	Liquid phenolic adhesive for bonding plywood	F. A. Hughes Ltd., U.K., and Catalin Corp., U.S.A.
Catacol	Phenol-formaldehyde resin adhesive	Catalin Ltd., U.K.
Catalex	An expanded phenol-formaldehyde resin for thermal and sound insulation	Catalin Ltd., U.K.
Catalin	Cast phenolic sheets, rods, and tubes, etc.	Catalin Corp., U.S.A.
Catalin Styrene	Styrene molding compounds, glues varnishes and casting resins	Catalin Corp., U.S.A., and Catalin Ltd., U.K.
Celastoid	Cellulose-acetate sheets and extruded materials	British Celanese Ltd., U.K.
Celastoid Wireweld	Cellulose-acetate sheets reinforced with wire gauze	British Celanese Ltd., U.K.
Celeron	A group of laminated phenolic plastics	Continental-Diamond Fibre Co., U.S.A.

Cellastine	Black molded sheets	British Celanese Ltd., U.K.
Celloboard	Continuous boards made of chips and sawdust	Vere Engineering Co., Ltd., U.K.
Cellobond	A thermosetting-resin adhesive for bonding plastics to wood and metals	F. A. Hughes & Co., Ltd., U.K.
Cellomold	Cellulose-acetate molding powder	F. A. Hughes & Co. Ltd., U.K.
Cellon	Cellulose-nitrate sheets, rods and tubes	F. A. Hughes & Co. Ltd., U.K.
Cellophane	Regenerated cellulose in thin sheets for wrapping purposes, sometimes waterproofed with a coat of cellulose nitrate lacquer	British Cellophane Ltd., U.K., and E. I. du Pont de Nemours & Co., Inc., U.S.A.
Cellucraft	Cellulose acetate and cellulose nitrate spray coating	Detroit Macoid Corp., U.S.A.
Cellulate	Cellulose acetate decorative sheets	National Plastic Prods., Co., U.S.A.
Celluloid	Improved cellulose nitrate, with camphor	Celanese Corp. of America, U.S.A.
Cel-O-Glass	Wire screens coated with cellulose acetate, for doors, windows, lamp shades, etc.	E. I. du Pont de Nemours & Co., Inc., U.S.A.
Celotex	Fiber insulating, building and hard boards	Celotex Ltd., U.K.
Cerrusco	Texture paint	Cellon Ltd., U.K.
Cerrux	Synthetic finish, air-drying and stoving	Cellon Ltd., U.K.
Certus	A casein cement for bonding wood to plastics	Central Chemicals Co. Ltd., U.K.
Charmour	A cellulose acetate for lamp shades	Celanese Corp. of America, U.S.A.
Chequerplast	Laminated sheets for flooring and industrial uses	Holoplast Ltd., U.K.
Clair de Lune	A cellulose-acetate material for lamp shades	Celanese Corp. of America, U.S.A.
Clarifoil	Cellulose acetate transparent foil and paper	British Celanese Ltd., U.K.
Claudilithe	Casein plastics	La Claudilithe, France

Cocoon	Vinyl and vinylidene plastics sprays that form flexible, rubbery, waterproof films, for roofing and coating in general; also known as Liquid Envelope, Brevon, Strippable Coatings, etc.	. . . .
Colasta	Phenolic molding compounds	Colasta Co., Inc., U.S.A.
Collodion	A solution of cellulose nitrate in a mixture of 60% ether and 40% alcohol, for making fibers and films	. . . .
Compreg	Plywood of 1/16 of an inch rotary-cut yellow birch layers, bonded with about 30% resin; tensile strength 54,000 p.s.i.	Forest Products Laboratory, U.S.A.
Conolite and Conelon	Lightweight construction boards made by impregnating glass fibers with 20% thermosetting resin; specific gravity 1.15, tensile strength 120,000 p.s.i., for use in aircraft, panelling and light structures	Consolidated Vultee Aircraft Corp., U.S.A.
Consoweld	A high pressure laminate for panelling, etc.	Consolidated Waterpower and Paper Co., U.S.A.
Co-Ro-Lite	A phenolic resin-impregnated vegetable fiber product for furniture, etc.	Columbian Rope Co. U.S.A., and Canadian Bridge Building Co.
Corroplast	Corrugated phenolic, paper-base laminates, for roofing	Holoplast Ltd., U.K.
Corrulux	Corrugated panels suitable for skylights; lightweight, shatterproof, and resistant to chemicals and weather changes	Corrulux Corp., U.S.A.
Crinothene	Polyethylene rippled lamp shades	I.C.I. Ltd., U.K.
Cristallex	Polystyrene plastic materials	Le Cristallex, France
Crystallite	Acrylic molding powder	Rohm & Haas Co., U.S.A.
Crystallin	Cast phenolic plastics	Crystallin Prods. Corp., . . .
Cruveroid	Embossed and decorated plastics sheets	Cruver Mfg. Co., U.S.A.
Decarlite	High pressure laminates	Decar Plastics Corp., U.S.A.

Dec-O-Ply	Plywood panelling embossed to imitate leather	Aetna Plywood and Veneer Co., U.S.A.
Dekorit	Phenolic resins	Uhlhorn Bros., Ltd., U.K.
Delaron	Paper- or linen-base phenolic laminates for panels, furniture, etc.	De La Rue Plastics Ltd., U.K.
Diakon	Methyl methacrylate resin molding powder	I.C.I. (Plastics) Ltd., U.K.
Dilecto	Phenolic laminates	La Fibre Diamond, France
Distrene	Polystyrene sheets and tubes	BX Plastics Ltd., U.K.
Don	Aluminum stair treads with polyvinyl chloride non-slip inserts	Small & Parkes, Ltd., U.K.
Dri-Film	Silicon water repellent	General Electric Co., U.S.A.
Duco	Cellulose nitrate lacquers with pigments and plasticizers, for quick-drying lacquers which give good adhesive films	. . . .
Dufaylite	A resin-impregnated, honeycomb material for walls and partitions	Dufay-Chromax Ltd., U.K.
Dulux	An alkyd coating material	E. I. du Pont de Nemours & Co., Inc. U.S.A., and I.C.I. Ltd., U.K.
Dura-Clear	Polyethylene film	Harwid Co., U.S.A.
Duralux	Lightweight, shatterproof, and chemical-resistant panels, for skylights and partitions	Corrulux Corp., U.S.A.
Duraplex	Air-drying and baking finish alkyd resins for finishing and coating	Rohm & Haas Co., U.S.A.
Durethene	Polyethylene film	Durethene Corp., U.S.A., and Durez Plastics & Chemicals Inc., U.S.A.
Durez	Phenol formaldehyde condensates for plywood and coatings	Durez Plastics & Chemicals Inc., U.S.A.

Durite	Phenol furfural products for electrical fittings and insulation	The Borden Co., U.S.A.
Ecolac	An air-drying lacquer and adhesive for plastics	Mass & Waldstein Co., U.S.A.
Ellifilm	Phenol-formaldehyde solutions for coatings, bonding, and impregnating	Beetle Elliot Plastics Ltd., U.K.
Elo	Phenolic molding powder	Birkby's Ltd., U.K.
Epok	Phenol-formaldehyde condensates and impregnating compositions	F. A. Hughes & Co. Ltd., U.K., and British Resin Prods. Ltd., U.K.
Erinite	Alkyd-resin coating compositions	Erinoid Ltd., U.K.
Erinofort	Cellulose-acetate sheets, rods and tubes	Erinoid Ltd., U.K.
Erinoid and Erinoid	Casein materials, sheets, rods and tubes	Erinoid Ltd., U.K.
Erinoplas	Cast phenolic materials	Erinoid Ltd., U.K.
Etchwood	Plywood panels wire-brushed to remove the softwood and retain the hard grain in raised relief	Davidson Plywood & Lumber Co., U.S.A.
Ethocel	Ethyl cellulose film	The Dow Chemical Co., U.S.A.
Everwear	Asbestos and thermoplastic resin for floor tiles	Everwear Installations Ltd., U.K.
Exton	Monofilament nylon fibers	E. I. du Pont de Nemours & Co., Inc., U.S.A.
Fabrod	Bakelite combined with asbestos	. . . .
Farlite	Phenol- and melamine formaldehyde impregnated paper laminate for tables and counter tops, sometimes with a thin metal layer under the outside decorative film	Farley & Loetscher Mfg. Co., U.S.A.
Farlwood	A laminated product with a natural wood finish	Farley & Loetscher Mfg. Co., U.S.A.
Faturan	Phenolic molding resins	(of German origin)
Ferobestos	A laminated material from asbestos and synthetic resins	Ferodo Ltd., U.K.

Fiberglas	Glass filaments bonded with polyester resins	Owens-Corning Fiberglas Corp., U.S.A.
Fiberlac	Cellulose nitrate lacquer	Monsanto Chemical Co., U.S.A.
Fiberloid	Plasticized cellulose nitrate sheets, rods and tubes	Fiberloid Corp., U.S.A.
Fiberlon	A cast phenolic plastic	Fiberloid Corp., U.S.A.
Fibestos	Highly-plasticized cellulose acetate sheets, rods and tubes	Monsanto Chemical Co., U.S.A.
Fibreglass	Rigid boards of felted fibers bonded with resins, for heat insulation	Fibreglass Ltd., U.K.
Firmoid	Cellulose acetate covering materials	Bluemel Bros. Ltd., U.K.
Flex-O-Wall	Embossed vinyl wall covering	Robinson Industrial Crafts Ltd., U.K.
Flexseal	A laminated plate glass with a vinyl resin interlayer that has an extension for sealing into the window frame, mainly used for aircraft windows	Pittsburgh Plate Glass Co., U.S.A.
Flotofoam	An expanded plastic material for insulation made of a blend of acrylic, vinyl and urea resins	U.S. Rubber Co., U.S.A.
Formalin	Phenolic casting resin	National Plastic Products Co., U.S.A.
Formapex	Synthetic resin-bonded paper or fabric building boards	Ioco Ltd., U.K.
Formica	Phenol- and urea-formaldehyde laminated sheets for wall lining and table tops. Variegated designs are placed on the outside lamination. Also produced with asbestos paper, cloth bases, and with metal foil for conducting heat.	The Formica Co., U.S.A., and Thos. De La Rue & Co., Ltd., U.K.
Formvar	Polyvinyl formal powder	Shawinigan Ltd., Canada
Forticel	Cellulose propionate	Celanese Corp. of America, U.S.A.
Fortisan	A strong cellulose acetate fiber of extreme fineness (0.0001 in. in diam.), origi-	Celanese Corp. of America, U.S.A.

	nally developed for parachutes, but also used in fabrics	
Fuller 901	A casein glue	H. B. Fuller Co., U.S.A.
Futurit	Phenolic molding resins	(of German origin)
Pyrban	Flame-resistant sheeting	Stewart Hartshorn Co., U.S.A.
Galalith(e)	(Meaning "milkstone") Casein sheets, rods and tubes, etc.; not a trade name	. . . .
Gedoline	Polystyrene plastics	Huiles, Goudrons et Dérivés, France
Gelva paint	Suspended pigment in a water solution of polyvinyl acetate resin and a wetting agent; dries quickly to a durable, water-resistant film	Shawinigan Prods. Corp., U.S.A.
Gelvar	Polyvinyl acetate powder	Shawinigan Ltd., Canada
Glacite	Acrylic sheets	Monoplast Chemical Corp., U.S.A.
Glasweld	Glass-cloth-reinforced polyester pipes; withstand pressure, heat and chemicals	U.S. Plywood Corp., U.S.A.
Glos	An early name for rayon because of its gloss, but has been abandoned	. . . .
Glyptal	Glycerine-phthalic anhydride coating compositions, for lacquers and insulation	General Electric Co., U.S.A.
Gobanyle	Polyvinyl chloride plastics	Saint-Gobain, France
Gordon Aerolite	Reinforced plastics structural members	Aero Research Ltd., U.K.
Haveg	A phenolic resin containing asbestos fibers; acid resistant and withstands up to 265°F. (130°C.)	Haveg Corp., ...
Hexcel	Structural honeycombs; glass-cloth or paper base	California Reinforced Plastics Co., U.S.A.
Hi-Den	Impregnated and compressed wood	Hiduminium Engineering, Ltd., U.K.

Hollo-Tech	Hollow core plywood	Technical Plywoods, U.S.A.
Holoplast	A hollow, paper-base laminated panel for partitions, furniture, etc., produced in the standard size of 8 x 4 ft. and 1 inch in thickness	Holoplast Ltd., U.K.
Hyden	Impregnated and laminated veneers	Parkwood Corp., U.S.A.
Hy-Du-Lignum or Hydulignum	Birch wood veneers impregnated with vinyl formal resin and compressed both sidewise and edge-wise; tensile strength reaches 45,000 p.s.i.; mainly used for airplane propeller blades	Hordern-Richmond Ltd., U.K.
Igolit	Polyvinyl chloride pipes for plumbing	(of German origin)
Imperial Ester	Glycerol resin for varnishes and lacquers	Hercules Powder Co., U.S.A.
Indeton	Plastics laminated with wood core	Buffelen Lumber & Mfg. Co., U.S.A.
Indur	Phenolic resins and laminating varnishes	Reilly Tar & Chemical Corp., U.S.A.
Insol	A casein glue	Croid Ltd., U.K.
Insurok	Laminated plastics for industrfial uses	The Richardson Co., U.S.A.
Intelox	Cellulose acetate butyrate extruded sections for table and counter edges	Extruded Plastics Inc., U.S.A.
Iporka	Expanded urea-formaldehyde rubber, molded into blocks for cold storage	(of German origin)
Isoflex	Corrugated cellulose acetate multi-layer sheets for thermal insulation	BX Plastics Ltd., U.K.
Isopol	A modified polystyrene with 75% styrene and 25% isoprene; has hard clear surfaces with the characteristics of polystyrene except its brittleness; fractures without sharp edges	Union Bay State Chemical Co., U.S.A.
Ivoricast	A shock-resistant cast phenolic with wood flour filler	West Coast Enterprises, . . .

Ivryne	Casein plastics	Etablissement Feuillant, France
Jablin	Laminated wood of high density	Moulded Components (Jablo) Ltd., U.K.
Jabroc	Laminated wood of high density	Moulded Components (Jablo) Ltd., U.K.
Jicwood	Laminated woods with tensile strength up to 45,000 p.s.i.; mainly for aircraft	Jicwood Ltd., U.K.
Jixonite	Non-absorbant composite material with good heat and sound insulating properties	Jicwood Ltd., U.K.
Kalistron	Vinyl sheeting materials with colors fused to undersides, for wall covering and upholstery	U.S. Plywood Corp., U.S.A.
Keebush	Phenol formaldehyde composition for chemical plants	Kestner Evaporator Co., U.K.
Kerr panels	Panels made of glass-fiber mats impregnated with polyester resin, for interior partitions, outside walls and skylights	A. H. Kerr & Co., U.S.A.
Kinonglas	The first safety glass marketed; consisted of two plates of glass with a cellulose nitrate between, and was first used for protection against chips from machines	(of German origin)
Klinger	Floor tiles of asbestos and synthetic resins	Richard Klinger Ltd., U.K.
Kodapak I	Cellulose acetate sheet	Eastman Kodak Co., U.S.A.
Kodapak II	Cellulose acetate butyrate sheets	Eastman Kodak Co., U.S.A.
Koroseal	Polyvinyl-chloride, rubber-like coating materials, sheets and tubes	B. F. Goodrich Co., U.S.A.
Krylon	Vinyl coatings	Foster & Kester Co. Inc., U.S.A.
Lactonite	Casein sections	British Lactonite Ltd., U.K.
Laitzo	Casein cement for bonding wood	Casein Industries Ltd., U.K.
Lamicoid	Phenol- or urea-formaldehyde laminated materials for elec-	Mica Insulator Co., U.S.A.

	trical insulation and decorative objects	
Lamidall	Polyester-coated decorative panels	Woodall Industries Inc., U.S.A.
Lanital	Casein fibers, superior to wool in silkiness and resistance to moth attacks, but inferior in general properties	(of Italian origin)
Lauxite	Liquid urea-formaldehyde adhesive	Monsanto Chemical Co., U.S.A.
Lecite	Acid resisting cement with furfuryl alcohol resins	Electro-Chemical Supply & Engineering Co., U.S.A.
Lifewall	A vinyl wall covering	Pantasote Co., U.S.A.
Lignolite	Laminated lignin plastics	Marathon Corp., U.S.A.
Liquid Strip	Vinyl strip coating	American Resinous Chemicals Corp., U.S.A.
Limaca	Laminated sheets for decorative walls	National Plastic Products Co., U.S.A.
Lorival	Phenol-formaldehyde molding powder	Lorival Mfg. Co., Ltd., U.K.
Louverglas	Cellulose-acetate louvers for decorative lighting	Doane Prods. Corp., U.S.A.
Lucite	Ethyl and methyl methacrylate molding powder, extruded sections, and cast and molded sheets	E. I. du Pont de Nemours & Co. Inc., U.S.A.
Luma-Blok	Translucent polystyrene blocks for interior partitions only	British Moulded Plastics Ltd., U.K.
Lumapane	Wire screen coated with cellulose acetate	Celanese Corp. of America, U.S.A.
Lumarith	Plasticized cellulose acetate sheets, rods and tubes, and molding powder	Celanese Corp. of America, U.S.A.
Lumarith EC	Ethyl cellulose molding powders, sheets and films	Celanese Corp. of America, U.S.A.
Lumite	Woven vinylidene chloride fabric for wall covering, etc.	Chicopee Mfg. Co., U.S.A.
Lustron	Polystyrene plastics materials cements, tiles, etc.	Monsanto Chemical Co., U.S.A.

Luxorite	Egg-crated louvers for diffusing light	The Franco-British Electrical Co., Ltd., U.K.
Luxwood	Laminated phenolic plastics with photographic reproduction of wood grain on the surface(1), for furniture making	The Formica Co., U.S.A.
Lynx	Plastics flushing tank	Shires & Co., U.K.
Makalot	Phenolic resins, protective coatings and adhesives	Makalot Corp., U.S.A.
Marblette	A cast phenolic resin	The Marblette Corp., U.S.A.
Marley	Flooring tiles with synthetic resin composition	The Marley Co., Ltd., U.K.
Marlite	Plastics wall panels	Marsh Wall Prods., Inc., U.S.A.
Marvalon	Paper coated with vinylite resins and reinforced with cellulose fibers, for wall coverings, etc.	Munising Paper Co., U.S.A.
Melmac 483	Phenol-modified melamine formaldehyde solution for laminating fibrous materials	American Cyanamid Co., U.S.A.
Melmac 592	Melamine-formaldehyde molding resin with a mineral filler; withstands up to 300 F. (149 C)	American Cyanamid Co., U.S.A.
Melmac 1077	Melamine-formaldehyde molding resin with cellulose filler, for lacquers, enamels, varnishes, etc.	American Cyanamid Co., U.S.A.
Melocol	A polyamide-formaldehyde glue for furniture, plywood, etc.	Ciba Prods.,Corp., U.S.A.
Melopas	Polyamide formaldehyde for use in laminated panels, table tops, etc.	Ciba Prods. Corp., U.S.A.
Melurac 300	A melamine-urea-formaldehyde resin with a ligning extender used as an adhesive for water-resistant plywood	American Cyanamid Corp., U.S.A.
Micarta	Laminated sheets with a melamine-formaldehyde overlay, in decorative colors and designs, including photographic reproduction of wood, for use in table tops, furniture, etc.	U.S. Plywood Corp. and U.S. Mengel Plywoods, Inc., U.S.A.

Mipolam	Polyvinyl chloride copolymer sheets, rods and tubes, and floor coverings to replace rubber	(of German origin)
Mirasol	An alkyd varnish or lacquer	C. J. Osborn Co., U.S.A.
Mir-Con	A paper-base decorative laminate	Detroit Paper Prods. Corp., U.S.A.
Moldarta	Laminated wood for knobs, handles, etc.	Westinghouse Electric & Mfg. Co., U.S.A.
Monsoon	Silicone-resin formulation; water repellent for masonry walls	State Chemical Corp., U.S.A.
Mouldrite	Phenolic and urea resins and cements	I.C.I. Ltd., U.K.
Nitron	Cellulose nitrate sheets, rods and tubes	Monsanto Chemical Co., U.S.A.
Nixonite	Cellulose acetate sheets for glazing, etc.	Nixon Nitration Works, U.S.A.
Nylon	(Not a registered trade name) Super-polyamides, fibers, bristles, molding powder, etc.	E. I. du Pont de Nemours & Co. Inc., U.S.A.
Onazote	Expanded ebonite (hard rubber) for insulation and cistern floats	Expanded Rubber Co. Ltd., U.K.
Ondoïta	Phenol-formaldehyde plastics	Société du Férodo, France
Opalon	Cast phenolics	Monsanto Chemical Co., U.S.A.
Orlon	Acrylic fibers	E. I. du Pont de Nemours & co. Inc., U.S.A.
Panaplex and Panax	Laminated panels for shop fitting, etc.	North British Plastics Ltd., U.K.
Panelyte	Laminated phenolic sheets, tubes, and rods, for heat insulation, decorative panels, etc.	Regis Paper Co., U.K.
Panilax	Aniline-formaldehyde laminated sheets for electrical and heat insulation	The Micanite & Insulators Co., Ltd., U.K.

Papr-Tech	Impregnated plywood with paper veneers	Technical Plywoods, U.S.A.
Parkflex	Melamine-surfaced semi-flexible decorative laminates	Parkwood Corp., U.S.A.
Parkwood	Mahogany or other fine wood veneers in decorative patterns and pressed between sheets of cellulose acetate	Parkwood Corp., U.S.A.
Parogalithe	Casein plastics	Charentaise de Matières Plastiques, France
Paxolin	Phenolic laminated moldings, sheets, and tubes	The Micanite & Insulators Co., Ltd., U.K.
Permabond	Thermosetting adhesive for plastics	Polymer Chemical Co., U.S.A.
Permali	Impregnated and compressed wood	The New Insulation Co., Ltd., U.K.
Permaply	Phenolic resin-bonded plywood,	Venesta Ltd., U.K.
Perspex	Acrylic resin sheets and rods for glazing, etc.	I.C.I. Ltd., U.K.
Pheenoglaze and Pheenorock	Synthetic preservatives for wood, plaster, etc.	Phenoglaze Ltd., U.S.A.
Phenac	A phenolic resin varnish or lacquer	American Cyanamid Co., U.S.A.
Phenalin	Cast phenolics	E. I. du Pont de Nemours & Co. Inc., U.S.A.
Phenco	Tiles and floor covering materials in rolls 12 yd. long and 3 ft. wide	Phoenix Rubber Co. Ltd., U.K.
Phenrok	Laminated phenolic materials made to Federal specifications	Fabrikon Prods. Inc., U.S.A.
Plaskon	Alkyd, urea and melamine formaldehyde condensate molding powder, adhesives, etc.	Plaskon Division, Libbey-Owens Glass Co., U.S.A.
Plastacele	Plasticized cellulose acetate sheets, rods and tubes, and molding powder	E. I. du Pont de Nemours & Co. Inc., U.S.A.
Plastazote	Expanded polyvinyl formal for floats and heat insulation	Expanded Rubber Co. Ltd., U.K.

Plasterez	Synthetic resin paint for plywood, plaster, etc.	I. F. Laucks Inc., U.S.A.
Plasti-Cell	Expanded polyvinyl chloride, for floats and heat insulation	Sponge Rubber Prods. Co., . . .
Plasti-Cleer	Calendered vinyl film	Goodyear Rubber Industries, Inc., U.S.A.
Plastic Wood	Wood cellulose dissolved in ether or other solvents, for filling or building up small sections; can be worked like wood, but has a tendency to shrink. Plastic wood may also consist of cellulose nitrate and a plasticizing agent dissolved in acetone or ethyl acetate, and mixed with wood flour to reduce shrinkage.	. . . .
Plasticite	Laminated wood with thermoplastic resins	Goshen Veneer Co., U.S.A.
Plasticoil	Cellulose acetate and cellulose acetate butyrate with fluorescent materials, for lighting and decorating	Schwab & Frank Inc., U.S.A.
Plastiktrim	Cellulose acetate and cellulose acetate butyrate architectural moldings	R. D. Werner Co. Inc., U.S.A.
Plastilite	Cellulose acetate and cellulose acetate butyrate architectural moldings	Wilson Metal Prods. Co., U.S.A.
Plastipaste	A plastics screen for doors and windows	N.Y. Wire Co., U.S.A.
Plastiply	Resin-bonded plywood	British Plywood Manufacturers Ltd., U.K.
Plastose	Phenol-formaldehyde plastics	Société du Férodo, France
Plastrim	Extruded cellulose acetate and cellulose acetate butyrate architectural moldings	Michigan Moulded Plastics Inc., U.S.A.
Plaxpak	Extruded polyethylene sheeting	Plax Corp., U.S.A.
Plexiglas	Acrylic and methacrylic sheets, rods and tubes, for glazing and decorative uses	Rohm & Haas Co., U.S.A., and Société Als-Thom, France

Plexigum	Acrylic interlayer for safety glass	Rohm & Haas Co., U.S.A.
Plimber and Plimberite	Boards made of wood chips impregnated with synthetic resin	British Plimber Ltd., U.K.
Plio-Tuf	A blend of phenolic resin with a butadienestyrene rubber, for the production of parts of great toughness and low water absorption; originally marketed as Tuf-Lite	Goodyear Tire & Rubber Co., Inc., U.S.A.
Pluto	Boards of asbestos bonded with synthetic resins	Cape Asbestos Co. Ltd., U.K.
Plyglass	Two layers of glass with an interlayer of plastics-bonded glass fibers	Plyglass Ltd., U.K.
Plymax	Sheets of aluminum mounted on a plywood backing	Venesta Ltd., U.K.
Plymetl	Laminated wood with galvanized steel faces	Haskelite Mfg. Corp., U.S.A.
Plyophen	Phenolic resins for coatings, adhesives, etc.	Reichhold Chemicals Inc., U.S.A.
Polloplas	Urea-formaldehyde plastics	Etablissements Kuhlmann, France
Polyclad	Polyvinyl chloride paint	Carboline Co., U.S.A.
Poly-Kleen	Polystyrene cleaner	Schwartz Chemical Co. Inc., U.S.A.
Polytex	Laminated styrene boards	Bushing Co. Ltd., U.K.
Polythene	Polyethylene plastics materials	E. I. du Pont de Nemours & Co. Inc., U.S.A.
Polytile	Polystyrene tiles	Stone & Simmons Ltd., U.K.
Preg-Tech	Impregnated and compressed plywood	Technical Plywoods, U.S.A.
Pregwood	A wood laminate impregnated with phenolic resin and cured into a hard sheet	The Formica Co., U.S.A.
Prespine	Phenolic resin impregnated chipboards	Curtis Co. Inc., U.S.A.

Progilite	Phenol-formaldehyde plastics	Résines et Vernis Artificiels, France
Protekwood	Plywood consisting of hardwood veneers between two sheets impregnated with asphalt and resin, the sheets being bonded with urea formaldehyde; total thickness 5/32 of an inch.	U.S. Plywood Corp., U.S.A.
Prufcoat	Protective coatings	Prufcoat Laboratories Inc., U.S.A.
Prystal	Phenol-formaldehyde condensate cast sections	Catalin Corp., U.S.A.
P.V.C.	Polyvinyl chloride rubber substitute, for floor tiles, etc.	BX Plastics Ltd., U.K., and others
Pyralin	Plasticized cellulose nitrate extruded sections	E. I. du Pont de Nemours & Co. Inc., U.S.A.
Randalite	A birch veneer bonded to kraft liner	U.S. Plywood Corp., U.S.A.
Rayon	A general name for artificial fibers made from cellulose nitrate, cellulose acetate or cellulose derivatives; are mildewproof, durable and easily cleaned but do not have the permeability and soft feel of silk. (see also Glos)	. . . .
Realwood	Phenolic-impregnated laminated wood	The Formica Co., U.S.A.
Reinforced Vue-Lite	A cellulose acetate laminate with wire gauze	Monsanto Chemical Co., U.S.A.
Resimene	Colorless melamine-formaldehyde resins that dissolve in water or ethyl alcohol, for impregnating paper and fabrics and for lamination	Monsanto Chemical Co., U.S.A.
Resinox 6952	A phenolic molding compound with a fine fibrous filler, for high impact strength	Monsanto Chemical Co., U.S.A.
Resinox 10900	A mica-filled phenolic molding powder	Monsanto Chemical Co., U.S.A.
Resinprest	Resin-bonded plywood, for external uses	M. & M. Woodworking Co., U.S.A.
Resistoflex	Polyvinyl alcohol plastics, adhesives and ceramic binders	Resistoflex Corp., U.S.A.

Resolite	Translucent panels of 70% polyester resin reinforced with 30% glass fibers	Resolite Corp., U.S.A.
Reynolite	Phenolic materials	Cutler-Hammer, Inc., U.S.A.
Rezitex	A plastics coating for plywood, stucco and bricks	I. F. Laucks Inc., U.S.A.
Reziwood	Phenolic laminated wood	I. F. Laucks Inc., U.S.A.
Rezyl	An oil-modified alkyd varnish or lacquer	American Cyanamid Co., U.S.A.
Rhodialine	Cellulose acetate plastics materials	Société Rhône-Poulenc, France
Rhodialite	Cellulose acetate plastics materials	Société Rhône-Poulenc, France
Rhodoid	Cellulose acetate plastics materials	M. & B. Plastics Ltd., U.K.
Rhodoline	Polystyrene plastics	Société Rhône-Poulenc, France
Rhodopas	Polyvinyl chloride plastics	Société Rhône-Poulenc, France
Rhodophane	Cellulose acetate plastics materials	Société Rhône-Poulenc, France
Rhodoviol	Polyvinyl alcohol plastics materials	Société Rhône-Poulenc, France
Rhoptix	Cellulose acetate plastics materials	Société Rhône-Poulenc, France
Rockite	Phenol-formaldehyde molding powders and extruded sections	F. A. Hughes & Co. Ltd., U.K.
Rotoform	Acrylic sheeting made by centrifugal force	Goodyear Aircraft Corp., U.S.A.
Royalite	Expanded synthetic rubber of copolymers of styrene and butadiene acrylonitrile	U.S. Rubber Co., U.S.A.
Saflex	Polyvinyl butyral for safety glass	Monsanto Chemical Co., U.S.A.
Sandura	Urea-alkyd paper-backed plastics for wall covering, etc.	Sandura Co. Inc., U.S.A.
Saran	Polyvinylidene chloride fibers (textiles for wall covering) and extruded sections	The Dow Chemical Co., U.S.A.

Sar-Rez	Urea resin for coating wood surfaces	Saro Laminated Wood Products Ltd., U.K.
Sealtuft	Vinyl material for wall covering, etc.	The Jason Corp., U.S.A.
Selectron CR-39	An allyl diglycol carbonate casting resin	Pittsburgh Plate Glass Co., U.S.A.
Semastic Tiles	Thermoplastic tiles with resinous binders	Semtex Ltd., U.K.
Sicalite	A casein plastics material	(of French origin)
Silastic	Silicone rubber	The Dow Chemical Co., U.S.A.
Stripcoat	A solution of ethyl cellulose for dipping purposes, to produce thin, strippable, waterproof protective coats	The Dow Chemical Co., U.S.A.
Structoglas	Corrugated fiberglas laminated panels for skylights and light wall panels, translucent or opaque	International Molded Plastics Inc., U.S.A.
Styrofoam	Polystyrene foam expanded 42 times its original size, for insulation at low temperatures	The Dow Chemical Co., U.S.A.
Styron	Polystyrene molding powders	The Dow Chemical Co., U.S.A.
Sundora	Cellulose acetate sheets for lamp shades	E. I. du Pont de Nemours & Co. Inc., U.S.A.
Sunex	Transparent plastics sheets	American Phenolic Corp., U.S.A.
Survon	Nylon monofilaments	I.C.I. Ltd., U.K.
Sylastic	A rubbery white silicone rubber with good adhesion to various materials	The Dow-Corning Corp., U.S.A.
Syntex	Alkyd varnished, lacquers and paints	Jones-Dabney Co., U.S.A.
Synthane L-RF	A laminated phenolic material with matted cotton fibers to give high impact strength; thickness varies from 1/32 of an inch to 2 inches	Synthane Corp., U.S.A.
Synthawood	A wood and synthetic resin material	Peatly Prods. Ltd., U.K.

Teflon	Polytetrafluoroethylene resin	E. I. du Pont de Nemours & Co. Inc., U.S.A.
Tego Film	A phenolic dry film for bonding plywood	British Tego Gluefilm Ltd., U.K.
Tekwood	Plywood with a paper veneer	U.S. Plywood Corp., U.S.A.
Tenaplas	Polyvinyl chloride compounds for sheets, tubes, etc.	Tenaplas Ltd., U.K.
Tenite I	Plasticized cellulose acetate extruded sections and moldings	Tennessee Eastman Corp., U.S.A.
Tenite II	Plasticized cellulose acetate butyrate extruded sections and molding powders	Tennessee Eastman Corp., U.S.A.
Tenite III	Cellulose acetate-propionate for extrusion and moldings of high impact	Tennessee Eastman Corp., U.S.A.
Texolex	Fabric-base phenolic laminates	Bushing Co. Ltd., U.K.
Thermazote	Expanded phenolic sheets for thermal insulation; can also be faced for use as panels, doors, etc.	Expanded Rubber Co. Ltd., U.K.
Tilon	An adhesive with a synthetic base, for fixing polystyrene tiles	. . . .
Traffolyte	Urea formaldehyde laminated boards	De La Rue Plastics Ltd., U.K.
Triplex	Safety glass with polyvinylbutyral interlayer	Triplex Safety Glass Co. Ltd., U.K.
Tru-Grain	Paper cellulose wall covering	The Ullman Co. Inc., U.S.A.
Tuf-Lite	See Plio-Tuf	. . . .
Tufnol	High pressure paper- or fabric-phenolic laminates	Tufnol Ltd., U.K.
Tufstuf	Cellulosic extrusion	Whiteford Plastics Co., U.S.A.
Tygan	Woven fabric in a wide range of colors and designs, for upholstery	Fothergill & Harvey Ltd., U.K.
Tynolex	Paper-base phenolic laminates	Bushing Co. Ltd.,U.K.

Uformite	Urea-modified melamine formaldehyde for coatings and varnishes	Rohm & Haas Co., Resinous Prods. Div., U.S.A.
Unichrome	A plastic coating for metals	United Chromium Inc., U.S.A.
Urocristal	Urea formaldehyde cast plastics materials	De Laire, France
Utilex	Plasticizdd cellulose acetate film	Utilex Ltd., U.K.
Varcum	A phenolic resin for paints and varnishes	Varcum Chemical Corp., U.S.A.
Varlar	Impregnated paper with thermoplastic resins for wall coverings	Varlar Inc., United Wallpaper Inc., U.S.A.
Versibond	Melamine laminate bonded to metal backings for sink and table tops, etc.	The Ohio Rubber Co., U.S.A.
Vetroloid	Embossed cellulose acetate sheets for decorative uses	British Celanese Ltd., U.K.
Vimlite	A saran screen filled with a cellulose acetate film; transmits ultraviolet light and is used for glazing greenhouses and farm buildings	Celanese Corp. of America, U.S.A.
Vinal	Vinyl acetate for safety glass	Pittsburgh Plate Glass Co., U.S.A.
Vinylite A	Polyvinyl acetate	Bakelite Co., Div. Union Carbide & Carbon Corp., U.S.A.
Vinylite Q	Polyvinyl chloride	Bakelite Co., Div. Union Carbide & Carbon Corp., U.S.A.
Vinylite V	Copolymer of vinyl chloride and acetate	Bakelite Co., Div. Union Carbide & Carbon Corp., U.S.A.
Vinylite X	Polyvinyl butyral	Bakelite Co., Div. Union Carbide & Carbon Corp., U.S.A.
Viscoloid	Cellulose nitrate rods, sheets and tubes	E. I. du Pont de Nemours & Co. Inc., U.S.A.

Vitapane	Cellulose acetate sheets for glazing	Arvey Corp., U.S.A.
Vitrite	Urea-formaldehyde cement	Stanley Smith & Co., U.K.
Vitrocelle	Transparent cellulose sheets	Dalle Preres et Lecomte, France
Vitromast	Caulking materials	The Atlas Mineral Prods. Co., U.S.A.
Vuelite	Embossed cellulose-acetate sheets for fluorescent light fixtures and shatterproof glass	Monsanto Chemical Co., U.S.A.
Wall-Ever	Vinylite wall coverings	Delaware Floor Prods. Inc., U.S.A.
Warerite	Paper-base laminates for wall panelling and furniture, etc.	Warerite Ltd., U.K.
Wascolite	Acrylic domes mounted in copper or glavanized iron frames, for skylights	Wasco Flashing Co., U.S.A.
Weldwood	Waterproof plywood, welded with a plastic resin glue line	U.S. Plywood Corp., U.S.A.
Welvic	Polyvinyl chloride extrusion compositions, sheets and paste	I.C.I. Ltd., U.K.
Westplak	Continuous laminates	Western Prods. Inc., U.S.A.
Weyroc	Resin-bonded sawdust, for floor tiles, boards, etc.	The airscrew Co. & Jicwood Ltd., U.K.
Whitcol JBN	Emulsifiers for removing oil-laden dirt from concrete slabs	I.C.I. Ltd., U.K.
Xon	Resin-bonded wood waste	Scientific Creators Inc., U.S.A.
Xylonite	Cellulose nitrate sheets, rods and tubes, hardened with camphor	BX Plastics Ltd., U.K.
Zapide	Leathercloth coated with polyvinyl chloride for wall panelling, counter tops, etc.	Ioco Ltd., U.K.
Zenaloy	Reinforced plastics materials	Zenith Plastics Co., U.S.A.

ILLUSTRATIONS

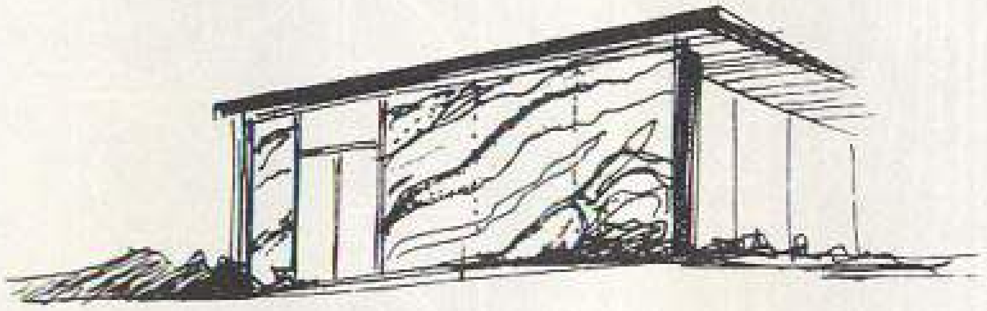

Fig. 1.--A house with a single, prefabricated wall panel

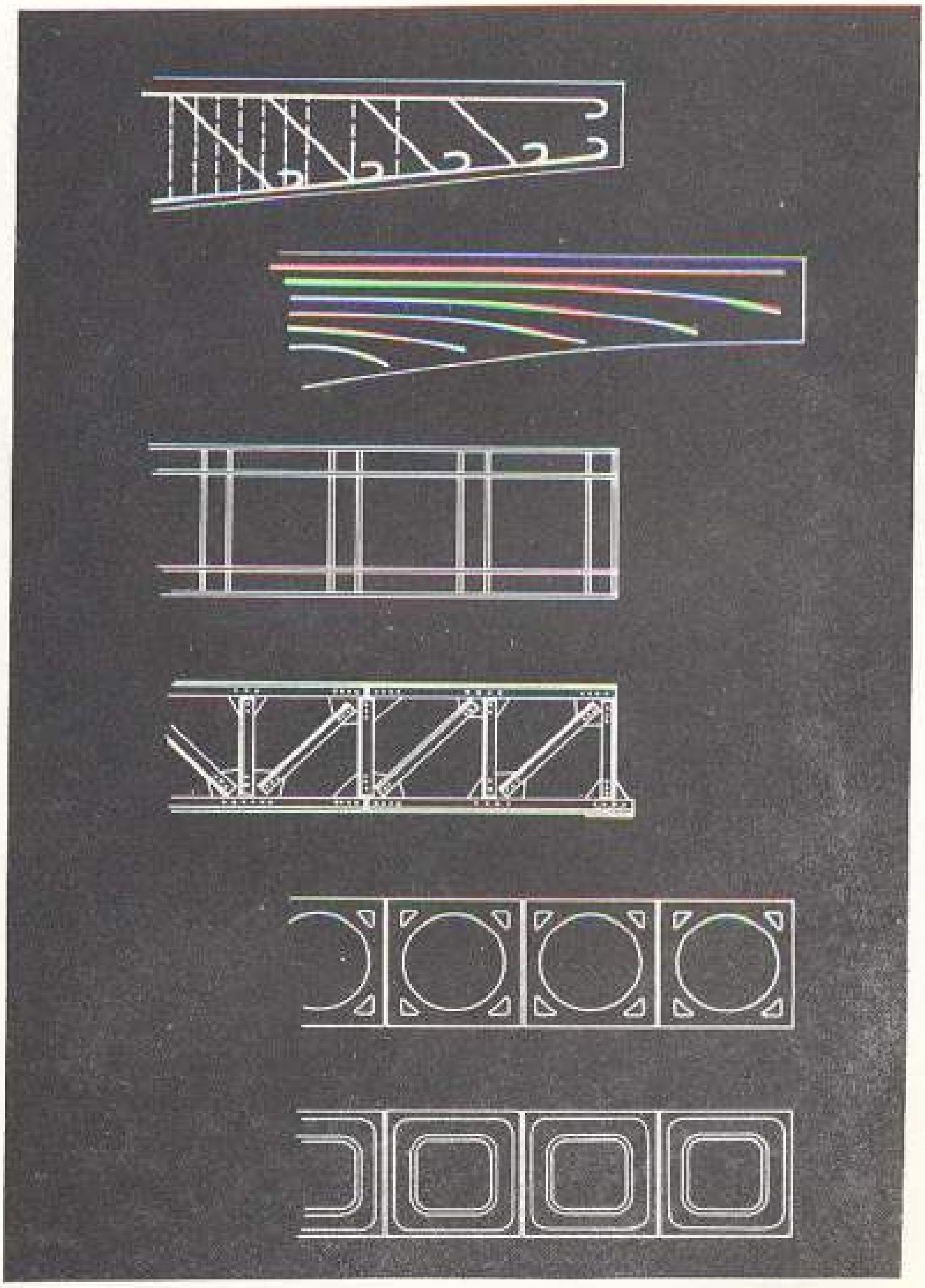

Fig. 2.--Comparisons between utilitarianism and esthetics as applied to structural elements--cantilevers and girders.

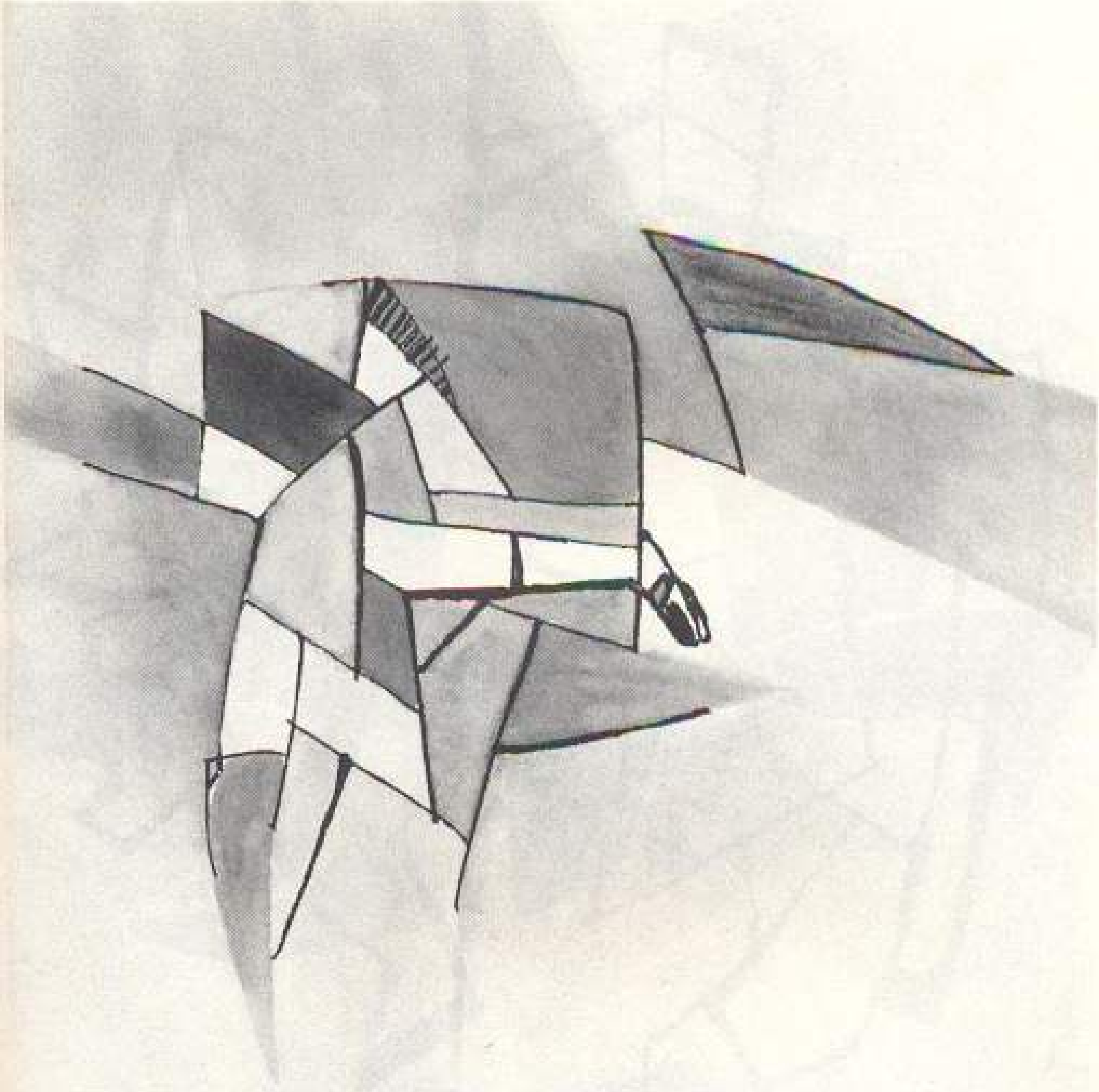

Fig. 3.--Design for a "stained-glass" window

Fig. 4.--"Two Dancers;" design for a transparent partition

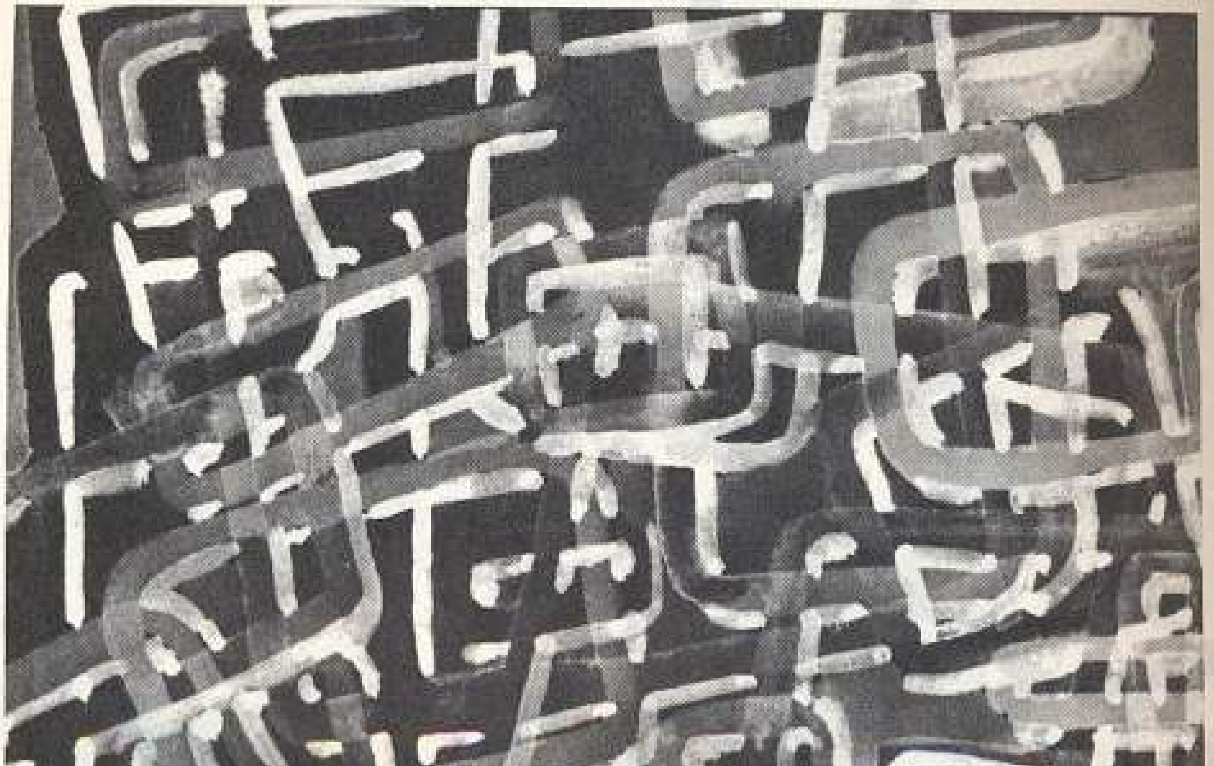

Fig. 5.--A decorative scheme for a partition

Fig. 6.--"Undelivered Calories No. 1;" a decorative design for a partition.

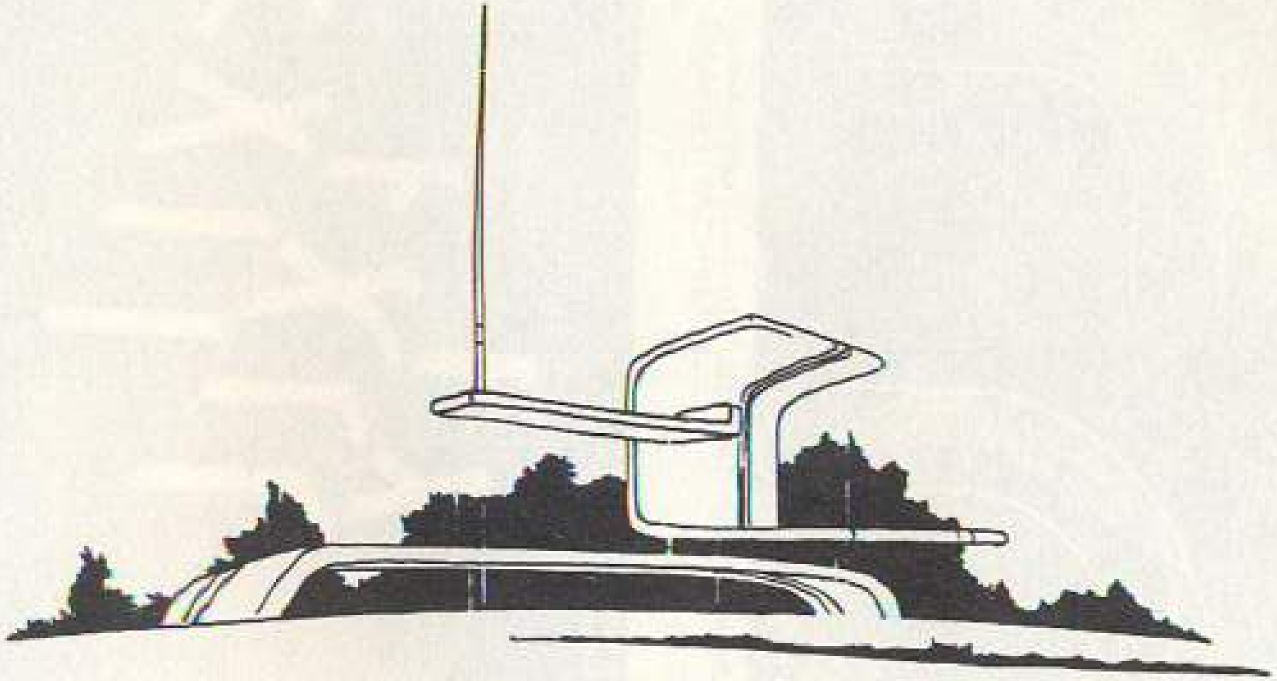

Fig. 7.--A park memorial

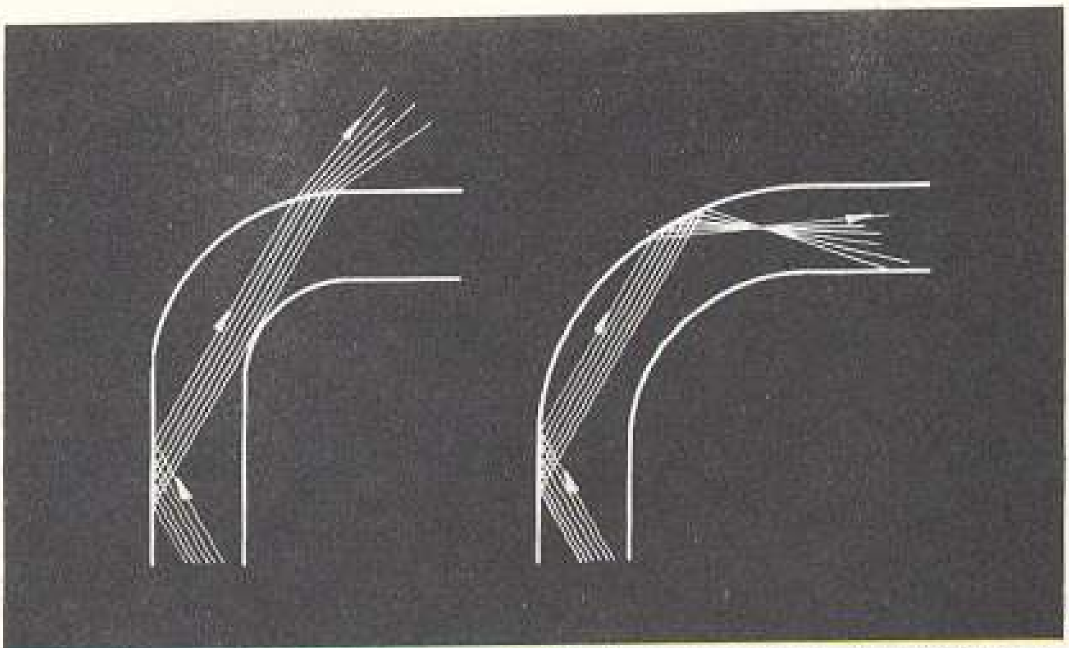

Fig. 8.--Refraction of light at sharp bends, and "piping" light by internal reflection.

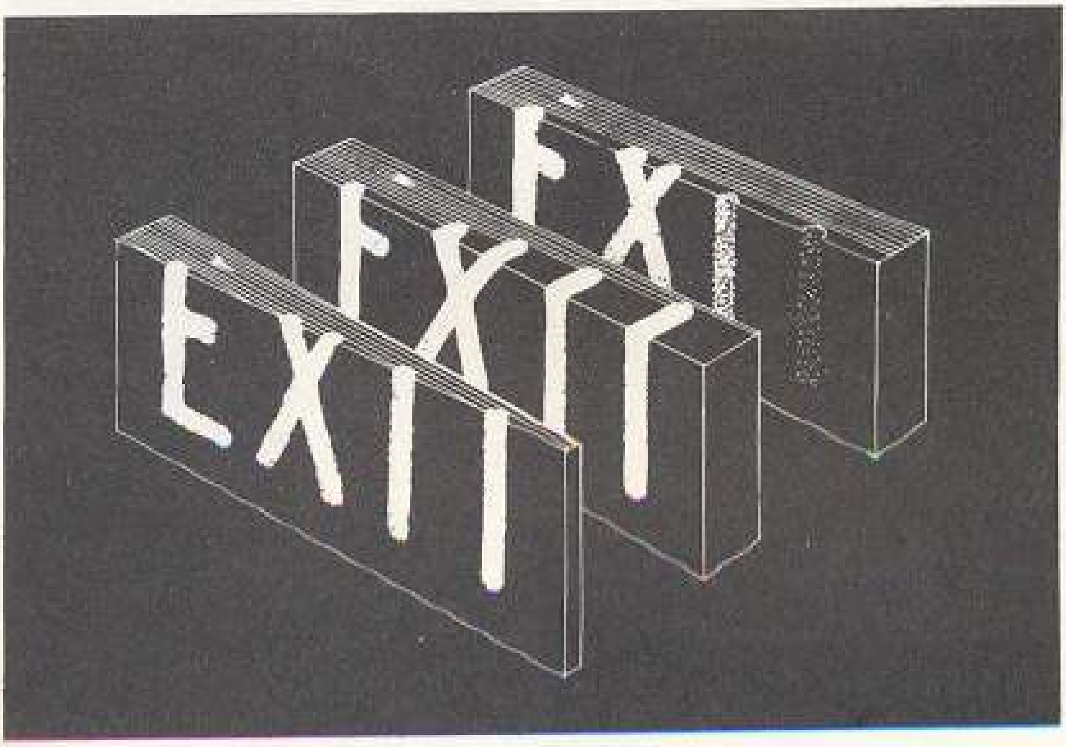

Fig. 9.--Edge-lighted signs

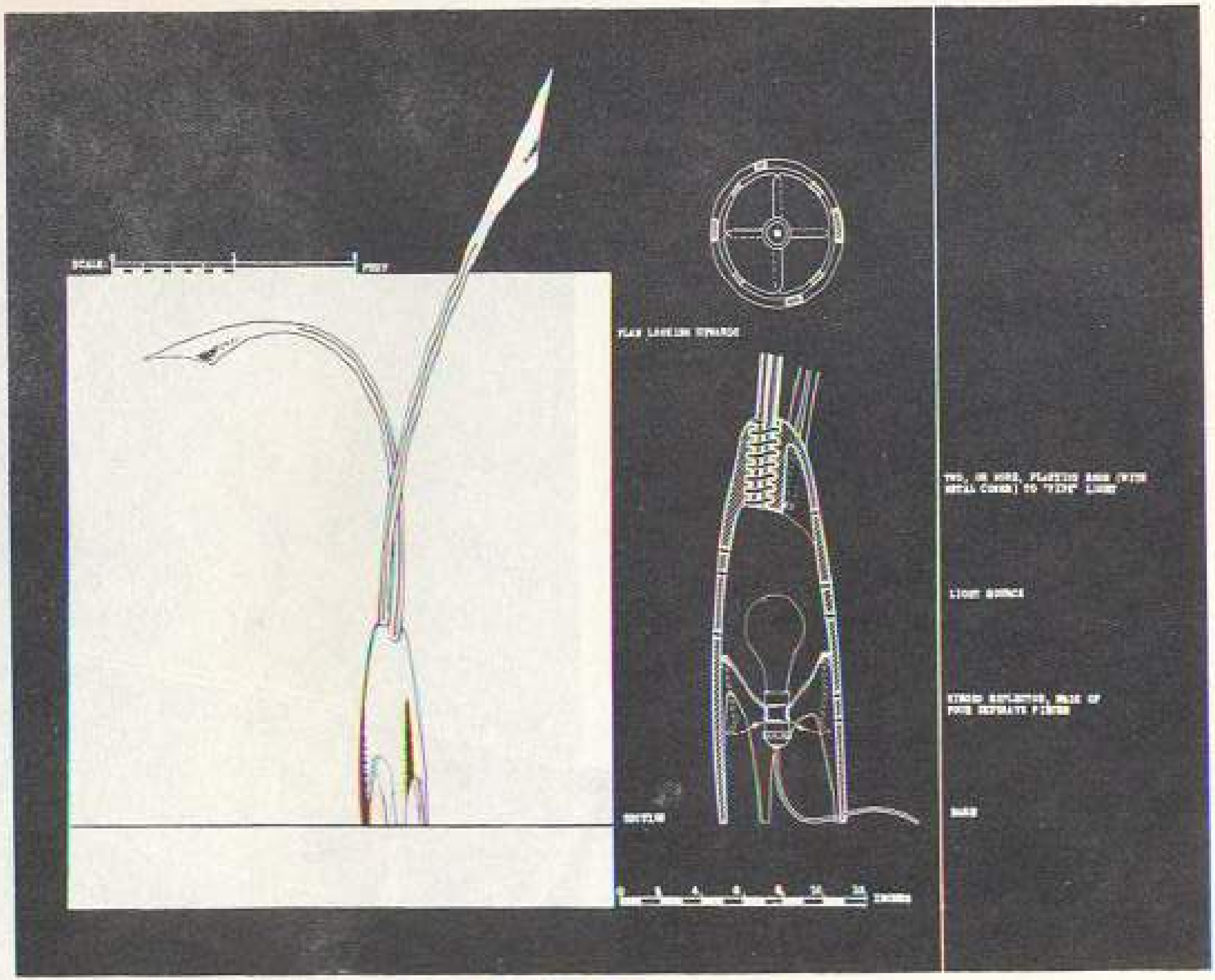

Fig. 10.--A plastics floor lamp

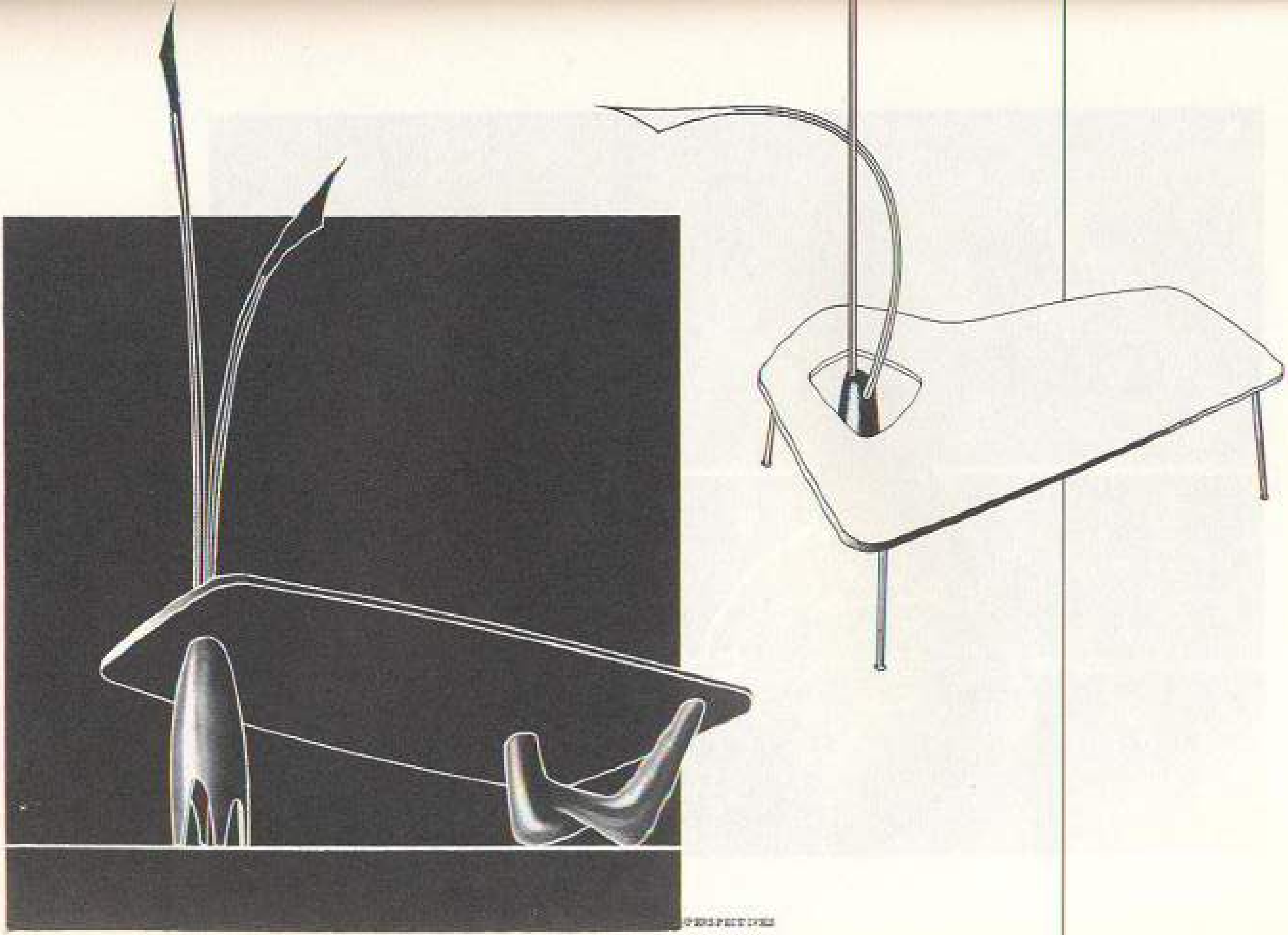

Fig. 11.--Plastics floor lamp used in connection with furniture

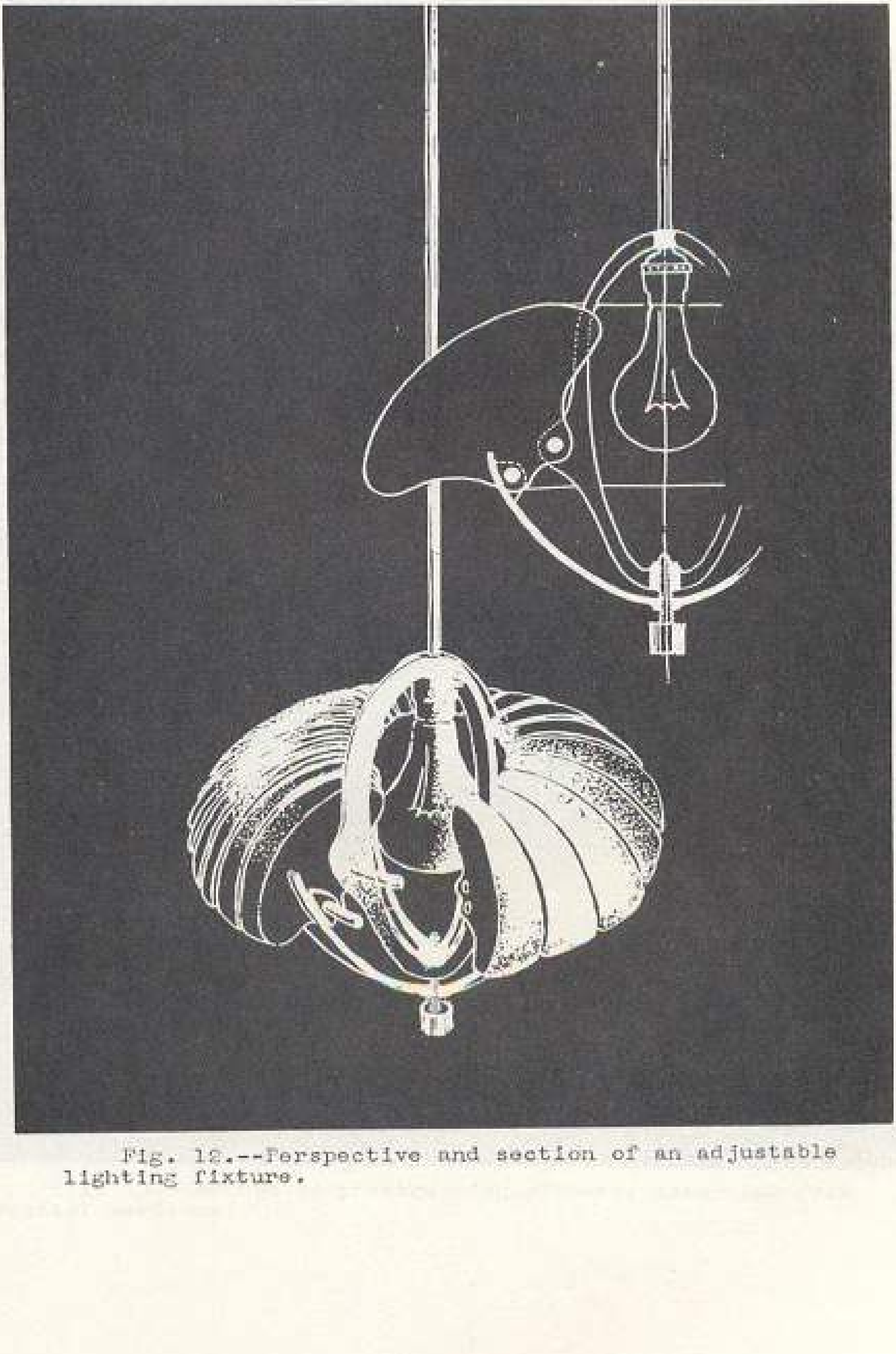

Fig. 12.--Perspective and section of an adjustable lighting fixture.

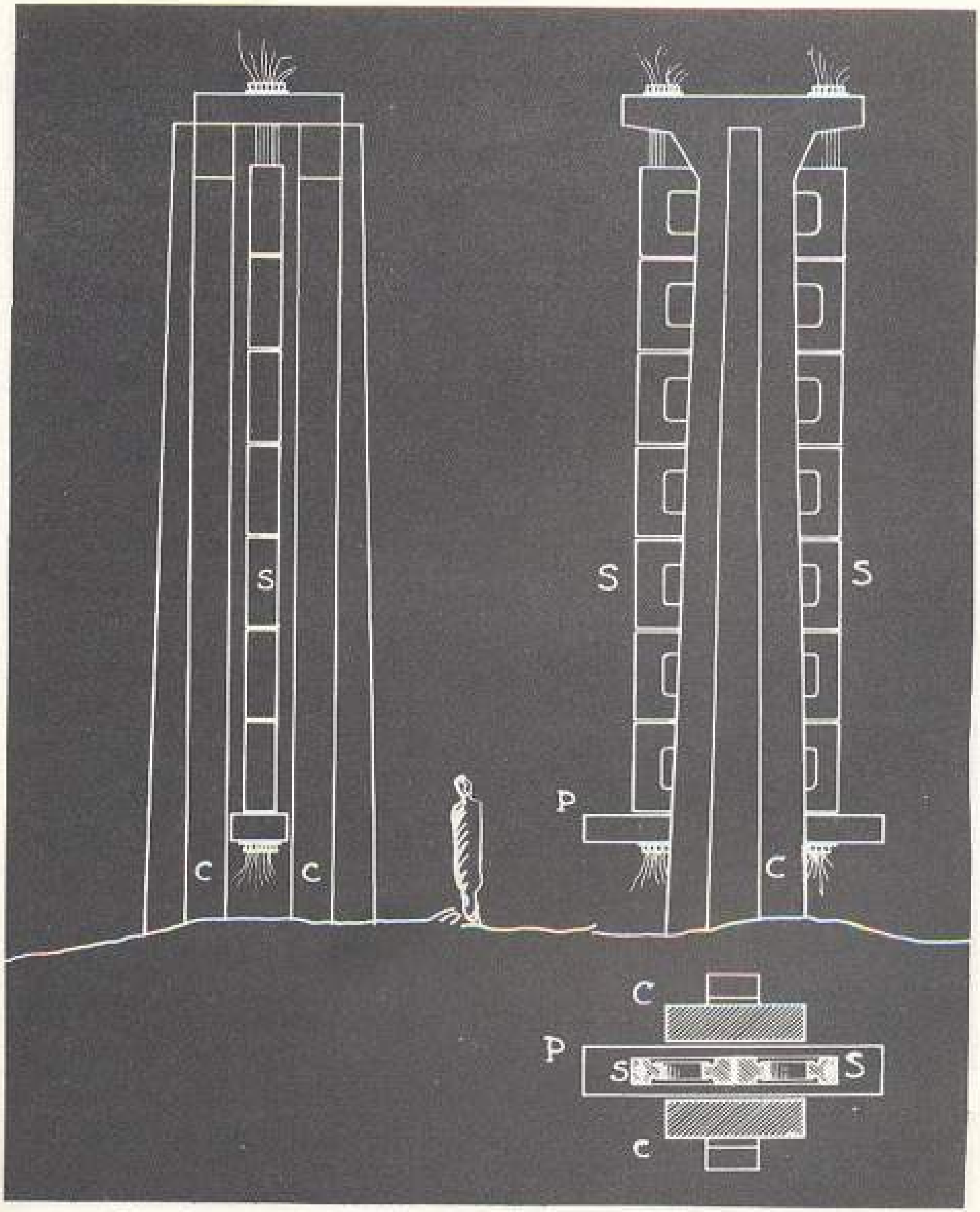

Fig. 13.--Method of prestressing girders, assembled from precast sections.

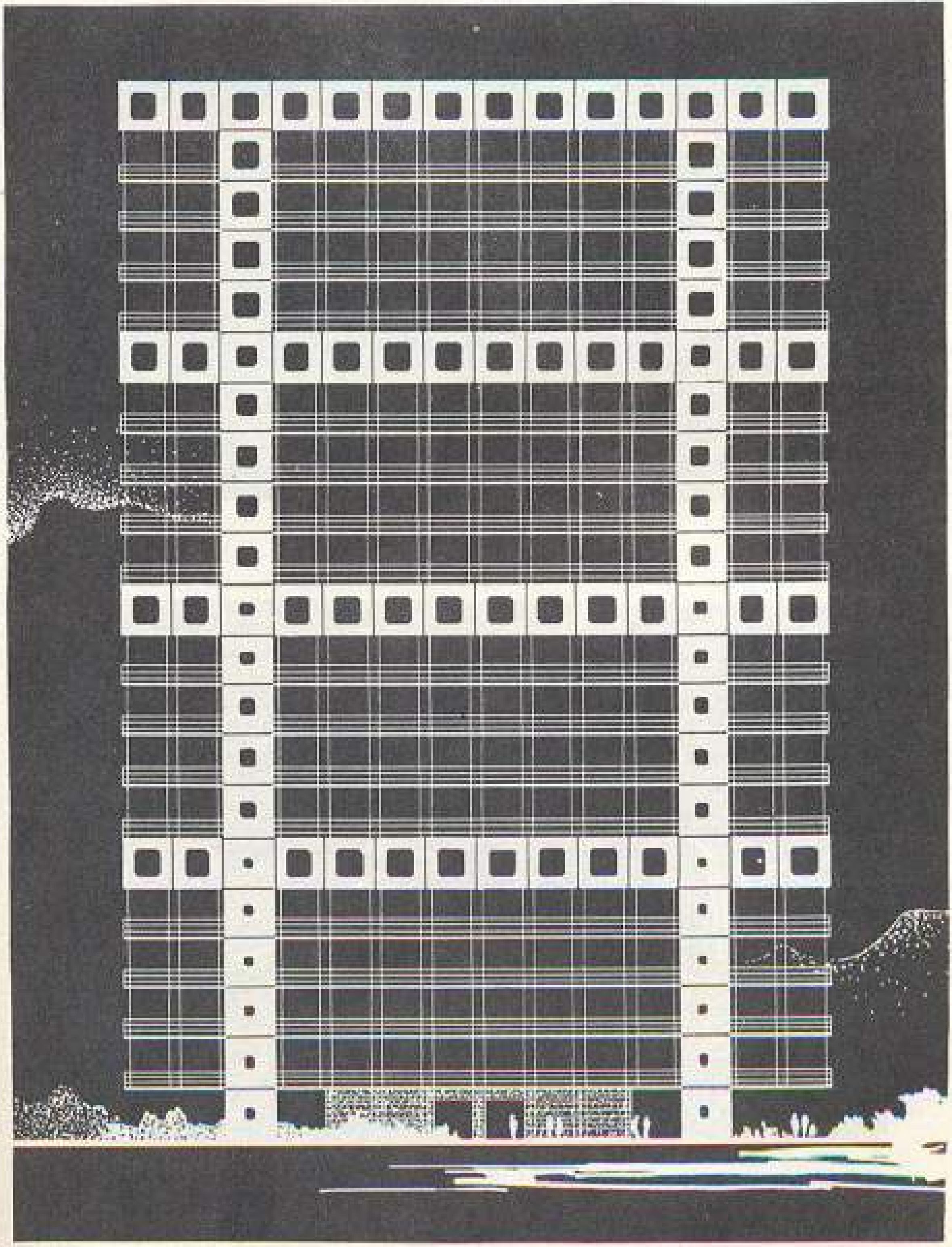

Fig. 14.--A tall building with floors suspended from prestressed, precast girders.

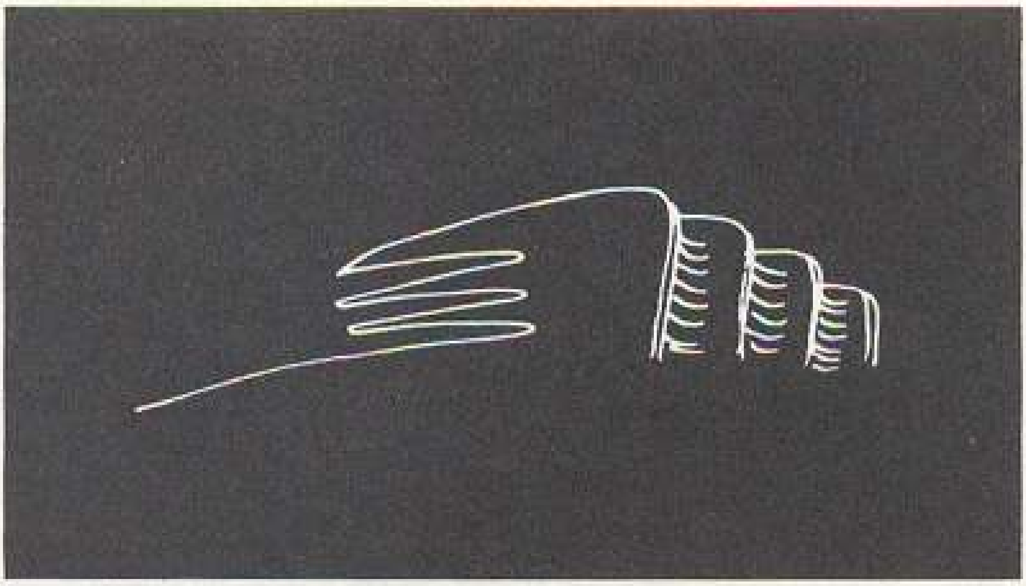

Fig. 15.--A factory

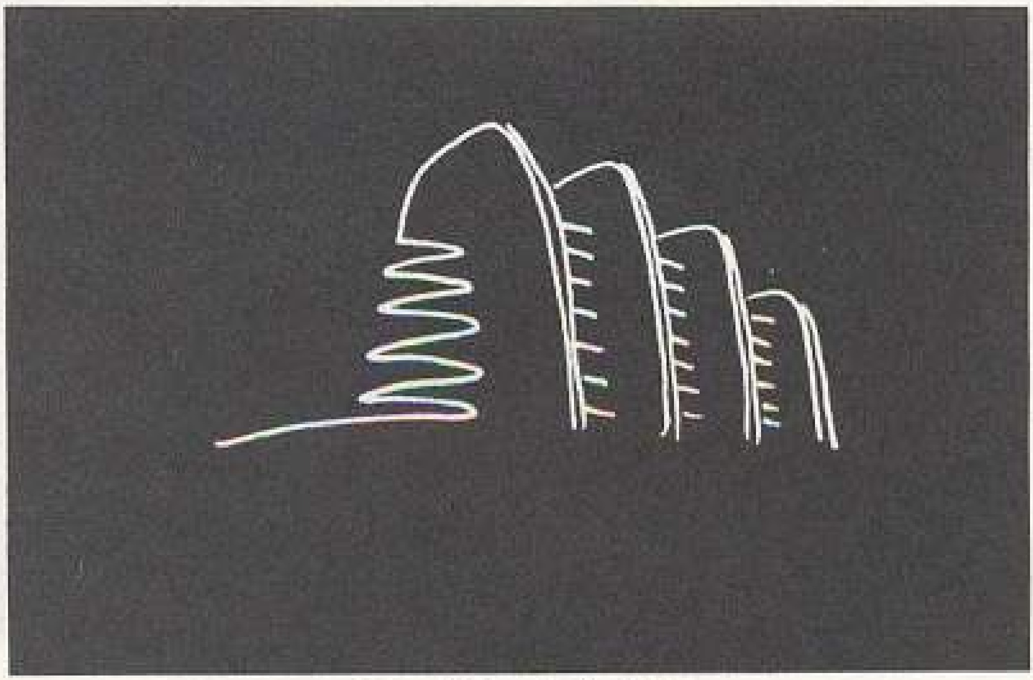

Fig. 16.--A factory

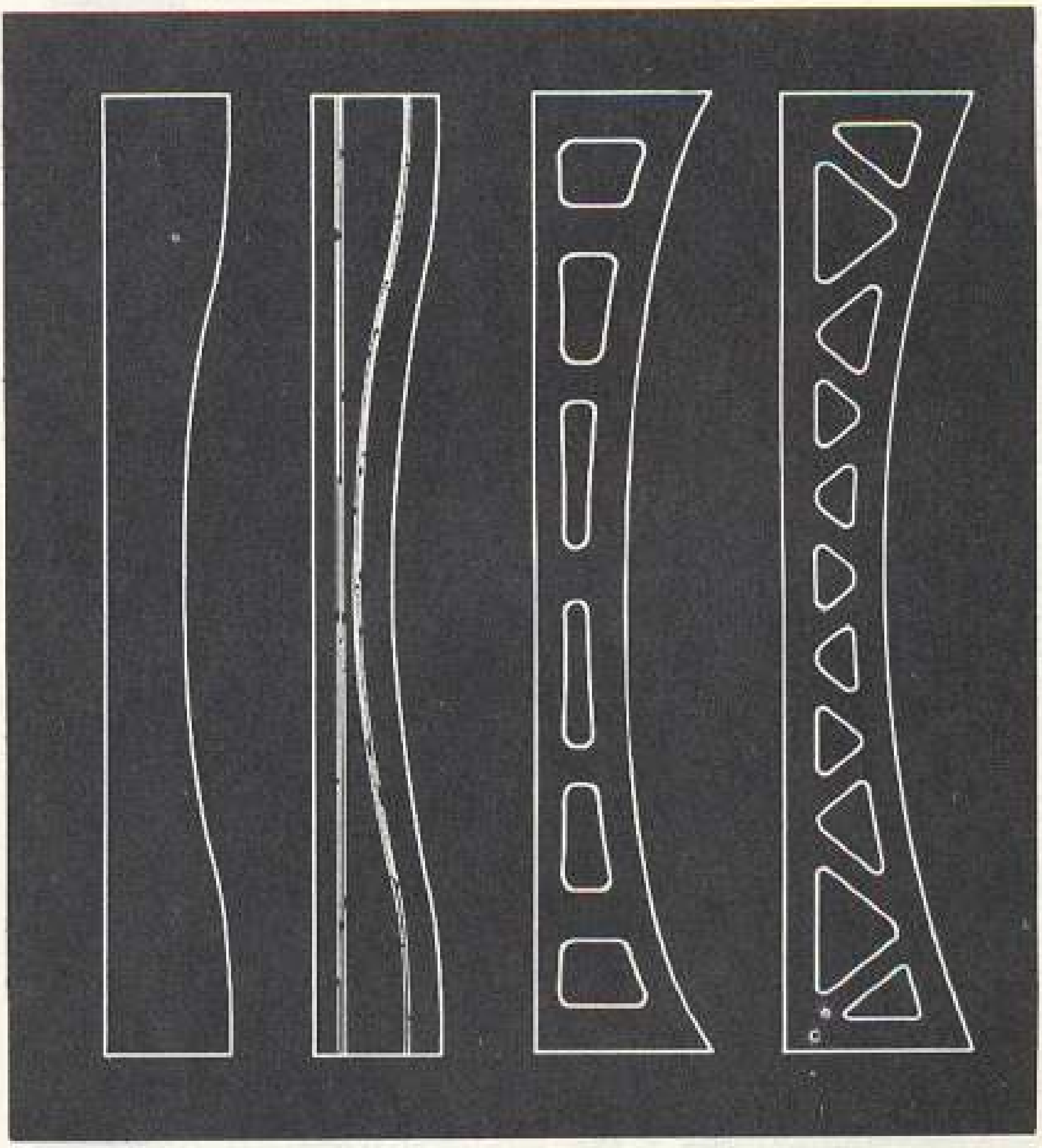

Fig. 17.--Cast or laminated plastics beams with variable depths and cross-sections.

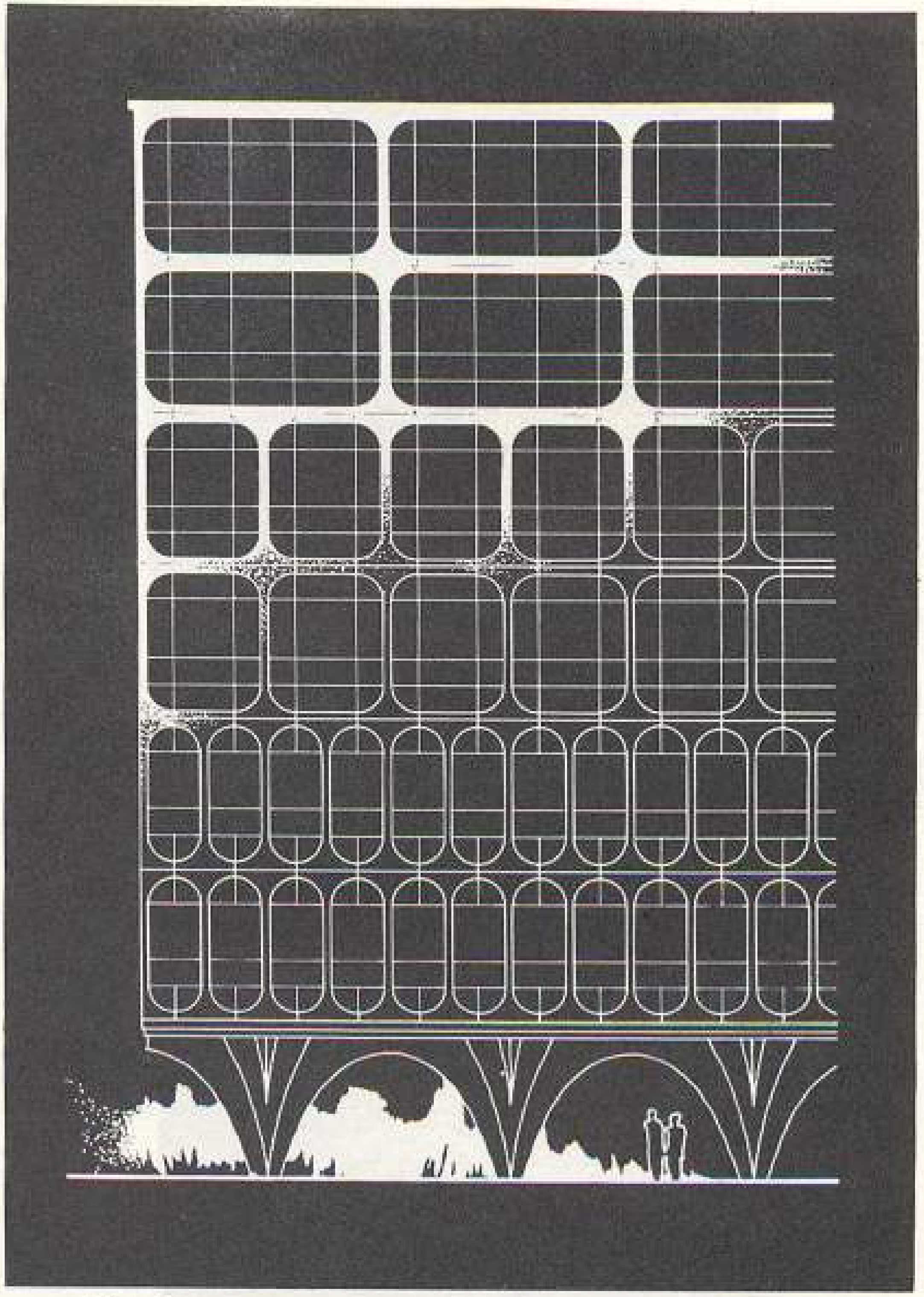

Fig. 18.--A tall building with all-standardized parts

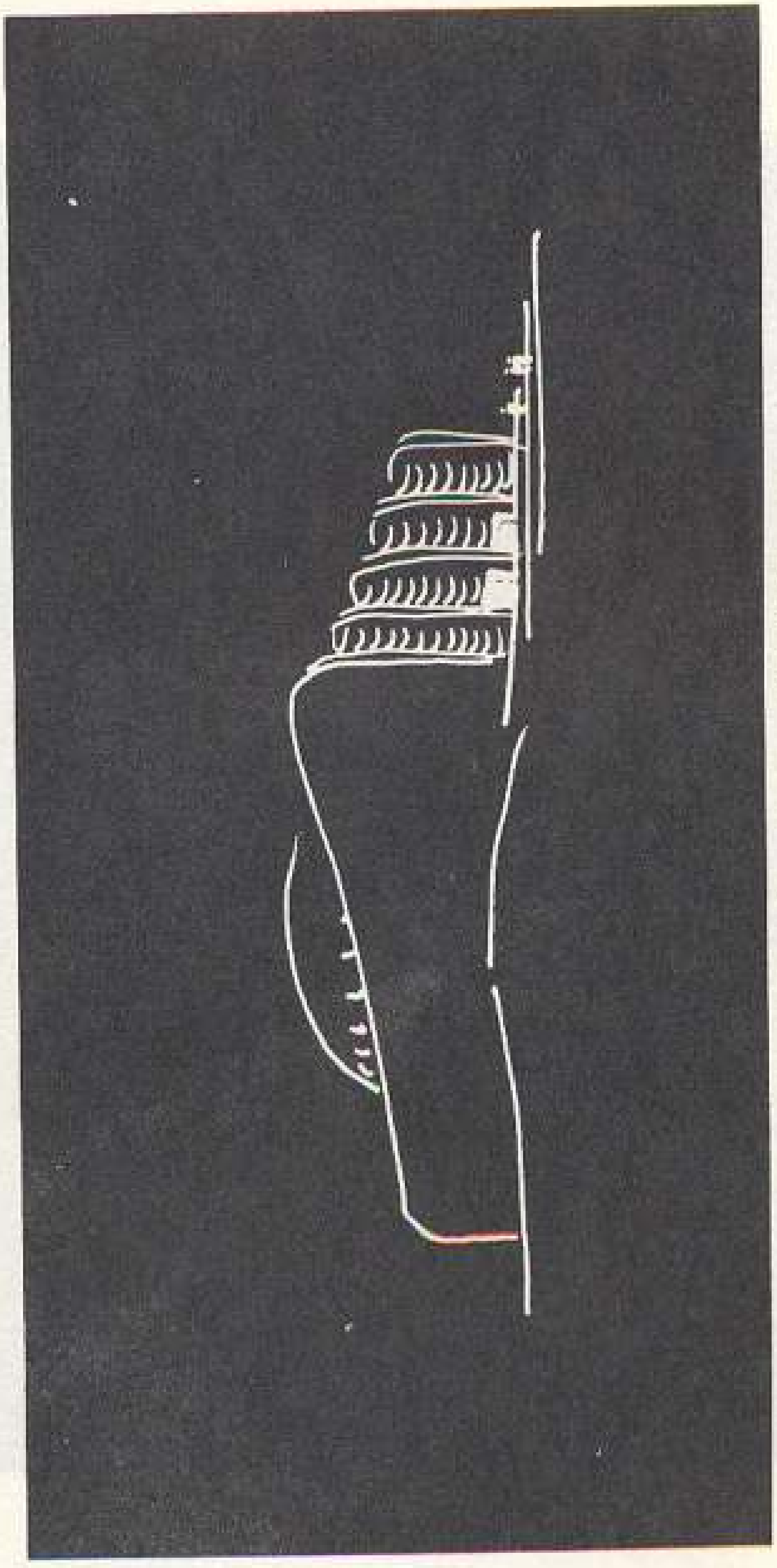

Fig. 19.--An assembly hall

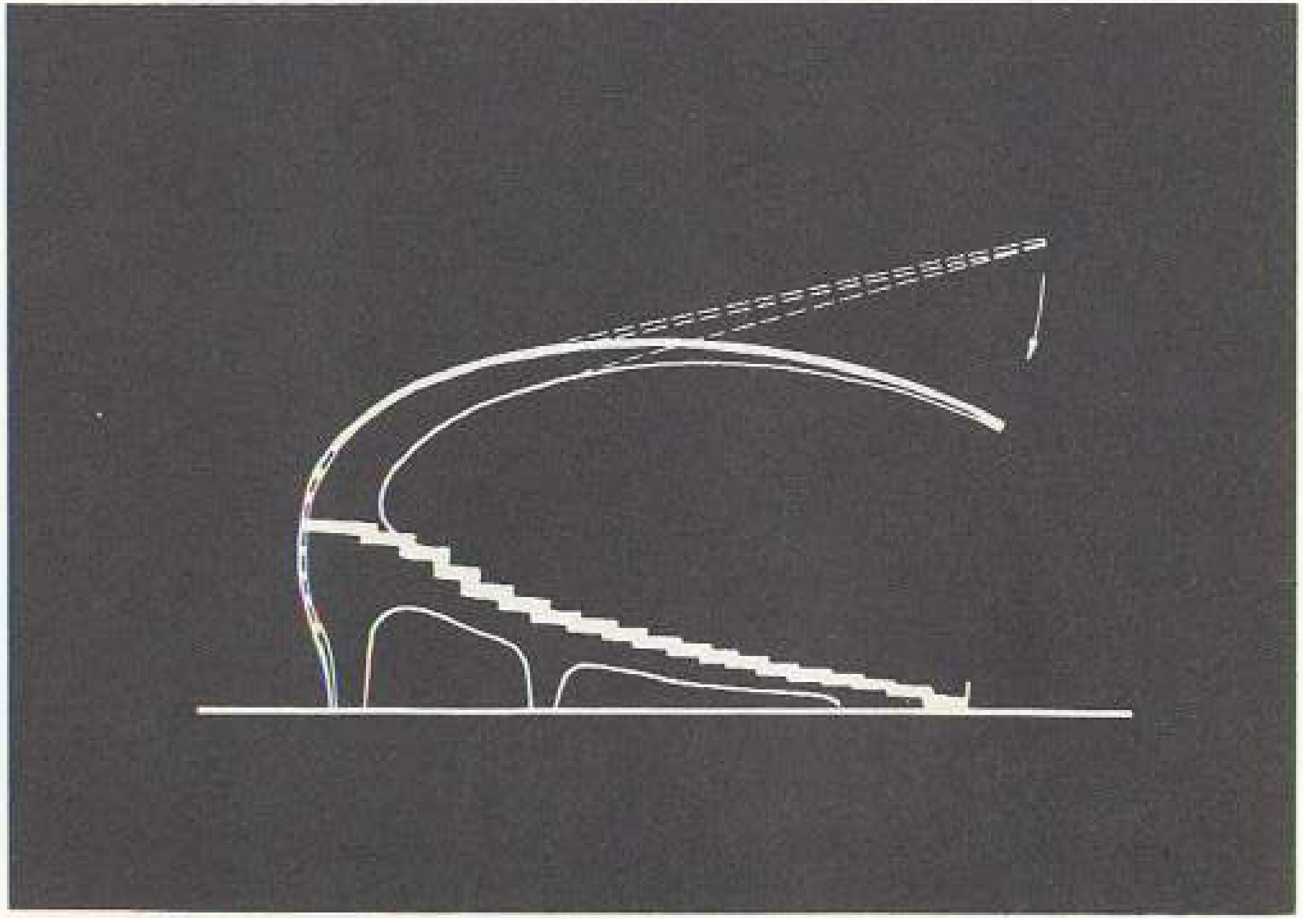

Fig. 20.--Elevational section in a stadium, showing the excessive deflection of the cantilevered roof.

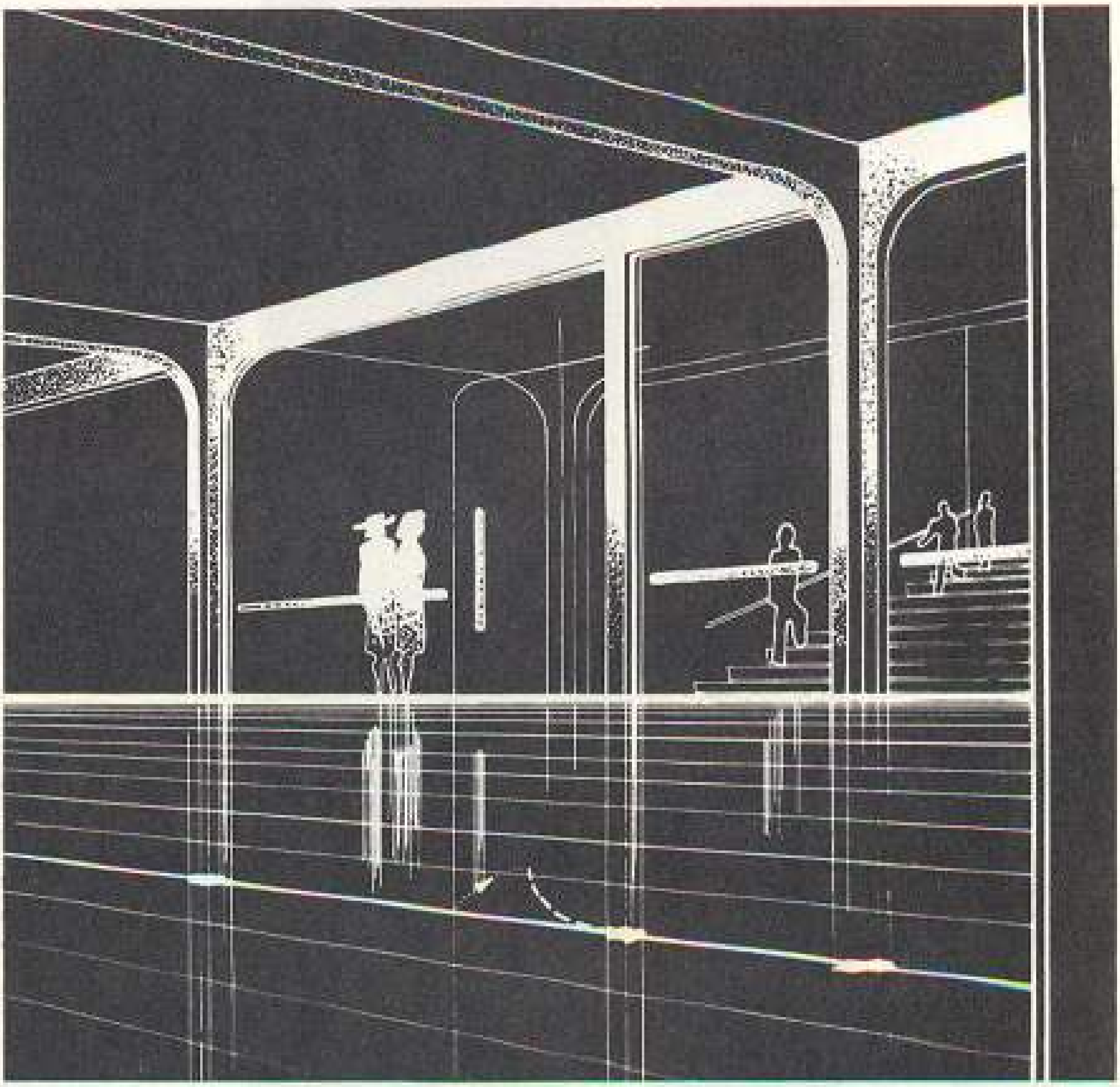

Fig. 21.--Perspective of an entrance to a building, with a flexible door

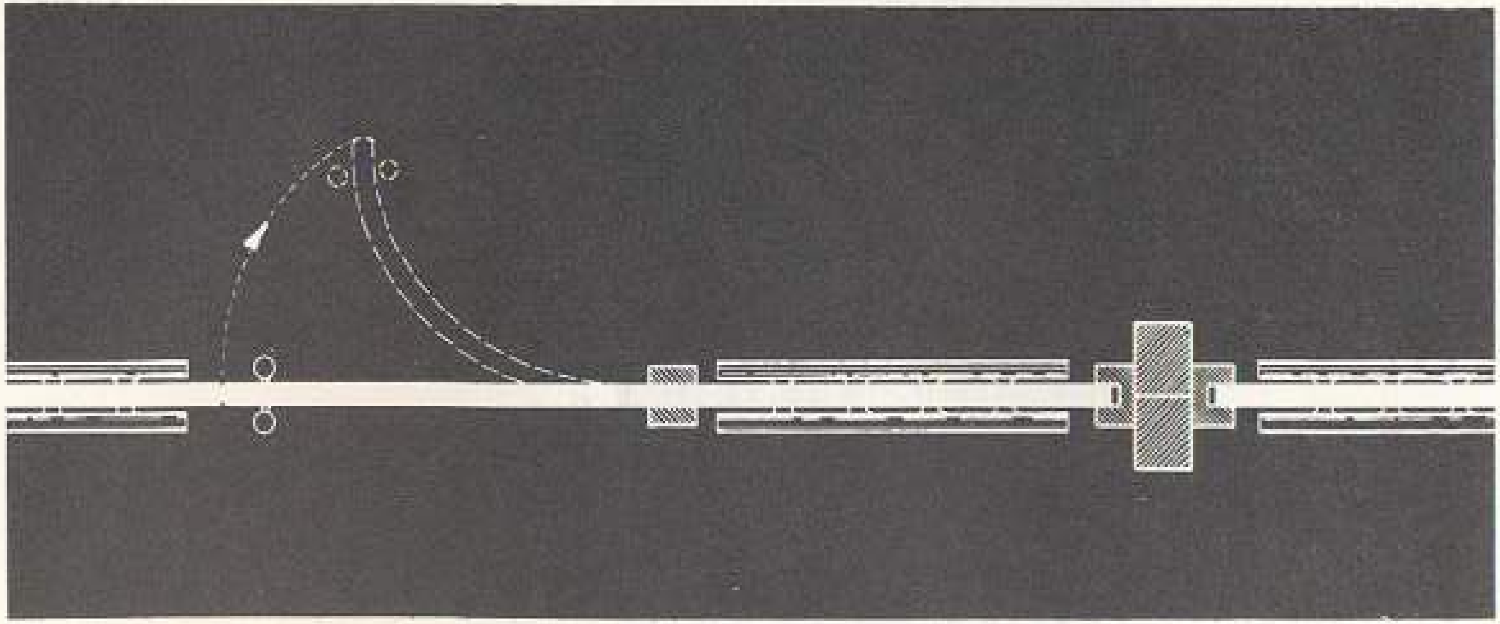

Fig. 22.--Sectional plan of the flexible door in fig. 21

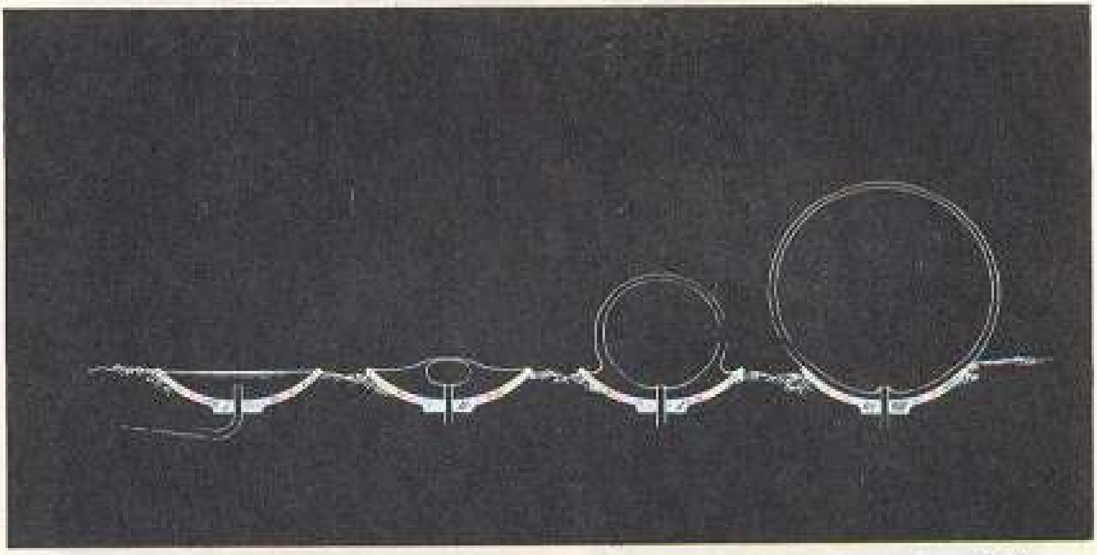

Fig. 23.--Successive steps in the blowing of a plastic shell

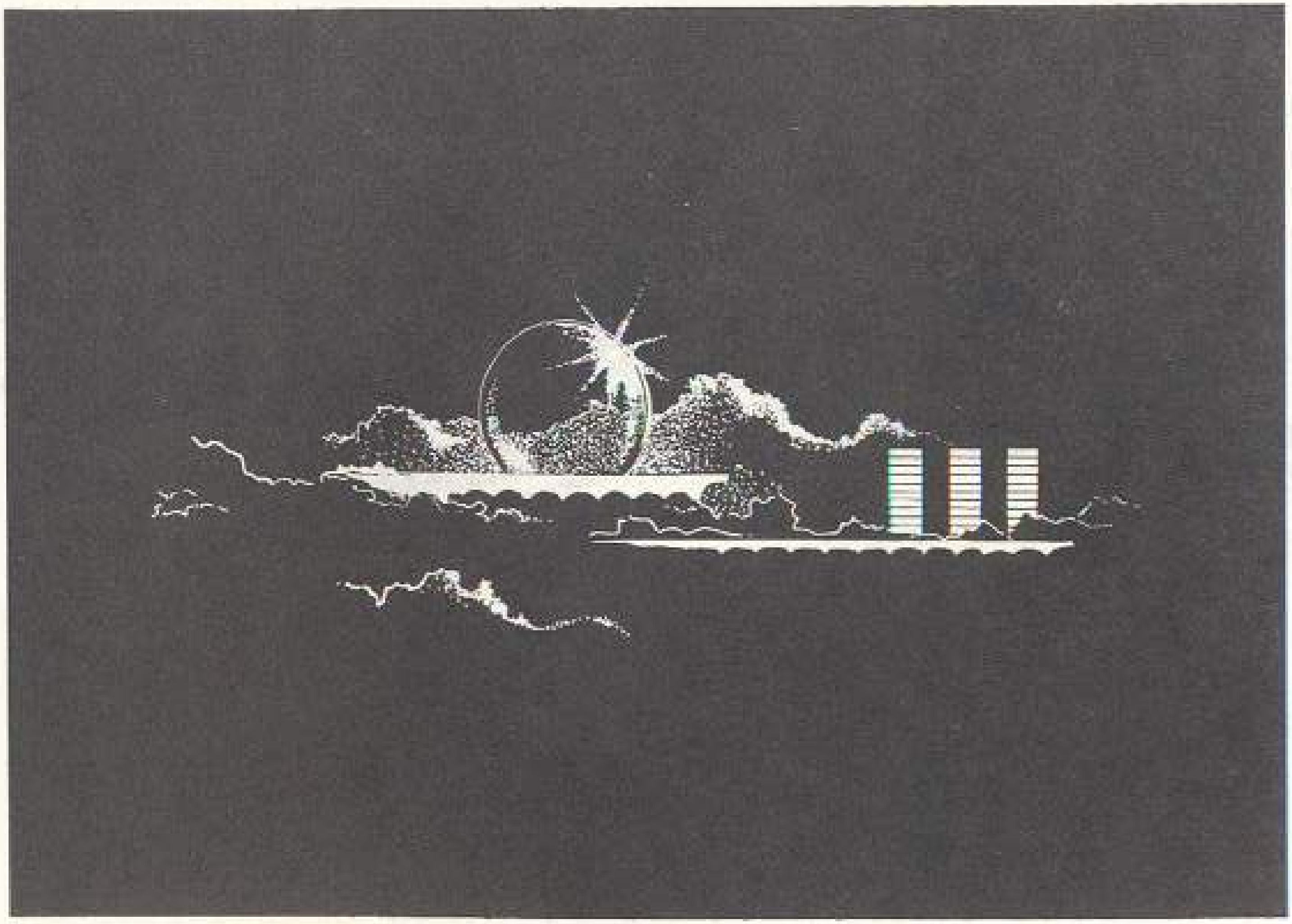

Fig. 24.--A planetarium

Fig. 25.--A research institute

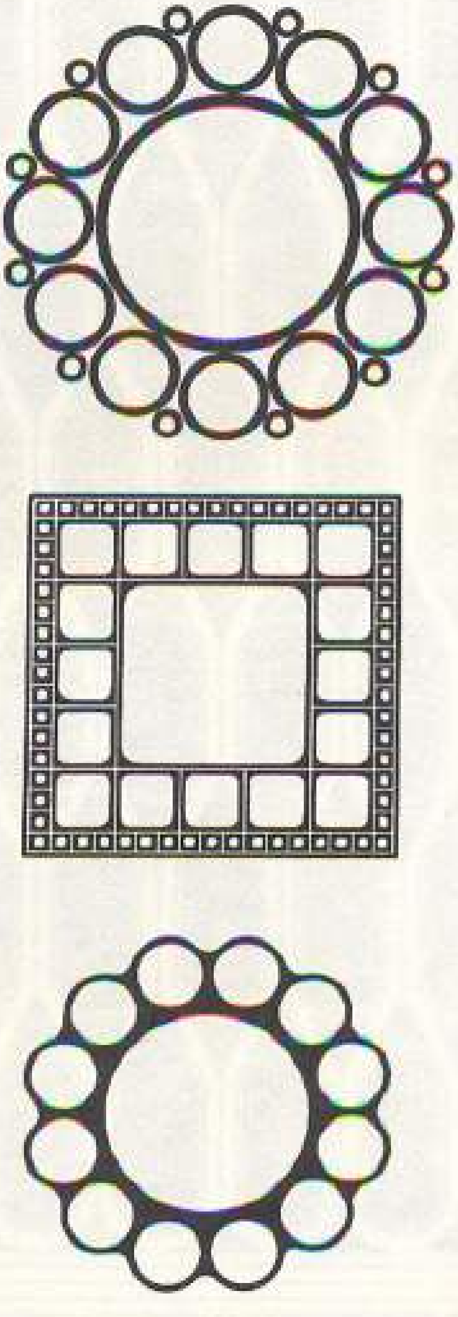

Fig. 26.--Cross-section of extruded columns

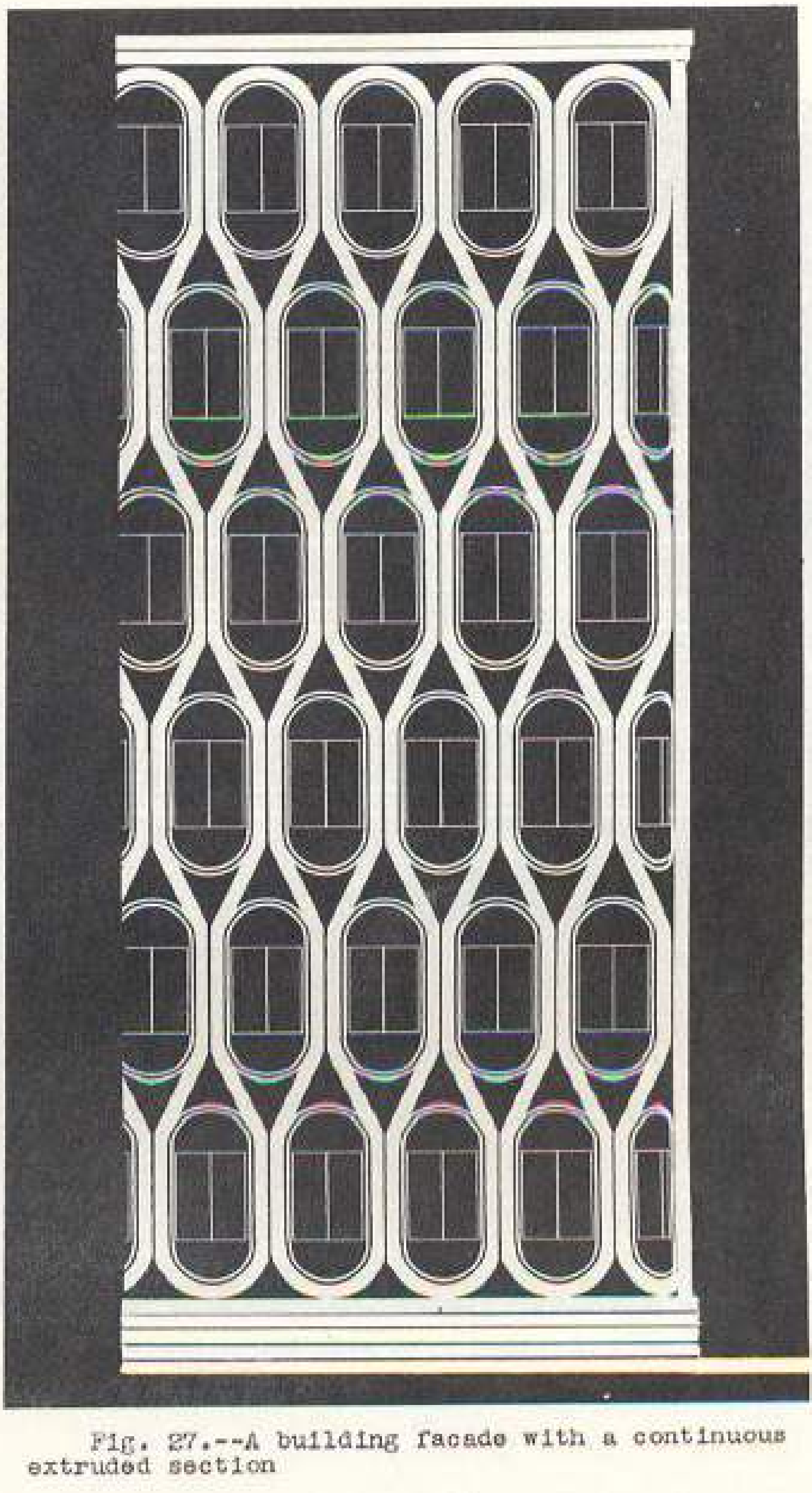

Fig. 27.--A building facade with a continuous extruded section

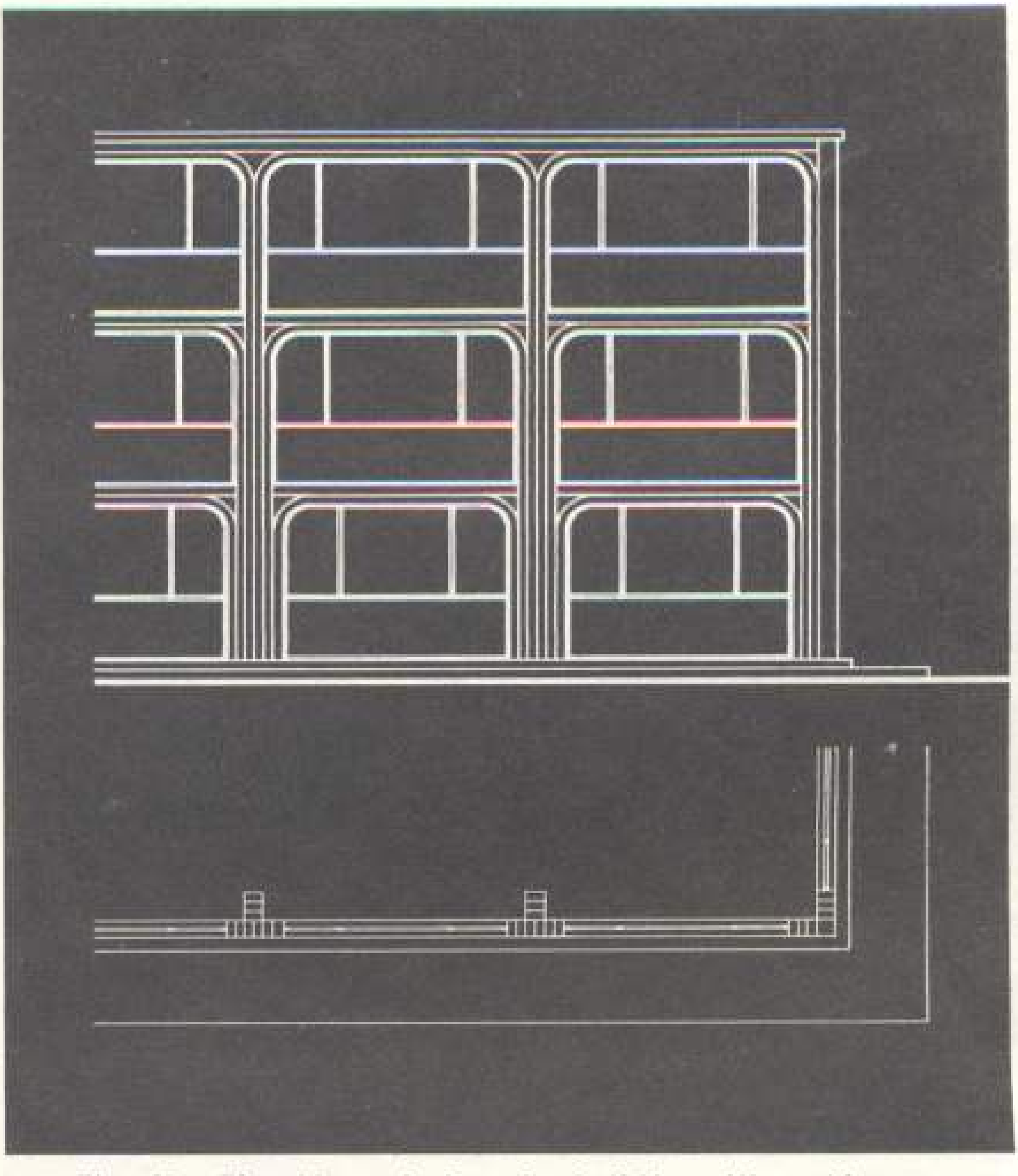

Fig. 28.--Elevation and plan of a building with continuous, extruded structural members.

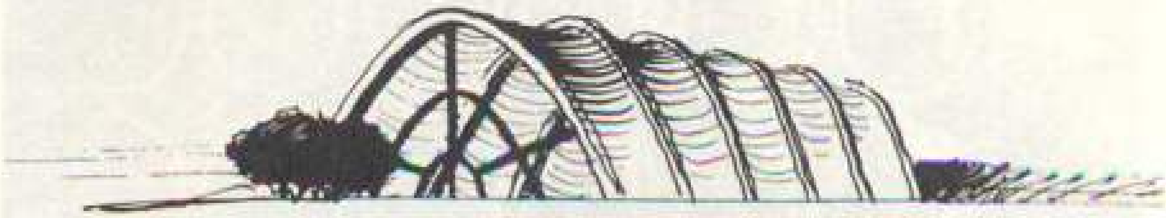

Fig. 29.--A hangar with continuous roof-covering sheets

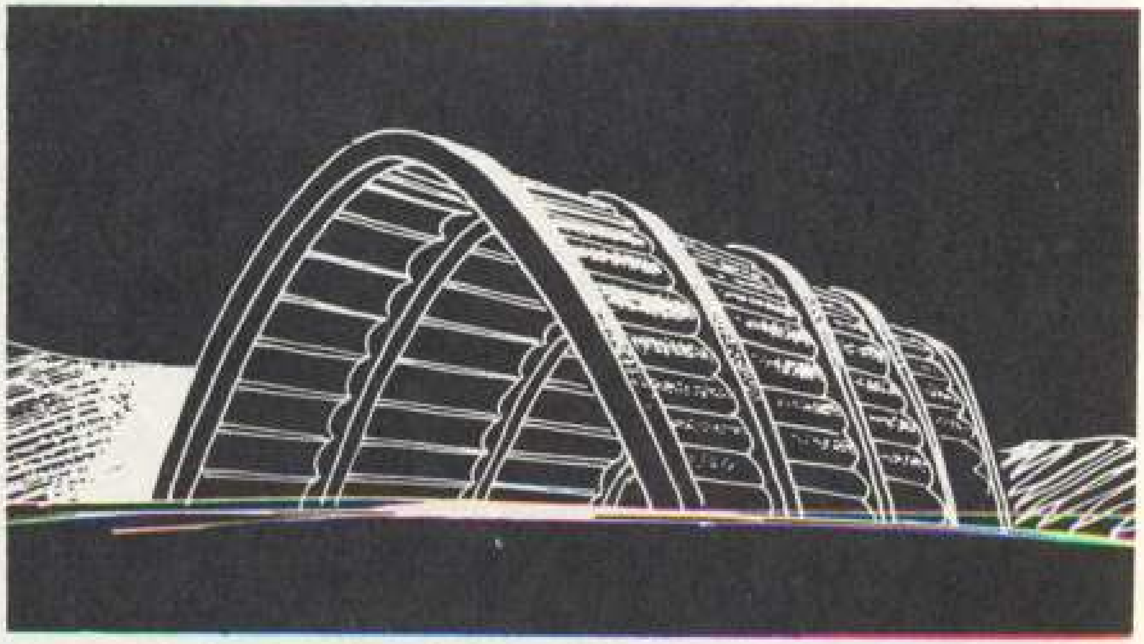

Fig. 30.--A hangar with push-fitted plastics sheets

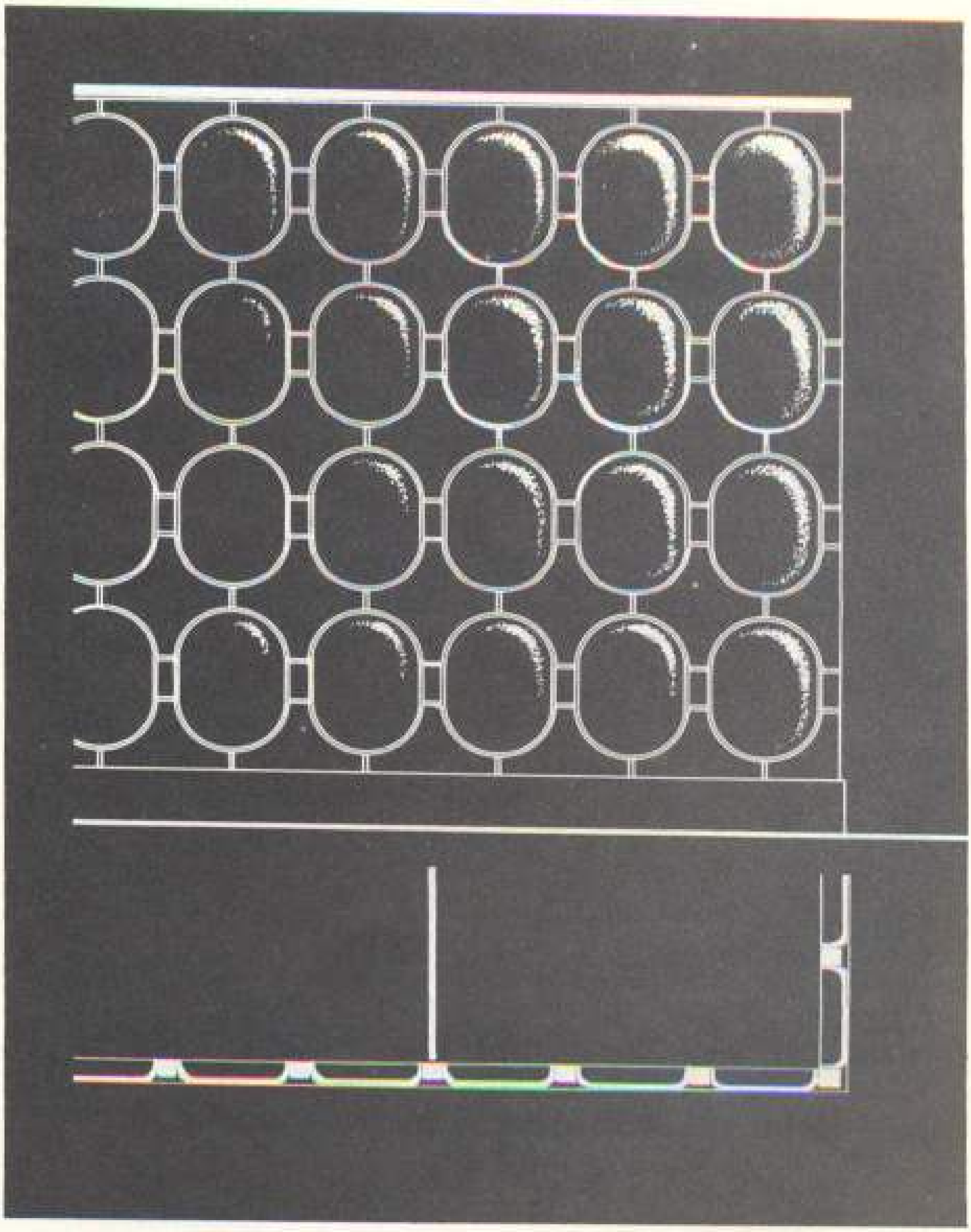

Fig. 31.--Elevation and plan of a building with molded windows

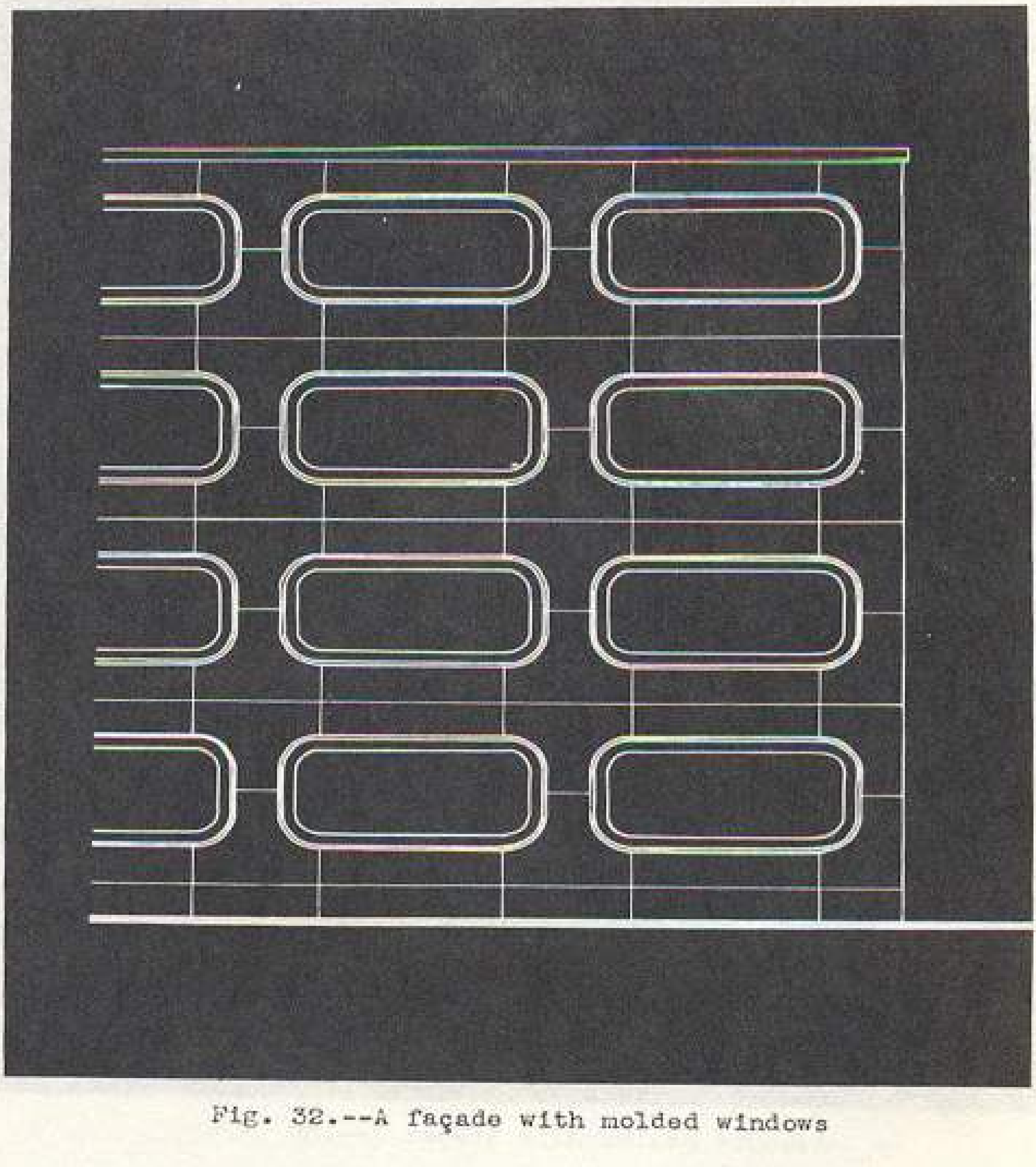

Fig. 32.--A façade with molded windows

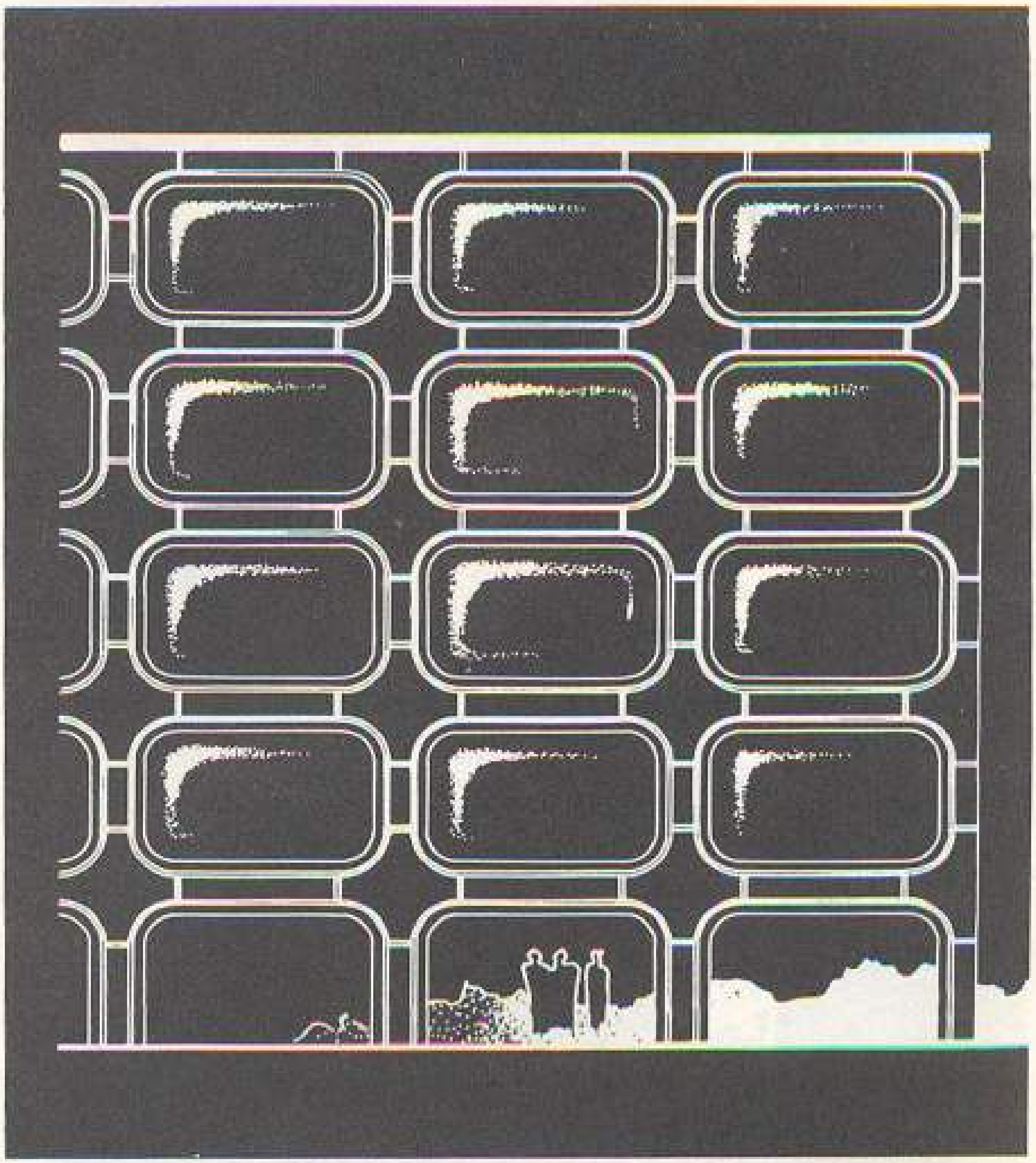

Fig. 33.--A façade with molded windows

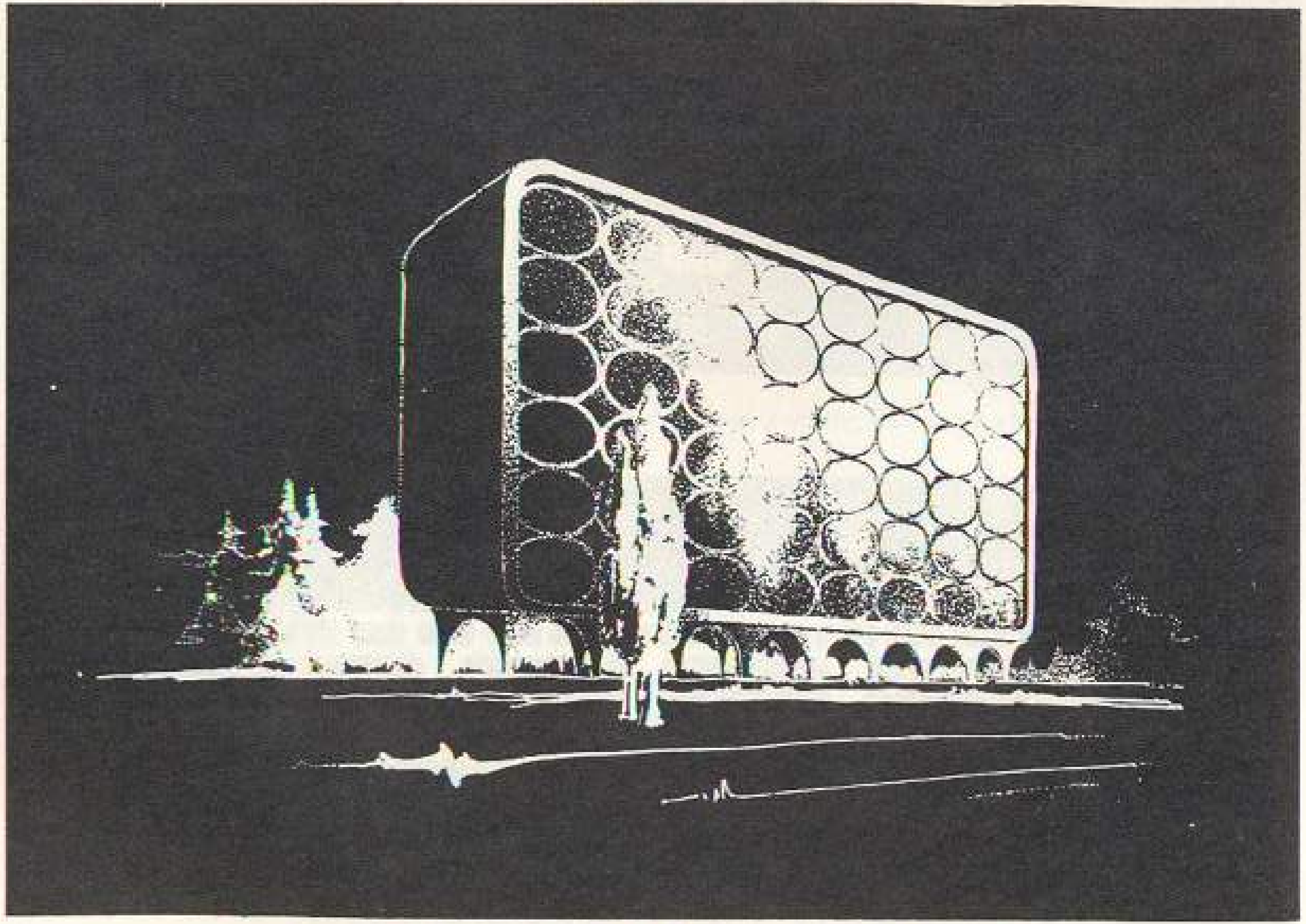

Fig. 34.--Perspective of a building with molded windows

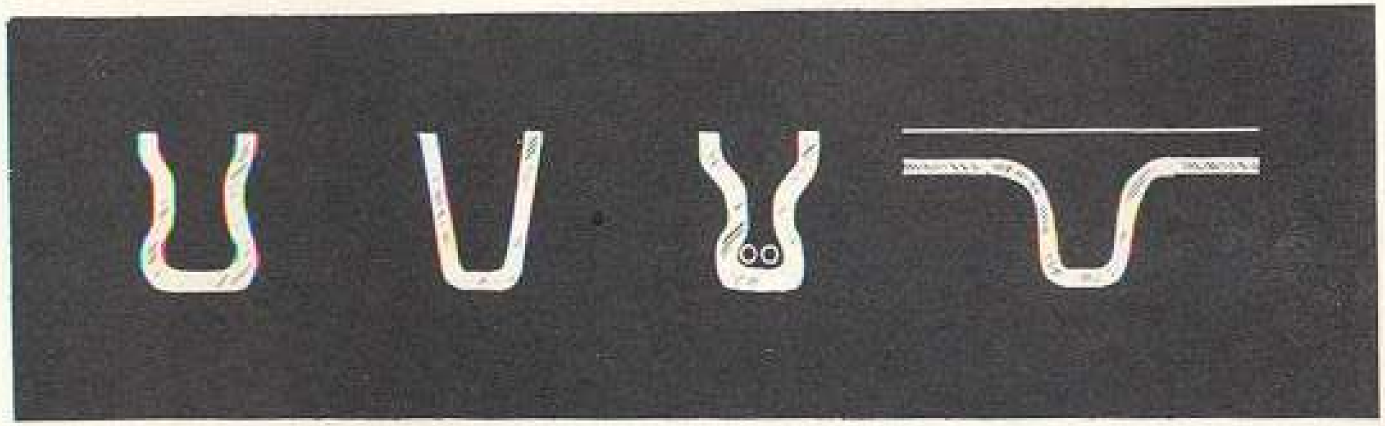

Fig. 35.--Cross-sections of prefabricated form for casting plastics structural beams

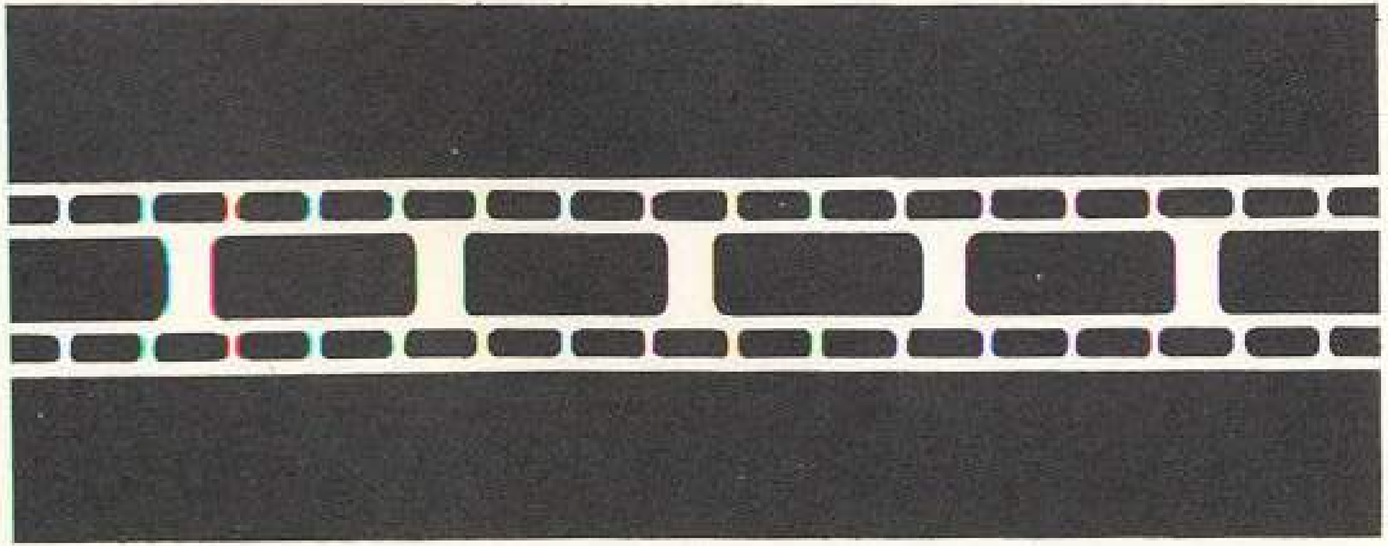

Fig. 36.--Section of a composite roof panel

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