AN INDUSTRIAL PLANT FOR THE POLAROID CORPORATION

A Thesis Submitted in Partial Fulfillment
of the Requirements for the Degree of
Master of Architecture
at the
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John N. Morphett, A.R.A.I.A.
Bachelor of Engineering.
University of Adelaide.
South Australia (1955).

Dean Pietro Belluschi.
School of Architecture and Planning.

Lawrence B. Anderson.
Head of the Department of Architecture.
Dean Pietro Belluschi  
School of Architecture and Planning  
Massachusetts Institute of Technology  
Cambridge 39, Massachusetts.

Dear Dean Belluschi,

In partial fulfillment of the requirements for the degree of 
Master of Architecture, I herewith submit the thesis entitled,  
"An Industrial Plant for the Polaroid Corporation."

Sincerely yours,

John N. Morphett.
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To:
My wife Vivienne, for her patience and interpretive ability.
Title: An Industrial Plant for the Polaroid Corporation

Author: John N. Morphett

This work will comprise a study of the physical needs and requirements for a medium sized factory manufacturing photographic film, followed by the design of the plant layout and buildings, on a site at Waltham, Massachusetts.

During the course of the study, emphasis will be laid on adopting the physical work environment to human needs. It is widely recognised that worker's efficiency is more or less increased when improvements are made in the working environment. Building spaces organised in an attractive manner and situated in a pleasing locality, provide good advertising and add to prestige, as well as increasing efficiency and keeping production costs to a minimum.

On the other hand, it is realised that expenditure on "improvements" is not always reflected in positive savings in production. Often, as the result of the pressure of competition there may be over-emphasis of some aspect of human conditioning which may not contribute to favourable working attitudes. Thus there is often confusion regarding the possible outcome of any given innovation in this field. It is necessary always to relate physical conditions to the attitude of the workers. An attempt will be made to clarify the impression on man of his working environment, considering such factors as the size of the working space, the noise problem, color and lighting, air conditioning, the dust problem, plant amenities etc.
It is hoped that a careful study of these conditions applied to the requirements of a particular industry will help to clarify some of the problems arising in the planning of new factories.
THE BACKGROUND
GROWTH OF A LARGE-SCALE ECONOMY

"The development of the modern industrial process has been intertwined so closely with changes in economic organisation that neither can be explained without reference to the other."  James A. Quinn.
The home-centered industry of the medieval town, with its small number of journeymen and apprentices was confined mostly to small localities with few outside connections. Free artisans manufactured goods and sold them directly to customers; master craftsmen trained apprentices in their own establishments or hired travelling journeymen; the customs of the guilds, rather than competitive bargaining governed the rights and duties of masters, journeymen and apprentices to one another and to the public. Everywhere the personal element and the human scale predominated, from the tilling of the soil, through industrial processes, to commercial transactions.

Contrast these earlier economics with contemporary economic enterprises, utilising long-range communication and transportation systems to collect raw materials from many parts of the earth, to sell finished products on every continent and to operate branch offices in many regions. Continuous increases in the size of machines, individual manufacturing plants and integrated economic groups are now characteristic of the growth of our large-scale industries.

This new economic order, brought about through the Industrial Revolution by advances in technology and political responsibility, is characterised by freedom of the individual and of unrestricted competition between individuals. Private ownership of wealth and individual control of economic enterprise is restricted only so far as is necessary to keep law and order. Theoretically every individual is permitted to seek any job he wishes, to work under any conditions he chooses to accept
and for any wage he can command. If he cares to do so he can start any kind of business or industry, provided he can obtain sufficient money or credit. He can hire and discharge workers, buy raw materials competitively and offer goods for sale at any price he wants to ask.

Such changes in the size and character of economic enterprises have not been introduced without accompanying problems, many of which have yet to be solved in terms of our cultural, economic and aesthetic ideals.

The greater efficiency of large-scale activity increases the difficulties faced by smaller competitors, often forcing them out of business. The conflict between what is best for men and what is best for machines again arises. Similarly the greater size of individual machines and their integration with complex production lines, make difficult their ownership by individual labourers.

Semi-automatic and automatic production lines decrease the number of workmen needed in selective fields and change the emphasis on skilled and semi-skilled labour.

The greater number of employees in a large-scale enterprise increases the degree of anonymity and impersonality of contacts between management and labour. Industrial bargaining power tends to become unbalanced because the worker can seldom become an enterpriser and if he loses his job he loses his entire wage, whereas management's profit is lessened by only a small fraction.
The widespread adaptation of diverse occupations into an integrated economy makes the economic welfare of each person dependent on large numbers of strangers, over whom he has little direct control. Individuals tend to feel insecure and unhappy, with the feeling that they have no say as to their future destiny.

The seriousness of these problems brought about by the conflict between men and machines is emphasised by Sigfried Giedion "...the equilibrium that went out of human life with the coming of the Industrial Revolution has not been restored to this day. The destruction of man's inner quiet and security has remained the most conspicuous effect of the Industrial Revolution. The individual goes under before the march of production; he is devoured by it"
"Power, work and regularity are adequate principles of action, only when they co-operate with a human scheme of living."

Lewis Mumford.
Traditionally, large-scale industrial management has pictured the internal organisation of an enterprise as a formal rational structure consisting of ideal positions and relations which take the form of an administrative hierarchy in which superiors have the right to issue orders to subordinates. Lines of communication - downward in the form of orders, questions and information and upward in the form of reports, questions and grievances - permit the various levels to function together as a unit.

The validity of the idea that a formal plant organisation leads to the most efficient means of production, rests in part, on the concept of the industrial worker as an "economic man" whose behaviour is guided by his rational intelligence to attain a larger income for himself. It assumes that as an automatic being, he will react favourably to higher wages and better physical conditions of work.

Sociological and psychological researchers have discovered that there are serious weaknesses in this theory of economic motivation. While agreeing that a formal structure in management is necessary for the convenient running of industry they point out that there exists an informal structure created within the factory by personnel themselves. The need for men to be liked and approved as human beings and not treated as parts of an economic machine has led to the development of more informal relations between management and employees and amongst the employees themselves.
It is when the informal organisations or groups or cliques of workers can be made to work sympathetically with the formal hierarchy that harmonious plant operations can be achieved. An individual's favourable attitude towards change or improvements in his working environment largely depends on this total picture of labour relations within the firm. Workers will be receptive to physical changes only if they are already reasonably satisfied with their job and employers.

Thus, it is necessary when planning a factory to take into account the informal as well as the formal structure of the organisation. Many questions may be brought up concerning the status of employees which have a vital effect on their attitudes towards their work. For example, a decision on whether to provide a single entrance for management, office and factory staff may or may not produce beneficial results. Providing management-worker relations are good, a common entrance will help to produce a feeling of equality within the staff. The factory men will arrive at work more neatly dressed, they will feel they are part of the whole plant, not just a small section of it. With the opportunity for informal contact between sections of the staff there will be more understanding and less criticism of other departments. On the other hand, if management-worker relations are not amicable when the change is made, it may well be that the factory staff will distrust the move as an attempt to supervise their comings and goings more closely, the office staff may look upon it as a threat to their superior status, the management as an added nuisance to be borne for no good reason.
The success or failure of any aspect of plant design depends in the final instance, on the employees reaction to it, and it is necessary always to think in these terms if the objects of maximum efficiency and productivity are to be attained.
"A basic long-term aim of Polaroid is to provide means for all its employees to have a full and complete working life." Edwin H. Land.
The Polaroid Corporation came into existence as a result of inventions that made the control of polarised light available on a widespread basis for the first time. Dr. Land, the inventor of this process started manufacturing polarising sheet in a small research laboratory in Boston in the early thirties. With the development of more efficient methods of manufacturing the sheet, the company grew rapidly. During the war the company converted to the development and manufacture of war products involving the use of polarised light. Simultaneously it broadened its activities of research and production to non-polarising materials and devices. In 1948 a great development came with the invention of the Land Camera - a dry photographic process that produces finished positive prints in sixty seconds directly from the camera. It was hailed by the scientific world as one of the ten most significant inventions of the year and was an immediate success. Since then it has become the company's main activity with 93 per cent of the total income in 1956 derived from the sale of photographic products. Two camera sizes are now produced and four different types of film are sold in sizes to fit the two cameras. With progressive research going on continuously, the quality of the film has improved greatly and new types of film are being added to the range. Positive transparencies which can be developed in two minutes are now available. Research in the field of color is currently being carried out.

Until recently both production and research units were located at Cambridge, Massachusetts but the company is at present expanding its facilities for the production of photographic film with the construction of the second and final stage of a film manufacturing plant at Waltham, Massachusetts. The plant is a
complete manufacturing unit, related to the company's main office at Cambridge through the executive and buying and selling organisations of the company. The research and administration sectors are in Cambridge, conveniently located near scientific and cultural institutions.

It is the purpose of this thesis to redesign the company's plant at Waltham, Massachusetts, making use of the programme requirements based on the existing plant.
MAN - THE GROUP
Group activity is so common that it is often taken for granted. Individuals meet and act and work together and no matter how casual their relationship there is an interchange of experiences which results in group activity. When any sort of activity takes place where there is a feeling of 'we' there is a group experience which may range from the intimate relationship of family life to the relationship of those who work together on a machine in a factory.

In any group there seems to be a division of labour. Each person in the group finds the part he has to play and attempts to live up to the expectations that the group defines for him. To a certain degree, the individual seems to lose his own identity and his own individuality in the group activity. Certainly all knowledge and habits come from group experiences and therein lies the basis of group power. The extreme pressure of group expectation on human behaviour leads the individual to conform to the ideals and customs of his group. In order to understand and provide for the individual and his needs it is necessary to look into his background and understand what his group life with others does to and for him.

There are two aspects of this group behaviour which will influence the design of a factory, especially that of the employees' facilities. Firstly the design should be predicated on the assumption that individuals like to feel proud of their working environment, to be able to show it off to their friends and relatives as the place where they work. They like to belong to groups within the factory which may range in size from sports or social clubs down to the working team who eat together, or the members of a car-pool.
Secondly, the group background of the plant employees should be considered. Recreation and dining facilities and even washrooms and locker rooms should not be too different in character from the worker's outside environment. If such facilities are too primitive employees feel them inadequate; if they are too luxurious employees will feel uncomfortable using them and they will probably deteriorate rapidly through improper use.

Fundamentally all men have the same basic needs, but each one is the product of his own environment or class and will act differently according to his past experiences and group associations. The recognition of this will help in designing for the common needs of all men.
"We do not want to live in a world where the machine has mastered man; we want to live in a world where man has mastered the machine."

Frank Lloyd Wright.
Man, the most highly developed form of life, is incredibly complex. Each man reacts differently towards his environment, each is adaptable to a great variety of changes in it. There are however, limits to his endurance and intelligence and such limits cannot be exceeded if his maximum efficiency is to be exacted. Since man cannot be redesigned to meet the requirements of his job, a work plant has to be designed to meet the psychological and physiological requirements of man.

Man's physiological requirements are bound up with the five primary senses of sight, hearing, smell, taste and touch. Through these senses he perceives the objects and changes in his environment. On the basis of this perceived information he makes evaluations guided by his past education and experiences. The clarity with which information and problems are presented to him has a lot to do with the length of time he will take to come up with an answer and act upon it. This in turn has a profound effect on his concentration and endurance.

Disturbing, distracting or annoying aspects of a job, impair a worker's ability to do his work effectively. Poor lighting causes error, eye strain and irritability; excessive noise disrupts communication and mental concentration; prolonged vibration causes headache and fatigue; extremes of heat and cold diminish efficiency because much body energy is lost in adjusting to extremes in the environment. Thus if the environment can be tailored to the worker's physical dimensions and body mechanism it should be possible to channel much unproductive energy into positive production.
Man's psychological requirements are less obvious; he has many desires and motives that he knows nothing about, or is aware of only vaguely. The desire for a feeling of the significance of what he is doing, a feeling that he is respected for what he is and not merely for what he can do is a fundamental requirement of man's ego. Proper motivation or incentive to his self interest will go far in eliminating mistakes and delays due to these causes. Man is not an automaton, he is a being whose individual ego is constantly exerting and showing itself in preferences in clothing, automobiles, sports, food and women. Although no two men are identical in their preferences, certain generalities can be made. Most men prefer sunshine to rain, light to dark, cleanliness to filth and these general attitudes reveal themselves in his reaction to his environment. He will probably be confused or irritated by intermittent noise, a blinking light, or a pile of refuse near his machine. Any environmental factors that distract his mind will slow his work-pace and attention to these psychological needs will create a favourable response which will be reflected in his working efficiency.
THE PROBLEM OF SCALE

"Every magnitude has its own structure. If limits of scale are over-run either a new level is reached or the old level collapses. If two scales are mixed, confused - then there is an out of scale condition. The pattern loses the connectedness with its field. There is a state of crisis."  

Gyorgy Kepes.
The greatest challenge in modern industrial architecture is that of size. The sheer immensity of the scale presents a colossal problem in establishing some form of reference against which man may establish his position in relation to the structure before him.

The problem of size has come with the machine. Faced with the difficulty of housing ever bigger and more complicated machines and production lines man has lost himself in the maze of blank walls which cover up, rather than express their true intent. The enclosure of a great space, using the simplest and most economical means available has created an idiom in industrial architecture which is carried over into many buildings without thought as to their actual needs and requirements. The tiny door in a mile-long wall of asbestos may be exciting to the casual visitor, but to the man who has to walk through the door into the great space inside, twice a day for the rest of his life, it can become very depressing.

Thus the main problem in the scalar treatment of factories, is how to convey to their expression some sense of the power and movement they enclose, at the same time keeping in mind the necessity to relate all this to human beings.

In smaller, simpler plants, this problem can be solved quite simply by forgetting all about the industrial idiom, and designing on a human informal scale with the idea of creating a more intimate relationship between the factory and the employees and imparting a sense of being personally catered for.
With larger plants, the problem is not so simple. Breaking down of size by the repetition of small scale elements is useful only so long as it is not carried too far. In many cases the building itself can be broken up into such elements, either physically, by a division of processes within the plant, or visually by change of direction or grade, or by landscaping to limit the view obtained at any one time. With extremely large mechanical units, or with servicing units such as ducts etc., the equipment need not be totally enclosed and can be expressed with only small scale enclosures being necessary for the shelter of the operators.

Finally, it is necessary to create a sense of human importance in the plant; it must be planned to give the impression that it was not erected simply as a shed in which to manufacture articles, but that it is a structure in which people manufacture articles.
THE PLANT
THE REGION
The New England region and particularly the outer Boston suburban area is an ideal location for the proposed film manufacturing plant. The area has a large skilled labour force available for industry. Research facilities are convenient and the Polaroid Company has in the past concentrated its activities within the Boston metropolitan area. It considers that a close liaison between research facilities and manufacturing units is a necessary condition for efficient progress and for this reason the relationship of the plant to other sections of the company was considered of primary importance in the selection of the site.

The present locations of raw materials, mostly paper and chemicals, are widely scattered throughout the country. Similarly the markets for the finished goods are nation wide, with overseas markets beginning to expand. Thus location of the plant with respect to these factors is important only to the degree that transportation facilities must be adequate. At present most shipping of raw and finished materials is by truck, so a good road system is desirable.
THE COMMUNITY
The plant is located at Waltham, which is one of the communities on the western fringe of the Boston metropolitan area. Waltham is mainly a residential suburb of approximately 80,000 inhabitants. The density is fairly low, the housing facilities are good and rent levels are lower than in Boston. The suburban character and attractive surrounding countryside make Waltham an agreeable place in which to live. The city itself is very pleasant, with adequate community services in terms of schools, hospitals, parks etc.

The people of Waltham fall mainly into the middle income group of skilled tradesmen, technicians and office workers. They work in nearby light manufacturing industries producing precision instruments, electrical products, machinery and apparel. Some commute to Boston nine miles to the east and others work in the thriving commercial center.

Thus there is available a high quality labour force which will be attracted by the opportunity to work in good surroundings close to their homes.

Zoning ordinances are well established in the area, with one of the main industrial and commercial zones bordering the circumferential highway - Route 128. Situated on the edge of this zone at the corner of Main Street and Route 128, the plant is close to residential areas and undeveloped woodland. On page 30 is a zoning map of the Waltham area showing industrial locations in relation to the plant.
THE SITE
VIEW LOOKING SOUTH.

VIEW LOOKING WEST.
VIEW LOOKING NORTH.

VIEW LOOKING NORTH EAST FROM ROUTE 128.
Situated in an attractive valley surrounded by wooded hills, the site is irregular in shape and mainly flat, with some shallow slopes to the south and north. Precipitous hills showing rock outcrops amongst the trees bound the site on the north east side. To the east there is a patch of low-lying marsh land traversed by the power lines from the Boston Edison Company's transformer station on the southern boundary. Also to the south is the Boston and Maine railroad and the access road to Main Street. Route 128 the circumferential highway, runs along the north western boundary.

The prevailing winter winds are from the north west, while summer breezes come from the south west.

The flat land is good for building, but drainage is a problem in some areas with the water-table an average of four feet below the surface. The soil tests shown on page 36 indicate rock foundations an average of ten feet below the surface, permitting the construction of heavy buildings.

All essential services including water, gas and sewage are available at the site. Electric power at 13,000 volts, can be drawn from the adjacent Boston Edison transformer station. Fire protection, an important consideration with this type of manufacturing process, is supplied by the Waltham Municipality Fire Station situated less than one mile away at the city center.

Automotive access to the plant is excellent, with Main Street to the south leading to Routes 20, 128 and 117 nearby. These routes provide good access both into Boston and Cambridge and around the metropolitan area, connecting with interstate throughways.
Although it is not intended to use railroad transportation in the near future, the possibilities of making use of this medium are good, with a Boston and Maine railroad immediately to the south of the site.
BORING RESULTS (depths in feet).

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A

CIRCUMFERENTIAL

HILL

BEAR

CUTTING LANE

ST. MAIN

STOW ST.

SPENCER ST.

ROUTE 126

36 Acres

82

REPUSAL
THE PRODUCTION PROCESS
The film used in the Polaroid Land Camera is unique in that positive prints are obtained sixty seconds after the film has been exposed in the camera. The process by which the prints are made may be described briefly. The roll of film consists of a negative film, with positive sheet in close contact with it, the whole backed by light-proof protecting paper. Spaced at intervals along the film are air-tight pods of jellied reagent which are constructed of metal foil and plastic and sealed in such a way that they will open when pressure is applied, squeezing reagent between the positive and negative film surfaces. The camera is constructed in such a way that when the film is wound on after exposure, the pod passes through closely spaced rollers which break it and distribute the reagent evenly between the film surfaces. The reagent consists of developer and fixative in a jellied solution. The developer converts exposed silver halide grains on the negative into metallic silver, while the hypo dissolves all the silver halide not converted to silver. The silver ions in the hypo solution are then deposited very rapidly onto the positive sheet with the aid of a catalyst coating on the latter.

It can be seen then, that the production of the film requires several operations which include the mixing and synthesising of the necessary chemicals, the coating of positive and negative film and paper, the construction and filling of reagent pods, the cutting of paper and film into the required sizes and the final assembly, spooling and packing of the complete picture rolls.
Several types of film are now in production and they are made in two sizes:

Series 3 for the smaller Highlander Camera consists of:
- Type 31 - orthochromatic film
- Type 32 - panchromatic film

Series 4 for the larger Speedliner Camera consists of:
- Type 41 - orthochromatic film
- Type 42 - panchromatic film
- Type 43 - fast professional pan film
- Type 44 - very fast pan film
- Type 46 - projection film transparencies

The manufacture of these various types of film can be divided into two production operations together with the necessary warehousing of materials before, during and after operations. The film production flow chart on the following page describes the relationship of the various operations, and their physical requirements are set out in the following section.
(A) PROCESSING

1. Storage
   - Chemicals Mixing for Positive Film Coating
   - First Coating
     - Second Coating
   - Storage
   - Slitting
     - Storage

2. Storage
   - Masking Paper Coating
   - First Coating
     - Second Coating
   - Storage
   - Slitting
     - Storage

3. Storage
   - Developer Pod Solution
   - Slitting
     - Storage
   - Inspection
     - Storage
   - Pod Making
     - Storage

4. Storage

(B) ASSEMBLY

Positive Film Assembly - Sandwiching, Punching etc.

Negative Film Cutting

- Storage
  - Negative Film Spooling
    - Storage

Positive and Negative Film Splicing, Sealing, Wrapping, Boxing, Overwrapping

- Storage
  - Shipping
MANUFACTURING REQUIREMENTS
The following production requirements are necessary for present needs, with a reasonable allowance for expansion within the present production layout. It is anticipated that large increases in production will be met by duplication of the plant. Considerable internal flexibility of space is desirable for all operations, as continuous improvements are being made in production methods, with resulting changes in layout.

(a) Processing.
The area required for this operation is 30,000 sq. ft. The mixing, coating and slitting machines used, are not large and vibration and noise are not serious problems. A ceiling height of 12'-0" and a general floor loading of 200 pounds per sq. ft. are adequate. The raw materials used consist of chemicals and paper which are inflammable and explosive. It is therefore necessary to provide a fire-proof structure and one which is adequately vented against explosion. A high degree of temperature and humidity control is important in order to avoid expansion and contraction of paper during processing. Dust should be entirely eliminated from the atmosphere as it is particularly injurious to film during the coating processes. Due to the number of different types of film produced in batches, flexibility of space for storage between operations and for change over of machinery is necessary. Services to machines, which include the supply of electrical power, compressed air, vacuum lines, water and drainage should be laid out to achieve a maximum flexibility of machine arrangement within the processing area.
(b) **Assembly.**
The area required for this operation is 50,000 sq. ft. Separate assembly lines for Type 3 and Type 4 film are used and four negative spooler dark rooms each approximately 150 sq. ft. in area are required near the end of each assembly line. The machine sizes for sandwiching, wrapping and splicing of the film are not available, but floor loading and ceiling height requirements are similar to those required for the processing operations. Many of the machines in this area are noisy with a general noise level of around 70 decibels. Although there is no danger of explosion in the assembly area, the fire danger is considerable as the materials handled are very inflammable. Control of atmospheric dust is important and constant temperature and humidity within a five per cent maximum variation is necessary to enable the photographic materials to pass through the machines without buckling. A comprehensive system of services to machines, similar to that required for the processing area is necessary.

(c) **Warehousing.**
A total area of 40,000 sq. ft. is required for the storage of incoming materials, finished goods and to a lesser extent for goods-in-process. Most of the goods, with the exception of bulk chemicals are made up in variously sized small packages. These goods are palletised and stored and handled by lift-trucks. It has been found that a 3'-0" x 4'-0" pallet is most convenient for this purpose. A comparison of economies of stacking arrangements using this size pallet is shown on page 45. A 12'-0" stacking height is required, necessitating a 13'-0" clear ceiling height in the warehouse area.
Most of the goods handled are paper products and are subject to breakability and crushability as well as damage by moisture. Thus closed loading and unloading docks are required and complete temperature and humidity control of the warehouse area is necessary in order to provide time for the paper to adjust to the environment before processing, and to keep it in a constant condition during and after manufacture. In order to avoid deterioration of film emulsion, finished film storage must be refrigerated. Most storage of goods-in-process occurs between the processing and assembly operations, where batches of processed film await their turn on the assembly lines. Temporary storage between individual machine operations, is handled within the areas allocated to processing and assembly. The bulk chemicals which are of an explosive nature, are stored in underground tanks adjacent to the processing area. The tanks should be accessible for filling, but should be situated away from the inhabited areas of the site.

The approximate areas required for the storage and handling of goods are as follows:

- Loading and unloading docks 6,000 sq. ft.
- Despatch and receiving office 500 sq. ft.
- Incoming goods storage 14,000 sq. ft.
- Goods-in-process storage 10,000 sq. ft.
- Outgoing goods (refrigerated) storage 8,500 sq. ft.
- Waste paper storage 1,000 sq. ft.
In the upper drawing, the area of 90 × 36 feet permits the use of 9-foot aisles and the placement of 108 3 × 4 foot pallets on the floor, when the pallets are arranged so that the greater dimension faces the order picker (the aisle). In the lower sketch it will be seen that the area has 10-foot aisles, but that with the smaller dimension of the pallet facing the aisle, 120 pallets of the 3 × 4 foot size are accommodated on the floor. As a result:

<table>
<thead>
<tr>
<th></th>
<th>Upper Drawing</th>
<th>Lower Drawing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of square feet in the area</td>
<td>3,240</td>
<td>3,240</td>
</tr>
<tr>
<td>Area of the aisles, feet</td>
<td>1,944</td>
<td>1,800</td>
</tr>
<tr>
<td>Percent of total</td>
<td>60</td>
<td>55.5</td>
</tr>
<tr>
<td>Area covered by the pallets, feet</td>
<td>1,296</td>
<td>1,440</td>
</tr>
<tr>
<td>Percent of total</td>
<td>40</td>
<td>44.5</td>
</tr>
<tr>
<td>Pallets accommodated</td>
<td>108</td>
<td>120</td>
</tr>
<tr>
<td>Aisle width, feet</td>
<td>9</td>
<td>10</td>
</tr>
<tr>
<td>Number of aisles</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td>Aisle length, feet</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Length of the order picker's walk, feet</td>
<td>292</td>
<td>252</td>
</tr>
</tbody>
</table>

COMPARISON OF ECONOMIES OF STACKING LAYOUT
SERVICE REQUIREMENTS
The ancillary services necessary for the smooth running of the manufacturing process are divided into three groups.

(a) Offices.

Office space is required for:-

- Plant manager 200 sq. ft.
- Assistant manager 200 sq. ft.
- Two managers' secretaries 200 sq. ft.
- Personnel interview and employment office 150 sq. ft.
- Receptionist - telephonist 100 sq. ft.

All the above offices are best located away from the processing and assembly areas, but near to the visitor's entrance. It is desirable that the manager and assistant manager have private toilet facilities.

Other offices required are:-

- Despatch and receiving office located adjacent to loading docks 500 sq. ft.
- Ten plant engineers', supervisors' and secretarial offices adjacent to the processing and assembly areas. 150 sq. ft. each
- Quality control department with two offices, dark room and refrigerated storage room. 2,500 sq. ft.

(b) Staff Amenities.

The following amenities for the manufacturing staff of 300 were thought desirable by the Polaroid Corporation.

- A cafeteria-type dining room with kitchen equipped to serve full meals to one half the staff at a sitting.
- A staff lounge.
- A separate games room.
- A classroom equipped with projection equipment.
Toilets and locker rooms for 220 men.
Toilets, locker and rest rooms for 120 women.
First-aid center.
Outdoor recreation space, which would include a ball field.
Outdoor parking space for approximately 200 cars.

Morning and afternoon tea breaks as well as full lunches are taken in the dining room, so that it is necessary that the latter be closely related to all the manufacturing spaces in order to cut down on walking time.

The basic layout of dining room, kitchen and serving facilities for approximately 160 persons is predicated on the following information, based on two sources. *

A comparison of various seating arrangements shown on the next page, indicates that a diagonally spaced table system seating four persons per table, provides a good compromise between compact and extravagant seating. The area occupied is approximately 10 sq. ft. per seat, giving a total area required of 1,600 sq. ft. The length of servery counter varies with the type of food and size of the menu, but a good average is 1'-0" for every six diners.

The size of the kitchen for the service of two meals may be based on 5 sq. ft. each for the number of diners at one sitting, plus 50 per cent allowance for the second sitting. The total area of kitchen required is therefore 1,200 sq. ft.

The space requirements for alternative canteen seating arrangements.
Toilets and locker rooms can be located either in separate small groups near the working spaces or in one unit adjacent to the entrance and other facilities. It is considered that the latter location is more desirable providing the plant is designed in such a way that the toilets and locker rooms are easily reached from the working areas. Lockers for all personnel and toilet accommodations at the rate of 1 w.c. and 1 urinal for every 25 males and 1 w.c. for every 15 females are provided. A first-aid center for the treatment of injuries received during working hours is to be provided. It should contain a waiting room, two changing cubicles, examination room, office, dispensary and store. It is customary to staff such centers with a full-time nurse to deal with minor casualties, arrangements being made with a local practitioner for the treatment of more serious injuries.

(c) Plant Services.
The manufacturing processes require that essentially the whole of the manufacturing and warehouse area be fully air-conditioned to maintain a constant temperature and humidity. It seems reasonable then, that the small additional area taken up by offices and employees amenities be included in the air-conditioning system, if this can be done at little extra cost.

The area required for the air-conditioning room is 3,500 sq. ft. In addition there will be a boiler and mechanical equipment room of about 4,000 sq. ft. in area. As well as boilers and heat exchangers for space heating, the room will include compressors and pumps for compressed air and vacuum supply to the manufacturing areas. Both these rooms should be located centrally within the plant to reduce the length of supply lines to manufacturing areas.
The extensive system of power, water and drainage supply, in addition to air-conditioning requirements indicates that space occupying service supplies will be considerable. It therefore seems necessary to create service space as an integral part of the design, consideration being given to the flexibility of the space and the accessibility to supply lines for repairs etc.

In addition to the above services, it will be necessary to provide space for:

- A plant maintenance shop about 2,500 sq. ft.
- Electric switch room 1,000 sq. ft.
- Telephone equipment room 500 sq. ft.

These are in addition to the usual cleaners cupboards etc.
STRUCTURAL REQUIREMENTS
The choice of the right structural shape and materials for one given problem is generally based on some or all of these factors.

(a) The site, including the topography, nature of the subsoil, area to be built on, the value of the land and the possibilities for future expansion.

(b) The production requirements, which include the required floor loadings, optimum bay spaces and manufacturing spaces and the type of product flow (vertical or horizontal).

(c) The service requirements of spaces, power supply including lighting, heat transmission etc.

(d) Maintenance of the plant.

For the plant under consideration the way the above factors influence the choice of structure is discussed below.

The shape and size of the site in relation to the size of the plant indicates that the latter will be of more than one floor. The hard bed rock close below the surface will support a tall structure and will have sufficient bearing capacity to take the load from columns at widely spaced intervals.

The production requirements are very flexible, but the minimum bay space for the manufacturing and warehouse areas is 25'-0" x 25'-0". However it is desired that larger spans be used, particularly in the manufacturing areas. Floor loadings as previously stated are of the order of 200 pounds per sq. ft.

The air-conditioning and heating requirements indicate that the building should be as compact as possible, with insulated roof and walls and a minimum of windows.

The structure should be of fire resisting materials as the fire risk is considerable.
In the process area where explosion may occur, the main structure should be rigid, but the skin should be constructed so as to give way easily and quickly under pressure from within in accordance with the requirements of the next section. From the point of view of maintenance, materials which are corrosion resistant and which do not need painting are indicated.

From the above considerations it can be seen that a primary structure of concrete would be very suitable. Large, clear spaces are indicated for most areas, providing space frames or shell construction can be used to span these spaces economically. Concrete is generally not as economical as steel for industrial buildings in this country, but providing maximum use is made of precast units, the costs could become comparable. Generally, walls and roof will have to be of heavy materials to provide insulation and precast concrete units seem most suitable for this purpose. The exceptions to this are the blow-out walls of the process area, which must have very little inertia and hence should be of light timber or steel-panel construction.
LEGAL REQUIREMENTS
Generally the detailed laws and requirements relating to the construction of buildings are not appropriate for inclusion in this thesis, but a summary is given below of the pertinent requirements of the National Fire Prevention Association relating to exits from factory buildings and the explosion venting of buildings.


For general industrial occupancy there must be at least two exits per floor, as far removed from each other as possible. No person should have to travel more than 100 ft. to the nearest exit, except in the case of sprinklered buildings where the distance is 150 ft. From every point it must be possible to reach two exits by separate paths, except that the first 50 ft. of travel may be along a common path. Rooms with less than 25 people may have a single exit providing that the distance of travel is not more than 50 ft. All exit stairs, elevator shafts and other vertical openings shall be fire enclosed with material having a two hour fire rating. Exit stairs shall be a minimum of 44" in width and all exits shall be measured in units of 22", each unit having a capacity of 45 persons per minute. The maximum height of stair risers shall be 7\(\frac{3}{4}\)" and the minimum width shall be 9", no winding stairs are allowed and the minimum number of treads in a flight shall be three. Ground floor exits shall be wide enough to provide one exit unit for every 100 persons on the ground floor and one and a half units for every two units of stairs from upper floors.

For high hazard industrial occupancy (the process area), the requirements are the same as above except for the following.
There must be at least two exits from every room. The maximum distance of travel to the nearest exit must not exceed 75 ft. and an automatic sprinkler system or other means of protection must be provided.

( b ) Guide for Explosion Venting. N.F.P.A. No. 68.
The purpose of providing explosion venting in the walls or roof of a restricted area which is liable to explosion is to reduce the destructive effects of the blast. When an explosion occurs, the rate of pressure and temperature rise is very rapid. It is necessary to provide openings of sufficient area to relieve the explosion pressure as it builds up. The maximum explosion pressure decreases as the unit area of the openings increases, in the manner shown in the diagram on page 55. The diagram is the result of laboratory test explosions and recommended vent ratios have been modified according to practical experience giving the following values.

For large rooms or buildings over 25,000 cu. ft. containing hazardous equipment and enclosed by heavy reinforced concrete walls the ratio is 1 sq. ft. per 80 cu. ft. of volume.

When enclosed by light concrete or brick walls the ratio is 1 sq. ft. per 60-80 cu. ft. of volume and for light weight construction the ratio is 1 sq. ft. per 50-60 cu. ft. of volume.

These ratios apply to unrestricted vents.

However in practice, vents must be closed in order to protect the building from the weather or from unauthorised entry. Providing the closures are constructed of light paper or of light weight hinged panels that will swing outwards under any increase of pressure from within, they do not effect the internal pressure to any serious degree.
HUMAN REQUIREMENTS

"Sensory unpleasantness created by ugly form, color, feel, noises, temperature or smoke are so many obstacles on the road to our destination."

Raymond Loewy.
The main human requirements already briefly discussed, are those which concern man's comfort and freedom from fatigue in relation to his environment. They include the physical factors of noise, light, color, temperature, air-bourne irritants, the relationship of man and machine, size of the working space etc. Of these factors, the relationship of man and machine is not pertinent to this discussion and the problems of temperature and air-bourne irritants are automatically solved by the manufacturing requirements, which in this instance conveniently coincide with human requirements. The other problems are discussed singly below.

(a) Noise.
The problem of noise is a complex one, in that standards based on noise levels will not necessarily produce a satisfactory environment. The nature and frequency of the sound, whether it is continuous or intermittent etc. has a lot to do with human comfort. The loudest or most annoying noises are not always the most distracting and noises can be extremely irritating and still not effect a worker's health or efficiency. The first problem in noise control is to secure workers from hearing impairment due to excessive noise. Damage risk noise levels vary from 90 decibels to 120 decibels depending on the type and frequency of the noise. The noisiest machines in this plant, situated in the assembly area, produce an overall noise level of about 70 decibels and thus there is no likelihood of auditory damage. There remains the second problem of speech interference. The maximum speech interference level varies with the degree of communication efficiency required and in a factory where the normal level of speech is around 74 decibels, a background noise of 70
decibels can be tolerated, as continuous communication between workers is not a necessary part of their job. However, in offices adjacent to the assembly area, where telephoning etc. is a part of the job, it will be necessary to reduce the background noise level to around 35 decibels by the use of insulating partitions.

(b) Light
Adequate lighting in manufacturing plants is one of the most important requirements for human comfort. It is generally regarded that natural lighting, supplemented by artificial lighting produces the most pleasant environment from a physiological and psychological point of view. However, in plants such as this, where strict air-conditioning becomes a major factor, the amount of glass area must be reduced to a minimum. Thus, main reliance must be placed on artificial lighting, with a minimum of windows to satisfy human psychological requirements. Such openings as there are should be placed at, or above eye level, so that the people inside can get an impression of the surrounding outside conditions. The problem of light contrast comes in here; continuous unshaded strip windows are bad, especially on a sunny day, as brightness and glare from such strips is extremely distracting. Variation in lighting is also important and large glass areas opening onto pleasant landscaped gardens adjacent to the amenities and dining area, will provide a welcome variation from the controlled environment of the working spaces.

The optimum standards of illumination intensity for various tasks have been tabulated on numerous occasions and will not be repeated here, as detailed lighting design will not be carried out.
(c) Color.
As important as adequate standards of illumination are the effects of color and texture of surfaces in the immediate vicinity of the working environment. Color controls contrast and also effects human moods through mental and direct associations. It also plays an important role in the field of safety and identification, with consequent decrease in the likelihood of accidents and increase in efficiency of servicing and controls. Tabulated below is a summary of a color safety code used in the U.S. Navy shore installations and in many civilian plants. Also tabulated are colors for pipeline identification and the effects of color on mood.

### COLOR SAFETY CODE

<table>
<thead>
<tr>
<th>Color</th>
<th>Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yellow or Yellow and Black Bands</td>
<td>Used for hazards which the worker might strike against, fall into, or trip upon, such as low beams, stairways, edges of platforms. Since both colors are clearly visible, they can be used for marking aisles wherever motorized materials-handling equipment constitutes a danger to workers.</td>
</tr>
<tr>
<td>Orange or Chinese Red</td>
<td>For most dangerous hazards that can do serious bodily harm to a worker, such as electrical fuse box covers, crushing or cutting edges. Also useful on emergency switches.</td>
</tr>
<tr>
<td>Green</td>
<td>Associated with safety, and therefore used on emergency showers, first-aid room entrances, first-aid equipment cabinets, stretchers. A white cross is often superimposed on green</td>
</tr>
</tbody>
</table>
Blue Generally used on tags or signs which indicate something is out of order, or should not be moved.
Red Marks fire protection devices.
White Used for traffic control, to indicate traffic direction (via arrows), and to call attention to waste receptacles.

COLOR FOR PIPE LINE IDENTIFICATION

Yellow or Orange Dangerous materials, such as acids, gases, steam.
Blue Protective materials, such as fluids used to combat dangerous materials.
Red Fire protection equipment such as sprinkler systems.
Purple Very costly materials, or things of special value.
Others Safe materials.

EFFECTS OF COLOR ON MOOD

Red, Yellow, Orange As a group, these three create feelings of warmth and mild stimulation.
Red While exciting, it can have such negative effects as nervous tension, restlessness. It causes the individual to overestimate time, and weights. It is best used in modified rather than pure forms.
Orange Effect like that of red.
Yellow A cheerful color, with fewer negative effects than red or orange. Best used in modified or pastel form. Neutral.
Yellow-Green Restful, cool, relaxing, they generally reduce tension.
Greens and Blues Most useful for stationary and mental task areas.
Blue

Exactly opposite effects on human mood from red. Best used in modified forms when large areas are being covered.

Dark Colors

Therapists report these as neutral, but industrial experts consider them negative, depressing.

White

Effect ranges from neutral to positive. Easily dirtied, it also causes glare.

(d) The Working Space.

It is desirable that the size of the working space should be considered in relation to the workers as well as in relation to the production process. Many processes require very large unrestricted spaces where many hundreds of employees are working. In order to relate these spaces to human scale, they should be restricted either visually or by separation of functions so that each individual can relate to his environment, see himself as part of a group of workers and thus have the opportunity to feel he plays a significant part in the manufacturing process. Where there are more than one independant parallel production lines for example, they may be separated by service or circulation spaces, without sacrificing flexibility of layout to any great degree. As in all architecture, care must be taken in relating these individual spaces to create a unified whole. The breaking up of a unified production area into spaces that are not well ordered may create chaos worse than that it was intended to overcome.
BIBLIOGRAPHY


Space, Time and Architecture. S. Giedion.


Technics and Civilisation. Lewis Mumford.


Practical Plant Layout. (1955) Muther.


Chemical Engineering Plant Design. (1942)

N.F.P.A. Fire Codes. (1956)


AN INDUSTRIAL PLANT
FOR THE
POLAROID CORPORATION

A THESIS FOR THE DEGREE OF MASTER IN ARCHITECTURE
JOHN N. MORPHETT  M.I.T.  SEPTEMBER 1957

VIEW FROM NORTH EAST

SITE PLAN
SCALE 1/2000

MAIN STREET

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