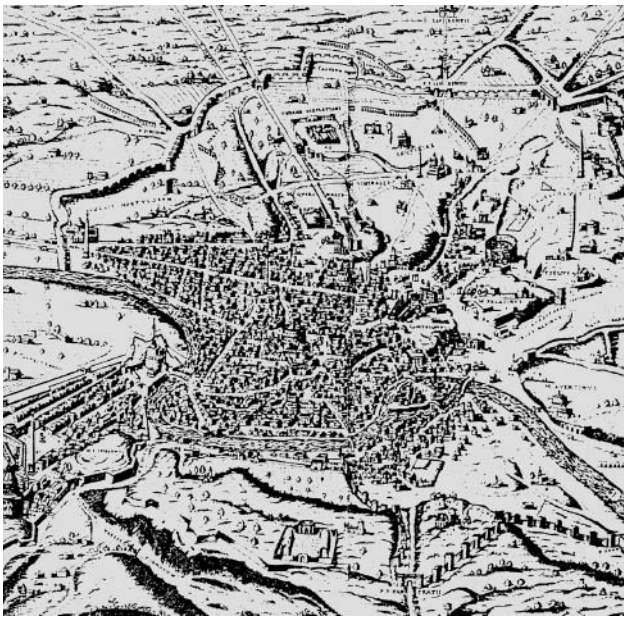
Edition Axel Menges GmbH
Esslinger Straße 24
D-70736 Stuttgart-Fellbach
tel. +49-711-5747 59
fax +49-711-5747 84



Frei Otto
Occupying and Connecting
112 pp. with 343 illus. in b&w, 161,5x222 mm, soft-cover, English
ISBN 978-3-932565-11-3
Euro 24.00, sfr 34.50, £ 19.90, US$ 36.00, $A 39.00

Cities, estates and routing systems develop, change constantly and fundamentally cannot be planned. Claims to ownership, land and building regulations, planning decisions and political interventions make it difficult for settlement structures to adapt to constantly changing requirements to such an extent that meaningful and totally ecological use of the surface of the earth is becoming increasingly difficult, although new techniques and flexible planning models mean that a connection could be found with the self-designing processes of urban-development history.

Plants are anchored in their location on the face of the earth, animals and human beings have mobile territory and encampments that become static with increasing density. Human settlements are organisms, but they are not hereditarily anchored in their form like corals, sponges or beehives. They often grow and shrink at the same time. Their form can almost never be called chaotic. Typical self-formation processes lead to astonishing genetic optimization in the course of time. Processes of change have become so rapid today that current urban-planning theories have been overtaken.

But high effectiveness of self-created, in other words unplanned settlements in terms of energy and biology is totally achievable today in »natural« town and transport planning and leads to ecologically meaningful solutions that are also full of beauty.

The study was written in the context of special research into »natural constructions« by the Deutsche Forschungsgemeinschaft, and has hitherto been available only in German and as a working paper for circulation between those involved in the research project.

Frei Otto is one of the 20th-century's most important architectural visionaries. Although at a first glance his buildings like the German Pavilion for the 1967 World Fair in Montreal, designed with Rolf Gutbrod, the roofs for the Olympic buildings in Munich designed by Günter Behnisch or the project developed with Christoph Ingenhoven for a new main station in Stuttgart seem to be in the tradition only of the great constructors of this century like Felix Candela or Pier Luigi Nervi, his work goes way beyond mere construction. He is a technician, artist and philosopher in one, and his central concern is for a new and all-embracing link with nature in building.

2nd, unrevised edition

Distributors

Brockhaus Commission
Kreidlerstraße 9
D-70806 Kornwestheim
Germany
tel. +49-7154-1327-33
fax +49-7154-1327-13
menges@brocom.de

Buchzentrum AG
Industriestraße Ost 10
CH-4614 Hägendorf
tel. +41-062 209 26 26
fax +41-062 209 26 27
kundendienst@buchzentrum.ch

Gazelle Book Services
White Cross Mills
Hightown
Lancaster LA1 4XS
United Kingdom
tel. +44-1524-68765
fax +44-1524-63232
sales@gazellebooks.co.uk

National Book Network
15200 NBN Way
Blue Ridge Summit, PA 17214
USA
tel. +1-800-4626420
fax +1-800-3384550
custserv@nbnbooks.com

DA Information Services
648 Whitehorse Road
Mitcham, VIC 3132
Australia
tel. +61-3-9210 7859
fax +61-2-8778 7788
books@dadirect.com

Cities, estates and routing systems develop, change constantly and fundamentally cannot be planned. Claims to ownership, land and building regulations, planning decisions and political interventions make it difficult for settlement structures to adapt to constantly changing requirements to such an extent that meaningful and totally ecological use of the surface of the earth is becoming increasingly difficult, although new techniques and flexible planning models mean that a connection could be found with the self-designing processes of urban-development history.

Plants are anchored in their location on the face of the earth, animals and human beings have mobile territory and encampments that become static with increasing density. Human settlements are organisms, but they are not hereditarily anchored in their form like corals, sponges or beehives. They often grow and shrink at the same time. Their form can almost never be called chaotic. Typical self-formation processes lead to astonishing genetic optimization in the course of time. Processes of change have become so rapid today that current urban-planning theories have been overtaken.

But high effectiveness of self-created, in other words unplanned settlements in terms of energy and biology is totally achievable today in »natural« town and transport planning and leads to ecologically meaningful solutions that are also full of beauty.

The study was written in the context of special research »Natural Constructions« by the Deutsche Forschungsgemeinschaft, and has hitherto been available only in German and as a working paper for circulation between those involved in the research project.

Frei Otto is one of the 20th-century's most important architectural visionaries. Although at a first glance his buildings like the German Pavilion for the 1967 World Fair in Montreal, designed with Rolf Gutbrod, the roofs for the Olympic buildings in Munich designed by Günter Behnisch or the project developed with Christoph Ingenhoven for a new main station in Stuttgart seem to be in the tradition only of the great constructors of this century like Felix Candela or Pier Luigi Nervi, his work goes way beyond mere construction. He is a technician, artist and philosopher in one, and his central concern is for a new and all-embracing link with nature in building.

24.00 Euro
34.50 sfr
19.90 £
36.00 US $
39.00 $A

ISBN 978-3-932565-11-3

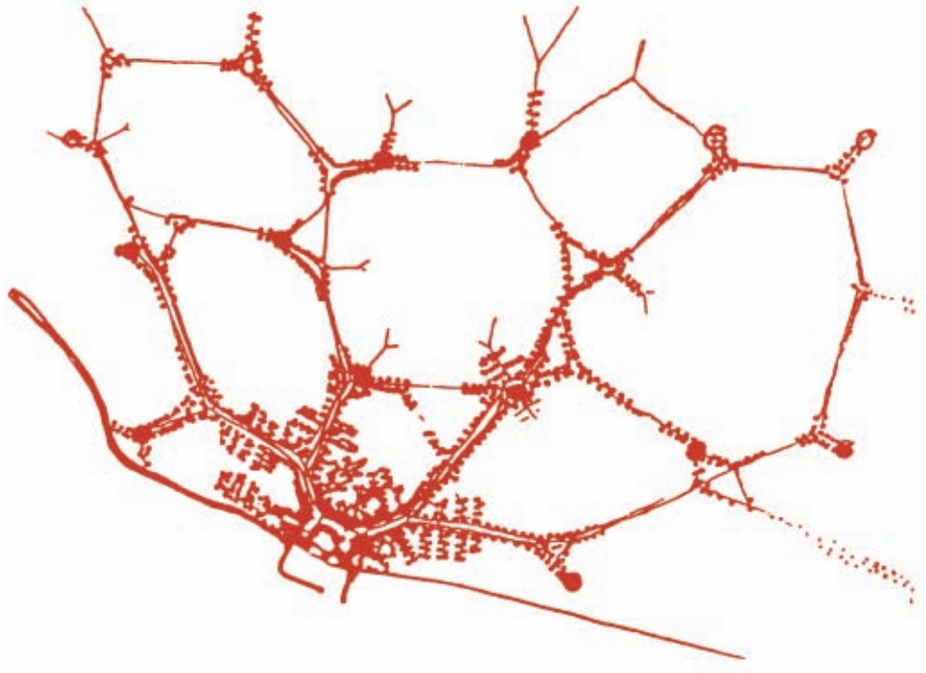
9 783932 565113 53600

Frei Otto **Occupying and Connecting** Menges

Frei Otto

Occupying and Connecting

Thoughts on Territories and Spheres of Influence with Particular Reference to Human Settlement



Edited by
Berthold Burkhardt

Frei Otto

Occupying and Connecting

Thoughts on Territories and Spheres of Influence with Particular Reference to Human Settlement

Edition Axel Menges

ISBN 978-3-932565-11-3

Printing and binding: Everbest Printing Co., Ltd., China

Translation into English: Michael Robinson
Editing: Nora Krehl-von Mühlendahl
Design: Axel Menges
Layout: Helga Danz

Contents

Introduction

Investigating »minimal pathways« was one of the first research subjects for the Institut für leichte Flächentragwerke at the Technische Hochschule in Stuttgart, newly founded in 1964. It was a subject I had already studied at the Entwicklungsstätte für Leichtbau in Berlin.

These experiments and numerous ways of generating minimal pathways – the shortest route between two random points – were published in the first little volume published in German and English, by the institute, *IL 1*. This interest in minimal pathways and minimal surfaces was initiated not least by interdisciplinary contacts with the geodetist Klaus Linkwitz in Stuttgart and the mathematician Stefan Hildebrand in Bonn.

Application-related research work on nets in nature and technology and on lattice shells followed as part of the special research on »Weitgespannte Flächentragwerke« (Wide-span two-dimensional frameworks; 1970 to 1985). The next special research project »Natürliche Konstruktionen« (Natural structures) at the universities of Stuttgart and Tübingen was devoted to the fundamentals of light-weight construction in nature and technology, continuously accompanied academically and stimulatingly by the Berlin biologist and anthropologist Johann Gerhard Helmcke. The special research projects of the DFG, the Deutsche Forschungsgemeinschaft (German Research Foundation), called into being in 1968 by the geneticist Helmut Baitsch and the then DFG president Heinz Maier-Leibnitz gave academics from different disciplines the chance to conduct joint basic research across subject areas. They are and were the actual predecessors of today's excellence initiatives, embedded in the structure of research and teaching in German universities at that time.

Of course housing estate construction and urban development were essential components in the special field of »Natürliche Konstruktionen« (Natural structures).

Two Stuttgart university institutions worked together on this sub-theme, the Institut für leichte Flächentragwerke and Klaus Humpert's Institut für Städtebau.

As is often the case in interdisciplinary research projects, relatively long lead times were often needed for various reasons. Different specialist languages, working methods and ways of thinking have to be understood by the partners, accepted or even adapted. Even while a special research project was still running it was possible for the IL and the town planning institute to publish important working approaches and results, above all a work by Eda Schaur on the subject of unplanned housing estates.

The present work on the history, origins, function and changes in housing estates and their connection may be seen as the beginning of a new way of looking at town planning as a field.

Knowledge of the self-perpetuating processes of natural occupation of points, lines, areas and spaces would have to be a fundamental requirement of any town planning. It is quite clear that few planners are familiar with them. Planning means applying knowledge. Architecture and planned towns come into being by arranging familiar things. Researching the processes of occupying and connecting in nature and technology requires a fresh start, with observations, experiments and the development of explanatory models.

Nets, paths, connection, nodes and occupied areas run all through our natural and technical environment, creating and influencing it. Knowledge about occupying and connecting is thus one key to understanding historical and modern contexts. Leonhard Euler's solution to the problem of the »Sieben Brücken von Königsberg« (Seven bridges of Königsberg; 1736) was the first mathematical network model, and is just as topical today as current tasks facing urban development and transport and communication technology.

These statements should only be seen as an introduction to a very broad subject. They are intended to stimulate people to look even more closely then previously at the surface of our earth, with open eyes, in order to learn how to understand the processes that shape its form.

They could then perhaps also lead to new concepts for planning towns and housing that run less counter to nature as a result of conscious integration or of promoting self-education processes.

I dedicate this work to my comrades-in-arms Berthold Burkhardt (member of the research team since 1964), Klaus Humpert, Marek Kolodziejzyk, Ulrich Kull, Klaus Linkwitz and Eda Schaur. I would further like to thank Berthold Burkhardt for his help in implementing the work in its present form. I would also like to thank Michael Robinson for the translation, Nora Krehl-von Mühlendahl for the editorial work, Helga Danz for the layout, and Dorothea Duwe and Axel Menges for making the book part of the Edition Axel Menges publishing programme.

Frei Otto

Terms

Human beings and animals, but also plants all occupy surfaces, but also points (locations), lines and spaces. However, the elements of non-living nature of all kinds also spread across the most diverse surfaces. The occupation may be mobile, but may also be static, may be random and chaotic, unplanned and planned, planned and altered, improved or worsened, alienated or simply made more natural by self-constitution processes.

A *territory* is the living space and sphere of influence of animals, the *habitat* of plants (or rocks), the *situation* of fields, sites, farmland. For human beings, exterior and interior immediate surroundings, such as a house and a garden, play a significant role. Familiar ground and human spheres of influence, often known as *territories*, distance themselves. They strive to achieve the greatest possible intervening distance.

The closest proximity with which animals and humans can position themselves is largely dependent on the physical construction of their bodies. In the case of human beings, one speaks of a *private area* and *bodily contact*.

The root stocks of plants, the nests and colonies of animals and the houses of human beings, together with connecting paths, are the distinguishing marks and static elements of occupied surfaces.

The sphere of influence of individual human beings is mobile. Only a sleeping human being rests and occupies *his own portion* of the Earth's surface, *his property.* The most restricted form here, the bed, may sometimes only exist for a single night. The pretension of considering a part of the Earth's surface to be one's property is an *invention* of modern and recent human history.
In fact, ground being declared property often retards and hinders the processes of natural and peaceful occupation.

However, only a person familiar with these processes can engage in conflict limitation. Research into these processes supports the peaceful coexistence of human beings and nature.

Part A
Processes of occupation

The occupation of points, lines, surfaces, spaces

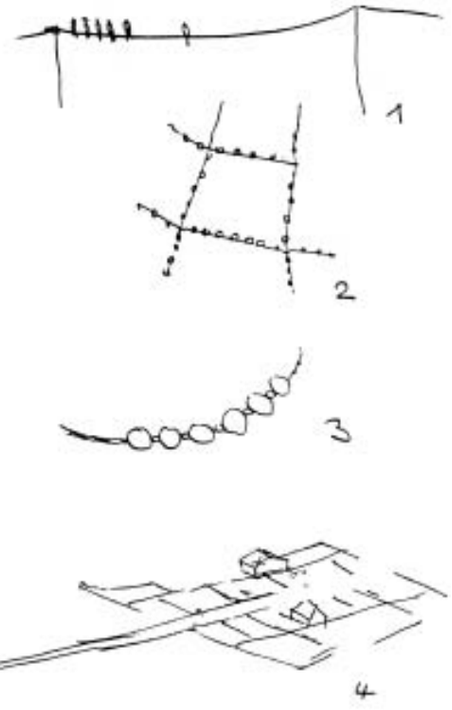
Occupying specific points

Free-standing trees and towers at a distance from other constructions statically occupy a location, a point. A single bird on a roof ridge, ready to fly away again – that is, a temporary presence – occupies a point. Occupying specific points may also imply distancing.

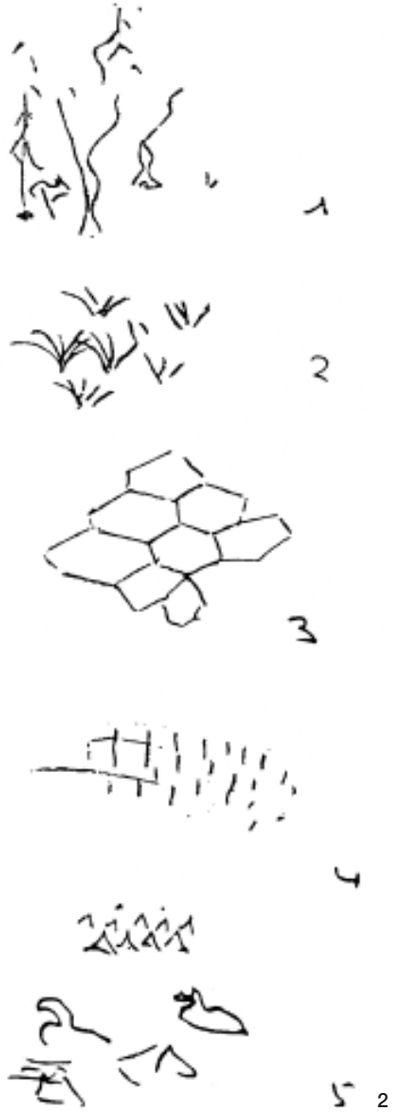
Linear occupation

Birds sit on a wire, close together (illus. 1.1) yet with a minimum interval between allowing them to launch immediately, or not to come too close to their neighbours. Glue beads and fog dew (illus. 1. 2) on spiderwebs arrange themselves on threads like strings of pearls (illus. 1.3).

Plots of ground occupy surfaces on roads (illus. 1.4). There are countless further examples.



1



2

Occupation of surfaces

Trees stand in a wood (illus. 2.1), green plants create a dense lawn (illus. 2.2), cells structure the surface of thin membranes in animals and plants (illus. 2.3), stones form the surface of paved streets and paths (illus. 2.4), hard mineral crystals striate sandpaper. Seagulls build their nests close together (illus. 2.5) with a minimum interval in between, in the same way as human beings occupy beaches and bathing areas.

Occupation of spaces

Countless occupations of three-dimensional space are recognizable, e. g. stars in space, flocks of birds and fishes, the water droplets in a cloud, molecules of aromatic substances in the air, molecules in crystals, sand grains in a sand pile, lights in Manhattan, to name but a few examples from living and non-living nature and technology.

Natural and technological occupations

Occupations belonging in the areas of non-living nature, living nature and technology can be distinguished. To a great extent, technology utilises occupation mechanisms from non-living nature and spontaneous physical or chemical processes. Geodesy or the division of the Earth's surface can be considered a planned, i. e. less natural occupation mechanism. The division of the Earth's surface into meridians and circles of latitude, for instance, is both artificial and at the same time useful.

Almost all natural occupations are subject to self-constituting principles of varying strength. This is especially clear in the »occupation« of an even surface by shrinkage cracks (in clay or glazes), which predominantly enclose hexagonal surfaces and whose key points, in an ideal situation, form a triangular pattern.

The occupation (structure) of the surfaces of leaves or insect wings and to a great extent the occupation of territories by animals and human beings can be placed in the same category.

Mobile and static occupations

Birds of prey have mobile territories, whose situation depends among other things on the population density, behaviour and incidence of their prey animals.

The same is true of many animals and also of human beings who hunt. The narrowest human territory is one's own private sphere. Like the entity it belongs to, it is mobile.

Firmly rooted plants have static habitats for the duration of this rooting. Due to drifting seeds or tendrils, they are mobile for the purposes of distribution, or territorial expansion. Animals which create dense or established colonies also occupy a part of the Earth's surface during the time they are resident.

In cities, paths and large houses reduce human mobility. Towns with a high degree of mobility can adapt their size and situation to deal with processes which accelerate, retard or even force the abandoning of an occupation.

The primordial and basic human settlement forms can be observed in particular in the spontaneous occupation of bathing areas and beaches by bathers, but also in trailer and tent cities in which no form of intervention by planning has taken place. It is clear that in these situations settlement structures with typical properties, details and forms develop which are common to different countries and cultures, and are not even greatly changed by climatic influences.

Random occupations

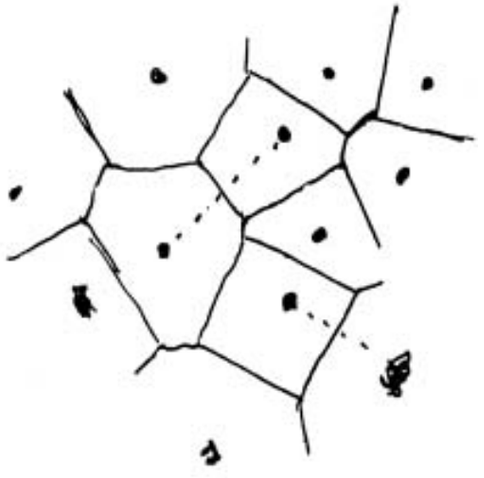
Occupation structures which show no principles of regulation whatsoever can be described as random or chaotic. However, there appear to be no occupation processes without principles of regulation. For the most part, their order is simply difficult to recognize, even where coincidences have had an effect.

The places where seeds carried by the wind land can be described as random. Only a few of the seeds germinate and take firm root in favourable habitats. Only a few plants grow to maturity. The elimination processes influence the occupation of the situation and the form of all surviving plants. Coincidence is regulated.

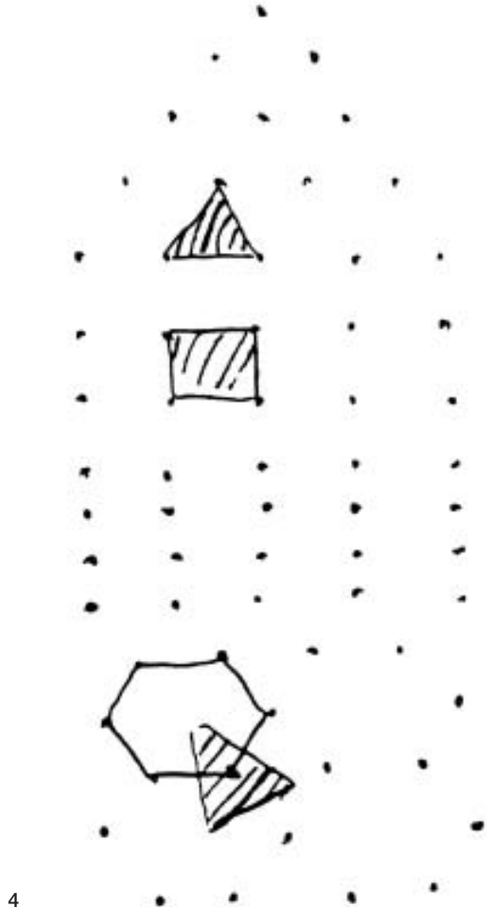
It is revealing to study random occupation systematically. A suggested experiment:

Allow a variety of objects to fall from a balcony on a clear day. The situation, form, size and density of the type of territories associated with such »random occupations« can be determined.

If, for instance, one demarcates the territory of an object by the perpendicular bisectors of the nearest points, it can easily be seen that the majority of these territories are hexagonal and border on six neighbours. Only in exceptional cases do pentagonal territories form, or the borders of four territories converge on a single point (illus. 3).



3



4

Planned occupations

The peculiar human drive towards order which enables humans to create structures using technological means and also to recognize, maintain and measure structures more easily, automatically leads to planned occupations.

The most familiar structures occupy surfaces with a 3-, 4- or 6-cornered grid, forming hexagonal, quadratic, rectangular, rhomboid or triangular territories (illus. 4). Every planning, whether of a road with boundary posts, division of plots of ground or the building of multi-storey structures, relies on a knowledge of the rules for one- to three dimensional occupations. In evaluating the results, it is in theory irrelevant what materials are used to plan the occupation. And yet the materials (T-square, curve template, optical instruments and computers, use of construction machinery, planting and harvesting instruments) do have an influence on the outcome.

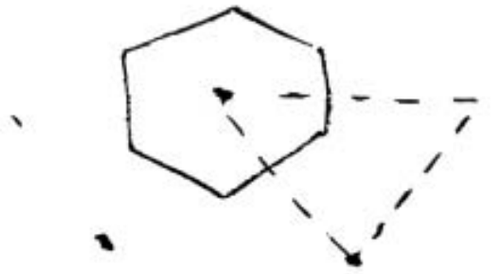
Distancing occupations

Objects which occupy points, lines, surfaces or spaces at the largest possible intervals are described as distancing occupations. This can be seen when, for instance, birds sit on pylons with the largest possible interval between them. The way lone predators mark out their territories is a typical distancing occupation process. However, hunters, trappers and village land/forest husbandry associations also have »territories« situated at the largest possible intervals (illus. 5,6).

5

The occupation structures have entirely typical forms, which will be described in detail later in this text.

Distancing occupations and processes which initiate or promote them are common in non-living nature and have many variations. Examples include the configuration of cracks in drying clay layers or in hardening rock. Thermal columns are also distributed over the Earth's surface in a distanced way. With grasses, trees, tall buildings and towers, which usually show distanced occupation on ground level as well, the third dimension starts to open up. Typical examples of three-dimensional occupations include birds' nests, many spider-webs and space frames for all kinds of high-rise buildings. Distancing occupations in three-dimensional space are also numerous.



6

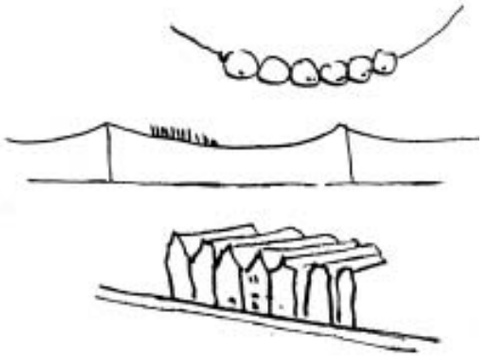
7

Molecules in gases and liquids move away from one another. In enclosed spaces, they take up positions as far away from each other as possible. This is shown especially clearly in the expansion of strongly fragrant substances. A similar procedure can be seen in the ice crystals of cirrus clouds. This is especially clear in the so-called anvil shape of a thundercloud, which, in contrast to the lower-lying cumulus clouds, drifts apart. The same can be observed in cirrus clouds and freezing contrails (illus. 7).

Attractive occupations

When objects which are mutually attractive to one another occupy lines, surfaces or spaces, this can be referred to as attractive occupation. Attractive occupation is characterised by the close proximity of the occupying elements.

Strings of pearls, birds flocking on cables and houses built close together along roads are typical representatives of attractive occupation of linear elements (illus. 8).



8

Attractive occupation of surfaces can be seen in throngs of people. The closest possible proximity is to be in bodily contact. Normal attractive occupation excludes private area.

Many animal species »huddle« together, creating dense occupations. Seagulls brood close together, but in such a way as not to endanger each other or to prevent a quick takeoff.

Seen from above, the herds formed by herd animals have rounded forms, which, even during rapid movement, maintain a minimal circumference and are reminiscent of drops of mercury rolling over rough terrain.

The same is true of flocks of birds and shoals of fish moving in space. Even during rapid movements, individuals maintain the closest possible proximity. The outlying flyers always press towards the centre. The flock has a boundary layer, although this is not necessarily distinct. The form of the flock seen as a whole is related formally not only to soap bubbles in the wind, but also to moving drops of oil floating in water (illus. 9).

9

As with a flat plane, there are many ways for three-dimensional »territories« to fit together in three-dimensional space. The most familiar involve the placing together of cubes or blocks. Their key points form a Cartesian grid network.

The closest configuration, creating the minimal surface area and placing the key points extremely close together, is assumed by soap bubbles of the same size. This is however a highly complicated configuration, in which every single bubble has a slightly different form. This is the structure of foam.

Such foam formations and structures with a high degree of order which are often described superficially as chaotic are shown and described in detail in the series of publications by the Institut für leichte Flächentragwerke (see p. 112, bibliography).

Occupations which are both attractive and distancing

Many occupation mechanisms show both kinds of occupation simultaneously. Gregarious birds such as starlings, sitting on an electrical cable, initially huddle together nervously, but also keep a certain distance, in order to be able to flee. Nesting gulls or settling people converge while keeping their distance (private area, individual territory). Perhaps one could include in this category of occupation stars drifting apart in outer space, which are however held together to form galaxies?

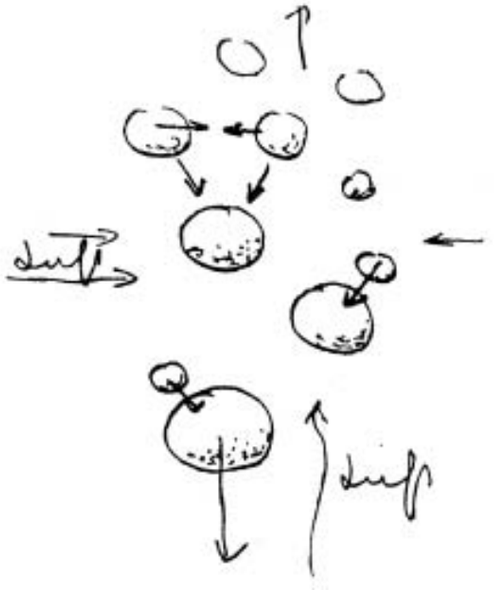
Animals or human beings hunting in groups keep together while at the same time occupying the largest possible hunting territories. Inhabited forest houses or colonists' homesteads occupy a surface in a way which is both attractive and distancing. The same is true of defensive castles, as well as agricultural villages with closely-packed houses.

Many examples can also be cited from the occupation of space taking place in terms of surface area, whether frost crystals, hairs, bushes, grasses, bamboo or trees.
Human beings build high-rise buildings in which people live closely packed together, or towers which allow antenna to transmit electromagnetic signals over a wide area.

Attractive and at the same time distancing occupations are also numerous in the third dimension. Molecules in gases and liquids distribute themselves at the maximum distance from one another. When absorption capacity (saturation) is reached, they combine to form densely-packed crystals and create solid bodies, which then occupy nearby objects of any form or float distanced from each other in space (air or water). The whole weather cycle is affected by attractive and distancing occupations playing out in three-dimensional space. Not only do areas of high and low pressure, and also localised thermals with simultaneous formation of a spiralling column of air, take up distancing/attractive positions on the earth's surface, but cloud formation, rain and snowfall processes are created or affected by distancing/attractive occupation processes. Water molecules distribute themselves in the air in a distancing way. When saturation is reached, water condenses around particles of solid substance which have also distributed themselves in space in a distanced way. These may be fine dust or rust particles (silver iodide crystals, the so-called rainmaker's substance, are extremely attractive to water particles). Extremely small water droplets, which initially float at a distance, form inert, flat mist with indistinct outlines. As the moisture level increases, the mist precipitates on the ground (wet fog), or rises with the air that has been warmed by condensation.

Water droplets floating in a high density are presumably attractive to each other in the same way as soap bubbles on water surfaces. The droplets become bigger, while the total surface area of the drops in relation to their volume becomes smaller. During this process, energy is released, and a horizontal air movement towards the centre of the cloud is created. The larger droplets do sink, but are drawn upwards by the warmed air. The upper side of the cumulus cloud has a sharp outline (illus. 10). Cumulus clouds normally reach unsaturated zones, where the external droplets evaporate, cooling in the process. Their molecules take up distancing positions again. The cloud loses its sharp outline, it becomes »tattered«, grows old, and »thaws out«, sometimes to the point that it disappears. When clouds rise to a great height, as with thunder clouds, they reach zones which are so cold that their water droplets abruptly freeze to form extremely fine ice crystals, which clearly and visibly tend away from each other, forming the »big hat« of the »anvil«, which often forms a cirrostratus cloud which covers the sky, but also frequently disappears.

Water droplets within the cloud become ever bigger in the up draft. If the speed with which the air is rising and the speed with which the ice particles are falling balances out for a time they may freeze to form hailstones, reaching abnormal size. Winter snow on the other hand is usually created when warm rain falls through a zone of cold air close to the ground. Dry snowflakes fall in a distanced way, wet snowflakes fall in clumps.



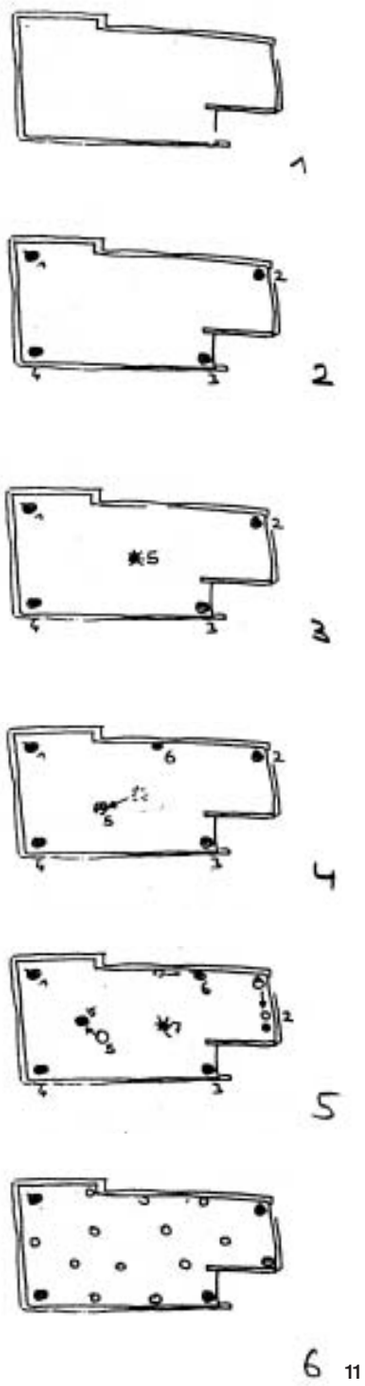
10

Distancing and attractive processes in the context of settlement and house construction

The preceding demonstrations will be expanded on, with further details and experimental plans in the field of distancing and attractive occupation.

On the distancing occupation of a surface

Example 1
When a restaurant is being occupied (illus. 11.1), the corners are preferred (illus. 11.2). The places along the walls or in the central area are only filled afterwards (illus. 11.3 and 4). As the room fills up, the shifting of chairs and tables can be observed as seating is moved (illus. 11..5). This ceases once the room is fully occupied (illus. 11.6). Occupation has temporarily become static, but only until chairs become free again.



11

Example 2
Distancing occupations can be empirically predicted or outlined relatively well. Positions at the furthest distance to each other (illus. 12 A) can be quickly identified (illus. 12 B).

However, in this example, the occupation of an island, occupant number 5 must remove himself when occupant number 6 arrives (illus. 12 C).

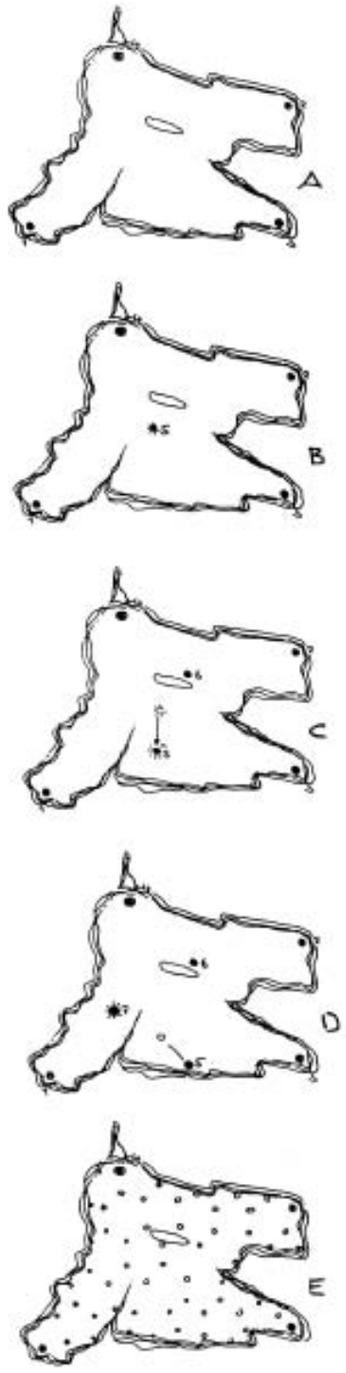
He must move again when occupant number 7 assumes his relatively stable position (illus. 12 D).

If further occupants are added, a pattern of occupation is formed which primarily depends on the form of the surface that can be occupied, and secondarily depends on the sequence of occupation (illus. 12E).

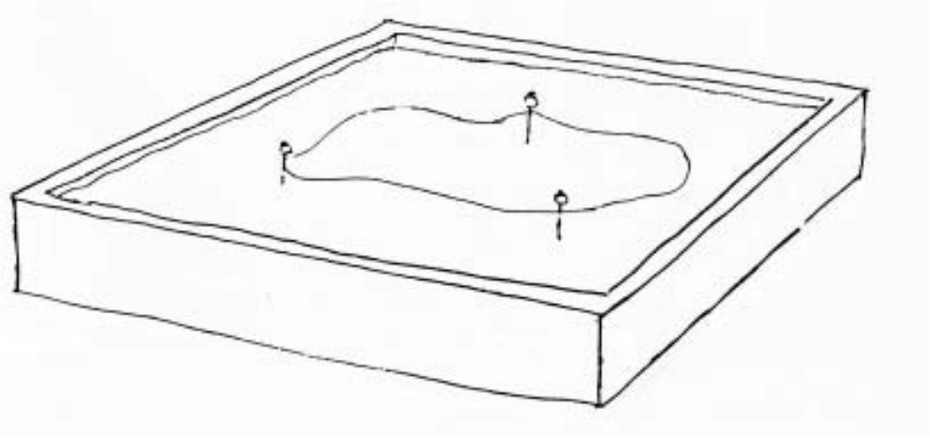
The sequence of occupation plays a larger role if migration of occupations is prevented or simply hindered.

As has already been mentioned, distancing occupations can frequently be observed in animals who maintain a distance from others and in people.

Studying the occupation of surfaces in field experiments is certainly a worthwhile exercise for behavioural studies, urban development and architecture. Cameras on the ceilings of tall meeting rooms and guest houses and on towers overlooking beaches and open air swimming pools and ongoing mapping of the territories of lone predatory animals all present opportunities for this. Logging the nests of bird species which settle in a distancing way in solitary trees and woodland in order to comprehend spatial settlement mechanisms in nature is particularly demanding, but no less informative.



12



13

The experimental apparatus

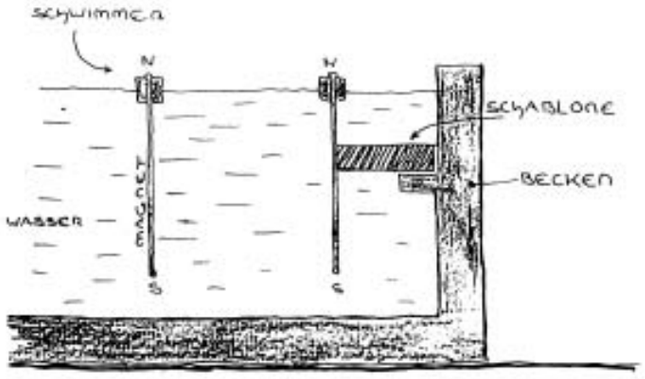
This device was developed by us to directly investigate distancing occupations. Small rod magnets float on water, each with the same pole uppermost (illus. 13). The magnets repel each other and move away from each other. They adopt a form of occupation which can be described as distancing (illus. 14).

Ordinary steel needles which have been passed over a permanent magnet and thereby magnetised are used. Small balls of polystyrene serve as buoys. Beneath the water, a template marks the surface which can be occupied. The best results are achieved when the template is approximately in the centre of the group of magnetised needles. The exactitude with which the distancing occupation establishes itself is remarkable.

Once they have reached their position, the magnets remain there as if held in place by invisible threads, even when violently disturbed. They can remain in this position for days.

The photos with which the experimental results are documented were taken using a very simple apparatus (illus. 15). It is best to cover the feet of the tripod in black so that they do not reflect in the water.

When making more detailed observations, it may be advisable to use the minimal path apparatus developed by the Institut für leichte Flächentragwerke (IL) as a recording apparatus.



14

15

So far, too few experiments using this apparatus have been able to be made. However, it appears to be universal. One can place any number of points, up to about a hundred, on any surface. In addition, varying the magnetic field strength can alter the distances, thereby increasing and reducing the associated territories. When carrying out the experiments, changes in field strength are very easily achieved by placing two or more needles on a buoy (illus. 16).

16

The experiments previously carried out with this simple apparatus do not as yet lead to a definite conclusion. It could be observed that when points were added, the whole movement system changed, unless the occupiable space had sharp corners. The so-called occupiers almost always remain in these corners.

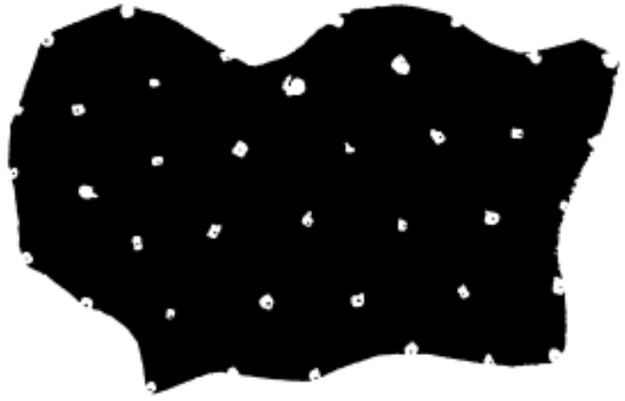
It can further be observed that as the number of points increases, they arrange themselves into a regular triangular grid, which however is usually disturbed at the edges by the boundaries of the surface (illus. 17). This disruption does not take place if the occupied space is triangular or hexagonal and the points are free to arrange themselves in a triangular grid.

Time exposure allows the migration of the points to be captured. When one or several points are added or removed, migration results.

The floating magnetic needles in a triangular frame (illus. 18) and in a rectangular frame (illus. 19) present their south poles uppermost. The needles in the water can be seen.

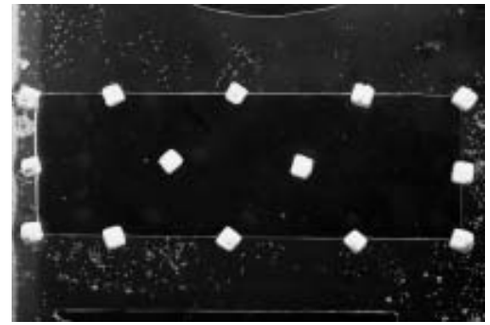
Experiments of this type were carried out in different frames with different numbers of points, with the power of the magnets remaining almost the same in each case:

Eight points in a triangular frame (illus. 20), 14, 17 and 19 points in a rectangular frame (illus. 21–23).



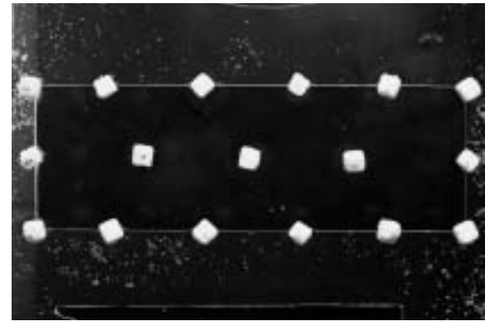
17

18

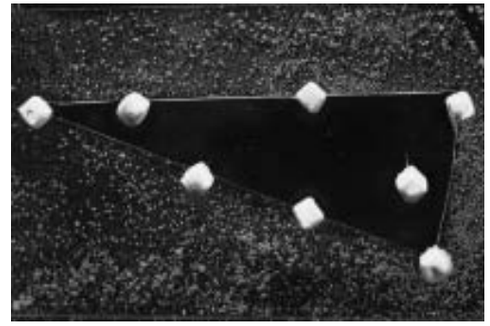


21

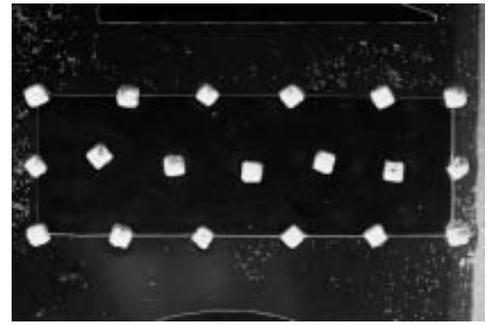
19



22



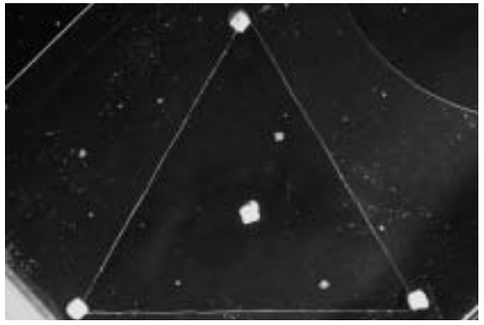
20



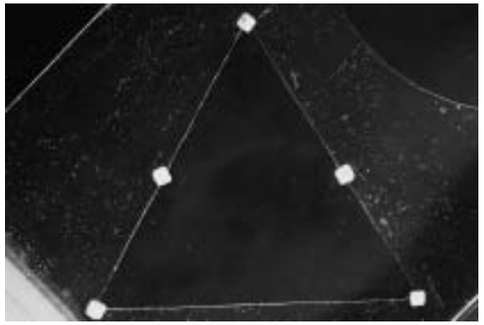
23

Distancing occupations with 4 to 20 points in a rectangular frame (illus. 24–35).

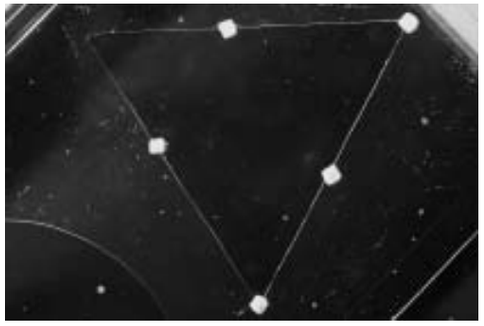
24



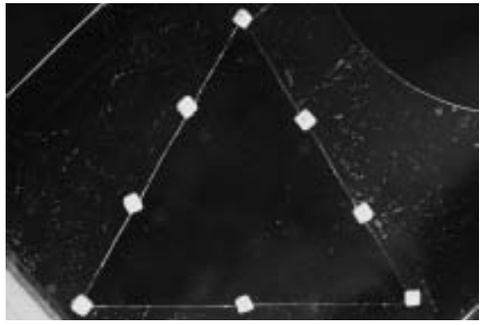
25



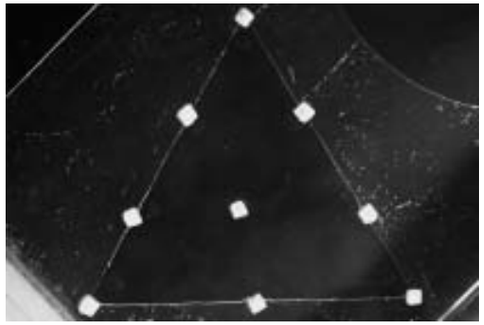
26



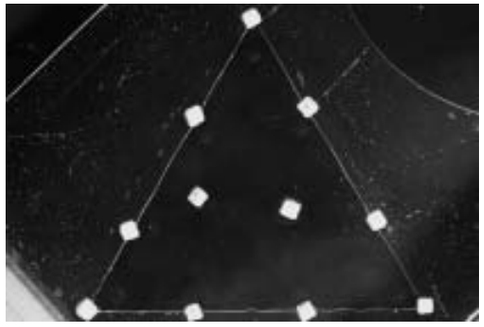
27



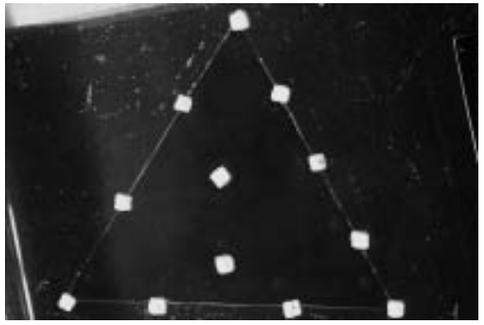
28



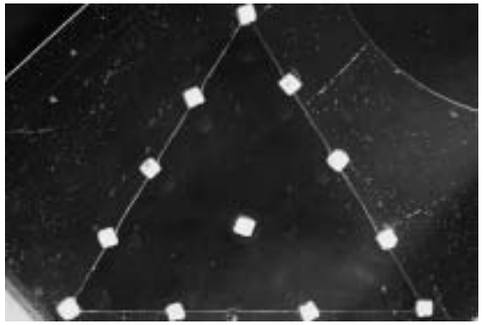
29



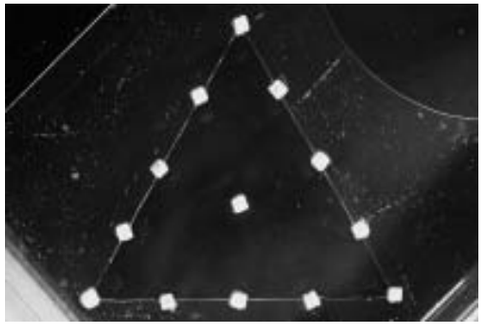
30



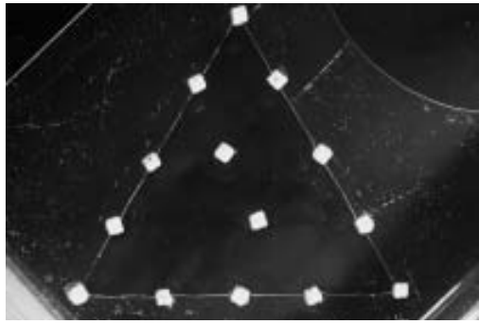
31



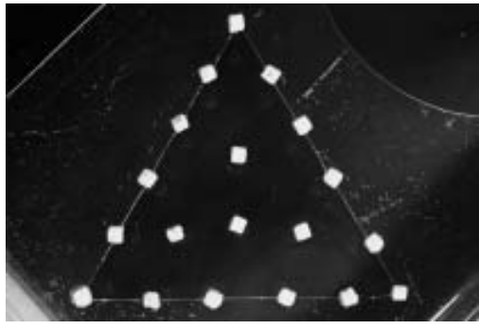
32



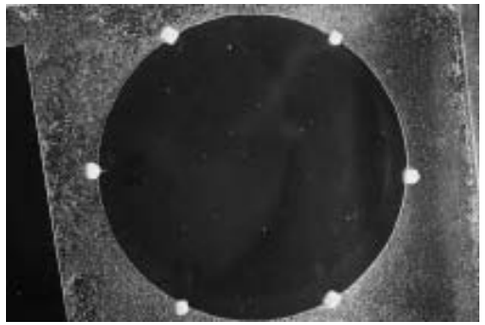
33

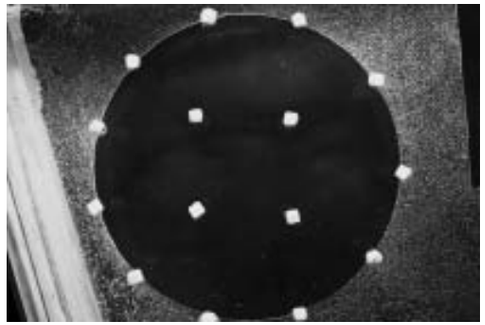


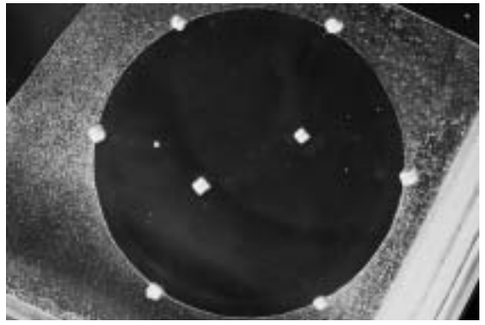
34

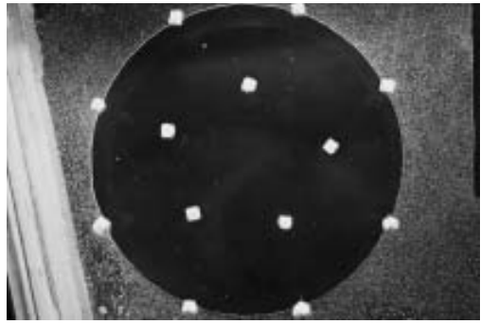


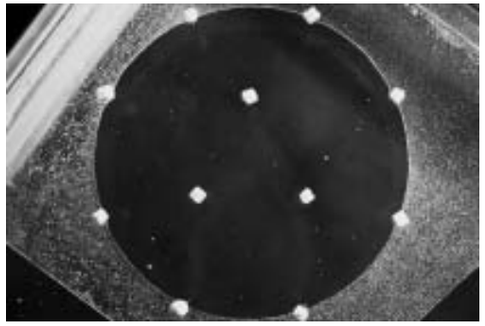
35

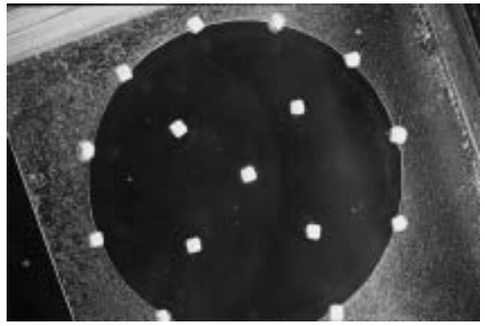

36

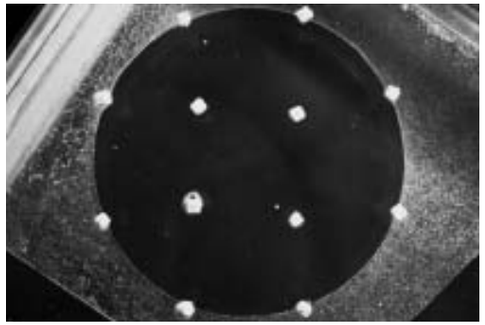

40

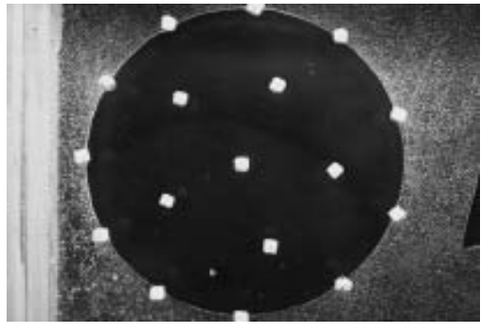

37


41


38

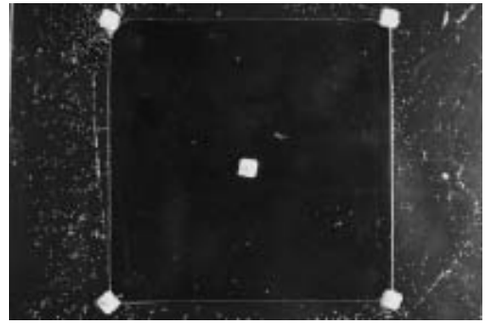

42

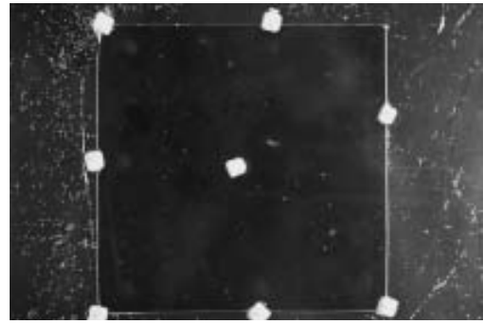

39

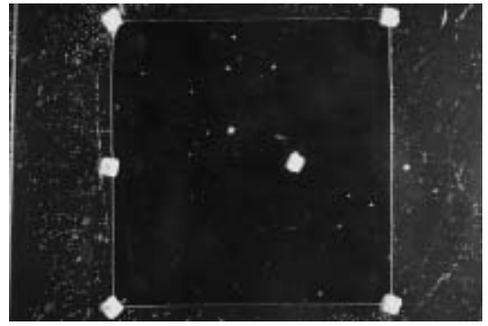

43

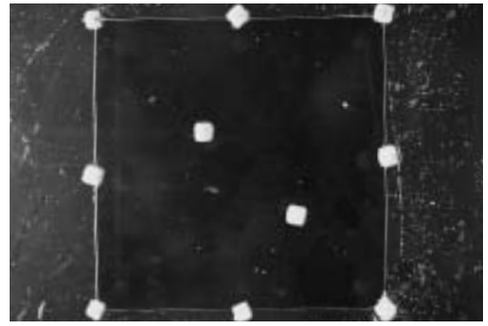
Occupations in a circular frame with 6 to 20 points (illus. 36–43).

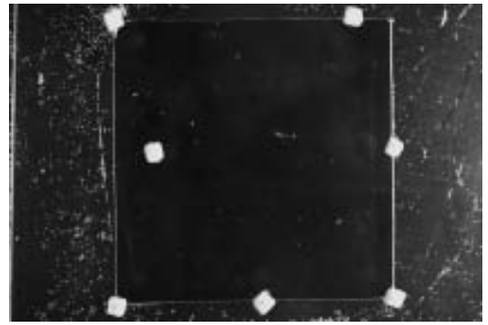
Occupations in a quadratic frame with 5 to 20 points (illus. 44–49).

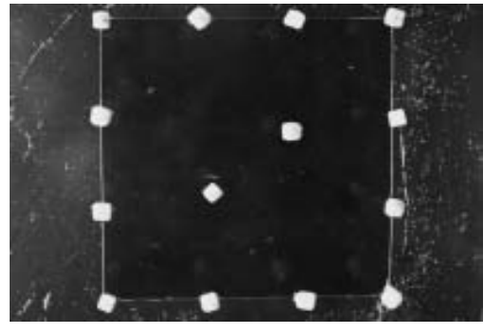

44


47


45

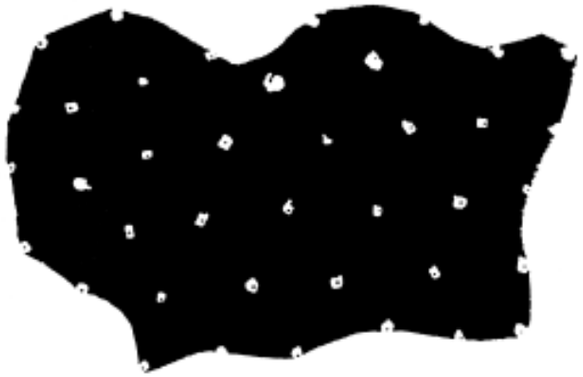

48


46

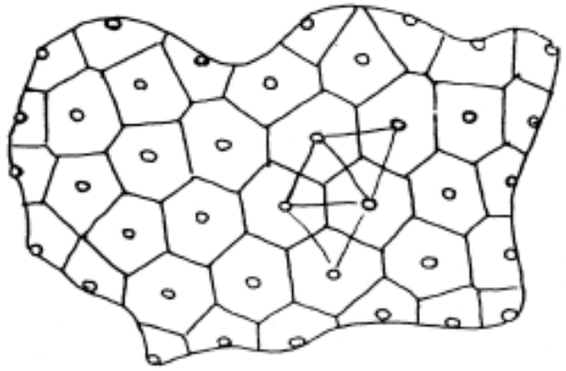

49

The more points are inserted into a surface of any form or size, the more they order themselves into a grid of equilateral triangles, with hexagonal territories (illus. 50). The boundaries of the territories are usually defined by the perpendicular bisectors of neighbouring points' connecting lines (illus. 51).

The experimental results often show several solutions produced by the same number of points in the same frame. It is valuable to know this if, as might be expected, computer programs are developed which simulate the distancing occupation of a given number of points at a given field strength on a given surface. At present, no such programme is known. The experiment, however, allows ambiguous results to be found quickly.



50



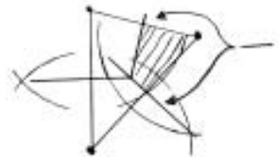
51

The territory

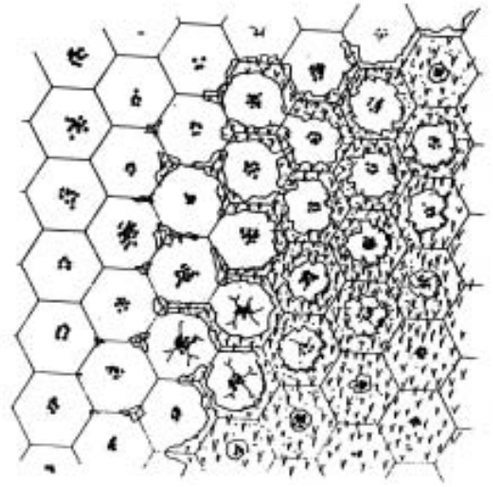
The territories associated with the equilateral triangle grid are equilateral hexagons (illus. 52, 53). In a triangular grid, circular territories of equal size can also be formed (illus. 54).

However, the size of the actual territories can vary greatly (illus. 55). Ideally, cleared spaces in wooded expanses arrange themselves into a triangular grid for optimal utilisation of wood and fields. However, this circumstance is never observed in its ideal form.

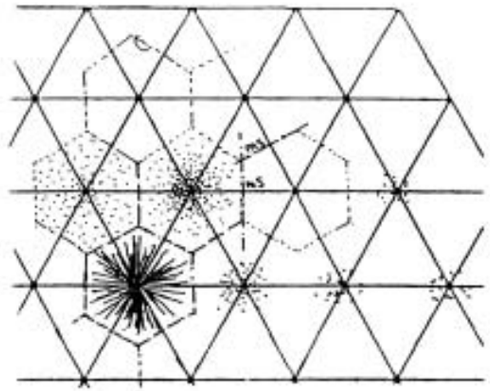
Growing and shrinking territories are possible in a triangular grid (illus. 56). A triangular grid allows further subdivision with a further triangular grid with correspondingly small territories (illus. 57).



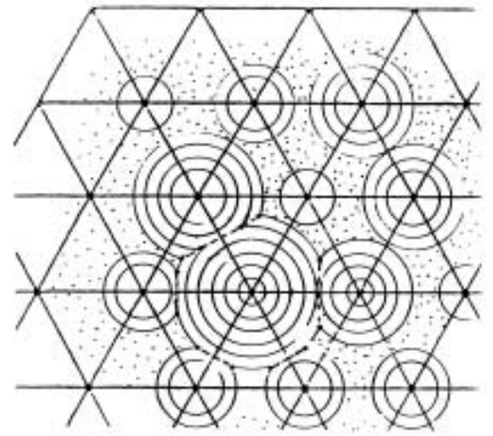
52



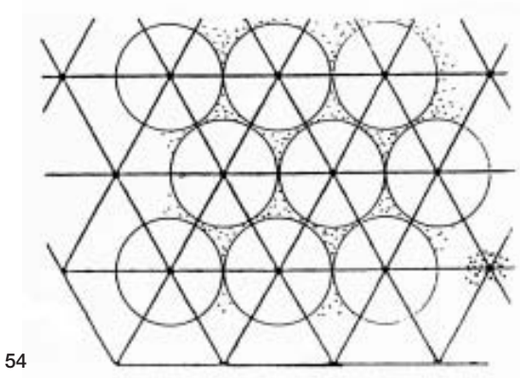
55



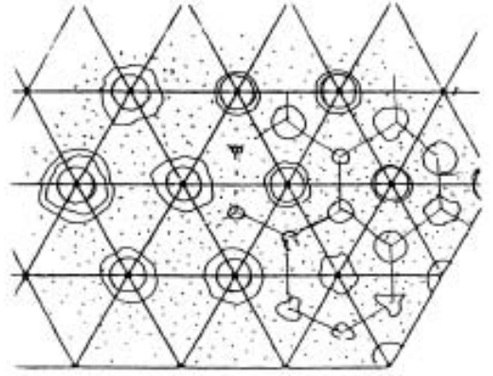
53



56



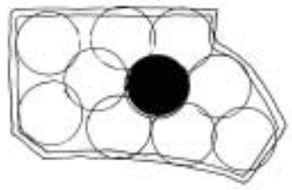
54



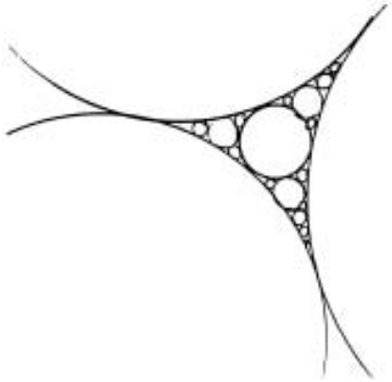
57

A simple method for determining sensible territories involves experimenting with round discs. This process can also be simulated on a computer (illus. 58).

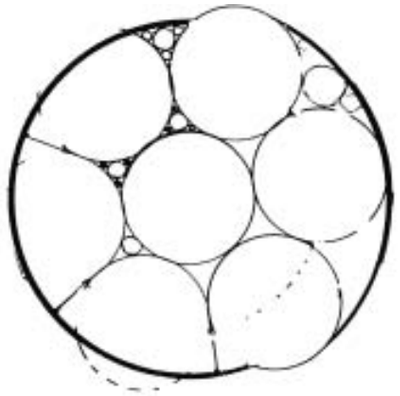
In surface occupations, the »corners« in between circular surfaces can be occupied by smaller round surfaces (illus. 59, 60).



58



59



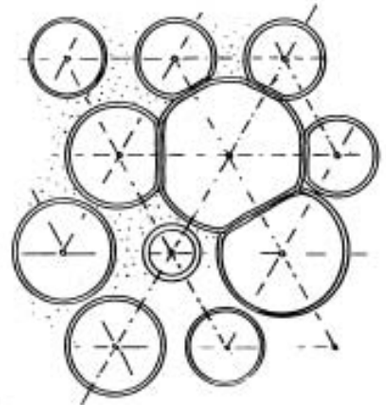
60

The flexible territory in (self-constituting) triangular grids

The size of territories can vary. Rings cut from rubber tubes, which arrange themselves within certain limits, can be used to simulate territories of different sizes (illus. 61–63).

Rubber rings form rounded occupations that depend on their size (illus. 64).

However, rubber rings and disks leave corners free at the boundaries of their territory. Under certain conditions, these can be an advantage. If these lacunae are not desired, the soap-bubble method may be useful, creating rafts of bubbles, as described below (illus. 65).

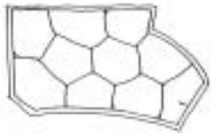


63

61

62

64



65

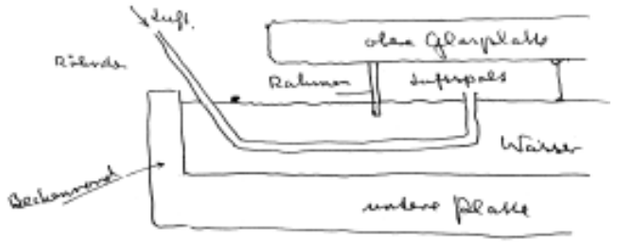
Soap bubbles

The experimental setup makes use of the Institut für leichte Flächentragwerke's minimal path apparatus (illus. 40). This involves a horizontally oriented glass plate suspended at a defined interval over the surface of a pool of water. The frame which is to be tested is hung underneath the apparatus' glass plate, with its lower edge submerged in the water (illus. 40). Then soap bubbles are blown into the gap in between until they completely fill the frame (illus. 66–68).

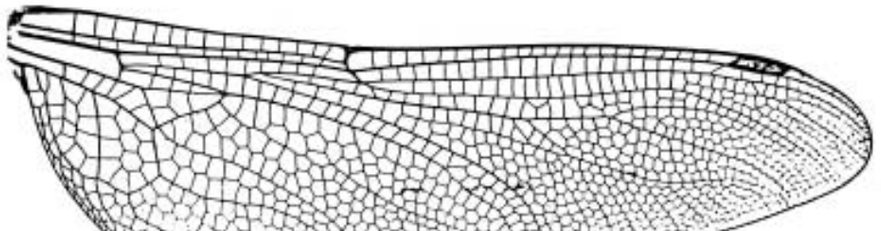
This method allows the network of a dragonfly's wing, for instance (illus. 43) to be compared with occupation by soap bubbles (illus. 44). All the bubbles' extensions touch the frame at a right angle. These are mainly straight with a few slightly crooked extensions in the corners.

66

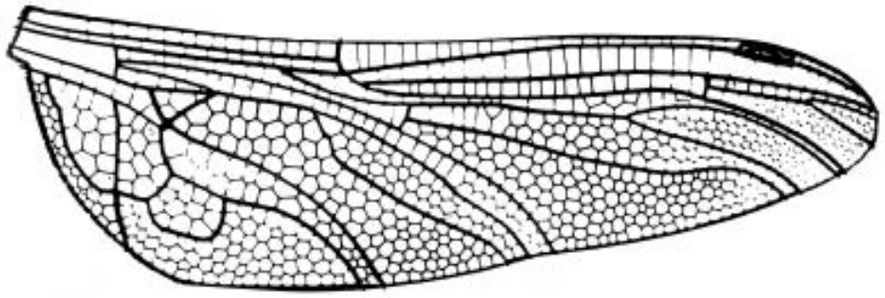
67



68



69

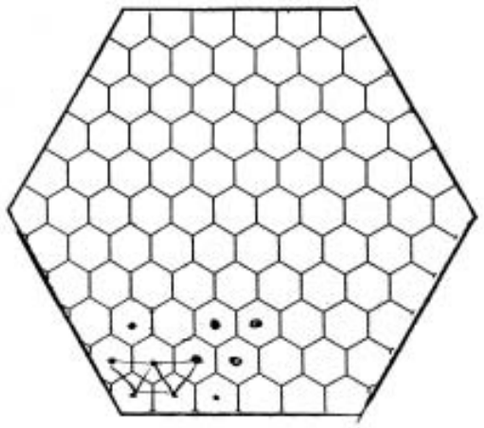


70

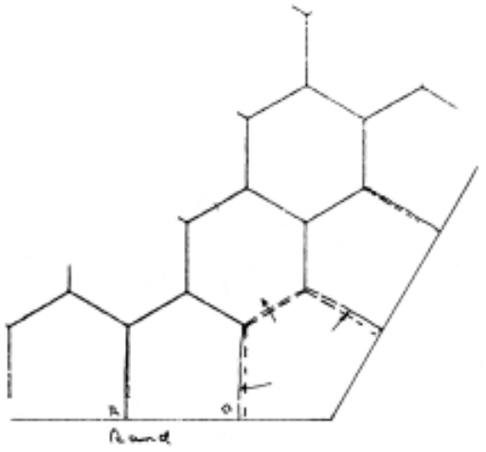
Most of the units are hexagonal. Quadratic, pentagonal and hexagonal examples do however exist.

Territories of the same size form best in a hexagonal frame. The central units are hexagonal, the outer units pentagonal. In the corner areas, mild distortions appear in units of equal surface area (illus. 71–73).

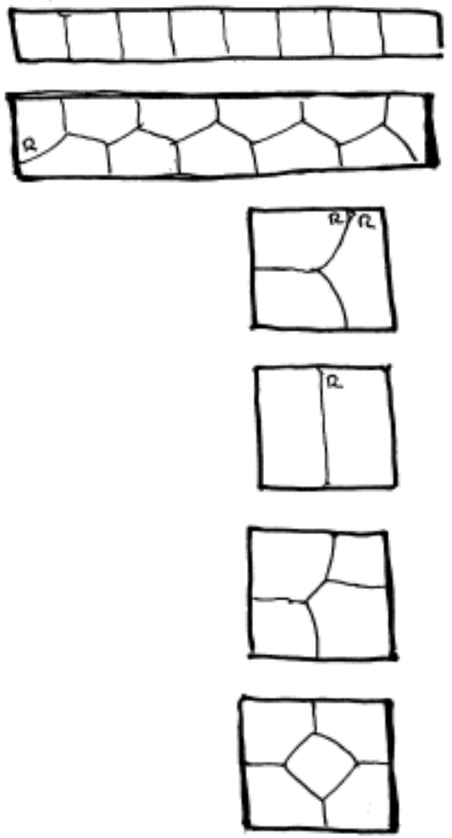
The blowing of bubbles of equal size into differently formed frames has not previously been investigated, although the self-regulation process of objects of the same cross-section in rectangular and round frames is, for instance, extremely important for the packaging industry. Previously all that was known is that a hexagonal pattern appears in the central area (illus. 74).



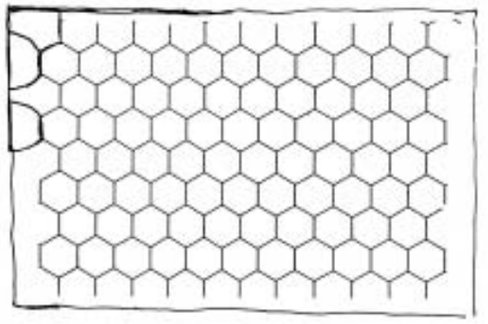
71



72



73



74

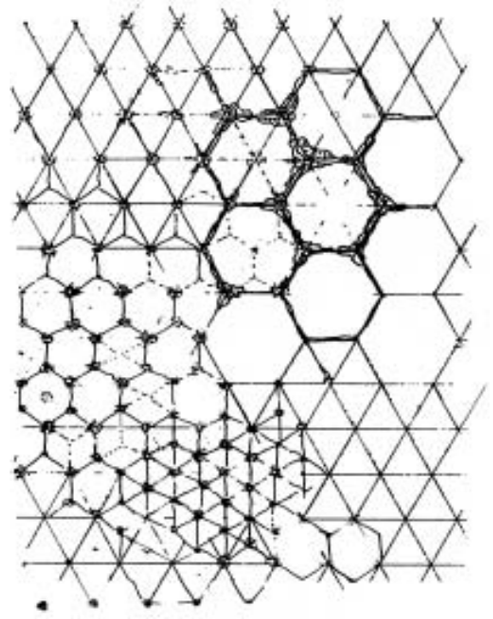
Patterns and grids

Thanks to the investigations with magnetised needles and soap bubbles, it is known that in the case of large surfaces the patterns which form consist of hexagons (illus. 75.1). The framework of occupation points associated with this is a triangular grid. The quadratic grid (illus. 75.2) in its pure form is almost exclusively artificial. Its territory is also a square.

Hexagonal grids are also commonly formed. Their territory is a triangle (illus. 75.3). A hexagonal grid can be created from a triangular grid if points are removed. In (illus. 75.4), territories of the same size are recorded.

The advantages of the hexagonal grid resulting from the triangular grid have a broad spectrum of application. Any expansion or subdivision is possible (illus. 76).

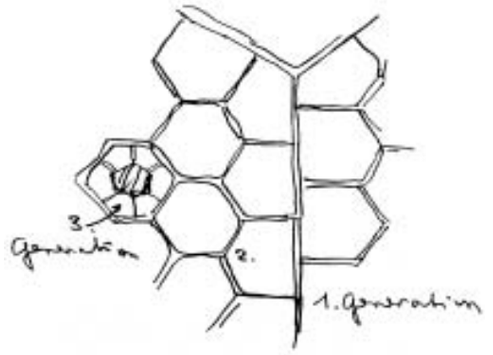
75



76

Natural patterns

When layers of paint or clay shrink due to drying, the non-cracked expanses can be considered as »territories«. The majority of these »territories« are hexagonal. The key points of the surfaces form a clear triangular grid. Often, many generations can be seen, with an increasing number of pentagonal surfaces (illus. 77).



77

Quadratic and rectangular grids

Occupation in quadratic and/or rectangular grid form is the commonest in technology, urban development and architecture. There are convincing reasons for this. The advantages are most obvious in the case of smaller objects. Crates and packages are produced from lengths as cubic or flat rectangular goods– or as rectangular goods made from paper, cardboard, sheet metal or plywood.

Different products can be housed in them. Crates are relatively stable in transport and fill the loading surfaces of transport apparatus with few or no gaps between (illus. 78).

Cubic packaging is even used when tubes or cylindrical or spherical objects, whose smallest volume is reached when arranged in a triangular grid, need to be transported in large numbers. This makes the insertion of partition walls necessary, in order to prevent the transported goods from spontaneously sliding into the most compressed formation.

A similar situation occurs in buildings. Due to the buildings' edges, smaller rooms make it essential to build in solid partitions. Rectangular buildings usually require rectangular rooms. If, for instance, more than 20 workspaces in large-scale offices or a factory facility with lighting on all sides have to be accommodated, attraction-orientated occupations are suddenly possible. In the case of a still larger group of »territories«, attractive occupation patterns are almost always more economical, and can be considered in planning from the outset.

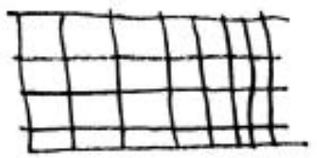
Quadratic and rectangular grids also dominate in practice in the case of buildings. To be more exact, right angles dominate, although it can be easily proved that the overall requirements in material for residential or rented accommodation, warehouses or factories does not necessarily demand a cubic construction. The advantage of right-angled structures resides solely in their having previously been more simple to plan and the use of linear and right-angled serial products and their adaptation, transport and mounting apparatus. However, this advantage does not necessarily remain if rooms have a span of over 20m. In this case, the advantages of rectangularity mentioned cannot be made use of. Very light constructions, which can enclose rooms with any ground plan economically and allow a sensible internal occupation, are indicated in this situation. This is true of large factories as well as sport and function halls of all kinds, if the internal functions do not require a right-angled occupation pattern. This is especially true of tall automated storage facilities for small parts. In these, huge cubes are created throughout from time to time.

The next biggest unit is a quadratic or rectangular »block« bordered by roads. This has been realised in countless places all over the world.

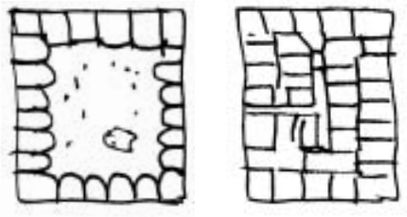
Houses are initially arranged along the frontages (illus. 79), then access roads are introduced (illus. 80), until the most dense occupation possible is achieved. Occupation of transport paths is described in part B from pp. 94 onwards.

Opening up of vertical space in intensively exploited areas is achieved, with few exceptions, through vertical staircases. Diagonal braces, required for construction reasons, are situated in areas where they are not so noticeable. The vertical and horizontal lines are the significant occupation directives of high-rise construction all over the world, regardless of country, culture or climate zone.

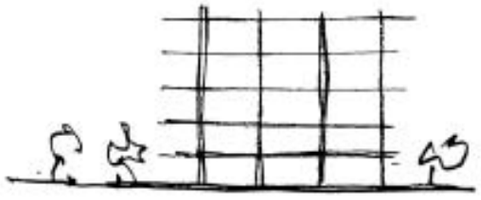
The high-stacked grid structures are used even when the building materials used in construction allow any form of construction, e.g. ferro-concrete (illus. 81). However, possibilities for opening up the third dimension have as yet not been fully exhausted. This 5000 year task remains relevant, or rather has become so again.



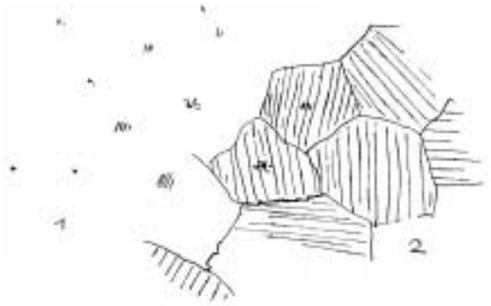
78



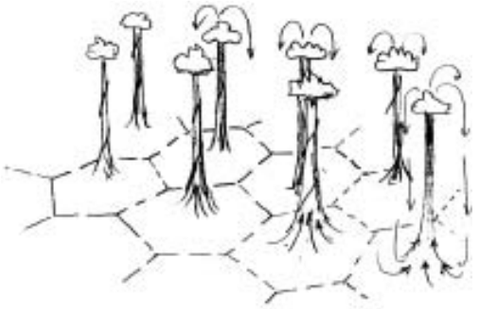
79
80



81



82



83

84

Crystallisation on surfaces

Zinc crystals on hot-dip galvanised iron sheets are interesting. When the sheets are taken out of the bath of molten zinc, crystallisation takes place in seconds. The crystallisation is clearly punctate to begin with (illus. 82.1), and expands until it encounters a neighbouring crystal (illus. 82.2). Only exceptionally are territory boundaries straight, due to the effects of crystal lattice structures. Here as well, the majority of the occupied territories are hexagonal. The method of cooling has a significant influence on the territories' structure.

Thermal columns

Two everyday phenomena both demonstrate distancing occupation: updraughts caused by inert cold air and strong sunlight (illus. 83), and cold cream poured into coffee, which initially spreads out along the bottom of the cup, and then rises in concentrated columns, whereas the dark coffee sinks in a hexagonal pattern (illus. 84).

In theory, thermal columns in a regular landscape should form a triangular grid. The position of the columns can be seen by the cumulus clouds which are frequently created. In a landscape with many gliding bird types (e.g. buzzards), these will usually circle in the centre of an updraught column. In this case, the birds' territory is identical with the thermal's »territory« or sphere of influence. Thermal columns are favoured by glider pilots. They are not always made visible by clouds. Experienced glider pilots, making long-distance flights from one column to the next and crossing the downdraught zones in between at high speed, have a »feeling« arising from experience which allows them to find the next column even without clouds. Knowing the pattern of the columns, as well as the causative factors, e.g. dry cereal fields, factories, villages and large sealed surfaces assists in finding the columns, whose exact location can be determined with the variometer (vertical speed indicator). The processes in the coffee cup are very similar to the natural processes, as are those taking place in a cooking-pot before uncontrolled boiling initiates. The forms which are created in the coffee-cup are known as Bénard cells.

They correspond as far as is possible to territories in distancing occupations. They can be reconstructed very precisely in an experiment. Other forms, especially so-called spinners can also be created and made visible.

This and similar formations are described in the working group Synergistics, led by Hermann Haken and Wolfgang Weidlich in the special study area »Natural Constructions«.