SPACE STANDARDS AND CONFIGURATION IN RESEARCH LABORATORIES

Final report

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Bill Hillier
Alan Penn
Tadeusz Grajewski
Richard Burdett
John Musgrove

Unit for Architectural Studies
Bartlett School of
Architecture and Planning
University College London

Final report on space standards and configuration
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1.00 Introduction

In January 1985 the Laboratories Investigation Unit of the Department of Education and Science commissioned the Unit for Architectural Studies at the Bartlett School of Architecture and Planning, University College London, to carry out a pilot study into current practice in the design and use of research laboratories. In particular the research team were asked to ascertain how far the standards and recommendations based on the pioneering Nuffield studies of the 1950's still formed an adequate base for design guidance in the present day, and for planning in the future.

This report gives a brief summary of the aims of the pilot study at the outset, followed by the main findings across the sample as a whole. The main findings are in two groups; those which are to do with space standards in metric terms, and those which are more concerned with spatial configuration and layout of benching. It concludes with a discussion of the areas in which the Nuffield findings and recommendations may now be considered to be out of date, and makes a number of recommendations on both standards of provision and choices of plan layout in research laboratories and the implications for design. Most importantly, it highlights the urgent need for detailed research in this area across a much larger and more representative sample than was possible at this pilot stage.

A detailed summary of findings is given in Appendix 1. Since the whole study and report are closely linked to the original Nuffield report (The Design of Research Laboratories, Nuffield Foundation Division for Architectural Studies, OUP 1961) a brief summary of that study and its main findings and recommendations is given in Appendix 2. A full list of the laboratories which have been visited, analysed or observed in whole or in part, is given in Appendix 3.

2.00 The pilot study

2.01 Aims

The aims of the pilot study were to investigate:

a. how far the Nuffield recommendations could still be regarded as adequate to the design of research laboratories today in terms of the detailed requirements to which that report attended;

b. how far new issues which have arisen since Nuffield required research and documentation for use at the design stage.

It was noted that these <u>new</u> issues were likely to be of two types:

- those which were due to changes in the scope of scientific research, its techniques, and the organisations which carry it out, and;

- those which could not be analysed by the methods available to the Nuffield team, but which advances in building-analytic and utilisation techniques now lay open to study.

It should perhaps be noted that in this preliminary study the UAS was asked to concentrate on space standards and layout in laboratories rather than, at this stage, trying to cover the whole range of environmental and servicing variables which formed a part of the original Nuffield study.

2.02 The sample

The final sample of buildings for which findings are included in this report consists of seven laboratories on five sites, and totals over one hundred and thirty laboratory "rooms". The main sample is of five seperate buildings:

Medical Research Council LMB old building, Cambridge. (MRC old) 2nd & 3rd floors.

Medical Research Council LMB new building (1980), Cambridge. (MRC new) 2nd & 3rd floors.

Imperial Cancer Research Fund, Lincolns Inn Fields. (ICRF) 5th & 6th floors.

British Gas Research Laboratories, Fulham site 1966 building. (B.Gas) 1st, 2nd & 3rd floors.

Schlumberger Cambridge Research Ltd, Cambridge Science Park.

In addition to these two contrasting laboratories at University College London, Department of Chemistry, were used to test analytic and observation techniques:

UCL Sandoz laboratory

UCL "Nuffield" laboratory

The findings for these two laboratories are included in the tables since they have been observed and analysed with the same degree of rigour as the main sample.

A considerable number of other laboratories have been visited. Some have been analysed and observed in a preliminary way, during the sample selection stages of the study (see reports to steering committee, Interim Report and Appendix 2. for list). These have provided a very useful background to the findings presented here, but are not referred to in the data.

3.00 The pilot study findings

The main findings of the pilot study concentrate on four issues;

a. standards of space provision per individual both in terms of space allocated by the organisation, and in terms of actual space utilisation. Space provision is measured in the same terms that were used for the original Nuffield study, bench length, total floor area and free floor area;

b. measures of efficiency of space provision and of space utilisation - these are in the form of ratios in the original Nuffield terms of free floor area to bench length, and in terms of notional space allocation to actual utilisation;

c. the study of adaptations to the configuration of benching and equipment layout, as this is seen as giving valuable insights into the real changing needs of the modern working scientist;

d. the study of the utilisation of space, with emphasis on the level of the group as well as that of the individual, and the effects of layout and adaptation on interaction.

The main findings on standards of provision and measures of efficiency will be dealt with in section 3.10, those on layout and configuration will appear in section 3.20, whilst those on patterns of use appear in section 3.30 .

3.10 Allocated space standards

The main findings of the Nuffield study concerning general laboratory space (Part II, Ch.1, pp38) are summarised in the form of "satisfaction tables" in terms of bench length per person. In order to evaluate whether the Nuffield recommendations are still applicable the UAS study measured the bench length allocated to each individual in a sample of 132 laboratory "rooms" in five buildings. The findings are summarised in Table 1.

Laboratory	Bench length metres/person
UCL Sandoz	3.32
UCL Nuffield	5.77
MRC 2nd old	2.72
MRC 3rd old	5.85
MRC 3rd new	7.68
ICRF 5th	4.32
B.GAS 1st	5.87
B.GAS 2nd	3.65
B.GAS 3rd	9.16
Schlumberger	17.23

Table 1. Mean bench length allocated per person (scientific and technical) by floors across the sample of buildings.

This compares to a total allocation recommended in the Nuffield study of between 4 and 5 metres per person (including sink and fume cupboards but allowing for space saving by sharing in groups of two or three people per bay).

It is clear that there is a very wide variation between buildings, and even between floors in a single building. The mean of 6.56 metres per person is somewhat higher than the Nuffield recommendations, but is perhaps unduely affected by the case of the Schlumberger laboratory where the policy was to allocate bench space largely to technical staff since all scientific staff were allocated seperate office space. If account is taken of office workspace allocated to scientists the mean across the sample falls to 5.60 m/person, which is near enough to the original upper limit of the Nuffield recommendation to suggest that there is a general shift to these more generous allocations. However, some laboratories seem to be able to cope with a good deal less - for example the second floor of MRC - and still remain world leaders in terms of their research "product". This is pointed out by the large variation across the sample, for a mean of 6.56 the standard deviation was relatively large at 4.03 indicating that it would be rash to make a firm recommendation without further study of precisely what accounts for this variability.

A high level of variability was also noted by the Nuffield team, and formed the basis of their choice of the satisfaction table as a means of presenting their findings. Their satisfaction tables note that the degree of variability is related principally to two factors; whether the staff are "scientists" or "assistants", and to the scientific discipline concerned. The Schlumberger case raises the nature of management policy in allocation of workspace as another important variable.

In the current study a distinction was made between scientific and technical staff in terms of allocation of space. Table 2 shows the mean bench length per laboratory broken down in this way.

Laboratory	Bench length m/scientist	Bench length m/technician
UCL Sandoz	3.40	30.04
UCL Nuffield	5.77	----
MRC 2nd old	3.17	4.92
MRC 3rd old	4.25	13.78
MRC 3rd new	6.21	1.46
ICRF 5th	6.82	9.70
B.Gas 1st	15.65	7.07
B.Gas 2nd	4.83	3.74
B.Gas 3rd	4.10	10.41
Schlumberger	----	17.23

Table 2. Mean bench length per scientist and technician by floors in the sample.

The range of variation of bench length allocation is clearly higher for technicians than for scientists; for a mean across the sample of 10.92 metres per technician the standard deviation is 8.21, for the scientists the mean is 6.022 and the standard deviation 3.60.

The finding that the mean allocation of bench space to technicians is higher than to scientists is in direct opposition to the Nuffield findings and recommendations, although it does seem to make good sense.

At the same time that measurements of bench length allocations were made, measurements of space allocation were also undertaken. The Nuffield study found that the <u>only</u> criteria to which scientist's subjective preferences were related (measured by questionaire techniques) was the free floor area per person, whilst the other factors - built-up floor area, bench length, number of people per room, number of re-entrant corners in a room, number of island benches and ceiling height - all failed to correlate significantly (pp50). Table 3. shows the total floor area and the free floor area allocated per individual across the sample.

Laboratory	Total floor area/person	Free floor area/person
UCL Sandoz	8.55	5.07
UCL Nuffield	7.99	4.24
MRC 2nd old	4.35	1.98
MRC 3rd old	9.43	4.42
MRC 3rd new	12.34	5.30
ICRF 5th	7.18	4.40
B.Gas 1st	16.95	8.43
B.Gas 2nd	10.67	6.07
B.Gas 3rd	18.16	9.87
Schlumberger	45.10	30.04

Table 3. Total floor area and free floor area allocated per person by floors across the sample.

It can be seen that once again there is a high degree of variation across the sample in the allocation of space considered as free floor area (mean 7.98, standard deviation 7.65), and as total floor area (mean 14.07, standard deviation 11.11). There is, however, a consistency between the areas for each building; the more total floor area, the more free area in any building. But when we compare this to the bench lengths given in Table 1. we find that the same consistency is not present. Nuffield notes (p164) that an index of the efficiency of a building can be said to be the amount of available bench length for a given floor area. This can be measured as a ratio of free floor area to bench length in any laboratory, the lower the figure, the more "efficient" in Nuffield's terms. This ratio is of course prior to any allocation policy, and so should overcome the type of variations which appear in the case of Schlumberger for instance. It is also possible to make a direct comparison to the Nuffield "recommended" laboratory layouts as a point of reference. Table 4. gives the ratio of free floor area to bench length for all the floors in the sample, it also gives this ratio for the two extremes of the Nuffield recommended layouts which vary on the basis of distance from bench to bench.

Laboratory	Free floor area/bench length
UCL Sandoz	1.547
UCL Nuffield	.735
MRC 2nd old	.724
MRC 2nd new	.795
MRC 3rd old	.773
MRC 3rd new	.733
ICRF 5th	1.025
ICRF 6th	.926
B.Gas 1st	1.391
B.Gas 2nd	1.253
B.Gas 3rd	1.133
Schlumberger	1.727
Average	1.064
Nuffield (5'6"bay)	.838
Nuffield (7' bay)	1.507

Table 4. Ratio of free floor area to bench length in the sample of buildings compared to Nuffield recommended plans.

These figures show a remarkable consistency within particular buildings, MRC for instance varies between .724 and .795 even though the actual allocation of space varies quite markedly from floor to floor. More importantly, these figures indicate an actual "efficiency" in Nuffield's own terms significantly higher than even the most efficient of Nuffield's recommendations. The theoretical ratio calculated for the original design for ICRF on the basis of a 6' bay dimension is 1.309, the two floors studied have now achieved significant gains in "efficiency" to 1.025 and .926 respectively. This seems to suggest that the benching layout has been significantly modified by user adaptation towards increased efficiency.

The ratio for British Gas varies from 1.39 to 1.13, this is again consistent for the building, of an order approaching the Nuffield recommendations, though clearly different to either MRC or ICRF. The only "open plan" laboratory in the sample is the Sandoz lab at UCL, this approaches the Nuffield recommendation for "efficiency" very closely at 1.55, although it was designed on a completely different basis. It is likely that the incorporation of circulation space in the laboratory area which becomes necessary in open plan designs leads to the fall in efficiency. The least "efficient" plan in these terms is Schlumberger's. This may in part be due to the need for large free-standing items of equipment, placed centrally in rooms surrounded by circulation space, which are a characteristic of the type of research which takes place there. This cannot be the only criteria, however, since these are also a characteristic of British Gas which has a significantly lower ratio. It should also be noted that Schlumberger was studied at a very early stage in its lifecycle, and so has been subject to relatively few user adaptations, it is possible that once these inevitable adaptations take place the efficiency will rise to a level more comparable to British Gas.

The consistency noted within buildings across the sample seems to suggest three possible explanations;

- that within each of the buildings there is a consistent effect from the functional requirements of the discipline involved;

- that there is a consistent effect from the management policy of the organisation with regards to space provision;

- that there is some consistent and necessary relationship between the overall building design, its servicing or structural module, or some other factor of its basic design strategy, which governs the user adaptations which are possible in the remainder of its lifecycle.

But the explanation in terms of disciplinary differences seems only to account for some of the consistencies found within buildings; at British Gas there is a wide variation of disciplines and their functional requirements - reflected perhaps in the wide variation of space provision (Table 1.) - but a striking consistency from floor to floor in terms of efficiency of provision. There again, the explanation in terms of management policy runs into similar difficulties; allocation policies seem to work at the level of applying metric standards of allocation to individuals, but the great variations found in allocated space standards within single buildings - MRC for example - suggest that the reasons for the consistencies of efficiency found within buildings must lie elsewhere. It seems most likely that the consistencies result from two factors; the pressure for adaptation towards maximum efficiency from the building users, and the constraints put on this adaptation by the nature of the building itself.

In relation to the original Nuffield recommendations (see Appendix 1.) five main points can be made about allocated space standards:

a. the mean across the sample indicates that the standard of space provision (5.6m bench length/person) is now up to the most generous of the Nuffield recommendations (20' - 6 metres - per person);

b. the bench space allocation to technicians is on average higher than to scientists, although - significantly - there is greater variation across the sample for technicians than for scientists. This is in direct opposition to the original Nuffield findings;

c. there is a direct relationship between the allocation of space measured as total floor area, and that measured as free floor area within any building, but this does not hold for space allocation measured as bench length. It seems that some buildings are more "efficient" in Nuffield's terms than others;

d. in general it seems that building users adapt buildings to be more efficient during that building's lifecycle, and for any particular building this increase in efficiency reaches a general limit to what is possible;

e. it seems that the limiting factor is in the nature of the strategic design decisions around which the original building was built, and in these terms the Nuffield recommendations limit the scope for adaptation - and so increased efficiency - to a greater degree than other design types. The one exception to this rule is that of the UCL "Nuffield" design which in fact adopts a number of significant variations on the Nuffield theme, including the use of a shorter corridor to external wall dimension leading to rectangular rather than long-thin laboratories. It is perhaps informative that the degree of real user adaptation which has taken place in this laboratory is relatively low.

3.11 Actual space utilisation

Although it seemed clear that space allocation - and in particular the efficiency of design for maximum bench length - were largely the product of user adaptation within the constraints imposed by the building itself, it was not clear to what extent this was related to actual building use. Following the Nuffield principle of making direct observations of use, the present study also made direct observations, though the methods used were somewhat different. In the Nuffield study a number of individuals were observed at intervals throughout a whole year, in the present study time forbade that approach; instead all the people on any particular floor of a building were observed by means of "snap round" techniques a large number of times over a period of two or three days. This approach has a number of advantages over the original Nuffield methods of study. In addition to allowing a direct comparison of actual densities of space use with the notional space allocation, since it observes all the people present at a particular time it allows an objective assessment to be made of the effects of sharing space and group work, which were only briefly discussed by Nuffield. It also allows a detailed analysis to be made of where in the building different types of activity and interaction take place - issues which were hardly touched by Nuffield (see Section 3.20).

In this way it was possible to compare the notional usage of space and bench length, as it was allocated by management in any building, to the actual usage observed in that building. Table 5. shows the mean bench length per person observed by floors across the sample of buildings.

Laboratory	Bench length m/person (actual)	Bench length m/person (notional)
UCL Sandoz	34.75	3.32
UCL Nuffield	14.14	5.77
MRC 2nd old	19.01	2.72
MRC 2nd new	35.63	----
MRC 3rd old	21.04	5.85
MRC 3rd new	32.08	7.68
ICRF 5th	12.23	4.32
ICRF 6th	9.08	----
B.Gas 1st	47.20	5.87
B.Gas 2nd	15.45	3.65
B.Gas 3rd	33.57	9.16
Schlumberger	28.63	17.23

Table 5. Bench length per person (observed) by floors across the sample of buildings.

If this is compared to the notional bench length allocated per person a number of points become clear;

- the overall observed density of use ranges from one half to one tenth the notional allocation. This agrees broadly with a number of previous studies in the area (see for instance Rawlinson C. in Space Utilisation, Spon 1984).
- there seems to be little in the way of a direct relationship between notional allocation and actual use. The parametric correlation between the two is low at .26 .
- within a particular building, MRC for instance, there is a clear pattern of less density in the new building than the old.
- overall the most densely populated building is ICRF, followed by the Nuffield design labs at UCL (at UCL this may in part be due to an above average population of undergraduate students doing research projects during the summer term observation period).
- the least densely populated is the first floor of British Gas, closely followed by the new building at MRC, Sandoz at UCL and British Gas third floor (at Sandoz the low density may well be due to a larger allocation of space entailed in open planning).

Table 6. gives the total and free floor areas per observed

person over the sample.

Laboratory	Total floor area/person (observed)	Free floor area/person (observed)
UCL Sandoz	101.46	61.48
UCL Nuffield	19.68	10.49
MRC 2nd old	28.96	12.97
MRC 2nd new	78.75	31.07
MRC 3rd old	34.00	16.11
MRC 3rd new	50.03	21.34
ICRF 5th	20.26	12.28
ICRF 6th	15.45	7.41
B.Gas 1st	106.61	43.58
B.Gas 2nd	32.95	16.09
B.Gas 3rd	67.34	38.02
Schlumberger	70.89	47.95

Table 6. Total floor area and free floor area per person (observed) by floors across the sample of buildings.

The use rates in terms of metric area agree in general with those for bench length shown in Table 5. More interesting is the relationship between the notional allocation of space, Table 3., and the observed space usage in Table 6. Here the relationship seems at first to be confused, but if we find the ratio of notional space allocation to actual densities of use a pattern begins to appear. Table 7. gives this ratio for bench length, total floor area and free floor area.

Laboratory	Bench length (notional/ actual)	Total floor area (notional/ actual)	Free floor area (notional/ actual)
UCL Sandoz	.096	.084	.082
UCL Nuffield	.408	.406	.404
MRC 2nd old	.143	.150	.153
MRC 3rd old	.278	.277	.274
MRC 3rd new	.239	.247	.248
ICRF 5th	.356	.354	.358
B.Gas 1st	.124	.159	.193
B.Gas 2nd	.236	.327	.377
B.Gas 3rd	.273	.270	.260
Schlumberger	.602	.636	.626

Table 7. Ratio of notional space allocation to actual space use measured in terms of bench length, total floor area and free floor area per person across the sample of buildings.

Most striking is the consistency across the three measures of usage, bench length, total floor area and free floor area. This confirms the general relationship between bench length, total floor area and free floor area within any single floor.

There is, however, a high degree of variation across the sample, from .096 to .602 for bench length, for instance. Although the low factor for Sandoz is likely to be due to the high amount of circulation space in the open plan, whilst the high factor in the case of Schlumberger is possibly due to the allocation policy mentioned previously.

Beyond this, the reasons behind the variations across the sample, of either notional space allocation, actual space utilisation densities, or the two measures of "efficiency", are at present unclear, and in view of the limited size of the sample it would be unwise to draw too many conclusions on this matter. However, it has already been noted that the "morphological" measure of efficiency - the free floor area/bench length ratio - seems to be most strongly related to the constraints imposed by the individual building design.

To go one step further, it is possible to test the degree to which this measure of "efficiency" is related to actual use densities by means of a parametric correlation. The findings of a correlation r= .7767 for use density measured as free floor area per person, or .4749 for bench length per person indicates that the more efficient the planning, the greater the actual density of utilisation. This finding has obvious implications for cost effective - and functionally efficient - design.

In terms of the ratio of notional allocation to actual use density, there is virtually no relation to "morphological" efficiency, r= .1219 , but there is a relatively strong relation to notional space allocation in terms of bench length, r= .7642 , with only a weak relation to actual use density, r= -.3691 . The relationship between notional and actual densities has already been noted, r= .26 . This suggests that the morphological measure of efficiency, which seems to be most strongly influenced by the design of the building itself, in some way determines actual use densities. This would in turn indicate that actual use densities may be strongly influenced by building design.

In terms of the original Nuffield recommendations three main points can be made about actual space utilisation;

a. actual utilisation rates are very variable, this confirms the original Nuffield findings;

b. the variation seems to be most closely related to the free floor area/bench length ratio, the more efficient in Nuffield's terms the more efficient in terms of actual utilisation rates;

c. most strikingly, notional allocation standards seem to be virtually unrelated to actual use densities.

All together this suggests that the layout of the building itself is more important in determining actual utilisation rates than management allocation policies, and that in order to give guidance on space allocation we need to look in detail at laboratory layout.

3.20 Layout adaptation

One of the most important and consistent points noted throughout the range of buildings was that all are subject to some degree of user adaptation.One key result of these adaptations - the increase in efficiency of provision of bench length - has already been noted in section 3.10 , and it has been suggested that this is related to the break-up of long runs of benching, the creation of smaller spaces within laboratories, and perhaps, to the ways in which scientists locate the equipment used for different procedures. The Nuffield study noted that scientists invariably were using areas of benching and equipment in a number of different locations in the laboratory, and not infrequently outside it. This was also our own informal observation. The Nuffield recommendations - in particular the recommendation for very long, thin laboratory bays - were based on the assumption that it is preferable to keep all the seperate pieces of benching together in a single long, straight run. This assumption is testable we feel by the study of the ways in which scientists adapt and use their laboratory space.

The most frequent and consistent adaptations held two things in common:

- the break-up of space, and;

- the linking together of these smaller pieces of space by dominant lines of local circulation which seem to "integrate" the pattern of space at the level of the single laboratory room;

These are dealt with in turn in sections 3.21 and 3.22. Their effects on observable patterns of use are dealt with in section 3.30 .

3.21 The break-up of laboratory bays

The most consistent adaptation found in all laboratories in the sample was to increase the bench space available by turning benches at rightangles to the main run, installing floor mounted equipment within the main area of free floor space and by the use of permanently parked trolleys. One marked effect of this was the creation of small, sub-divided areas within each of the laboratory bays (see ICRF 5th floor layout Fig 1a & b), with only the minimum possible width of circulation space linking them together. The nett result was that the free floor area in any laboratory is broken up into a series of smaller and larger, more or less "convex" spaces, all linked together into a continuous system of open space. Table 8. gives the average number of convex spaces in each laboratory room, their average metric area, floor by floor across the sample.

Laboratory	Mean number of convex spaces	Mean area of convex spaces (sq. metres)
UCL Sandoz	20.4	9.71
UCL Nuffield	7.25	2.36
MRC 2nd old	3.36	3.32
MRC 2nd new	4.90	2.28
MRC 3rd old	6.15	2.83
MRC 3rd new	5.29	2.70
ICRF 5th	3.18	5.55
ICRF 6th	2.85	3.21
B.Gas 1st	11.20	2.89
B.Gas 2nd	7.33	3.84
B.Gas 3rd	6.10	4.40
Schlumberger	8.00	5.87
Mean	6.66	3.84

Table 8. Mean number and area of convex spaces per laboratory room by floors in the sample.

The consistency across the whole sample is remarkable, as is the small mean area of the spaces - 3.84 sq.m. Closer examination however, reveals quite telling differences from building to building;

- at first sight there seems to be a direct relationship between the average size of convex spaces on a laboratory floor, and the free floor area/bench length ratio (Table 4.) overall the correlation is .699 , indicating that the more space is broken up, the more efficient in terms of bench length;

- this correlation is marred by the three floors of British Gas which show an almost perfect inverse correlation -.994 , the larger the spaces, the larger the bench length efficiency. The correlation for the sample without British Gas is equally good at .97 ;

The apparent contradiction is resolved by looking at the plans for British Gas (Figs. 3 a,b & c). Whilst most of the buildings in the sample were similar in that they provide benching mainly around the perimeter of laboratory bays, British Gas differed in their use of large scale equipment and purpose designed rigs. These were generally located at the centre of a room, leaving free floor space around the perimeter. The result on the efficiency of space provision is obvious; for laboratories with perimeter benching, efficiency gains lead to the break-up of space into small sub-areas; for laboratories using large equipment and rigs, the larger the spaces - and items of equipment - the more efficient.

This suggests that at least some of the disciplinary differences in space needs noted in Nuffield bear a relation to the morphological differences of space provision for different layouts. It is with a view to investigating some of these more subtle configurational properties of laboratory layout that we now turn to the way these "broken-up" spaces are linked together.

3.22 Local circulation space

The second factor - the linking together of these local, sub-divided areas by strong linear circulation links - can be seen most clearly in the plans of ICRF (Figs 2a & b). Here there are a number of strong linear links, deep within the laboratories, which connect a number of bays together, providing a second means of circulation from bay to bay, without needing to resort to the use of the main corridor. These internally linked sets of bays usually, but not always, are associated with single research groups, and seem to describe what are seen as not only distinct groups of spaces, but also "boundaries of knowledge".

The characteristic of the linear circulation link within the laboratory is not only a characteristic of ICRF, it occured in all the buildings studied though in somewhat different forms. Figures 4a,b & 5a,b show the floor plans for the MRC old and new buildings. Here it can be seen that the links exist, but instead of linking bays deep within the laboratory, they link them just inside the door from the main corridor. Again though, they seem to form distinct groups of spaces, and again these are associated in general with research groups.

In British Gas (Figs. 3a,b,c) it has already been noted that the layout of laboratory space is somewhat different. There are large items of equipment which tend to have a whole room devoted to them. They are situated centrally with circulation organised around them peripherally. This same pattern is repeated at Schlumberger (Figs 6a,b,c) in the drilling mechanics and fluid mechanics laboratories. In these situations the break-up of space is only by the installation of the items of equipment, and as has been noted it seems as though, in the interests of efficiency of space provision, the break-up of space is actively avoided, larger spaces are favoured, since these are more efficient in terms of bench length (or rig length) to floor area ratio. Here it seems as though the linear links needed where space is actively broken up, are not called for, and it is tempting to suggest that this may be because there is no call for ease of circulation between different items of equipment, or different procedures as is required in laboratories concerned with bench scale work.

A comparison of all the floors can most easily be made by reference to Figures 2a,3c,5a,6c. which give what we call an "axial" representation of the open space in the plan, in which the detailed break up of space is ignored, and only the links between spaces are drawn as straight lines. In this case the local integrating circulation links within laboratories are marked in a heavy line.

Three points are clear:

a. the consistency with which these local links appear throughout the sample;

b. the variation in their relation to the main corridor in different buildings, in some they are consistently deep from the corridor (ICRF for example), in others they are generally shallow (MRC), in others there is a broad mix of deep and shallow within a single floor;

c. the links form "rings" of circulation with respect to the corridor in some cases (ICRF), and in others form the main branches of a "tree" (MRC).

These patterns of layout seem often to be the result of user adaptation, and modification over time, within the constraints imposed by various strategic design factors - in particular the location of drainage with relation to benching - though often great lengths are taken to overcome these constraints and maintain a particular configuration of circulation.

In previous studies of building interiors such consistent and active adaptation has often been related to particular functional requirements of the users concerned, it seemed possible that this would be no exception. The space utilisation observations were reviewed, therefore, on a space by space basis.

3.30 Detailed space use and interaction

We have already noted that densities of space use increase with the degree of break-up of free floor area (section 3.11). The main findings in this section of the study, however, were related to the effect of the layout and configuration on patterns of use, and in particular of the effect of the consistent patterns of adaptation noted in section 3.22 on different densities of use for different types of activity.

Informal observations suggested that laboratories consisting of predominantly "deep" circulation links - such as ICRF - had a very different kind of "working atmosphere" to those which had predominantly "shallow" ones like the old building at MRC. It seemed possible that this difference in perceived atmosphere was related to different patterns of occupancy and interaction in the two buildings, and if this was the case it should be possible to detect these different patterns of use and to see if - as seemed likely - there was any relation to the different patterns of configuration of space in the two buildings.

Systematic observations were carried out on whole floors of each of the buildings over a period of a number of days on a strict, repetative basis to get statistically significant densities of space use. Three categories of space use were observed;

a. people who were talking - a simple objective measure of interaction;

b. people who were standing - these generally seem to be those whose work needs them to move about, and so to use the circulation links;

c. people who were sitting - those who do not need to move about to such a great extent.

The distance of each individual observed was measured from the local circulation link or "core" within each laboratory room. Laboratory rooms were classified according to whether they had "deep" or "shallow" circulation links. Table 9. gives the mean distance in metres of individuals within laboratories from the local circulation links, for each of the three categories of space use. The standard deviation is given in brackets below each figure. A division is made into shallow and deep laboratories where both types occur on a single floor.

Laboratory	Talking	Standing	Sitting
UCL Sandoz all deep	5.43 (2.43)	3.56 (2.48)	0 (all on - core)
UCL Nuffield all deep	0.33 (0.47)	2.1 (1.38)	0.06 (0.2)
MRC 2nd old shallow core	0.92 (0.88)	0.88 (0.97)	1.85 (1.2)
MRC 2nd old deep core	1.14 (1.17)	0.94 (1.42)	1.52 (1.5)
MRC 2nd new all shallow	0.3 (0.25)	0.83 (0.85)	1.5 (1.06)
MRC 3rd old all shallow	1.17 (1.22)	1.41 (1.07)	2.03 (1.1)
MRC 3rd new shallow core	0.4 (0.45)	1.2 (0.65)	1.3 (0.87)
MRC 3rd new deep core	1.1 (1.1)	0.99 (0.67)	1.9 (0.44)
ICRF 5th all deep	0.93 (1.48)	2.85 (2.07)	1.09 (1.06)
ICRF 6th all deep	0.87 (0.97)	2.05 (1.13)	0.3 (0.78)
B.Gas 1st shallow core	0.5 (0.41)	0.6 (0.74)	1.52 (0.7)
B.Gas 1st deep core	0.5 (0.71)	1.4 (0.55)	0.7 (1.12)
B.Gas 2nd shallow core	2.7 (0.81)	1.57 (0.66)	4.5 (1.19)
B.Gas 2nd deep core	0.06 (0.17)	0.59 (1.16)	0.05 (0.14)
B.Gas 3rd all shallow	1.2 (1.09)	0.71 (0.86)	1.5 (0.83)
Schlumberger all shallow	1.17 (1.13)	1.66 (0.17)	2.92 (1.35)

Table 9. Mean distance (metres) of talking, standing and sitting people from the local circulation links

There are three main points to be noted from this table of distribution of activities;

a. in all cases except UCL Sandoz - the open plan laboratory - people talk and interact with each other relatively close to the local linking circulation line;

b. in all deep cores except those on the second floor of the old MRC building and the third of the new one, standing people are further from the linking lines on average than sitting people - that is people sit deep within the laboratory despite this being on an internal circulation route;

c. in all shallow cores people sit deep from the core, that is deep in the laboratory, and stand close to it.

The pattern seems clear; on average people who are standing, and likely to need to take advantage of the circulation links for moving around, place themselves close to those links, whether they are deep or shallow in the laboratory; people who are sitting place themselves deep in the laboratory regardless of whether that places them close to, or far away from a linking core; and, people interact close to the linking cores regardless of where these are in the laboratory.

This pattern is very consistent when we take account of the averaged location of individuals, and suggests that the configuration of the layout may have a direct effect on this sort of pattern of use and interaction in research laboratories. To test this apparent relationship further required the use of statistical correlations between metric depth from the linking cores, and the location of people. Table 10. gives parametric correlations for all three categories of people. These correlations have also been checked in the form of scattergrams, and where there were "confounding" observations the correlation showing the major underlying trend is given below in brackets.

Laboratory	Talking	Standing	Sitting
UCL Sandoz all deep	.346 (.557)	-.752	----
UCL Nuffield all deep	-.913	-.242 (-.547)	-.889
MRC 2nd old shallow core	-.868	-.873	.11
MRC 2nd old shallow+deep	-.672	-.733	-.698
MRC 2nd old all lab units	-.707	-.606	-.693
MRC 2nd new all shallow	----	-.961	.918
MRC 3rd old shallow core	-.846	-.796	.136
MRC 3rd old all lab units	----	-.583	.003
MRC 3rd new shallow core	----	-.222	.327
MRC 3rd new deep core	-.309	-.875	.225
MRC 3rd new all lab units	-.192	-.385	.147
ICRF 5th all deep	-.678	-.455	-.780
ICRF 6th all deep	-.55	-.12 (-.81)	-.63
B.Gas 1st shallow+deep	-.878	-.16	.24
B.Gas 2nd all lab units	-.456	-.31	.689
B.Gas 3rd shallow core	-.599	-.78	.00
Schlumberger shallow core	-.091	-.688	.466 (.645)

Table 10. Correlations with depth from the local circulation link for deep and shallow laboratories

The general trend highlighted in the previous section is confirmed by the parametric correlations:

- in all cases except Sandoz there is a negative correlation between the number of talking people and the depth from the internal linking circulation core, whether this is deep within the laboratory as in Nuffield (-.91), or shallow as in MRC (-.87), - interaction takes place at these local cores, and decreases as we move away from them;

- in all cases without exception standing people correlate negatively with depth from the local linking core, whether those are deep as in the MRC new building on the third floor (-.875), or shallow as on the second floor of the same building (-.961), - it seems that not only are standing people found near to circulation links, but they decrease in number as you move away from them. In this case, where all other factors to do with the building are held constant, it very suggestive that this relationship is to do largely with the layout of benching and equipment, and its effect on the configuration of the remaining space;

- the correlation with sitting people is some times negative - UCL Nuffield, MRC 2nd old, ICRF 5th & 6th, - and sometimes positive - MRC 2nd new, B.Gas 2nd, Schlumberger. This is again related to whether the floors concerned consist predominantly of shallow or deep core laboratories.

In terms of the original Nuffield recommendations there are a number of points to be made. It seems questionable in the light of these findings whether the view of research work which took as its unit "one man and his bench" is an adequate one to deal with the subtleties of space use in real laboratories. It seems that scientists prefer to sit deep within a laboratory despite Nuffield's unacceptable levels of glare, and that this is part of a more general pattern of space use which is, perhaps, more of a "privacy - community" dynamic than a purely ergonomic one. In the same way, the perennial need for more equipment and bench space leads to the scientist increasing the efficiency of provision within his given area to a level far beyond that envisaged by Nuffield. The way he does this seems to also to be related to this same sort of dynamic - the break-up of space to form local more private areas, coupled with the linear circulation links which become the main location of interaction within the laboratory.

Overall this seems to lend backing to the work by the Laboratories Investigation Unit since Nuffield which has suggested that group dynamics and spatial layout are more important features in the functioning of laboratories than Nuffield had allowed.

4.00 The implications for the designer

What does this mean for the designer? There seem to be a number of principles involved;

- all other things being equal, laboratory users will adapt layouts to maximise the amount of bench space within a given floor area. The degree to which this is possible depends largely on a number of strategic design decisions on fixed building elements, servicing strategies and module dimensions;

- the principle means of achieving maximum bench space is by turning benches and equipment through right angles, and breaking up the typical bay into a number of smaller areas. These areas are often associated with particular laboratory procedures since users tend to place items of equipment which are used at the same time, near to each other;

- the way in which the smaller areas are linked up within the laboratory unit forms "cores" of circulation space, which seem to bear a strong relation to the use made of different parts of the laboratory. The location of these core spaces, and the location of fixed items of equipment - sinks, fume cupboards etc. - with relation to them, seem to be key factors in dictating how laboratories function.

In terms of the Nuffield recommendations the following is clear:

1. The most generous bench length allocations are now the norm in the laboratories studied with a mean of between 5 and 6 metres per person.

2. The details of the Nuffield recommendations - the very deep laboratories in particular - lead to inefficiencies in provision of bench space for a given floor area.

3. There is a very clear relation between spatial layout and space use - in particular in terms of group interaction and sharing - of which no account was taken by Nuffield.

It seems clear that there is in principle little conflict between the aims of providing functionally effective laboratories and the need for cost efficiency in building form, if the most important criteria is to minimise the total area of laboratory space. It is equally clear that bench space needs have risen over the last 25 years, rather than fallen, and that it is possible that this trend will continue. The finding that user adaptation leads to an increase in the efficiency of provision of bench space, which seems to be constrained mainly by strategic design factors, holds out the hope increasing the provision of bench space in line with user needs, without greatly increasing the total floor area required - so long as the particular requirements of user adaptation are kept in mind.

Over and above this, the findings on space use and group interaction point the way towards far more effective laboratories in the future, where the requirements of researchers in terms space provision will be catered for in such a way as to allow them to take full advantage of the human resources which form such an important part of research organisations.

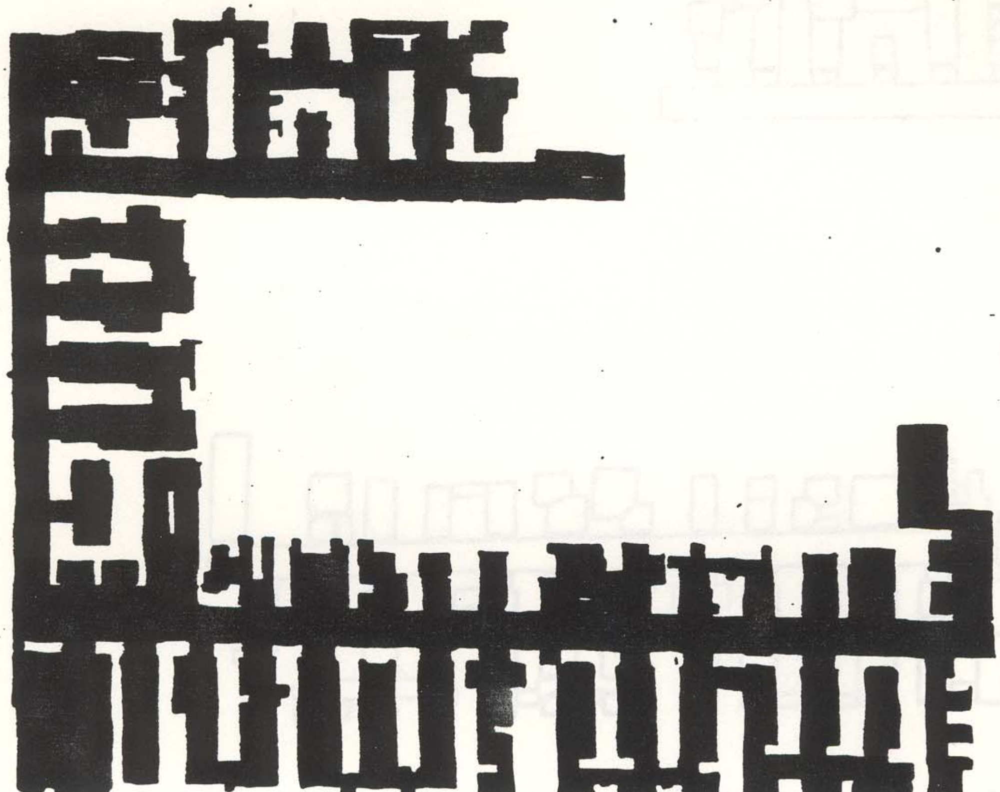

Figure 1b: free floor area of 5th floor at ICRF

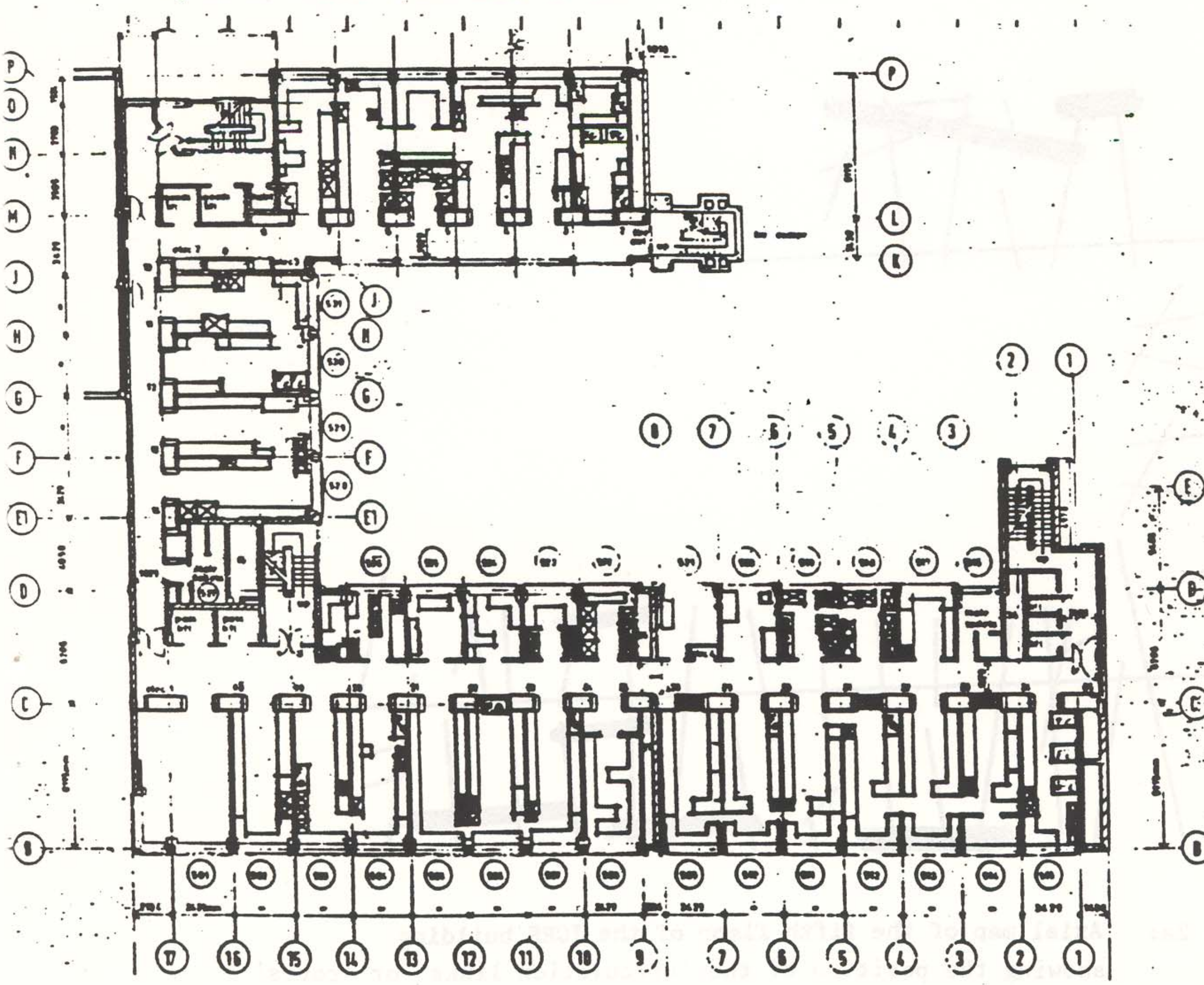

Figure 1a:5th floor plan of ICRF laboratories showing bench layout

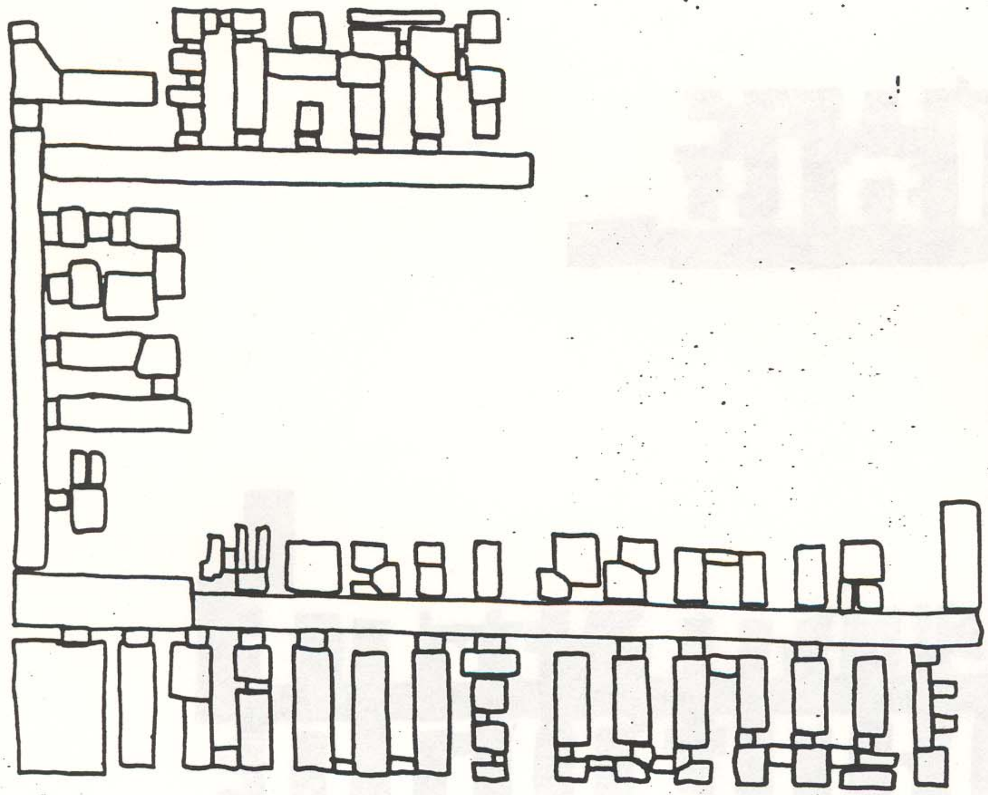

Figure 2b: Convex map of the fifth floor of the ICRF building

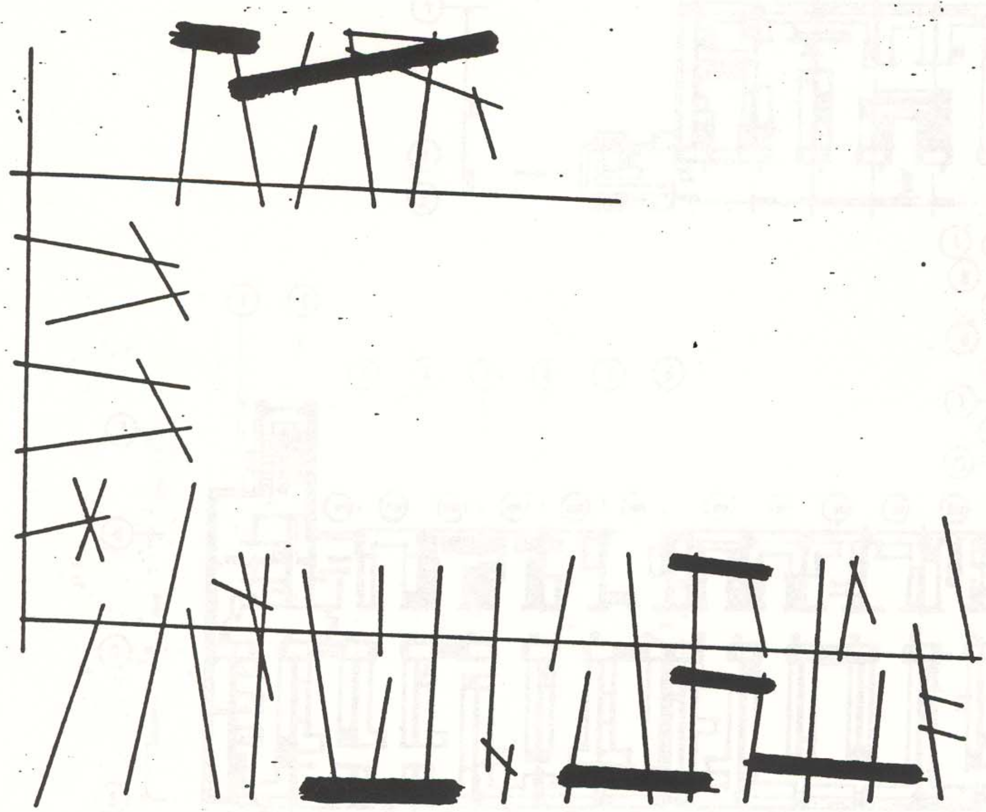

Figure 2a: **Axial map of the fifth floor of the ICRF building**
showing the position of the 'circulation links' or 'cores'
(in heavy black lines)

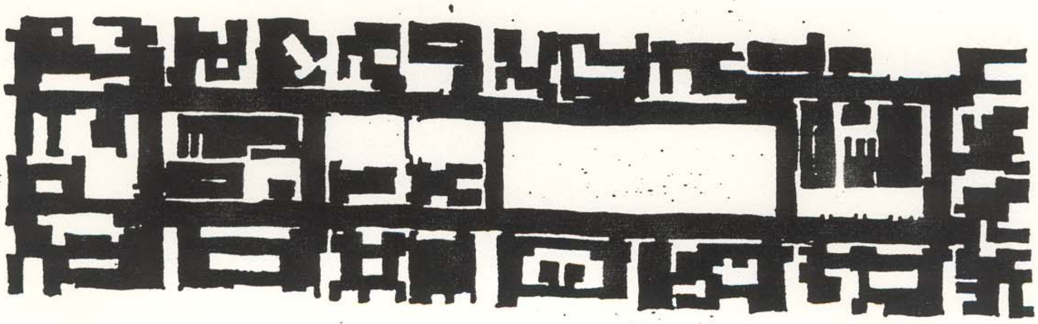

Figure 3b: free floor area (shown in black) of the 3rd floor at British Gas showing the centrally located equipment and peripheral circulation space

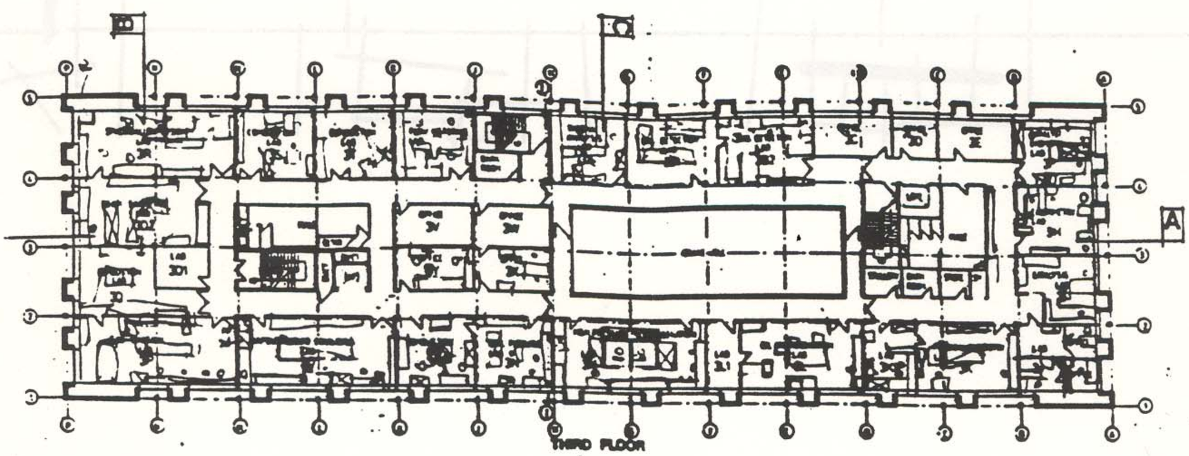

Figure 3a: Layout of 3rd floor of British Gas showing the location of large equipment in the centre of laboratory spaces

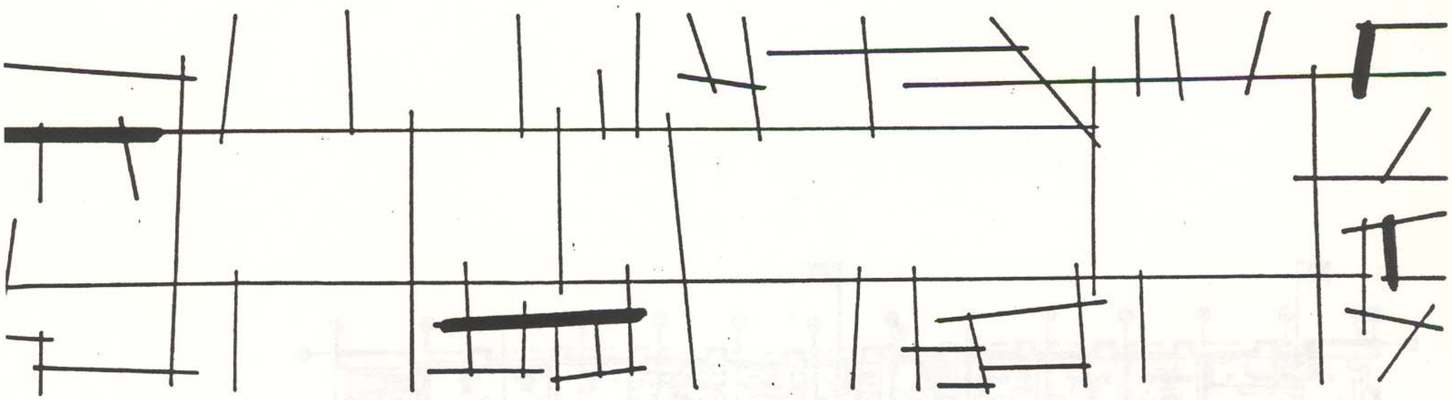

Figure 3c: Axial map of 3rd floor of British Gas showing location of 'cores' (in heavy black lines)

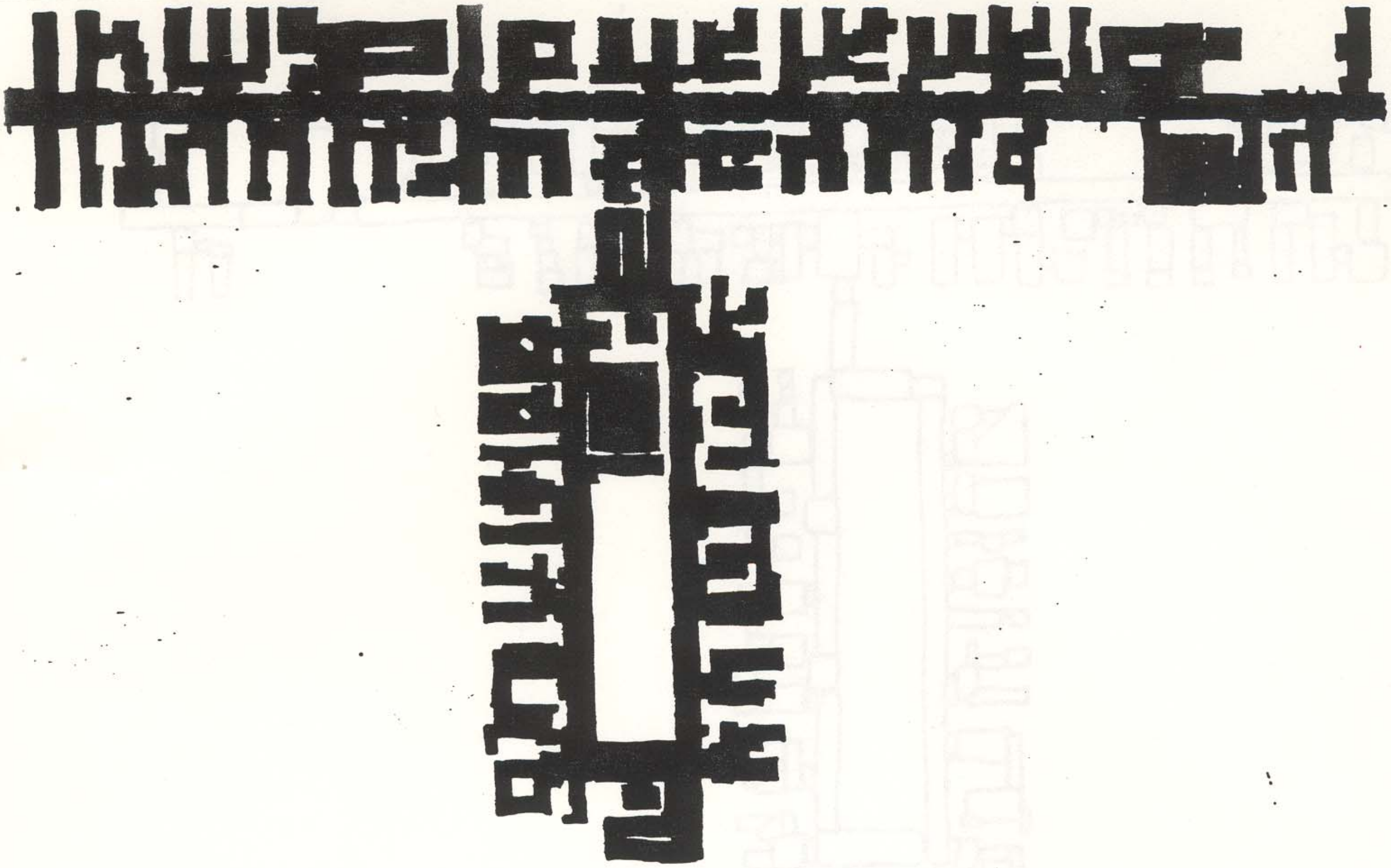

Figure 4b: free floor area of 3rd floor at MRC

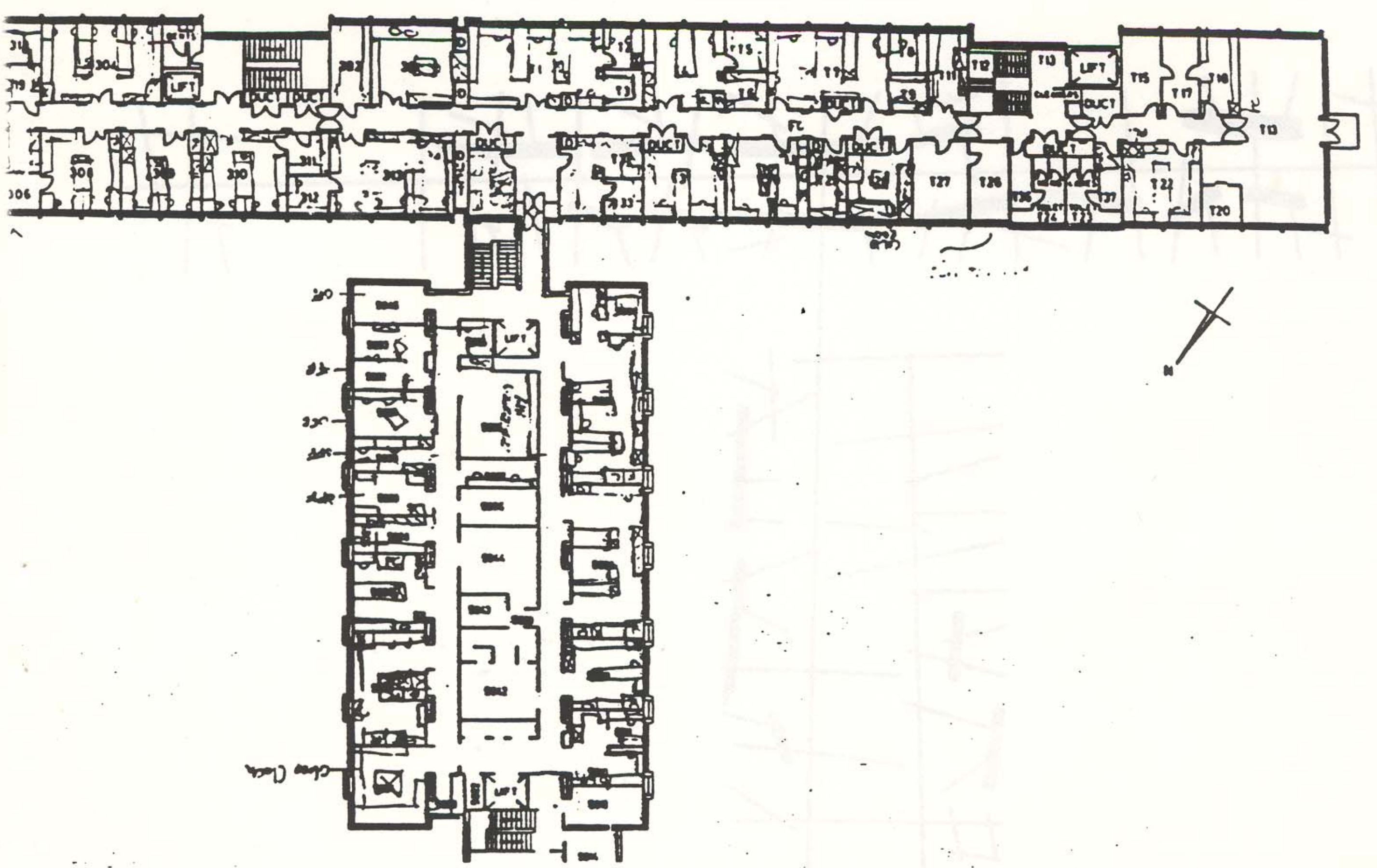

Figure 4a: Layout of 3rd floor at MRC showing the old building (horizontal section) and new section (vertical section below)

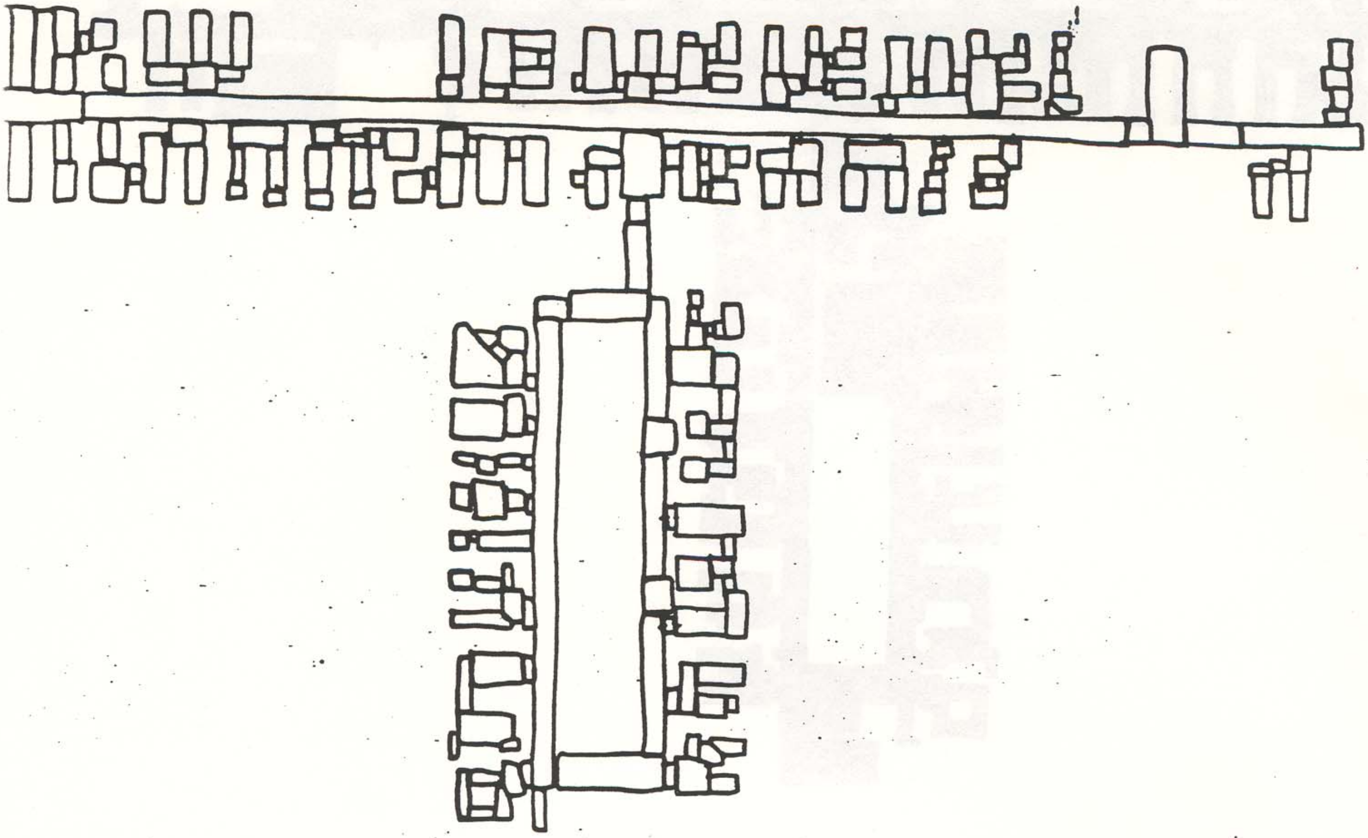

Figure 5b: Convex map of observed spaces of 3rd floor at MRC

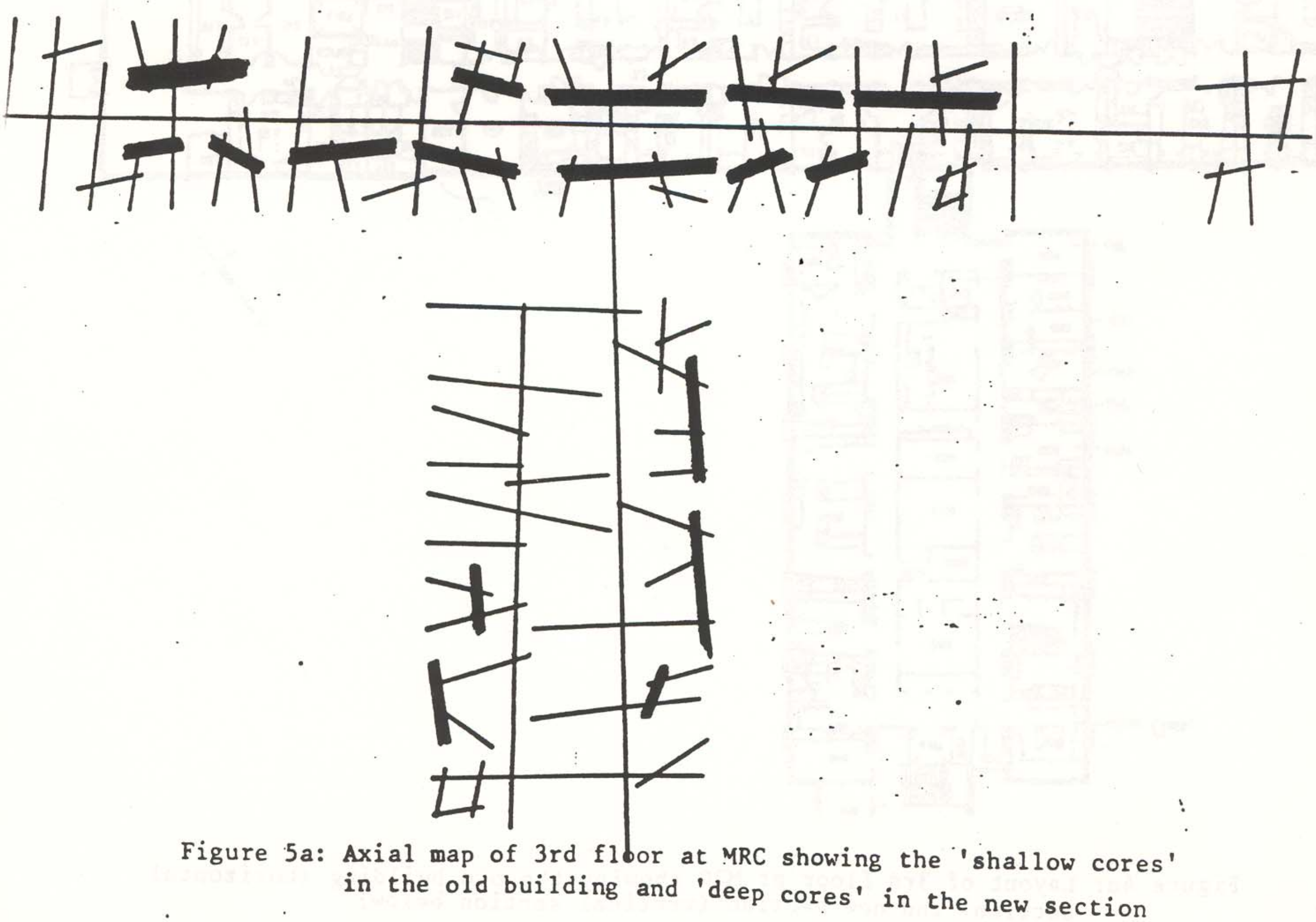

Figure 5a: Axial map of 3rd floor at MRC showing the 'shallow cores' in the old building and 'deep cores' in the new section

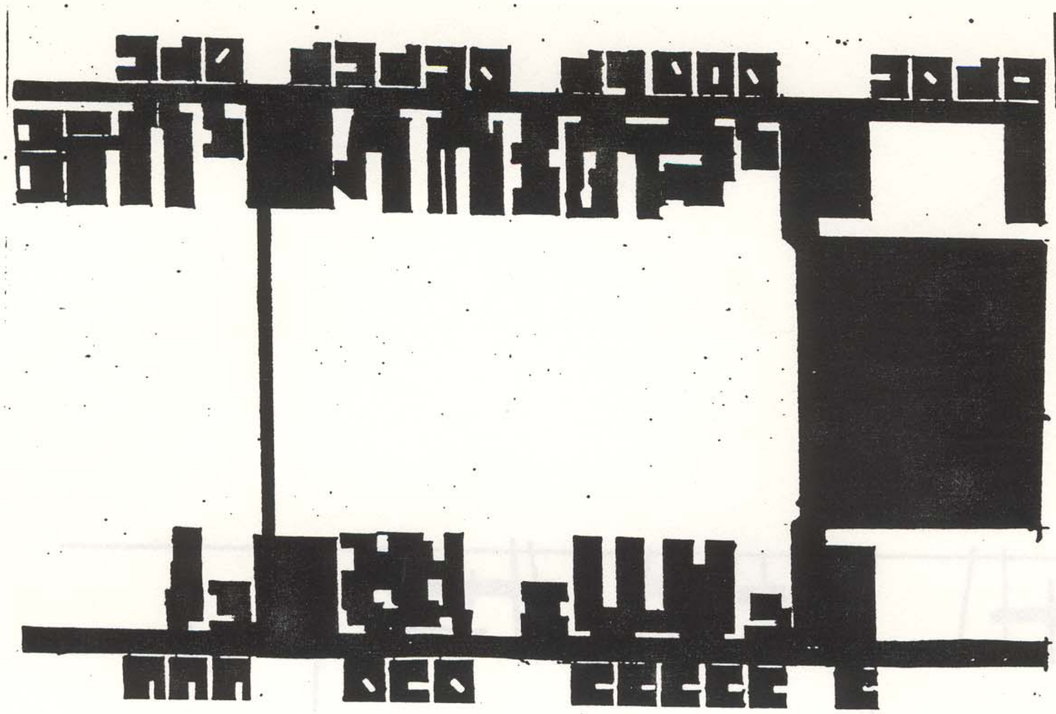

Figure 6b: free floor area (Shown in black) of the ground floor at Schlumberger

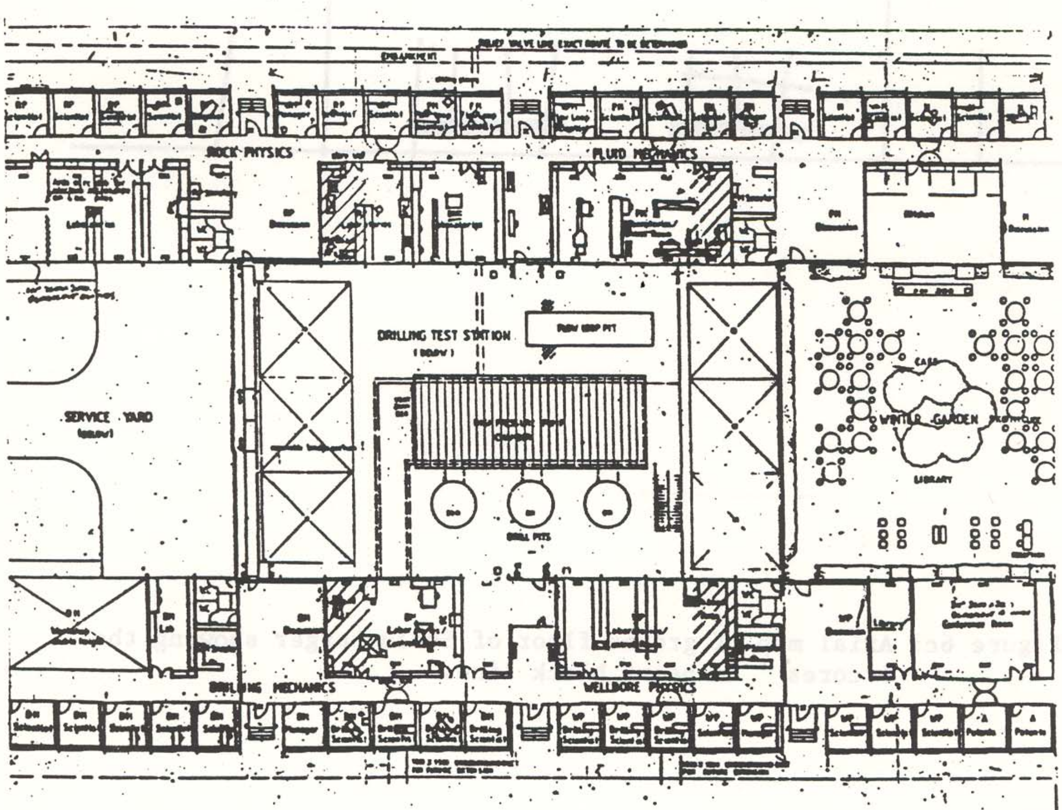

Figure 6a: Ground floor plan of the Schlumberger laboratory at Cambridge

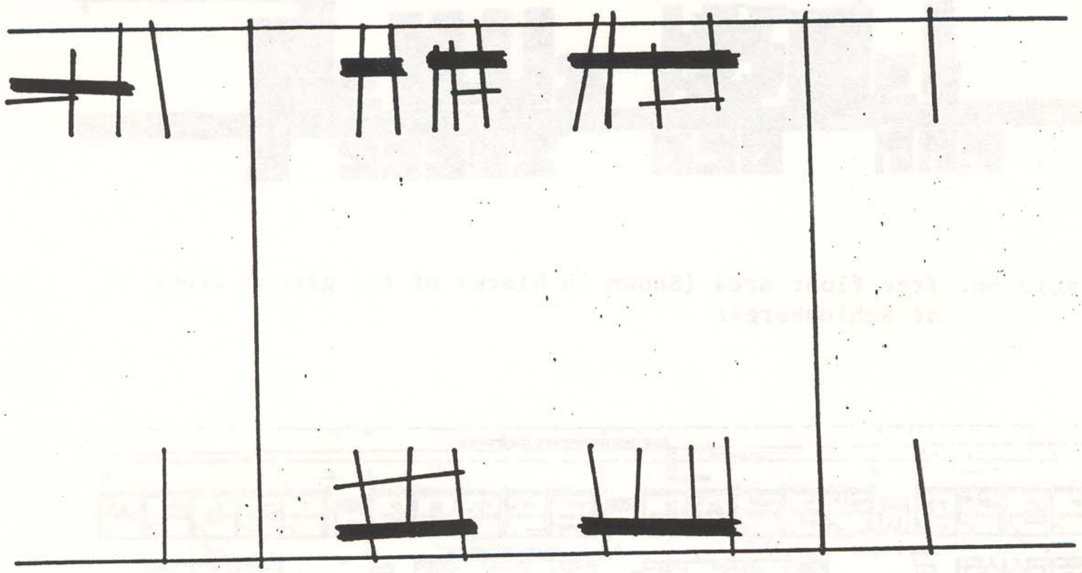

Figure 6c: Axial map of ground floor of Schlumberger showing the ' cores ' in heavy black lines

APPENDIX 1

Summary of findings

The UAS pilot study was set up to evaluate the 1960 Nuffield research into laboratory design. The UAS pilot study differed in intention from the Nuffield study in one key sense: work by the Laboratories Investigation Unit since Nuffield has suggested that group dynamics and spatial layout are more important features in the functioning of laboratories than Nuffield had allowed. Techniques of configurational analysis in conjunction with systematic observation of laboratories in use were therefore employed by the UAS, thus generating a large amount of space use data more rapidly than the Nuffield technique.

The pilot study was also able to look at a number of cases where laboratory layouts had been adapted over time. Studies of adaptation were seen as an important new source of data, bringing much greater realism to questions of space standards and layout design, especially taking into account the relation between patterns of spatial adaptation and patterns of use.

Although some of the results of the pilot study are fairly neutral with respect to the Nuffield design recommendations, others are clearly difficult to reconcile with that design philosophy, and suggest that a re-appraisal is an urgent necessity. These initial results can be presented under three headings: space standards, layout adaptation and space use:

a. Space standards

- there is a high degree of variation in the amount of space allocated to individuals across the sample of laboratories, and even from individual to individual within buildings;
- there is a clear relationship between space allocation in terms of floor area and bench length within individual buildings;
- the Nuffield measure of efficiency of design - the floor area/bench length ratio - varies considerably through the sample, but holds constant for different parts of the same building, suggesting that the original building design is implicated in some way;
- if we turn to actual space utilisation, there is again a high variation across the sample and even from one part of a building to another;
- there is no direct relation between notional space allocation standards and actual densities of utilisation;
- there is a direct relationship between the actual density of space utilisation and the floor area/bench length ratio;

- there is a direct relation between the notional allocation of space and the ratio of notional allocation to actual use - a measure of the functional efficiency of the laboratory;

So, it seems as though the building users have <u>adapted</u> the layout of their laboratories to increase their efficiency in terms of bench length for a given floor area. At the same time the consistency of that ratio for particular buildings suggests that there are design factors particular to the buildings which limit the efficiency which the building users are able to achieve.

b. <u>Layout adaptation</u>

- studies of layout adaptation show that working scientists invariably break up the long uninterrupted bench runs advocated by Nuffield to make them functionally effective for their changing purposes;

- these changes are neither random nor idiosyncratic, but show striking consistencies within the different types of laboratory;

- the size of the convex spaces is remarkably consistent across the sample, but the variation in average size is strongly related to the efficiency of provision of bench length with respect to floor area;

- adaptation, however, always results in the following:

    - the creation of smaller spaces in which to work, in spite of the fact that this leads to the allegedly undesirable "corners" and discontinuities in bench layout;

    - the linking together of these smaller spaces into groupings, by means of internal circulation links, which reflect and facilitate the relation of individual worker and groups;

    - these "circulation links" vary, however, in their location: sometimes they are "shallow" in the laboratory space, in spite of their proximity to the corridor; and sometimes they are "deep" in the laboratory, close to the external walls;

    - in either case, however, there is a clear "privacy-community" dynamic at work in the functional adaptation of laboratory layout by working scientists;

c. <u>Space use</u>

- these findings concerning space standards and adaptation are strongly reinforced by the space use studies of the pilot programme, which show that there is a strong statistical correlation between patterns of adaptation and patterns of use - to the point where it is clear that without careful analytic and quantitative studies of patterns of adaptation, the pattern of use would not be intelligible;

- the space use pattern only becomes clear if distinctions are made between different types of activity, since each activity relates in its own way to the adapted layout in laboratories. In particular:

  - sitting activities, such as writing and reading, take place within the laboratory space rather than in separate "offices" where these are provided. More typically such activities occur in smaller spaces deep in the laboratory, usually near windows (in spite of the Nuffield warning about glare);

  - non-interactive standing activities (such as bench work) are more broadly spread, but tend to cluster in larger spaces adjacent to the the "linking core" spaces, ie. standing activities are sensitive to the group dynamic of the laboratory even when they are not group activities;

  - this trend shows even more strikingly in the location of interactive activities, such as talking, and are strongly determined by the position of the "linking cores", whether they are shallow or deep in the laboratory;

  - these factors seem to combine to create quite different "working atmospheres" from one laboratory to another - and this is frequently said by the scientists concerned to be one of the crucial aspects of how a laboratory works and their assessment of the functional efficiency of the building.

APPENDIX 2

1.00 Summary of the Nuffield study (1)

1.01 Nuffield's method

The Nuffield study, which was carried out between 1954 and 1959, looked at 19 buildings over the period of a full working year. The following factors were studied:

- space usage in terms of bench length, free floor area and total floor area;

- bench services' usage in terms of the frequency with which differing provisions were used;

- natural lighting requirements for different laboratory activities;

- cost analyses of eight buildings.

Information on space use in terms of bench length, bench services usage and lighting levels was tabulated as frequencies of usage of differing provisions by different grades of staff in different disciplines. These were used to predict likely levels of satisfaction for any given provision.

The Nuffield study was explicitly "designed in terms of the individual scientific worker" since "there is little in the way of fixed organisational structure" in research institutions. The issue of laboratory layout was approached by "a statistical technique whereby the survey data relating to the needs of individuals can be combined." In other words, the issue of group or organisational dynamics and its possible relation to laboratory layout was explicitly excluded from the outset.

1.02 Nuffield's Recommendations

From this starting point the Nuffield recommendations were arrived at through a series of steps;

a. individual space needs were assessed in terms of how much bench run would be adequate for what proportion of the time;

b. given these metric standards maximally long straight bench runs were argued for as:

   i) providing for those occasions where long bench runs would be needed, and;

   ii) optimising the ratio of bench run to circulation area.

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1. - The Design of Research Laboratories, Nuffield Foundation Division for Architectural Studies, O.U.P. 1961.

c. reading and writing were not seen as appropriate activities within the laboratory itself since highly serviced laboratory space was more expensive than office space. Separate office spaces adjacent to the laboratory were therefore deemed preferable;

d. working areas under windows were argued against on grounds of safety, efficiency of service runs and excessive glare;

e. servicing should therefore be centrally rather than peripherally located, even though this was not necessarily the cheapest solution.

1.03 The Nuffield Design Philosophy

These arguments led to what became known as the characteristic Nuffield design, marked by:

a. the long thin laboratory unit with two parallel bench runs and central circulation;

b. a central corridor layout, either double-loaded with laboratory units or with labs on one side and special rooms and offices on the other;

c. connections between laboratories near the external wall;

d. niches adjacent to laboratories for reading and writing;

e. central services, effectively between the laboratory areas and the corridor, in vertical ducts;

f. different length of bench run according to status of user and scientific discipline;

APPENDIX 3

The following laboratories have been looked at and plans obtained where possible:

Smith, Kline and French labs
Heinz labs
Roche labs
Royal Holloway
Microbiology Compton
Oxford Physics
Charles Darwin Building, Bristol
Edinburgh Zoology
Birmingham Department of Mines and Metallurgy
Schlumberger Earth Research labs
MRC Molecular Biology labs, Cambridge
New Cavendish labs, Cambridge
PA Technology labs, Melbourne
NAPP labs, Cambridge
Department of Biochemistry, Cambridge
Water Research Centre, Swindon
British Gas labs, Fulham
Imperial Cancer Research Fund labs, Lincolns Inn
University College London, Dept. of Chemistry

Of these the following have been visited:

MRC Molecular Biology, Cambridge
New Cavendish labs, Cambridge
Imperial Cancer Research Fund labs, Lincolns Inn
British Gas, Fulham
Department of Biochemistry, Cambridge
University College London, Dept. of Chemistry
Schlumberger Earth Research, Cambridge
Water Research Centre, Swindon
NAPP laboratories, Cambridge
Department of Zoology, Edinburgh
Genome Unit, Edinburgh
British Petroleum Research Centre, Sunbury
Amersham International, Cardiff
St Georges Medical School, Tooting
Merck, Sharpe & Dohme, Harlow

Detailed spatial analyses and observations of use at both bench scale and at the level of whole floors have been undertaken at four laboratories:

Imperial Cancer Research Fund, Lincolns Inn
British Gas, Fulham
Medical Research Council, Laboratory of Molecular Biology, Cambridge, old and new buildings.
Schlumberger Earth Research Ltd., Cambridge.
New Cavendish Laboratories, Cambridge.
Department of Chemistry, University College London Sandoz and "Nuffield" laboratories.

Detailed spatial analysis including some new experimental methods has been carried out on plans of three laboratories:

The Sandoz sponsored labs at the Department of Chemistry, UCL
Water Research Centre, Swindon
Schlumberger Earth Research, Cambridge