# How day-lighting constrains access

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**Abstract**
The paper proposes that constraints on plan possibility imposed by day-lighting in turn place limits of a general nature on possible patterns of access. A typology of possible access systems is developed, all of which arise from two simple conditions imposed on day-lit 'strips' of accommodation: that all rooms be side-lit, and that all rooms be made accessible. The typology serves to formalise the various loosely-defined architectural terms used to characterise circulation systems: rooms in enfilade, corridor access, balcony access, staircase access. The paper goes on to classify the circumstances in which cycles can occur in the access graphs of side-lit buildings, focussing in particular on cycles created by courtyards and light-wells, whose sizes are related to considerations of lighting. It is argued that such effects should be allowed for in space syntax studies of permeability in buildings: otherwise there is a danger that what is due to the exigencies of lighting may be attributed to cultural or organisational imperatives.

## Limits on plan depth imposed by side-lighting

In most space syntax studies of access in buildings, the plan is taken as given, and the analysis proceeds directly to the properties of the graph of permeabilities. These graph-theoretic properties are then interpreted as revealing the character of the organisation occupying the building, or throwing light on cultural conceptions of the type to which the building belongs. Architectural plans are however constrained, of course, by several other 'generic functions' besides those of access. Arguably the most important of these, for many common types of building, are the functions of natural lighting, natural ventilation and outlook, all three provided by windows and the first two provided also by skylights. These act powerfully to constrain plan shapes and dimensions. It is reasonable to suppose that the limits on plan possibility imposed by lighting and ventilation, in turn place limits of some general nature on possible patterns of access. Should this be true, it would be important to identify precisely what characteristics are attributable to such a cause; otherwise the space syntax project runs the risk of attributing to cultural 'genotypes' what in truth has its origin in the exigencies of lighting and ventilation. This paper represents a preliminary attempt to explore and measure such effects.

Let us consider theoretical plans in which all rooms or spaces are to be naturally lit and ventilated, and have outlook provided, by means of windows. (For conciseness in what follows I shall use the word 'side-lit' to refer to provision for all three functions combined.) In practice this would typically cover most dwellings and other residential accommodation such as the private rooms in hotels, the wards in hospitals or the cells in prisons. It would apply to classrooms in schools, and to most shallow-plan offices, whether open plan or cellular. (In all cases we assume that small artificially-lit cupboards, stores, toilets etc can safely be ignored.)

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In all such buildings there must be an effective limit on depth in plan, to which daylight can penetrate to the interior, via windows. (We are discounting any possible top-lighting, which can occur of course only in single-storey buildings or just on the top floors of multi-storey buildings.) What value this maximum depth dimension might actually take in practice depends on a whole range of parameters: the minimum acceptable level of day-lighting at the worst-lit positions, the size of the windows and the height of the ceiling, the reflectivity of interior decorative finishes, and the presence or not of obstructions outside the windows. In order to avoid such detailed consideration of individual circumstances, we can look instead at the dimensions of depth of the plans of large numbers of existing buildings, where we can assume that - for the most part - competent builders and architects have actually achieved acceptable day-lighting at those points which are most distant from windows. (Which is not to say that the depths of those plans are maximal, simply that they do not exceed the maximum value.) Another source of information is in the rules of thumb or formal guidelines circulating among architects as to the feasible limits on plan depth for different side-lit building types.

Thus the wards of 19th century 'pavilion' hospitals - whose designers placed high value on the benefits of ventilation and sunlight - varied between 7 and 9 metres in width (Taylor 1997). The wards were lit from two opposite sides, so that the maximum distance from windows was between 3.5 and 4.5 metres. For day-lit factory buildings in the early 20th century, the rule of thumb was that, where spaces were lit from two opposite sides, the plan depth should not exceed four times the ceiling height (Souster 1919 p.32). Thus a 3-metre ceiling height would allow a plan depth of 12 metres. Among the designers and developers of late 19th and early 20th century American office skyscrapers - built before the introduction of fluorescent lighting and air conditioning - it was generally agreed that office floor-space could not be let commercially if it was more than 25 feet (7.5 metres) from windows (Willis 1995 pp.26-28). This limit applied to both cellular and open plan offices.

**Day-lit 'strips' and their access systems**

Whatever this maximum distance from windows might be, it sets an obvious constraint on plan shape. As the total area of the plan is increased, so it comes to meet the limit on depth in one direction (Figure 1a). Beyond that point, the plan must become extended into an ever-longer 'strip' in which the side-lighting comes from the two long sides of the plan. (In strips of finite length the two ends can also be side-lit.) Notice that I am saying rather little here about the geometry of the strip, other than it must not exceed the specified limit on depth. The strip could be straight or it could be curved. It does not have to take the maximum depth at every point along its length, but can fall below this limit, and so vary in depth. This is the process, I would suggest, which accounts for the appearance of 'wings' and 'ranges' in the plans of larger side-lit buildings of all types. A greatly extended strip can, in a real building, be cut up into lengths and re-connected into patterns of wings and courts. We will look at such options later.



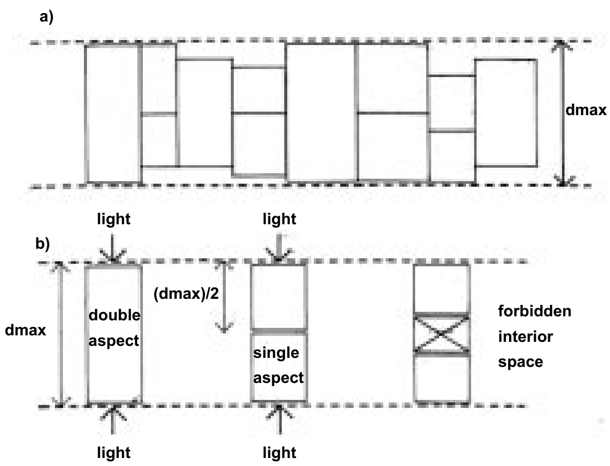


**Figure 1:**
**a) A day-lit 'strip' with maximum plan depth d.**
**b) Double-aspect room and single-aspect rooms in a day-lit strip, and a forbidden interior room.**

For the moment however, let us continue to consider a single linear strip extending indefinitely. Let us consider the possible ways in which the interior of that strip might be sub-divided into rooms. It can be completely undivided and consist just of open space, as in the wards of pavilion hospitals or the day-lit factories already mentioned. If the strip is divided into rooms with convex shapes, then in configurational terms - without saying anything more about their shapes or dimensions - we can distinguish two possible types of room (Figure 1b). A double-aspect room extends right across the strip and is day-lit from two opposite sides. A single-aspect room is day-lit just from one side of the strip. Two single-aspect rooms can be arranged back-to-back; and if the strip is maximally deep, then the wall separating the two rooms must lie along the geometrical centre line of the strip. Since we are considering wholly day-lit buildings, all rooms must be in contact with the exterior walls of the strip. And at no point may the strip be more than two rooms deep, since this would imply the existence of internal rooms without windows. These two room types - double-aspect and single-aspect - therefore exhaust all configurational possibilities. A day-lit strip may be planned as a continuous row of double-aspect rooms; as two rows of single-aspect rooms; or as combinations of double and single-aspect rooms in many mixtures and arrangements. In what follows, I will code arrangements of single-aspect rooms as 1, and of double-aspect rooms as 2.

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We are now in a position to compare these various generic room layouts within day-lit strips, in terms of possible permeabilities. The numbers of distinct ways in which access might in theory be provided could be very great, even in relatively short rows of rooms of these kinds. That is to say, there could be very many possible access graphs, differing in minor details. I propose to limit consideration to cases in which generic patterns of access of a uniform character are repeated along the entire strip. Different patterns are possible for ground floors and upper floors.

We will begin with the strip divided uniformly into a double row of single-aspect rooms (Figure 2). (We can then proceed to the simpler cases, of double-aspect rooms, and open plans.) For convenience I am going to show diagrams in which all these rooms are simple rectangles; although I suspect that similar principles governing access patterns would still apply to rooms of convex shapes but without the restriction to rectangularity. Consider the walls of the rooms: we can distinguish three types of wall, by their positions and orientations. There are window walls (W) coincident with the two edges of the strip; back walls (B) opposite the window walls; and side walls (S) joining the window walls to the back walls. It is possible to gain access to rooms, clearly, via walls of these three types.

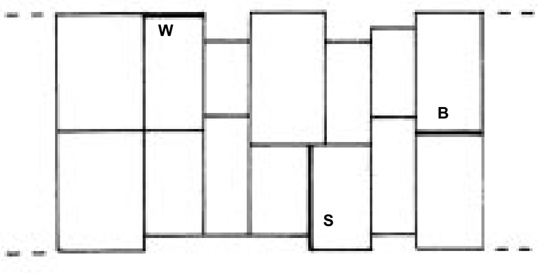


**Figure 2: Examples of window walls W, back walls B and side walls S in a side-lit strip divided into single-aspect rooms.**

Let us start with cases where access is provided by walls of one type only. In all the figures that follow, justified access graphs are shown alongside each arrangement. Suppose that access is gained uniformly to all rooms via window walls

W (Figure 3a). (The arrangement is coded W1.) All rooms, that is to say, are entered separately, directly from the exterior. This is quite feasible on the ground floor. It might seem an improbable kind of plan architecturally; but it certainly does occur, as in blocks of 19th century back-to-back houses, each of which comprises just one room on each floor. Access to the upper floors is obtained by staircases in the corners of these rooms. Since these are separate houses, there is no internal communication between one house and its neighbours. (On upper floors the same pattern is indeed highly improbable, and could only be achieved by the provision of balconies, which did not obstruct the day-lighting, on both sides of the strip, as in Figure 3b.)

A second possible pattern is for access to be provided only via side walls of type S (Figure 3c). This corresponds to the French principle of large-scale domestic planning by the arrangement of rooms in enfilade - in which case strictly speaking the doors should all be aligned. It is certainly possible to find examples of such double rows of rooms; although in practice there would be cross-links at intervals between the two rows, via walls of type B (Figure 3d). We will look later at an actual 19th century French plan of this type. The relevant code would be SB1, for single-aspect rooms connected via walls of type S and type B. There must also be access somewhere from the exterior, via a wall or walls of type W (or from the ends of the strip).



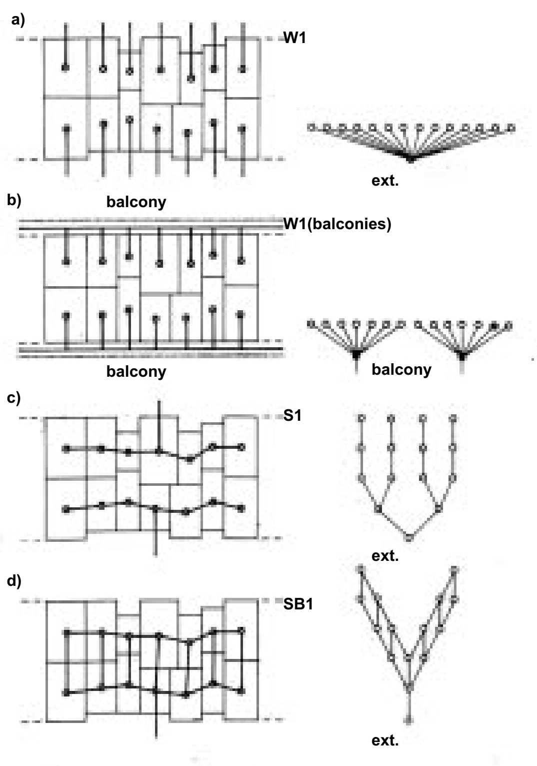


**Figure 3: Patterns of access in day-lit strips divided into single-aspect rooms,**
**a) via W walls at ground level,**
**b) via balconies and W walls at upper levels,**
**c) via S walls in enfilade, and**
**d) via S and B walls, in enfilade.**
**Justified access graphs, rooted in the exterior or in circulation spaces are shown in each case, in this and the following figures.**

Where strips are divided into single-aspect rooms only, and there are no separate circulation spaces, it is not possible to gain access to all rooms solely via the back walls B. (We will come shortly to the possibility of corridor access.)

For day-lit strips which are composed just of double-aspect rooms, there are analogous patterns of possible access (Figure 4). There are now no walls of type B. All rooms may be reached directly via window walls W, either from one side or from both sides of the strip (Figure 4b). The pattern is found sometimes in single-storey schools, where all classrooms are entered separately, directly from the playground - perhaps with a covered walkway running alongside the strip. Alternatively, all rooms may be connected in enfilade via walls of type S (Figure 4c). If the strip has a completely open plan (Figure 5), then access from the exterior must be gained somewhere via one or the other window wall, or via the end of the strip; and the effective interior circulation must run continuously along the strip, as for example as an aisle or aisles, passing say between the beds of a hospital ward or the machines of a factory layout.

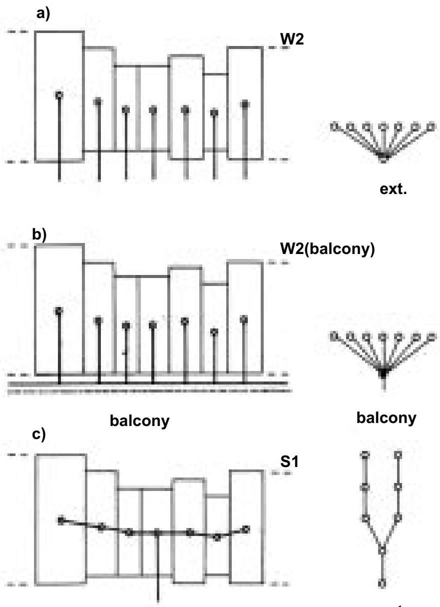


**Figure 4: Patterns of access in day-lit strips divided into double-aspect rooms,**
**a) via W walls at ground level,**
**b) via balconies and W walls at upper levels,**
**c) via S walls in enfilade.**

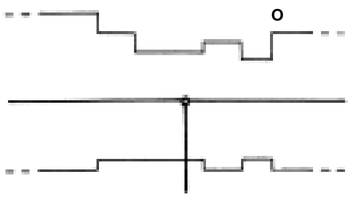


**Figure 5: Patterns of access in open-plan day-lit strips.**

It sometimes happens that daylight can be obtained only from one edge of a strip, for example where the opposite edge lies along a shared property boundary and must therefore remain 'blind' (Figure 6). In such cases the maximum plan depth is obviously halved, and the strip can either be sub-divided into single-aspect rooms (Figures 6a, 6b), or have an open plan (Figure 6c). As regards access, similar arguments to those for full-width strips apply.

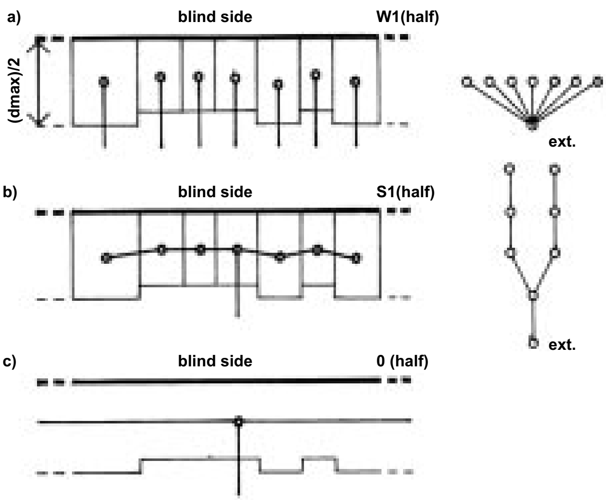


**Figure 6: Patterns of access in day-lit half-strips with one blind side, and thus with maximum depth (dmax)/2,
a) via W walls,
b) via S walls, in enfilade,
c) in open plan.**



So far we have considered plans composed wholly of 'useable space' or of 'habitable rooms' in which access is obtained either directly from the exterior to a room, or from one room to the next. Let us now introduce separate circulation spaces. These can in theory run alongside the window walls W (but in such a way as not to block the light), along the back walls B, or along the side walls S of rooms. As before, let us consider first the case of double rows of single-aspect rooms; and then turn to the simpler case of single rows of double-aspect rooms.

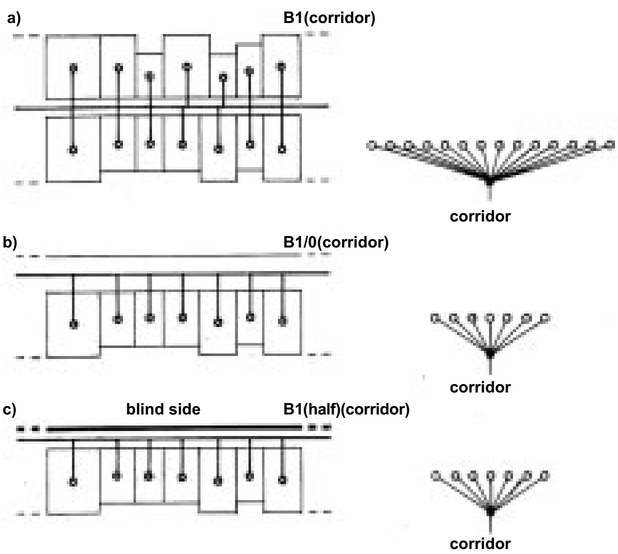


**Figure 7: Patterns of corridor access in day-lit strips divided into single-aspect rooms,
a) via B walls,
b) via B walls, one half of the strip being devoted to a day-lit corridor,
c) via B walls in a half-strip with one blind side.**

Continuous circulation spaces can be provided outside the window walls W on upper storeys in the form of open balconies, as already mentioned (Figures 3b, 4b). Separate access is then possible to all rooms via walls of type W only. Next, consider the possibility of access via walls of type B. These back walls of the two rows of rooms can be imagined as being pulled apart, and a central corridor introduced between them (Figure 7). Now for the first time it is possible to gain access to all rooms, from this corridor, via type B walls only (Figure 7a). By definition all rooms in such a plan arrangement must be single-aspect, and double-aspect rooms cannot be introduced. A second possibility is for the corridor to run alongside one window wall, and itself be day-lit. It then gives access to a single row of single-aspect rooms (Figure 7b). Unless this single-loaded corridor is wide - and becomes in effect an elongated open-planned space - the overall plan depth here might be expected to fall well below the maximum value for double-loaded corridor arrangements. A half-strip with a blind face can be accessed by a corridor as in Figure 7c.

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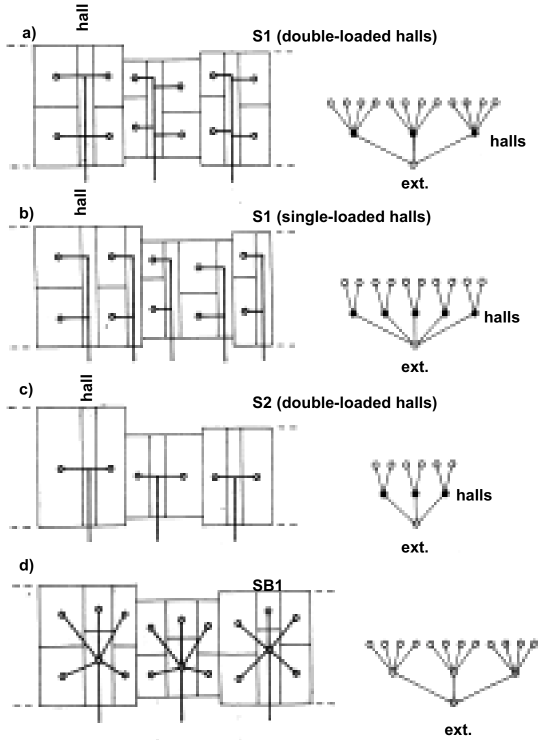


**Figure 8: Patterns of transverse 'hall' access in day-lit strips,**
**a) via 'double-loaded' halls and S walls, to single-aspect rooms,**
**b) via 'single-loaded' halls and S walls to single-aspect rooms,**
**c) via 'double-loaded' halls and S walls to double-aspect rooms,**
**d) via single-aspect hall spaces and S and B walls to single-aspect rooms.**

The third possibility is for walls of type S to be pulled apart, and circulation spaces introduced between them at intervals running transversely across the strip. Let us call such spaces 'halls', using the word in its most general sense, of a circulation space entered directly from the exterior, but without any further cultural connotations. Figure 8a shows an arrangement in which halls are introduced at every third position along the strip, and give direct access via S-walls to pairs of rooms on either side. We can think of these, by analogy with corridors, as 'double-loaded' halls. All rooms in this pattern are accessible from halls, and none needs to be accessed via a habitable room. It will be clear, I think, that should halls be introduced less frequently along the length of a strip, then this criterion could no longer be met. In practice we find this layout, or something like it, in rows of 'double-fronted' terrace houses with central hallways. A related pattern, with 'single-loaded' halls at every second position along the strip (Figure 8b), is found in rows of 'single-fronted' terrace houses with just two principal rooms on each floor (the classic 'two up, two down'). There are directly analogous patterns for strips made up of double-aspect rooms, separated by 'halls' at every second or third position (Figure 8c). Figure 9 shows the ground floor plan of a dormitory and recreation block in a military barracks (the Plymouth Citadel) which approximates the theoretical arrangement of Figure 8c.

I have introduced these last four patterns in terms of a distinct category of circulation space, the transverse 'hall'. More or less equivalent arrangements might be produced in another way: by planning a strip with double-aspect rooms in every second or third position, and allowing entrance into these rooms from the exterior W-walls. These double-aspect rooms then play the part of 'halls' through which all other rooms are accessed.



**Figure 9: First floor of Plymouth Citadel, recreation and soldiers' block (T. Rogers Kitsell, architect) from Marks (1927) Plate XIV. Compare the S2 (double-loaded halls) access pattern of Figure 8c.**

Finally there is the option where the hall itself is single-aspect and extends only part-way across the strip (Figure 8d), again at every second or third position. All rooms in the groups of three or five which surround the hall must then be made directly adjacent to the hall, if they are to remain just two spaces deep from the exterior. Again we can find many examples of these patterns among rows of terrace houses, as well as among the 'staircase access' to student rooms in the courtyards of Oxbridge colleges. Blocks of flats or maisonettes with balcony access provide analogous cases on upper floors.

Now obviously I would not want to claim that this listing of generic circulation patterns in day-lit strips is complete or that it rigorously exhausts all theoretical possibilities. It is a first exploration, arrived at by a somewhat intuitive route. I have made several simplifying assumptions. All rooms without exception are side-lit; I have considered for the most part repetitive patterns where access is only via one type of wall, W, S or B, or via some standard sequence of wall types; and so on. What is more, I have limited consideration so far to access graphs of tree form (they are spanning trees of the adjacency graph of rooms), meeting the most basic requirement of architectural circulation systems, that all rooms be accessible - the single exception being Figure 3d. I will come shortly to the question of cycles in graphs of permeability.

This said, these generic patterns do correspond broadly to what we find in practice in day-lit buildings of very many types, as the real examples have illustrated. Many more confirmatory examples could be cited if space allowed. Naturally in actual buildings one finds single-aspect and double-aspect rooms mixed together; and one finds different generic access patterns in different parts of the same building; as well as the occasional top-lit room among predominantly side-lit spaces. (A characteristic example of the latter would be the kind of top-lit, perhaps double-height hall found at the centres of the plans of large houses, banks or shops.) We will look at some historical examples shortly. But the various parts of the overall circulation system can generally be classified according to the categorisation set out above. What is more, the variety of generic patterns themselves is not very great. They correspond roughly of course to those types of circulation system to which architects have given special names, precisely because they occur so frequently: corridor access (single-loaded or double-loaded), rooms in enfilade, balcony access, staircase access. Notice nevertheless that I have arrived at the various arrangements by setting, in effect, just two fundamental conditions that layouts should meet: that all rooms be side-lit, and that all rooms be made accessible. I have said nothing more about the architectural programmes of those buildings in which the patterns are found. I am going to say rather little about how further choices might be made from these options in the design of particular types of building; other than to make one point about the internal connectivity of rooms.

In the arrangements of Figures 3a and 4a every single room is accessed directly from the exterior, and there is no internal access between rooms whatsoever. These are clearly unusual cases. Perhaps one might want to argue indeed that these do not correspond to single buildings at all, but to aggregates of many buildings. Certainly the blocks of back-to-backs which correspond to Figure 3a are aggregates of many houses. These are layouts and access patterns which would be selected only on relatively rare occasions. The patterns of Figure 8 with transverse halls are much more common: these are cases where rooms are connected internally in groups; but there is no interior connection between the groups. It is not surprising that these are found in terraced rows and blocks of flats. They do nevertheless appear in buildings occupied by single institutions, as in the examples of military barracks and Oxbridge colleges. Here the separate groups of rooms are connected externally at ground level across courtyards.

For access patterns within day-lit strips which connect all rooms via routes running wholly within the interior, we are limited to the enfilade arrangements of Figures 3c, 3d, 4c and 6b, and the corridor arrangements of Figure 7. (There is also the completely open plan.) The enfilade pattern creates a permeability graph that is characteristically deep in the syntactic sense. If the analysis so far is correct, then there are only two general ways of reducing depth in the access graphs of day-lit strips. The first is by creating direct access from the exterior, to all rooms separately or to small groups of rooms (via halls). The second is by means of corridors. By definition, the corridor is a depth-reducing device, giving access as it does directly to many other rooms. It is indeed the one method of providing continuous internal access to rooms in day-lit strips whilst not increasing depth in the permeability graph. No wonder that corridor access has become so general in large multi-room day-lit institutional and commercial buildings of all types.

In his classic paper on ‘Figures, Doors and Passages’, Robin Evans has written of the transition, in grand domestic architecture, somewhere in the period from the 16th to the 19th centuries, from a habit of planning principal rooms in enfilade, to the introduction of corridors (Evans 1997). Indeed Evans claims to have located - possibly - the very first appearance of the domestic corridor, in Beaufort House, Chelsea, built around 1597. In Renaissance villas and palazzi most rooms had more than one door and some had as many as four. Such thorough interconnection was seen as maximising the convenience of the plan. By the 19th century opinion had swung to the opposite extreme: it was terminal rooms, rooms with a single door, that were regarded as most convenient in the domestic context. Evans cites the English architect Robert Kerr as representative of this view. In his book The Gentleman’s House of 1864 Kerr emphasises “the wretched inconvenience of ‘thoroughfare rooms’, which made domesticity and retirement unobtainable” [Evans’s words].

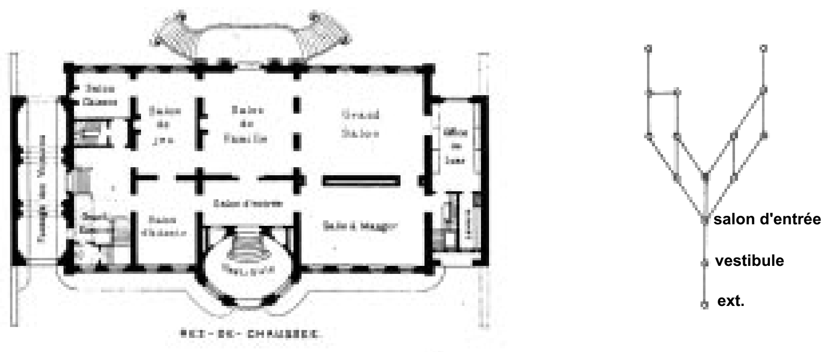


**Figure 10: Ground floor of house in Paris (Nolan and Convents, architects, 1860) from Kerr (1865) Plate 44; and its justified access graph. (Entrances at side and rear are ignored.) Compare the SB1 access pattern in Figure 3d.**

Figure 10 shows the ground-floor plan of a private hotel built in Paris in 1860, which is reproduced in The Gentleman’s House as an exemplar of ‘foreign arrangement’ and a warning - from the British point of view - of how not to do it (Kerr 1865 plate 44). The justified access graph is shown alongside. It is six levels deep at a maximum. The correspondence to type SB1 is very close, the main departures being introduced at the two ends of this short ‘strip’. (In drawing this graph I have ignored, for the sake of comparison with the next Figure, two subsidiary entrances at side and rear. These would reduce the overall depth, as direct entrances from the outside must always do.) We can contrast this French plan with an example used by Evans, the plan of Coleshill, Berkshire by Sir Roger Pratt, of 1650-57. This marks an intermediate stage in the transition from enfilade to corridor planning. Figure 11 shows the first-floor plan, with its access graph. The central corridor serves all rooms; but the grand apartments along one side of the plan are also connected in enfilade. The social purpose of course is to create independent access for family and servants, by the duplication of routes. Once the corridor is introduced, the depth is immediately reduced throughout, including the depths of those rooms that are also directly connected in sequence. The presence of the two parallel systems is signalled by the cycles in the graph.



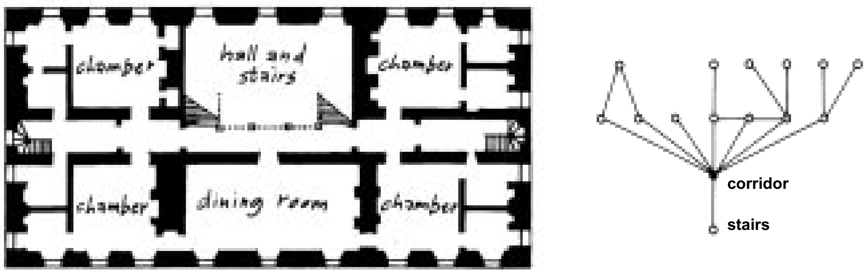


**Figure 11: First floor of Coleshill, Berkshire (Sir Roger Pratt, architect, 1650-57), redrawn from Evans (1997) p.72; and its justified access graph.**

**Types of cycle in the access graphs of day-lit buildings**

I propose to develop this general question of the introduction of cycles into the access graphs of day-lit buildings, by reference to a specific example: the old War Office Building in Whitehall designed by William Young and completed in 1906. Figure 12 shows the ground floor. The plan is composed of a ring of peripheral day-lit strips which surround two large courtyards, one quadrangular, the other triangular. Three further strips run across the interior of the plan from north to south, each lit from one side by a court and the other from smaller light-wells. In general the strips are of the type B1/O illustrated in Figure 7b, with wide single-loaded corridors; although on the north side of the quadrangle there is a short length of type B1 double-loaded corridor. Small groups of three or four adjacent offices have interconnecting doors, much like the plan of Coleshill; several architectural historians have commented on the affinities, at this point in the late 19th century, between office and domestic planning. No doubt these clusters of rooms corresponded to certain groupings within the organisational structure of the War Office itself.

The phenomenon on which I want to focus, as I said, is the appearance of cycles in the access graph of this plan (Figure 13, which relates to the ground floor only). At level 1 there are four entrances from the surrounding streets; at level 2 the main peripheral corridors and the quadrangular court; on level 3 all the rooms accessed from the main corridors, plus the three corridors that cross the plan; on level 4 the rooms accessed from these secondary corridors. There are three kinds of cycles, of differing sizes (numbers of edges). The first is what might be called a local cycle, where groups of three or four immediately adjacent rooms or spaces are all made mutually accessible. Three interconnected rooms create a triangular face in the graph, four rooms a quadrangular face. In the present graph there are numerous local triangular cycles introduced by the intercommunicating doors between pairs of offices, together with those offices' doors to the corridor. Cycles of larger size are introduced where several offices in sequence are connected in enfilade. None of these cycles reduces the depths of any of the offices, nor does their removal increase those depths, which are already minimised by the corridor system, as we have seen. To this extent there are no constraints placed by day-lighting on these kinds of options for introducing duplicate access, hence cycles in the graph.



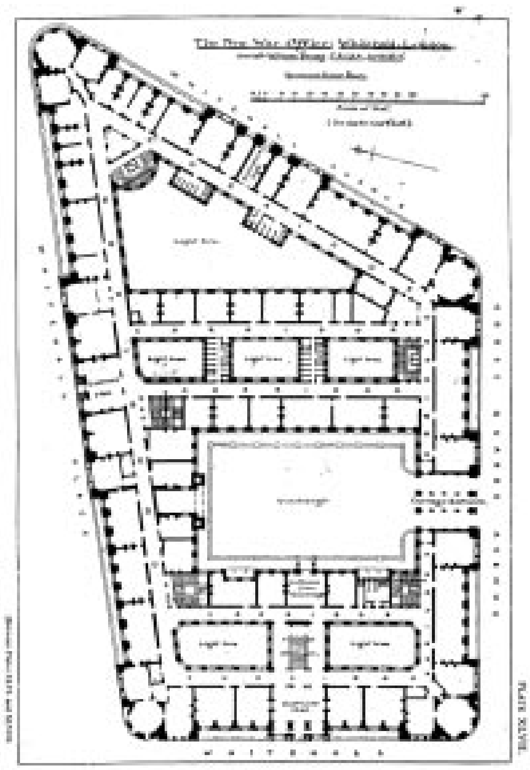

**Figure 12: Ground floor of the War Office, Whitehall, London (William Young, architect 1906) from Marks (1927) Plate XLVII.**

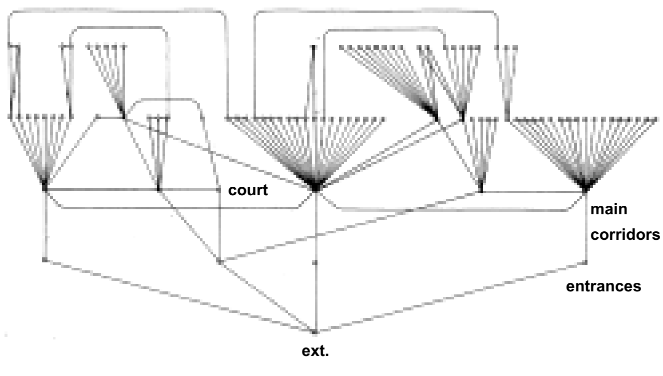


**Figure 13: Justified access graph of War Office plan, Figure 12.**

There remains a third type of much larger cycle, which arises from the fact that the day-lit strips surround closed courtyards and light-wells. Intuitively, one might perhaps expect these to have significance for the resulting depths of office spaces in the graph from the exterior; but they have no such effects at all. Figure 14 shows a slightly modified version of the plan. The peripheral ring of day-lit strip has been disconnected at the main entrance on the south side; and connections at the south ends of the interior strips running across the plan have also been broken. One could imagine the peripheral ring now being straightened into a single long strip, with three short side-branches hanging off it. All cycles created by corridors have thus been broken, and the corridor system has become a tree. Figure 15 gives the corresponding justified access graph. All office rooms remain at the same depths as before. They are all reached, as previously, by the typical sequences: entrance-corridor-room or entrance-corridor-corridor-room. (On the other hand, some graph distances between pairs of rooms have increased.)

I would venture the claim that these three types of cycle - local, enfilade and courtyard/ light-well - are the only types of cycle possible within plans composed of day-lit strips with corridor + enfilade access. (There are further external cycles in the complete access graph created by connecting the exterior vertex to multiple entrances - as at levels 0, 1 and 2 in Figure 15. And, naturally, if several floors are
05.14 included in a single graph, then multiple staircases and lifts can also introduce cycles.) The minimum metric dimensions of courtyards and light-wells are clearly dependent on day-lighting constraints. Without embarking on an extensive discussion we can say that, in general, the greater the number of storeys and the storey heights, the wider light-wells must be made in plan to preserve acceptable lighting levels in the rooms on the lowest floors.

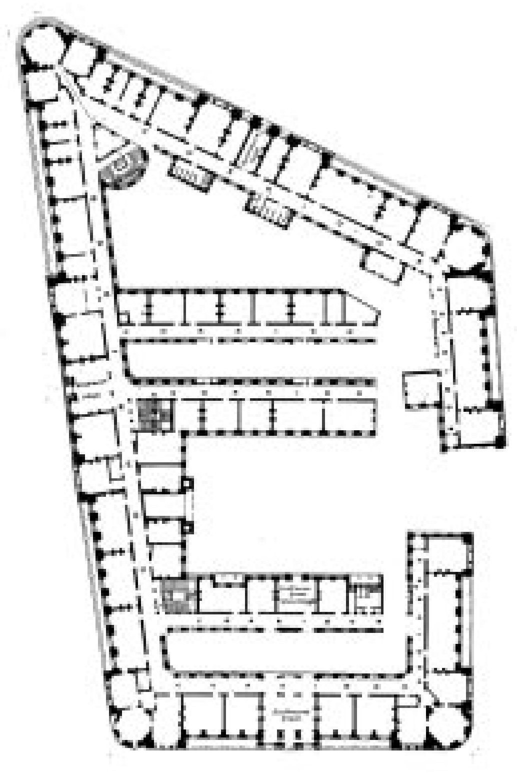

Figure 14: Modified version of War Office plan of Figure 12, in which the cycles formed by corridors around the two courts and access around the five light-wells have been broken.

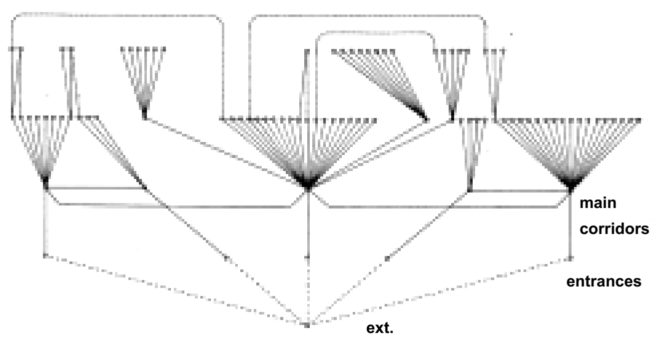


Figure 15: Justified access graph of modified War Office plan of Figure 14. Dotted lines show where cycles are formed by direct access between adjacent rooms. Broken lines show where cycles are formed by connecting the five entrances to the single vertex representing the exterior. Otherwise the graph is a tree.

Furthermore, where outlook, views and visual privacy are valued, these may provide good reasons for increasing the widths of courtyards beyond what minimal standards of day-lighting and ventilation would demand. In the Old War Office, all office rooms which are not round the outer edges of the plan look out onto the two large courtyards, while only (day-lit) corridors face onto the light-wells.

The sizes of cycles surrounding courtyards might in graph-theoretic terms (numbers of edges) be small. A rectangular courtyard could be surrounded by four straight lengths of corridor, a triangular court as in the War Office by just three corridors. The lengths of these cyclic routes in metric terms could however be large. In the War Office the quadrangle is about 100 feet (30 metres) across the narrow dimension, the small light-wells about 30 feet (9 metres). These courts create diversions, hence longer trips - measured as metric distances - between pairs of rooms on opposite sides, compared with straight-line measurements. To some extent the cycles around the courts moderate these effects, by allowing choices of routes, among which walkers would presumably pick the shorter. The modification of the War Office plan in Figure 14 to remove cycles had no effect in increasing depths in the access graph from the exterior. But it certainly does have the effect of increasing metric distances between many pairs of rooms, by the removal of alternative routes. Which effect is more significant, alternative routes created by courts, or the diversions of routes which courts necessitate?



**Metric distances in the circulation systems of buildings composed of day-lit strips**

I propose to conclude this paper with a brief exploratory investigation of these effects of courtyards on metric distances along circulation routes, in plans composed of day-lit strips. The analysis will be somewhat abstract, and as a result may be only indicative of what might apply in actual buildings. Let us consider plans made up of increasing numbers of finite lengths of day-lit strip, starting with just one strip. The actual (metric) dimension of length of one strip is notional: let us give it the value 1. All strips are of the same unit length, and can be joined at their ends into branching arrangements and courts. We will measure distances in these arrangements as shortest (metric) distances along sequences of strips. In the diagrams of Figure 16 I have drawn all configurations in an orthogonal format; hence the distance measurements will in effect be taxi-cab distances. I have drawn one representative case for each possible configuration of n strips. Thus the single possibility for two strips shows them joined to make a straight shape of length 2. But this should be taken to represent also that case in which the two strips are joined at right-angles to form an L, since the taxi-cab distance remains unchanged. Similarly for larger numbers of strips. (Distances between opposite sides of a court are measured around the sides of the court - just as a taxi-cab would have to make a diversion round a single block.)

Figure 16 illustrates all such possible configurations for increasing numbers of lengths of day-lit strip, between 1 and 7. A single four-sided court is possible, obviously, with four strips, and two adjoining courtyards with seven strips. In each case, I have measured shortest taxi-cab distances between all pairs of strips, taking the measurements from the centre points of strips, and counting the length of one strip as 1, as explained. I have then taken the mean of the distances between all pairs. As an example: there are two possible configurations for three strips: a single straight row, and a T-shape. In both cases there are three distances between pairs of strips. For the T they are 1, 1 and 1 giving a mean of 1. For the straight row they are 1, 1 and 2 giving a mean of 1.33. The idea, in architectural terms, is that these are plans with corridor access in which we are measuring the metric distances between all pairs of 'locations'. The 'locations' here are the mid-points of each length of corridor. In reality, these corridors would each give access to many rooms, in which case we should properly measure all distances, via the corridors, between all pairs of rooms. The measurements here are therefore a gross approximation, but still may be indicative of general trends. A further simplification is of course that all day-lit strips are taken to have the same length.

05.16

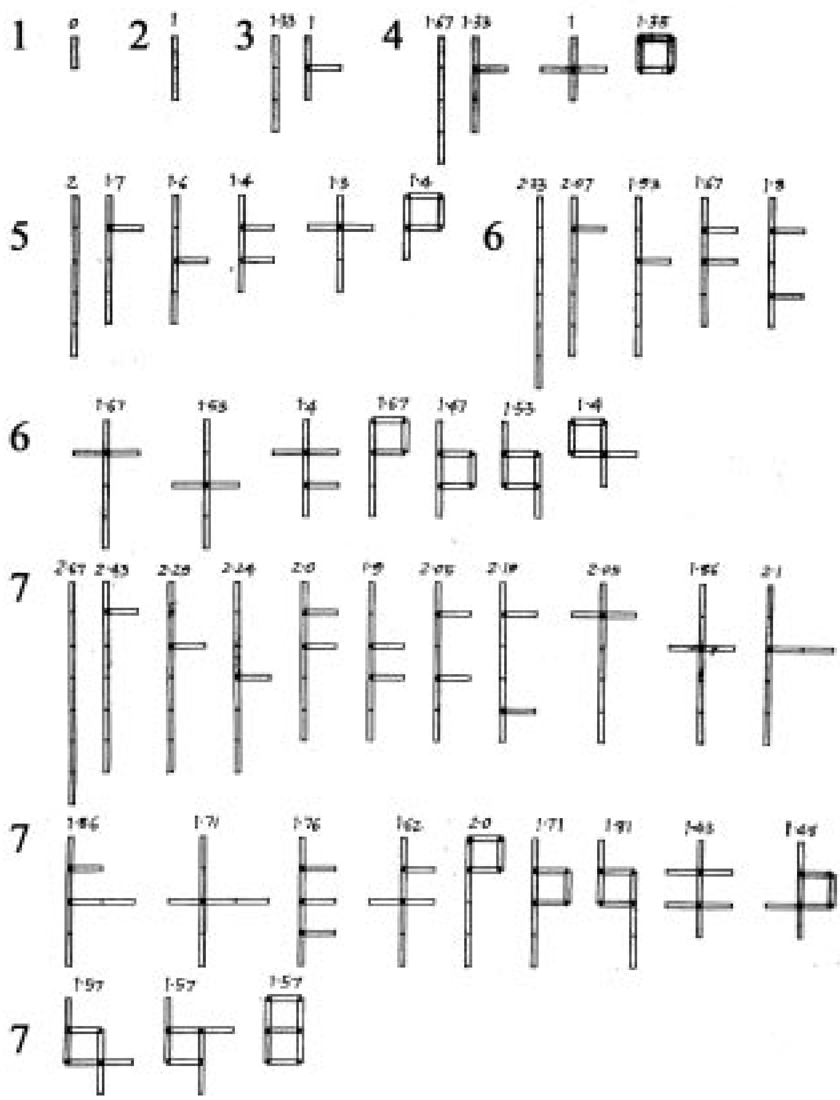


**Figure 16: Diagrams of possible configurations of day-lit strips joined at their ends, containing from 1 to 7 strips (numbers in bold). The number against each configuration gives the mean taxi-cab distance between all pairs of strips, taking the length of one strip as unity. In general this value is highest for simple straight rows, lower for courts or courts with attached arms, and lowest for cross-shaped or fish-bone shaped arrangements.**

But taking the experiment on its own terms, the results show that mean distances are minimised in configurations which are closest to cross shapes or 'fish-bones'. Mean distances are low in courts, or courts with attached wings; but they are not so low as in the crosses. This effect occurs because of the diversions created by courts: each side of a court is two units distant from the opposite side. Simple straight rows have, not unexpectedly, the highest mean distances of all. What these results suggest is that to disconnect a court and turn it into a long straight run, as we did with the outer cycle of corridor strips of the War Office, has the effect of greatly increasing metric circulation distances; but that had we reconnected those strips into a branching fish-bone configuration, we would have reduced mean distances below those in the original courtyard plan.

In the 1970s Philip Tabor made some more detailed calculations which serve to confirm these findings (Tabor 1976). He measured only a few plan configurations; but his measurements in each case were much more detailed and somewhat more realistic. He took four equal lengths of day-lit strip, imagined to be planned as double-loaded corridors, and disposed them variously in a single straight row, a four-armed cross and a court (equivalent therefore to three out of the four configurations for four strips shown in Figure 16.) He plotted distances between all pairs of locations in these three configurations as curves, the 'locations' being distributed continuously along the corridors. His calculations showed mean distances to be greatest in the straight row, less in the court, and lowest in the cross - as in Figure 16.



What do these results mean in practical architectural terms? Their significance, as Tabor points out, is likely to differ depending on the nature of the organisations occupying a building and the patterns of trips made by the occupants. Should few trips be made between widely separated rooms, then the differences in mean distances between the various plan shapes will have little consequence for the average length of all trips. Tabor expresses this effect in quantitative terms, as a theoretical 'propensity' for a building's occupants to visit nearby locations and so make shorter trips. When the value of this propensity is high, building shape has little effect on journey lengths; but when it is low, building shape becomes more significant. In the case of offices we might expect Tabor's propensity measure to be higher perhaps where a building is split into many small office suites rented to separate tenants, who have little business with each other. Here the distances between the entrance and the office suites might be more important than the distances between the suites. For a single large institution occupying one building, Tabor's propensity value could be lower, trips could be longer, and building shape therefore have more of an effect. In such circumstances day-lighting would indeed act as an effective constraint on access, and we might possibly see the consequences in practice, in preferences for cross-shaped or fish-bone type plans.

In any case, the diagrams of Figure 16 represent - within the stated limitations - all distinct configurations into which equal lengths of day-lit strip may be joined. And within each length of strip, there is a limited range of options for their generic circulation patterns, as we have seen. To this extent, it seems fair to conclude that day-lighting does indeed constrain patterns of access at both these levels; and that syntactic analysis should therefore take such effects into account.



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