INAR 413 BUILDING ECONOMICS
LECTURE 02
ECONOMIC ASPECTS OF DESIGN DECISIONS

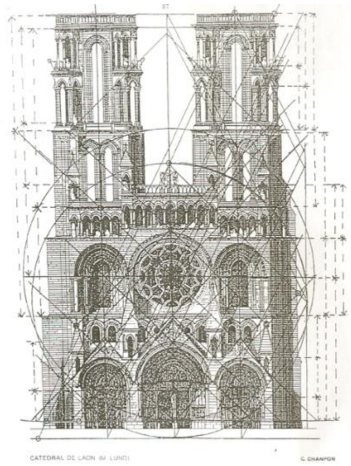
- Many of the world's greatest buildings are extremely complex in their external form, their internal plans, the variety of spaces they enclose, their materials, their decoration.
- The facades alone of cathedrals such as Chartres or Notre Dame astonish us by their wealth of detail; and though the basic plan of the great Gothic churches was relatively simple, the profusion of small chapels, the great traceries of the windows and roof, the host of buttresses and pinnacles externally gave enormous variety of space and form.
- The major buildings of the Italian Renaissance, tightly controlled though they were by the rules of classical proportion, both in plan and elevation, enclosed spaces rich in interest and surprise. The exuberant decoration of the baroque seems sometimes to overwhelm the basic forms of the buildings.

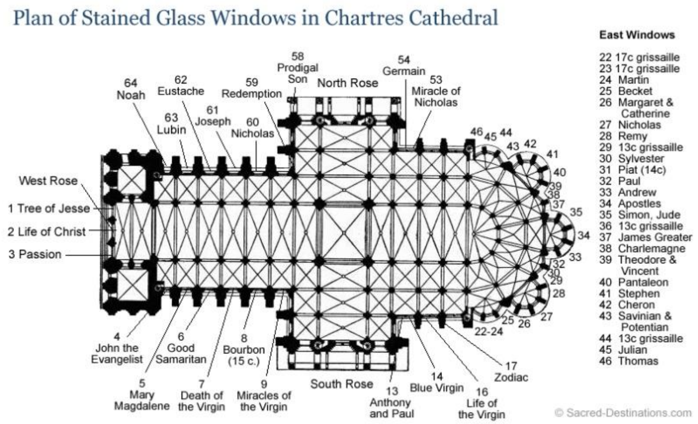
Chartres Cathedral, Gothic

Palais Ducale, Renaissance

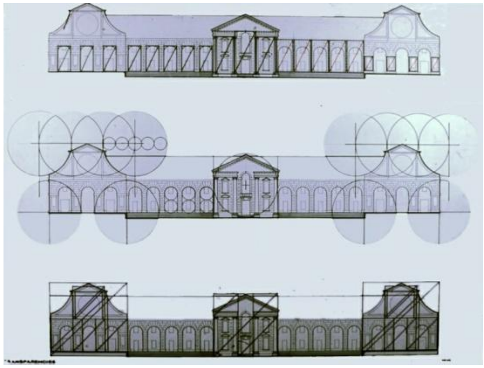
Santiago de Compostela, Baroque

- Yet underlying all this there was usually a guiding principle of organization — religious or secular. Rational planning has been known and practised at least since the ancient Greeks and often underlies the apparent confusion of even the most richly decorated building.
- But it is only in the twentieth century that a powerful and positive ideology of simplicity developed, becoming almost a religion with a host of prophets preaching their own versions — from Adolf Loos's credo that 'decoration is crime', Mies Van der Rohe with his aphorism 'less is more' to the many variants of (often confused) functionalism and rationalist design philosophies.
- But architects and public alike have continued to seek and to see interest in complexity of form and intricacy of detail.





Chartres Cathedral, Gothic



Regulating Lines the facade of Villa Maser by Palladio

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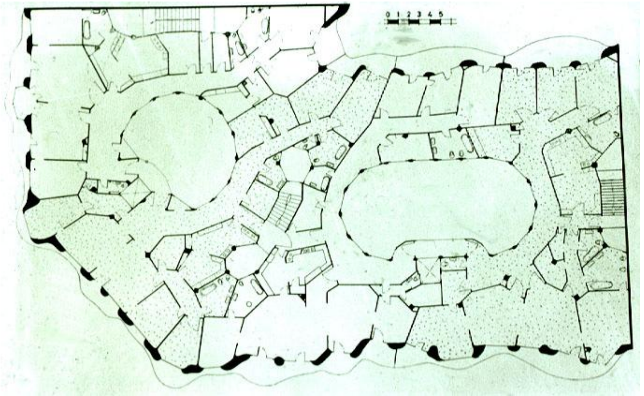
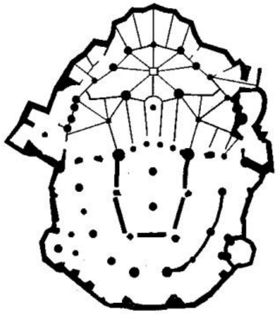
- 'Architecture' wrote Robert Venturi, 'is necessarily complex and contradictory in its very inclusion of the traditional Vitruvian elements of commodity, firmness and delight. And today, the needs of program, structure, mechanical equipment and expression even in simple buildings in simple contexts are diverse in ways previously unimaginable'. His answer to Mies van der Rohe was 'less is a bore‘
- Other architects have, throughout the twentieth century, also resisted the pressures towards stark functionality. To expressionist architects such as Antonio Gaudi and Eric Mendelsohn, straight lines were almost anathema;
- Gaudi's extraordinary Mila house in Barcelona exhibits curves and bulges along its street facade like, as one critic has said, the skirts of a Spanish dancer. His plans for the Church at Santa Colona would defy the bravest cost analyst. Gaudi, has commented that 'modern architecture conveys no sense of ecstasy, which is what I want my architecture to do'.



Casa Mila, Gaudi



Plan of St Colona Church, Gaudi

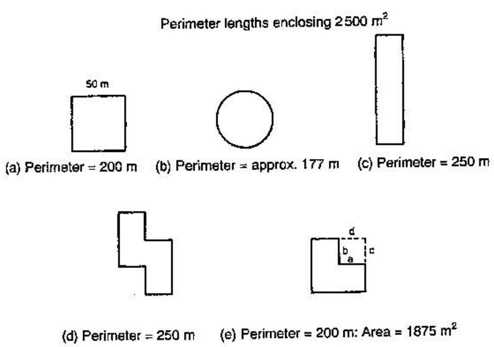
- Yet all the textbooks tell us that simple forms are cheapest.
- We live in an age when clients of almost every sort, public and private, seek buildings at minimum capital costs even though in reality over their lives they may not well provide the best value for money.
- So are we then condemned to cheap boxes with the occasional exercise in high-technology fantasy? Or is there a more subtle and complex relationship between the morphology of buildings, their quality and their cost, which allows variety and interest to be achieved with economy?

Anonymous Building

Barcelona Pavillion, Mies Van Der Rohe

Farnsworth House, Mies Van Der Rohe

- We consider first the simple mathematics of the relationship between the shape of a building and the probable costs of its major elements such as walls and roofs.
- It is obvious that the perimeter of a building of a given area will be a different length depending on the plan shape; and consequently the cost of those elements which are directly related to perimeter length such as walls will also vary with plan shape.
- Consider some possible shapes for a building of 2500 m^2. Because they have the same floor area, they could all potentially provide the same amount of physical accommodation, though different arrangements of the geometry will be desirable or indeed necessary to satisfy the functional needs of the building. The shapes illustrated do however have very different perimeter lengths, and as the costs of many building elements are directly related to the length of the perimeter, these costs will rise as the length increases.



Same area, different plan configurations

Baker Dormitory, Alvar Aalto

Building with square plan

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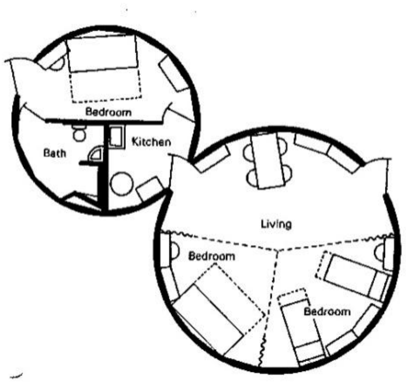
- The cost of walls is the most obvious and probably most important. If our sole objective were to minimize the length of wall needed to enclose a given space, we would design circular buildings. That of course creates problems, particularly problems of internal planning, fixtures and fittings. In a circular house fitting standard kitchen and bathroom units is hardly a possibility without wasting considerable space; even hanging pictures on the wall becomes a challenge.
- Yet some of the finest buildings throughout the history of architecture have been circular. The remarkable Pantheon in Rome, built for the Emperor Hadrian in the second century AD, has been imitated many times through later centuries.
- The traditional houses in many societies have been circular again not necessarily to save cost, though the saving in material may well have been one factor in their development.



Dymaxion House,
Buckminster Fuller

Pantheon, Rome

Traditional Circular Hut, Africa

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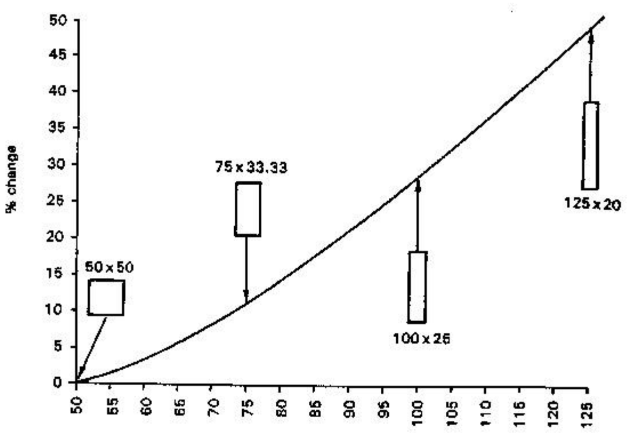
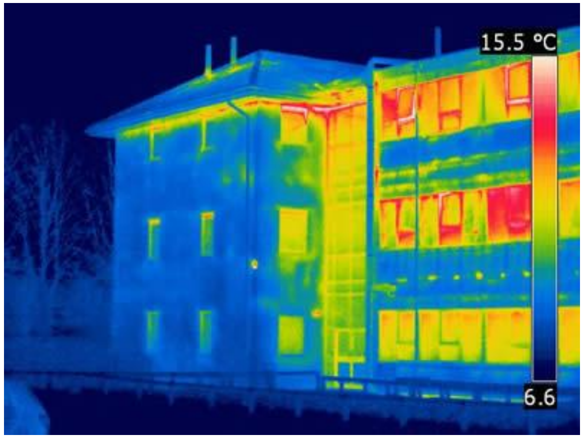
- Nevertheless, despite the virtues of the hexagon and the circle, square corners and straight walls have obvious advantages and in terms of perimeter costs alone, square buildings should be cheaper than rectangular ones. As a rectangle becomes longer and thinner (less square or deep) the percentage increase in perimeter is quite rapid.
- Furthermore it is likely that more window area will be required in the longer walls and the provision of windows can cost up to three times that of equivalent area of the wall material.
- This of course represents capital costs only. There is also a clear relationship between wall length on the one hand and long-term running and maintenance costs on the other. For example heat losses and gains will increase, as will the costs of cleaning and external painting.



Plan shape vs. Perimeter Length



Heat Loss in Buildings

Brick Wall Construction

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- External walls of course are not the only elements which vary with the length of the building's perimeter. It is also likely that distribution systems, such as water supply, waste disposal, electrical wiring, will also increase as the shape moves away from square. This is because the number of points needed to be served by such systems will increase, thus extending the lengths of these essentially linear systems.
- If there are strip foundations the costs of these too will show the same sort of relationship with shape as the costs of walls.

Mechanical Equpment Economy

Regular Strip Foundation

Irregular Strip Foundation

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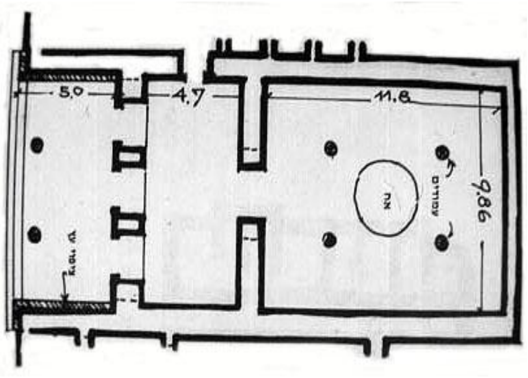
- Most buildings, historically, have in fact been either rectangular or based on systems of rectangle conjoined perhaps with limited curved elements. To see the truth of this simply scan through a well illustrated history of architecture, then think of the usual shape of the most common building type of all — the house — which throughout Europe and America, though less so in the Middle East and Africa, has been predominantly a basic rectangle. The reasons are not only to do with simplicity and costs of wall or roof structures; there are other factors.
- Perhaps the most important is that the longer wall area has itself major advantages. It allows more windows and provides more internal wall space. So in cellular buildings, which most buildings are, more of the smaller spaces into which the building is divided can have access to natural light and ventilation. In urban areas, the influence of street layout and relationships to other buildings has been important; for example narrow frontage houses have had advantages for speculative building developers; wide frontages have advantages for shops.



Mycenean Megaron


Modern Cottage

- The question of roofs is more complex. Thinking still in terms of a fixed floor area, we might expect the costs of a roof to depend mainly on the area to be covered, with relatively little variation with shape. But things are not quite so simple. Roofs comprise three integrated but distinct parts: the structure, the covering and the perimeter. Considering each in turn it can be seen that shape will have a significant but different influence on the possible structural solution and its cost.
- The single most critical factor in terms of cost is span. The less the span, the greater variety of potential solutions, including for example, timber, steel, in-situ concrete and pre-cast concrete; and, particularly significant for cost, the shorter the span, the less cross-sectional area of beams or trusses will be required. As span increases, some solutions will be eliminated (timber, for example); more reinforcement will be needed in a concrete and greater thickness of steel for structural steel solutions.

Short Span Timber Roof

Large Span Timber Roof

Titanium Roof

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- It may be quite straightforward, of course, to provide interior supports in the form of load-bearing walls or columns and to do so in ways which are compatible with the internal planning. This will keep the cost of the roof structure itself down; but load-bearing internal walls will necessarily be more expensive than ones which are not load-bearing, and the costs of columns when they are used solely as roof supports serving no other internal functions, can be considered simply as a further cost of roofing a wide space.
- Where large spaces are covered using columns as supports for the roof, the columns themselves may also serve many internal functions, supporting lightweight partitioning, intermediate floors and staircases. Architecturally, columns themselves become or can become in the hands of good designers powerful elements of interior form
- Internal load-bearing walls are also more than simply supports for roofs; if the plan requires division into many internal spaces with good sound insulation between them, the extra costs of full load-bearing walls may be relatively small.

Roof of Wimbledon Tennis Stadium

Roof System of a Factory

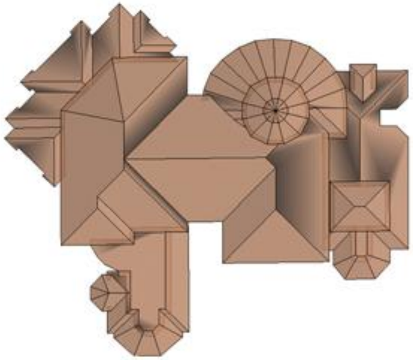
Columns of Boston Airport

ECONOMIC ASPECTS OF DESIGN DECISIONS

- So to summarize the argument on roofs so far, the costs of the structures required to support roofs will tend to be cheaper, the shorter the spans. This may favor a rectangular form, but where internal supports have multiple purposes there is likely to be little difference between deep, even square, and narrow plans. The key factors are almost certainly simplicity and rationality and the co-ordination of internal planning with supporting structures, whether they be walls or columns.
- In whatever way large spaces are spanned, the basic cost principle will remain that simple geometries will be more cost-effective.
- Span, however, is not the only issue; the overall complexity of the geometry, including the pitch or pitches is also important. Pitched, domed and highly articulated roofs will tend to be more expensive than flat roofs as the structural requirements are more complicated. But for any roof type, the greater the complexity of the building plan, the higher is likely to be the cost of the roof structure.

Beijing National Stadium

Southampton Stadium



Very complex roof configuration

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- The cost of the roof covering itself will be relatively insensitive to the building's plan shape, as it will be related primarily to area; but again although the total amount of material required will be roughly a function of area, labor costs will also be more a function of complexity of plan form. Complexity may also increase the quantity of material wasted as the amount of cutting required increases with the number of junctions and boundaries.
- The costs of roofing perimeter components on the other hand is determined largely by plan shape. Such elements as fascias, eaves, gutters, kerbs, parapets, rainwater pipes and the like will all increase with perimeter length of the building. This can be an expensive part of the whole roof structure; it often involves a variety of different trades to do relatively small, distinct operations, something which is bound to lead to low productivity and hence high labor cost. If the perimeter of the roof is not only long but complex, it will require more joints, ends and corners, which will further increase the cost.

Simple Glass Roof

Complex Glass Roof

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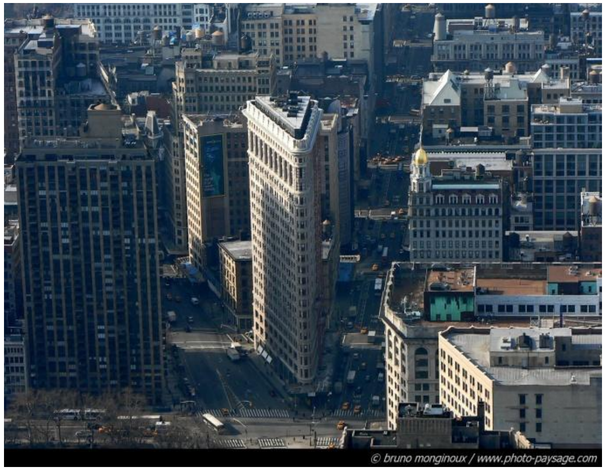
- All these arguments discussed so far on the relative cost efficiency of circles, rectangles and squares are very general. The actual shape of a particular building will in fact be greatly influenced, perhaps almost determined, by two other major factors and their effect on the costs of a particular shape: first is the nature of the site and secondly the internal planning requirements of the building.
- At the most obvious level, the site may virtually impose a shape on the designer. This is particularly likely to be the case in heavily built-up areas of course.
- If not actually determined by the site, the possible positions and forms of a building may be restricted by adjacent buildings or by landscape features such as slopes, trees to be retained, water courses, rock outcrops (which can be moved but at great expense).



Flatiron Building, New York

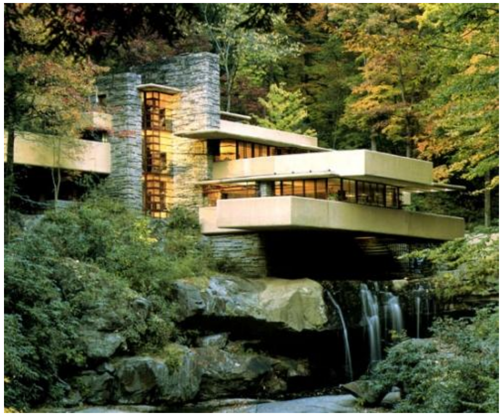
Military Barracks, USA

Street View, Brooklyn

- Even when there is some choice as to shape and position, physical features will influence potential costs. If for example the site slopes, a longer thin building will probably have lower foundation costs because of the reduced amount of cut and fill required; even a complex shape using the land contours may be cheaper than a simple one which requires, say, the removal of rock.
- It is also likely that there will be planning constraints on the use of the site, such as the maximum number of storeys allowed. The plot ratio, will dictate the size of the building in relation to the overall size of the site and of course the relationship of ground-floor area of the building to the total site area will affect the cost of external works. The smaller the footprint of the building on the site, the higher will be the costs of land-scaping and paving.
- The physical characteristics of the site may not be too restrictive, but nevertheless designers, clients and planners will want a building to respond to its particular location.

House on Sloped Site

Building/Plot Ratio



Fallingwater House, Frank Lloyd Wright

- Similarly, internal planning requirements might have implications for overall shape which outweigh advantages of simple rectangular or square forms. A major objective for any design is to provide internal spaces that allow a building's function to be fulfilled efficiently.
- For some industrial and commercial buildings these may restrict the planning possibilities considerably for example where a factory requires long production lines. But for most buildings, there will be very many ways of meeting clients' and users' needs. Yet for complex buildings an optimal solution, optimal in the sense that it meets a range of different requirements as closely as possible, may well be very difficult to produce within an obviously economic plan.
- Solving these problems is one of the designer's essential skills; and occupies much of the time and thought that goes into every project whether in the university design studios or the practice office.



Fiat Factory, Italy

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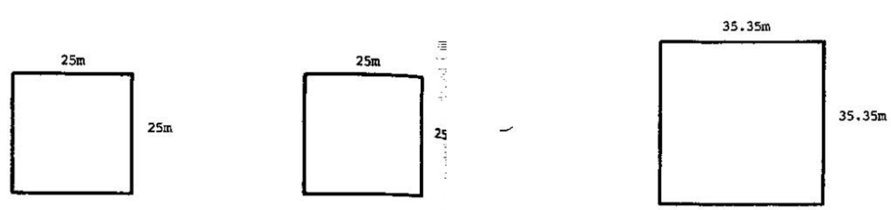
- The absolute size of a building and its height both have effects on the costs per m^2 of floor area.
- Buildings are three-dimensional objects and storey height is an important influence on cost. One way which used to be popular for making quick estimates (the cubic method) used volume as the basic comparator. However relating the area of wall to the total area of the floor — to produce a **wall to floor ratio** — has proved a simpler and reasonable way of assessing a building's cost efficiency. The wall to floor ratio is calculated by dividing the **external wall area** of a building by the **total gross floor area**. The gross floor area is defined as the total internal floor areas of all floors up to the internal faces of the external walls.
- If we increase the floor area of a simple single-storey building without changing its plan form or its storey height, the wall to floor area decreases. A large square building will have less wall per m^2 of floor than a small square building. Obviously if the storey height is increased there will be a higher wall to floor ratio in both buildings. The effect of two alternative ways of enclosing a given area, either with one large or with two small square buildings of two possible storey heights, is shown below. In terms of total wall area for given floor area the larger building will be less expensive, whatever the storey height.



A: Area of each building = 625m²
Total area = 1250m²
Length of Perimeters = 200m

B. Floor area = 1250m²
Length of perimeter. = 141.2m

Wall to floor ratios

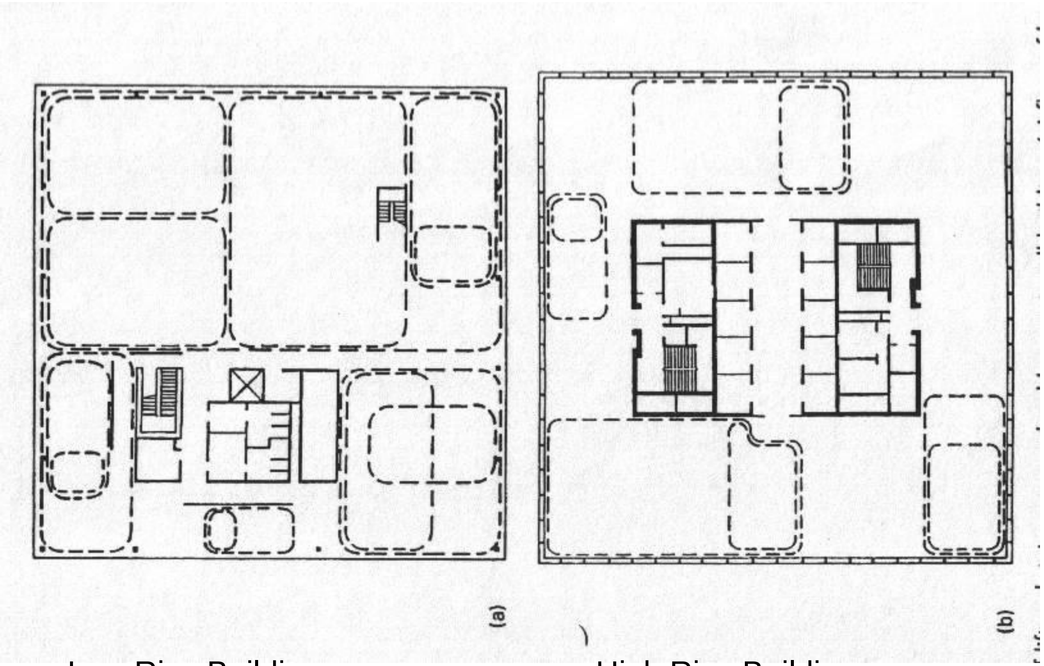
If storey height is 2.8m wall to floor ratios a

A: (200 x 2.8)/1250 =.448
B: (141.2 x 2.8)/1250 =.316

If storey height is 3.4m, wall to floor ratios

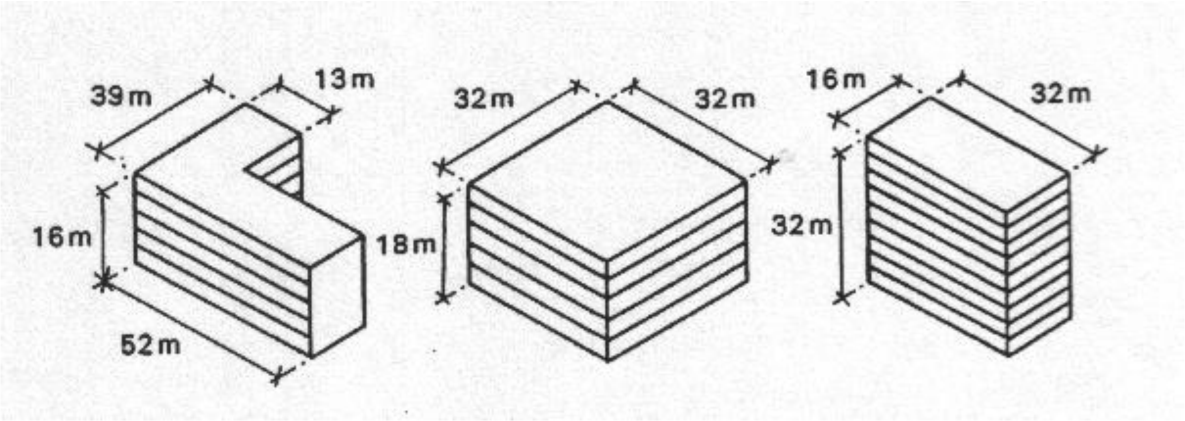
A: (200 x 3.4)/1250 =.544
B: (141.2 x 3.4)/1250 =.384

- One extremely important factor that is not immediately apparent is the impact of height on the ratio of net to gross floor areas. The greater the height of a building, the more people will be using it in total; there will need to be more and bigger lifts and stairways. But these will affect every floor and therefore increase the ratio of circulation to usable space. For example, five offices on the second floor of a two-storey building will be served by one small staircase; the same five offices on the second floor of a 15-storey building will have to share the space with perhaps three to four lift shafts and one or two wide stairways.



Low Rise Building High Rise Building

- The evidence and arguments above have suggested that simple, square — or rectangular — shaped buildings will tend to be less expensive in terms of some important cost elements, that large buildings tend to be less expensive per square meter of floor space than small ones and that high buildings cost more than low ones. It has also shown that the form of a building might be determined by many other factors than the relative costs of these elements. In this section a few very simple examples are examined to illustrate the interrelationship of some of these cost and morphological characteristics of buildings.
- The first example takes the form of a study made originally for the *Architects' Journal* and republished in *Planning Office space* (Duffy *et al.,* op cit. pp. 105-7). It examines the relative costs of three simple possible office shapes for a commercial office block of a total of 5000 m^2



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- The study was based on one real building and two possible alternatives with different shapes but as far as feasible, the same specifications. Two sets of comparison were made, one assuming air conditioning only in the square building where it was essential, the other assuming similar air conditioning in all the buildings. On the first set of comparisons the square, 5-storey alternative is the most expensive, the 9-storey rectangle, the second most expensive and the 5-storey L-shaped building the cheapest. As expected, the wall costs for the square are low but this is entirely outweighed by the cost of services; the higher rectangular building is more expensive than the lower L-shape mainly because of frame and upper floor costs.
- However if it is assumed that all three buildings are fully air-conditioned, the square building becomes the least expensive by a considerable margin.

WHAT WILL GOVERN YOUR DECISIONS AS INTERIOR ARCHITECTS?