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TYPICAL DANISH BUILDING SYSTEMS

Den polytekniske Læreanstalt, Danmarks tekniske Højskole

Technical University of Denmark. DK-2800 Lyngby 1980

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TYPICAL DANISH PREFAB FLOORS, WALLS AND FACADES

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TYPICAL DANISH BUILDING SYSTEMS

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It is my intention in this report to give a brief survey of typical Danish building systems. The report is divided into two main sections: Building Systems, which describes general Danish views on building systems; and Structural Systems, Examples, which covers building projects in the period 1960 to 1980.

The first main section also describes the various conceptions of the possibilities of prefabricated construction that were discussed at the beginning of its period of development, in about 1960, for example, open and closed systems, standardization, modular co-ordination, etc. I have found it reasonable to give a brief account of this discussion because the alternatives proposed and the views advanced at that time are equally topical today and are still used in the continuous adjustment of existing systems and the development of new ones, although the importance attached to them naturally varies, depending on the technology, economy, size of market, etc. in the region in question at the time in question.

This section should preferably be read in connection with "Typical Danish Prefab Floors, Walls and Facades", in which it is also noted that, with the development that has taken place, most components and their joints are today so standardized that one may truly speak of a "Danish building system", with floor and wall components that can be combined almost irrespective of their makes.

Nevertheless, the second main section, Structural Systems, Examples, illustrates the fact that there are not only many variants of "the Danish system", but also completely independent systems with a reasonable degree of utilization.

Finally, in a third section, the consequences of the desire for "flexibility" are discussed.

Translated by Pauline Katborg

Examples of building projects and systems are also to be found in Marius Kjeldsen's "Industrialized Housing in Denmark" (Danish Building Centre, Copenhagen, 1976), and in "Byggeindustrien" (published monthly by Teknisk Forlag, Copenhagen), and in the last section of "Slides and Lecture Notes" (Danish Building Research Institute, Hørsholm, 1980).

BUILDING SYSTEMS

"Standardization" ?

Standardization
Modular co-ordination
Functional requirements

The standardization, modular co-ordination and revision of building legislation (functional requirements) that started after the Second World War have proved to be of immense importance to modern building technology - for all types of buildings.

Open/closed system

Originally, a great deal of discussion went on about open versus closed building systems - catalogue construction versus type houses - and it was the open systems - catalogue construction - that enjoyed greatest official favour.

Catalogue construction - the multi-use building system

The philosophy was that these dimensional standards etc., should lead to the establishment of factories, each of them specialized (and highly mechanized) in the production of series of multi-use building components which could be linked not only mutually, but also with the components of other factories. It was presumed that the client, assisted by a few designers, would thereby be able to get a lot of "tailor-made" houses cheaply and quickly, constructed from building components from catalogues: "catalogue construction"/"catalogue housing".

Type houses - the systematized product

The opposite of this was closed systems - systems in which the organization, parties and product were geared (and locked) to just a few types of buildings that were marketed as "turnkey" products (type houses).

The discussion of the possibilities of open versus closed systems as regards adaptability to requirements, industrialization, cost-cutting, etc., is presumably of less relevance today.

Varied construction - each contract is a "closed" production of structural components

Firstly, the types of dwellings built have become more complex in step with the rising standard of living in Denmark, resulting in a wish for greater variation of architectural expression (environment, low-rise/high-density, etc.), so that standard components no longer constitute a very big proportion of the total output of structural components.

Fitting-out components independent of building system

Secondly, it has been acknowledged that the really big series - where standard units are alpha and omega - are best suited to such building components as kitchen units, refrigerators and stoves, etc., where the factories are so big that they are totally independent of even very large contractors. For example, all building projects are fitted out with components from one or other of the same few factories that make these products, and are therefore "open systems" as regards their non-structural components.

The standardization and modular co-ordination that have taken place have, on the other hand, been of great importance in the design, the factory production and the construction phases.

A large number of details are now known and are (almost) identical from product to product. The sizes vary in standard increments. Linkage is effected on the basis of setting-out lines in standardized grids (modular grids).

Value of the repetition factor.
Project
Production
Erection

Routine through repetition in work operations is ensured when, for example, the edge geometry of the components is limited to just a few shapes regardless of variations in the length and width of the various components. The linkability of identical or different, related types of components is also ensured. The design work is facilitated, since it is based on known dimensions, details, joints, etc., and the project can be built using the products of several competing firms without any re-designing. And, finally, the workmen on the site are familiar with both the function of the components and the erection technique.

Standard/variant/special components

Productivity

Purely for reasons of productivity, the aim should be to use the largest possible number of standard components and as few special components as possible. Those unavoidable individual wishes should preferably be supplied by simple variants of the standard - not by components that require special production methods.

"Definitions"

The designations "standard", "variant", "special" are, incidentally, rather poorly defined, depending as they do on an assessment that is based on the production apparatus of the supplier in question.

Standard components

"Standard components" are thus components which the supplier in question is always ready to produce and which he may even make for stock (not concrete components) - in other words, components that can pass through the production apparatus without more ado.

Variant components

"Variant components" are components that he may also be prepared to produce, for example, on the basis of factory-defined details, dimensional and section sketches etc., but which require planning, supplementary production plant, manual intervention in the otherwise automatic process or similar.

Both "standard" and"variant" thus often have nothing at all to do with any official standard, but express the factory's internal "standard" (procedure) - which may deviate from that of its competitors.

Special components

"Special components" require a special production apparatus or major alterations to the normal production apparatus on account of special dimensions, details, etc.

Wall component (example)

For example, a wall components factory may determine that all installationless walls with one height (or two heights) corresponding to Danish Standard for storey heights and normal (factory-specified) floor thickness are standard wall components provided they have a width that is a multiple of 12M (max. for example 84M) and a thickness of either 150 or 180 mm.

If a wall component contains embedded electrical installations, placed in a given pattern, the manufacturer may decide to include it in the standard, whereas other factories would call such walls variants.

Special electrical installations and doors, placed in accordance with a given dimensional system will normally result in the wall being regarded as a variant component.

Special doors, cams, reinforcement for longitudinal bracing walls, special thicknesses, lengths and heights, insulated sections, etc. mean that the normal wall moulds cannot be used, and the component is thus a special component.

It's the overall solution that counts

There is very little difference in the total construction cost of a project based on the use of the largest possible number of standard wall components and just a few special walls, on the one hand, and the cost of a project with greater variation in plan and facade and thus a relatively large number of variants and special components on the other. The preferred solution should be the one that gives the best utility value for the money, measured not in the cost of the wall components, but in terms of the total investment.

On the other hand, if the above arguments were used at all decisional levels, buildings would become too costly. A 10 or 20 or 30 per cent price supplement on a single type of component is of little importance to the total cost of a project, but 2 to 3 per cent of the total is often just enough to make the client reject the project as too costly.

Always seek the cheapest solution first

It is therefore clear that every effort must be made during the design work to seek the cheapest solution on the basis of experience, estimates and contact with manufacturers, and it is equally clear that consultants (architects, engineers) will never be able to make a good design without an intimate knowledge (personal or through persons permanently attached to the design team) of production and erection, whether the material is timber, steel, concrete or plastic.

Project details to suit production plant

Project details and production plant are two sides of the same coin, and the designer must therefore either relate his design to one or more known production methods or deliberate design for a new technology - and the latter takes a lot of doing - or, rather, takes a lot of men.

Compromise

Designing purely on the basis of productivity considerations leads to a lot of identical buildings and lack of layout variation. The needs of the users must be satisfied in an optimal way, and the only viable solution is a compromise between economy, technology and needs.

If a design team has sought the minimum solution in every respect, it will also be in a position to assess the supplements for deviations from the technological optimum. And it will then also be able consciously to seek the cheapest and best way of satisfying the needs: a variant should always be chosen in preference to a speciality. In the final count it is the client who decides on the basis of analyses of the consequences of alternatives. Many architects and engineers give up on these and other production-related problems, especially when the special character of a factory is first revealed after a tender.

Normal solutions

An increasing part of the detailed design process is therefore now shifting from the consultants to the contractors, who elaborate "normal solutions" that are placed at the disposal of the designers. In addition, the parties of the building sector have entered into co-operation on the elaboration of "standard solutions" under BPS (Byggeriets Planlægnings-System) (The Building Industry's Planning System).

"Building system" indefinable

It therefore probably serves no useful purpose to try to arrive at a unique definition of the terms "standard component", "variant component", "special component" and "building system". The first three normally depend on the production apparatus of the manufacturer in question. "Building system" is a term that is, for example, tacked onto the principle used for a specific project. Contractors like to talk about "their" building system, and that has its effect (?) when a firm wants to sell its know-how on licence abroad.

Only one Danish structural building system ?

As far as medium-rise housing within Denmark is concerned, I would be inclined to hold that we really have only one building system, based on hollow floor components, solid, unreinforced wall components, three known joints (floor-floor, wall-wall and floor-wall intersection) and a general knowledge of how to finish this structure. The system is normally used with load-carrying cross-walls, cf. figures 1 and 6. In saying this, I have probably trodden on the toes of some manufacturers. I should, perhaps, hasten to add that my remarks do not apply to industrial buildings and 1-2 storey buildings. The second chapter shows that we now have several new systems for these types of buildings.

System variants

"The Danish system" has a number of variants which cannot be attributed to specific contractors, although the following examples could be given (have) names.

Many/few layouts in the "system"

A building project may comprise many different types of dwellings (flats), where a limited number of components are combined in different ways on the basis of the modular grid etc., or a limited number of flat layouts, where each individual component has its ordained place in the general plan.

Structural systems

Building projects can also be categorized according to the structural system used: cross-walls, longitudinal walls, load-carrying skeleton, load-carrying boxes, combinations of cross-walls and longitudinal walls, etc. The options as regards layouts depend on the principle adopted, see the next chapter.

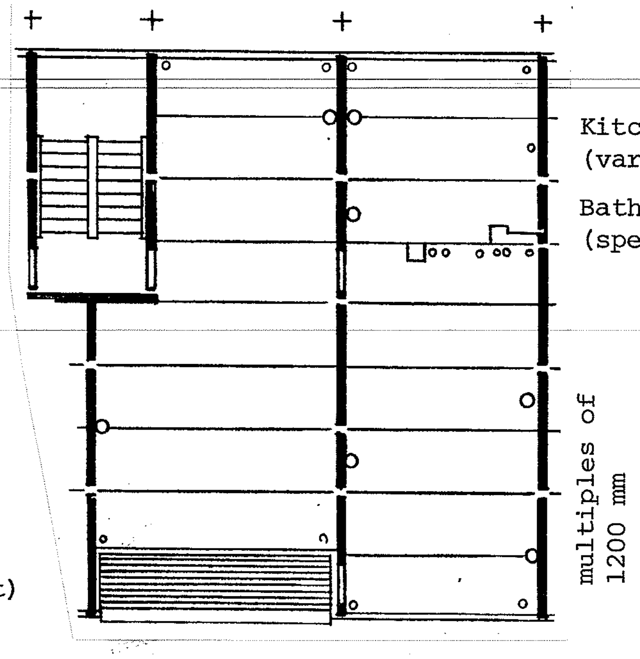


Figure 1

The design principle of the Ballerup Plan, a building project with many plans (25 different types of flats, total 1700 flats).

3 and 4-storey straight blocks of flats with an average of 5-6 staircases per block (2 apartments per landing).

Planning grid for floors and walls: 300 x 1200 mm (3M x 12M)
Storey height (gross) 2800 mm (28M).
Mid-wall/mid-wall = floor length = n x 300 mm.
Depth of building: p x 1200 mm = p x width of floor.
Width of wall component: 1200 and 2400 mm.
Wooden frame facade with the widths 1200, 1500 , 1800 mm.
Maximum component weight: 2.5 tons.

The floor components (cf. figure 2) consist of "standard floor slabs", "variants" at kitchen and along facade, and "special components" for balcony, staircase and bathroom. The kitchen and the bathroom installations (and appurtenant floors) are separated, since this means that the kitchen variants (in principle identical for all kitchens) and the special bathroom components (in principle identical for all bathrooms) can be used in all types of flats, regardless of the relative locations of the kitchen/bathroom.

The wall components (cf. figure 3) consist of "standard walls" (including varying electrical installations), "variants" with doors and "special components" at the staircase.

The Ballerup Plan (figures 1, 2, 3, (5) and 6) was built two years before - and is therefore closely related to - the project (Hedegården) described in: Munch-Petersen, "Typical Danish Prefab Floors, Walls and Facades", in the section Building-System-Key.

Philosophy of the Ballerup Plan, the open system

Variant component/special component

I will now discuss a few cases that illustrate the choice between variants and special components, partly in relation to the number of different layouts in the project (many/few).

Load-carrying cross-walls (were) the norm in the 'sixties

As mentioned, practically all industrialized building in the 'sixties was based on load-carrying cross-walls, a few longitudinal bracing walls (at the staircase), simply supported floors and non-load-carrying facades (lightweight or heavy, system-dependent), see, for example, figure 1 from the Ballerup Plan, which comprised 1700 flats with 25 different layouts (i.e. a project with a large number of apartment plans).

Structural considerations and sound insulation

The principle is consistent. A simple structural system. The components are easily "standardized". Any type of facade can be added since the facade is not part of the structural system. Party walls and staircase walls are heavy and therefore satisfy the requirements to sound insulation. These walls would have been made of concrete in any event, for reasons of cost and sound insulation, so why not utilize their carrying capacity at the same time ?

Figures 2 and 3 show the standard and variant floor and wall components for the Ballerup Plan.

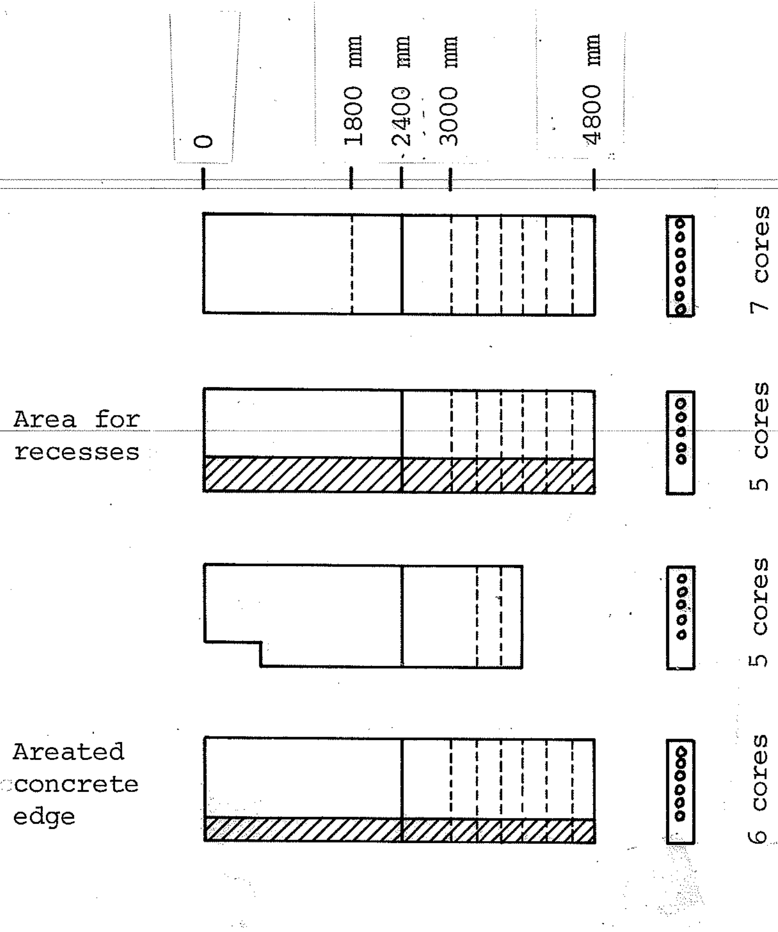
Figures 1, 2, 3, 4 and 5 show examples of the production simplification achieved by the component breakdown and design used. The normal joints between floor, wall and facade components in this system are described in Munch-Petersen, "Typical Danish Prefab Floors, Walls and Facades".

The simple component

When a highly mechanized production apparatus is to be used to produce components for a project with many different apartment plans, it is essential to divide the floors into as many simple and uniform components as possible.

The floor components

It was decided that the floor components should be made in steel moulds fitted to the factory's work-stations, on a closed, heavily mechanized conveyor belt, with the following work operations, one for each stop on the conveyor belt:



Type of floor component	Reinforcement
Standard	Normal
Recess	Heavy
Kitchen	Heavy
Facade	Heavy

Figure 2

Floor components for the Ballerup Plan, excluding special components for bathroom, balcony and staircase.

The "standard floor component" has the dimensions l, b, t: n x 300 (6 ≤ n ≤ 16), 1200, 185 mm, and is equipped with 7 longitudinal, circular recesses (7 cores). The mesh reinforcement is a welded mesh with 8 longitudinal bars (one for each cam) and transverse reinforcement at intervals of 300 mm. The mesh is available in 4 versions with 4 different diameters for the longitudinal bars, depending on the span.

For the "variant component" for recesses, use is made of mesh reinforcement with 1 number heavier longitudinal bars, since recesses of any reasonable shape can be placed anywhere in the hatched area, whereby up to two bars have to be cut to allow placing of the recessing box. 2 cores are left out in the component (because the longitudinal steel pipes used during casting cannot be taken out through the recessing boxes).

The "kitchen floor" is a special edition of this floor, since the component is only made in the edition shown and a mirror edition, cf. figure 5.

Production line

Cleaning and oiling mould, insertion of mesh reinforcement, insertion of any recesses, casting (i.e. insertion of circular pipes, casting, vibration and straightening of concrete: total time about 4 min.), control (any small adjustments) of surface, stacking of moulds (3 nos.), stacks pass into curing chamber (passage through chamber: about 4 hours), stocks pass out of chamber, unstacking, demoulding of floor components (which are transported to the storage yard).

All steel moulds had a width of 1200 mm and a length of 4800 mm.

Side moulds

The side moulds were fitted with fasteners and hinges, and were profiled either to give the normal, (shear-)keyed, self-shuttering component edge or to enable them to secure the aerated concrete blocks used as edge insulation of the facade-variant floor components.

End moulds

The end moulds were profiled to form cams and were equipped with holes to guide the steel pipes giving the 5/6/7 longitudinal, circular recesses (cores).

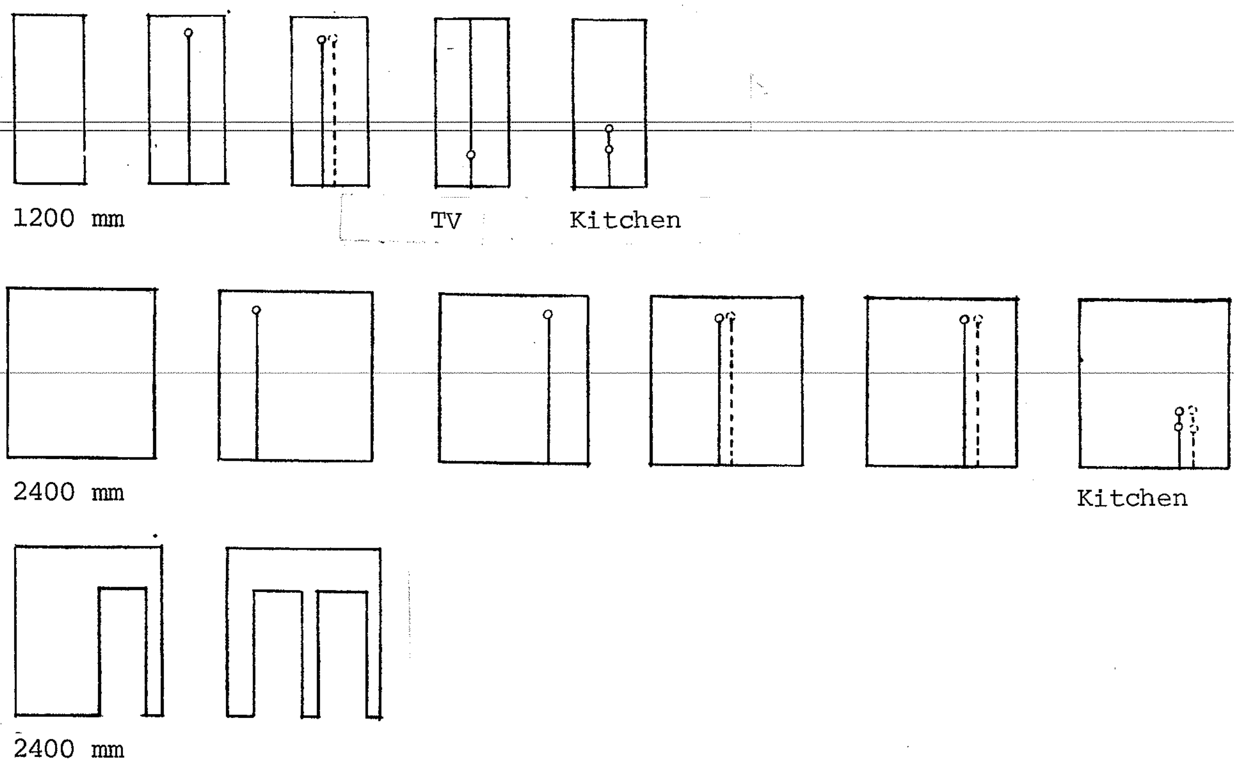
The end moulds were locked to the side moulds by the steel fittings that formed the shear-keys (cf. Munch-Petersen: Typical Danish Prefab Floors, Walls and Facades).

The caption of figure 2 describes the mesh reinforcement; 5 or 7 circular cores, recessing zone, etc.

Kitchen floor

Note that the kitchen floor now comes in 4 spans, but only with two types of corner recess, a right-hand and a left-hand recess, cf. figures 2 and 5. The assembly line is "used" to handling any length n x 300 mm ($6 \leq n \leq 16$), and it is a simple matter to add one of two possible kitchen recess-boxes in one corner of the mould.

Note also the caption of figure 1 on the separation of the bathroom and kitchen installations. The bathroom floors, with slope and cavetto, outlet, etc., were also made in 2 mirror editions, with a number of different spans, but were otherwise cast in special moulds as a solid floor components with the topside downwards to achieve the proper, smooth fall towards the floor outlet.



<u>Figure 3</u>

Wall components for the Ballerup Plan, excluding special components at the staircase.

The "standard wall" is unreinforced, with the dimensions l = 1200 or 2400 mm, h = 2582 mm, t = 150 mm.

"Variants" with "normal" electrical installations are shown (dottet line on the back of the component), for "ceiling outlet", TV aerial and kitchen installation by stove. (The electrical installation was distributed in the space between the wooden floor and the concrete floor slab to switches in door frames and skirting boards and to ducts in the wall component).

"Variants" with two "normal" door positions are shown.

The Ballerup Plan was a 2½-ton "system". A 5-ton system with heavier walls, concrete facades and possibly a wider floor (for example balconies) could - with the same flexibility in the cross-walls - be based on 2400 and 3600 mm wide walls. Considerably bigger wall components are normally used in Denmark today, and floor components now normally have a width of 2400 mm.

The wall components

The wall components were cast upright in steel moulds, assembled in batteries of 10 nos. wall components, 1200 or 2400 mm wide.

Vertical/horizontal casting

By casting the floors horizontally and the walls vertically, the components can be cast, transported and erected without having to be turned. The underside of the floor component is smooth, suitable for spray-painting. The other sides are not important in this connection. The surfaces of the walls are reasonably smooth - and identical ! - and are ready for papering.

However, in the case of walls, there is one problem, viz., that a number of installations, recesses and other operations can be performed more easily when the wall is cast horizontally - such operations include the insertion of mould fittings for complicated holes, including doors and windows (not to mention problems in connection with sandwich walls in the form of gables or facades with two layers of concrete and insulation in between, with special requirements to one or more surfaces).

Vertical/horizontal wall casting determines, for example, profiling of holes, component orientation, surface structure, etc.

The question of vertical or horizontal casting of walls depends on the technology of the factory, the wall details, etc., etc. The designer must know whether the component on which he is working is going to be cast vertically or horizontally in order to be able to give the recesses the right shape (bevel) for rapid and perfect demoulding. Moreover, there are often differences in the surface structure at top and bottom of horizontally cast wall components (steel mould side/machine-trowelling). In such case, the components may have to be turned "correctly" (identically) during erection, and that may result in a number of new variants.

Special components

The standard and variant components for the Ballerup Plan were suitable for mechanized production. The components normally had only one or just a few functions, and they could be combined in many ways. In addition, complex special components were produced that performed many functions. The production of these components was not, perhaps, quite rational, but on the other hand, it could be carefully planned, since all types of apartments used the same special components (bathroom, staircase, facade, etc.).

Bathroom floor component with all pipes

Note that the bathroom floor component shown in figure 1 contains all pipe and drainage installations, hot and cold water, hot water circulation, floor outlet, WC-connection, downpipe and ventilation unit. The bathroom is designed so that all these special holes are accommodated in a single component.

Staircase end-wall both bracing and equipped with electrical installations, TV, telephone, etc.

Similarly, it can be seen that the bracing wall also contains duct installations for main electricity supply, telephone, TV and meter cupboard. As the wall is a bracing wall, it is a special component on account of its heavy reinforcement, and the designers therefore try to accommodate as many other functions as possible in this wall in order to relieve other components of these functions.

There are thus either standard components and variant components, which are simple to produce, or special components, in which as many functions as possible are gathered within one component. At the same time, efforts are made to use the special component as often as possible in the project. For example, there were only two types of bathroom - that shown and a mirror edition, and there were only two different staircases - the two-flight staircase shown and a three-flight staircase.

Turn the bathroom the right way

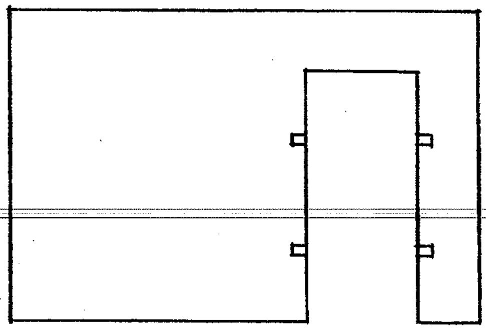
If the bathroom in figure 1 had been turned 90°, the duct and pipe recesses would have intervened in at least two floor components, and the floors might have had to have so many holes along the wall that they would have been unable to fulfil their load-carrying function.

Embedded installations give special components

If the installations had been embedded in the floors and walls, these floor and wall components would have been special components, difficult to make and perhaps only suitable for use in this one project - and perhaps only in this one flat.

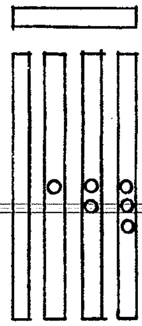
Installations/concrete component joints give problems

If such pipe installations were to be connected between two wall components or two floor components, problems would also arise with regard to tolerances and with regard to tightening joints and connections.

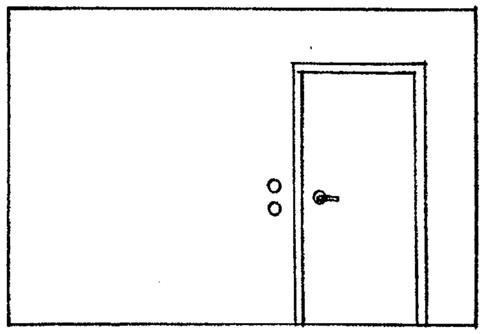


Wall component
The Ballerup Plan Solution

Door frame
(right and
left)



Door casings
1 horizontal
5-6 vertical
depending on
number of
electricity
outlets



Type house solution

Figure 4. WALL COMPONENT WITH DOOR AND SWITCH(ES)

The solution chosen for the Ballerup Plan is shown at the top. Here the functions are separated, so that the various manufacturers of sub-components have a simple production programme.

There is one variant wall component, the position of the door being fixed within the geometry of the wall component and the door opening being provided with blocks into which the door frame can always be screwed regardless of whether the door is to be right or left opening.

There are two variants of the door frame, a right and a left variant. The doors can thus be hung to open in any direction by turning the frame.

The casing, which covers the joint between the frame and the wall component consists of one horizontal casing and one vertical casing, which can, however, come in a number of variants, depending on the number of switches and sockets required.

All 200 possible combinations were naturally not used in the Ballerup Plan, but the factory was established on a long-term basis and it was impossible to predict which of the 200 combinations might be required.

A "type house solution" is shown at the bottom of the figure. Here, the number of variants is so small that the parts are embedded/assembled at the factory.

In type houses, all components are often "special" components

Type house manufacturers are faced with fewer difficulties. Owing to the limited number of layouts, the number of combinations of functions is also limited, and each floor and wall component can accommodate the functions required by the plan. At the same time, it must then be reckoned that each floor or wall component is predestined for just a single use. This situation is illustrated by the example shown in figure 4.

When a door is placed in a wall component, we get, in practice, about 200 different combinations of door hinges and switches etc., even though the door has one, and only one, placing within the geometry of the wall component. This large number of combinations arises from the fact that doors can be hung on the right side or the left side and can open inwards or outwards, in addition to which there can be up to three different switches or socket outlets in the door casings or beside the door.

The solution chosen for the Ballerup Plan is shown at top of the figure. Here, a simple construction programme has been achieved by separating the different functions.

A type house solution is shown at the bottom. When there are only a few layouts, the number of possible combinations is also limited, and most type house manufacturers will therefore most likely choose the bottom solution, in which the component can only be used in one way in relation to hinges and switches etc. Here, the latter are embedded.

Small/big components

The philosophy of the Ballerup Plan was based on the use of a relatively limited number of components with a maximum component weight of only 2-3 tons. It was reckoned that the additional cost of the relatively large number of crane operations would be weighed up by the simplification achieved in the production of the individual components. It seems that this philosophy is not correct with the present level of technology and wages in Denmark, and there is no doubt that component sizes there are increasing. A component weight of 5-8 tons has become normal. The difference between manufac-

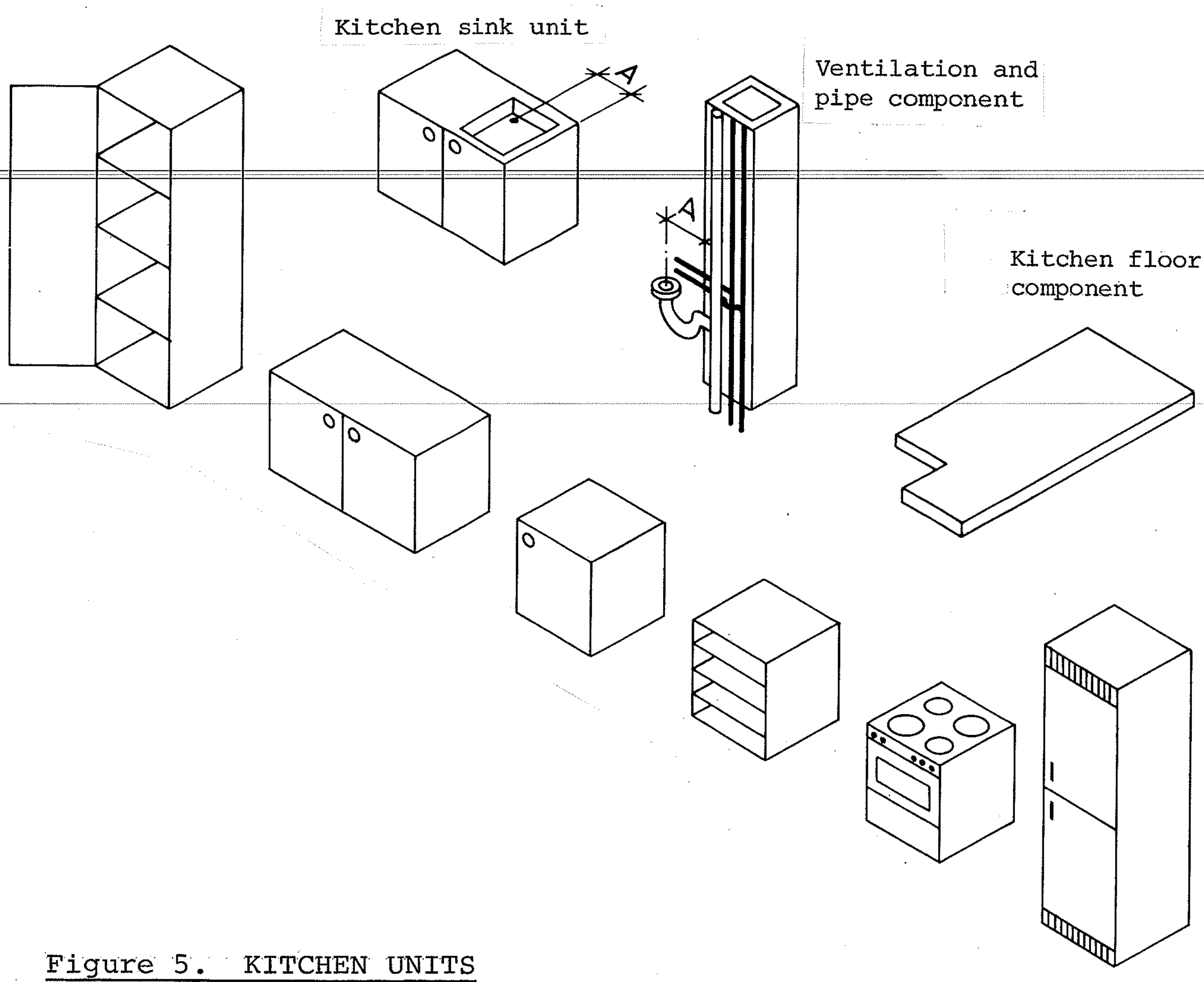


Figure 5. KITCHEN UNITS

This is the second example of a separation of functions with a view to achieving simple functional requirements for the components. The top line shows a floor component with a standardized recess that can only be placed in one of the corners of the component. The component is thus made in a right-hand and a left-hand edition. Cf. the caption of figure 2.

The ventilation and pipe component also comes in a right-hand and a left-hand edition, and both can be placed in the recess of the floor component. This means that the connection for the kitchen sink unit can, in reality, be placed in four different ways for each joint between the floor components, because each floor components has two recesses, in which the ventilation and pipe unit can be placed either right-handedly or left-handedly.

On the left in the top row, the kitchen sink unit is shown. This is available in a right-hand and a left-hand edition, the dimension A being the same in both.

The bottom row shows the kitchen sink units, kitchen cupboards, kitchen tables, stove and refrigerator. These can be combined in many ways, since their dimensions are co-ordinated in accordance with Danish Standard, such that the widths of 400 or 500 mm, or multiples thereof, and the heights of the stove and kitchen cupboards correspond to each other.

turers of type houses and manufacturers of components for projects with many different types of apartments are thus disappearing. Today, all components are relatively big and are equipped with so many embedments, special joint solutions, functions, etc., that they often have only a single use within the project.

Big components nowadays

Big components are "special"

Generally speaking, the number of variants and special components increases with increasing component size. The variations in layouts that can be achieved by combining the up to 2400 mm long wall components shown in figure 3 can naturally also be achieved with wall components that are, for example, up to 7200 mm long. However, the number of possible combinations is so great that most big wall components are special components.

Pro's and con's of small and big components

The advantages and drawbacks of big and small components can be summarized thus: Small components are easier to mass produce and must also be assumed to have a bigger market. Small components have multiple uses and should therefore provide access to a more open, stable market comprising many different types of dwellings.

Size of market

Number of joints

On the other hand, small components, for example, bricks, present a number of problems that have to be solved; there are a lot a joints, there is a lot of manual work, and there are problems of accuracy.

Accuracy

For big components, the opposite can be said to be the case. It is easier to satisfy the requirements to accuracy, erection is simpler and quicker, and there are fewer joints. On the other hand, big components are normally limited in usefulness, since the individual components are intended for a specific type of building and even for a specific type of apartment.

Storage and transportation problems

Very big components, for example, box components, which comprise a whole room, can give rise to storage and transporation problems.

Organizational talent essential

However, in the final analysis, the share of the market that can be won by a given building system depends not on the component size, but on the care and thoroughness with which the planning is performed, the price that is achieved, and the analysis that is carried out of the market.

With the development that has taken place, the old, rectangular, 4-storey blocks with which it was relatively easy to achieve high productivity have been replaced by low-rise/high-density projects, buildings with balconies, terraces, sculptural facades, etc. Financial success in industrialized building today is far more a question of organizational talent than it is of concrete technology and components sizes.

Modern, sculptural facades have increased the number of variants

There has been a tremendous increase in the number of details in recent years. A straight, rectangular block has few facade problems: one horizontal and one vertical facade joint, a corner joint between gable and facade, and possibly special joints at the basement, balconies and roof. In addition to these, the new projects have inward corners, projecting apartments and a number of combinations of different components, component sizes, and types of joints - for example, as a result of a staggered facade or floor-storey plan.

Where can/must/may the component be used ?

A company wishing to develop a new type of component must therefore decide in advance how many of the potential applications it intends to aim at as its market. If it intends to cover the whole market, it must be prepared for many dimensions and edge geometries etc. It is no good a company starting up a production with a simple type of component without being aware, in advance, that it has thereby limited its market or - also in advance - having ensured that its production apparatus can be switched to more complex components. The "field of application" of the component must be analysed and the decision taken on the basis of the probable reality that later conversions are going to be costly.

The relationship between the degree of complexity of a building and the number of components and variants to be produced can be illustrated by some known building systems.

The brick
Small
Multi-usability

A brick is normally made in a size that can be used for almost any type of building - if it is otherwise considered that the wage-bill involved warrants this. Conversely, one can visualize developing a building system that can be used for

The multi-usable, big-component system has many different details and components

almost all types of buildings - dwellings, offices, universities, power stations, etc. Such a building system does not mean that all components are in production, but that the applications and solutions have been determined.

The Ballerup Plan's system is only suitable for simple types of dwellings

The Ballerup Plan represents a building system that is based on a limited number of relatively small components, with which many different types of dwellings can be built. If the complexity of the building is increased, the system falls short and must be supplemented by a large number of special components. This means that the production is not competitive in relation to building systems whose basic components are, perhaps, not quite so rational, but whose entire production system is geared to making many different components with the same machines.

The "variable" production technique. Multi-use production apparatus

For example, today, wall components are seldom cast in batteries with standard widths, e.g. 1200, 2400 and 3600 mm. Instead, most factories now cast wall components in very long moulds, which are divided ad hoc for casting 2-3 wall components with the desired dimensions, or in moulds adapted to the project in question. All components factories now reckon that the 2400 mm wide floor component is the most commonly used dimension.

Complex buildings will still often be "cast in situ", a method in which individual variations can more easily - at a higher price - be fitted into the production.

3M x 3M grid for structural system

1M x 1M grid for lightweight components

Incidentally, I can add that experience with the statutory modular grids (3M x 3M for structural system and M x M, generally, for smaller components) shows that, in many cases, designers should not aim at getting the lines in the main 3M x 3M planning grid to coincide with the lines of a 1M x 1M grid for lightweight walls, cupboards, etc. The fact is that kitchen cupboards are almost always placed smack up against the rear wall. Lightweight walls are often based on their being placed close together with a tight joint between - possibly a glued joint. It is then not possible only to use standard components for lightweight walls between two load-carrying cross-walls. The dimensional deviations on the structural system are so big that they cannot be equalized in a glued joint. It is wisest to realize that the distance between two load-carrying walls can vary by approx. ±10 mm, while the sum of a series of lightweight wall components contributes 1 á 2 mm x the number of lightweight components to the inaccuracies. The last joint in a row of lightweight components must therefore be made in a special way, for example, by means of a capping or by shaping in situ.

Difference in accuracy structure/lightweight components

Generally speaking, the difference between the acceptable inaccuracies in the structural system and the natural inaccuracies in later works, lightweight walls, pipe installations, etc., is so great that a number of ways of equalizing deviations must be established.

Modular room dimensions are usually meaningless

Attempts to achieve modular room dimensions in multi-storey buildings are therefore often meaningless. There is, on the other hand, plenty of sense in analysing and determining, in advance, the relationship between the lines of the two grids for each separate lightweight component, determined on the basis of technical and function requirements etc. This relationship can often be expressed by a dimension.

Determined relationships between the 3M x 3M and the 1M x 1M grid

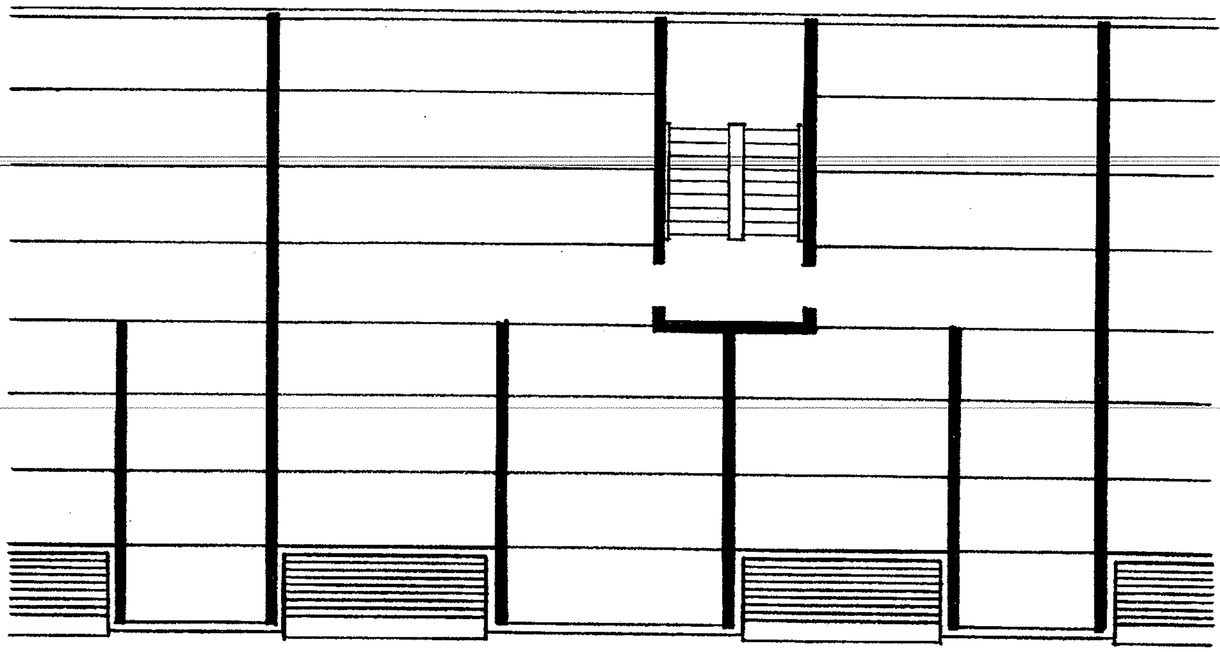


Figure 6. LOAD-CARRYING CROSS-WALLS, as used in, for example, the "Ballerup Plan" and in most other industrialized building projects in the 'sixties. (Part of the storey plan in a normally (3-) to 4-storey block, usually with 4-10 staircases and 2 apartments per landing).

Similar to M.K., page 60.

Note:

Additional information, photographs and slides of the projects described in the following are to be found in:

Marius Kjeldsen: Industrialized Housing in Denmark (given in the figure captions as "M.K., page xx)

Slides and Lecture Notes (given in the figure captions as SLN project x)

STRUCTURAL SYSTEMS, Examples

The choice of building system should be made very early in the design phase because this choice is decisive for the economy of the project and the layout options.

The system with load-carrying cross-walls is generally the cheapest system, provided the system is used as intended. Which system is going to be cheapest depends on the wishes formulated by the client and the architect, in co-operation with the engineer, with regard to layouts, flexibility (both at the planning stage and during later conversions), wishes regarding extraordinary qualities or regarding a sculptural, terraced facade. A wrong choice may make the project so expensive that it is bound to be rejected.

Load-carrying cross-walls

Load-carrying cross-walls with simply supported floor components constitute a common West European system. The principle of this system is shown in figure 6. See also figure 1 from the Ballerup Plan. Both figures show 12M wide floors. Today, the 24M wide floor is widely used, but the system as such is otherwise unchanged and still in common use.

The system is quickly and easily erected. It solves the problem of sound insulation between apartments. It gives the architect relative freedom to design the facade as a light or heavy facade etc., as this is not part of the structural system. The system is generally cheap on account of the simple, relatively uniform components that make up the structural system. It is easy to add balconies, either built in, as shown here, or as continuous balconies along the facade.

3M x 3M planning grid

The planning grid is a 300 x 1200 mm grid, with 300 mm increments in the centre-to-centre distance between load-carrying cross-walls, and with 1200 mm increments in possible building depths.

The flexibility which this system can give will be greatly restricted if a later decision is taken to modernize the building, even though the facades can be renewed.

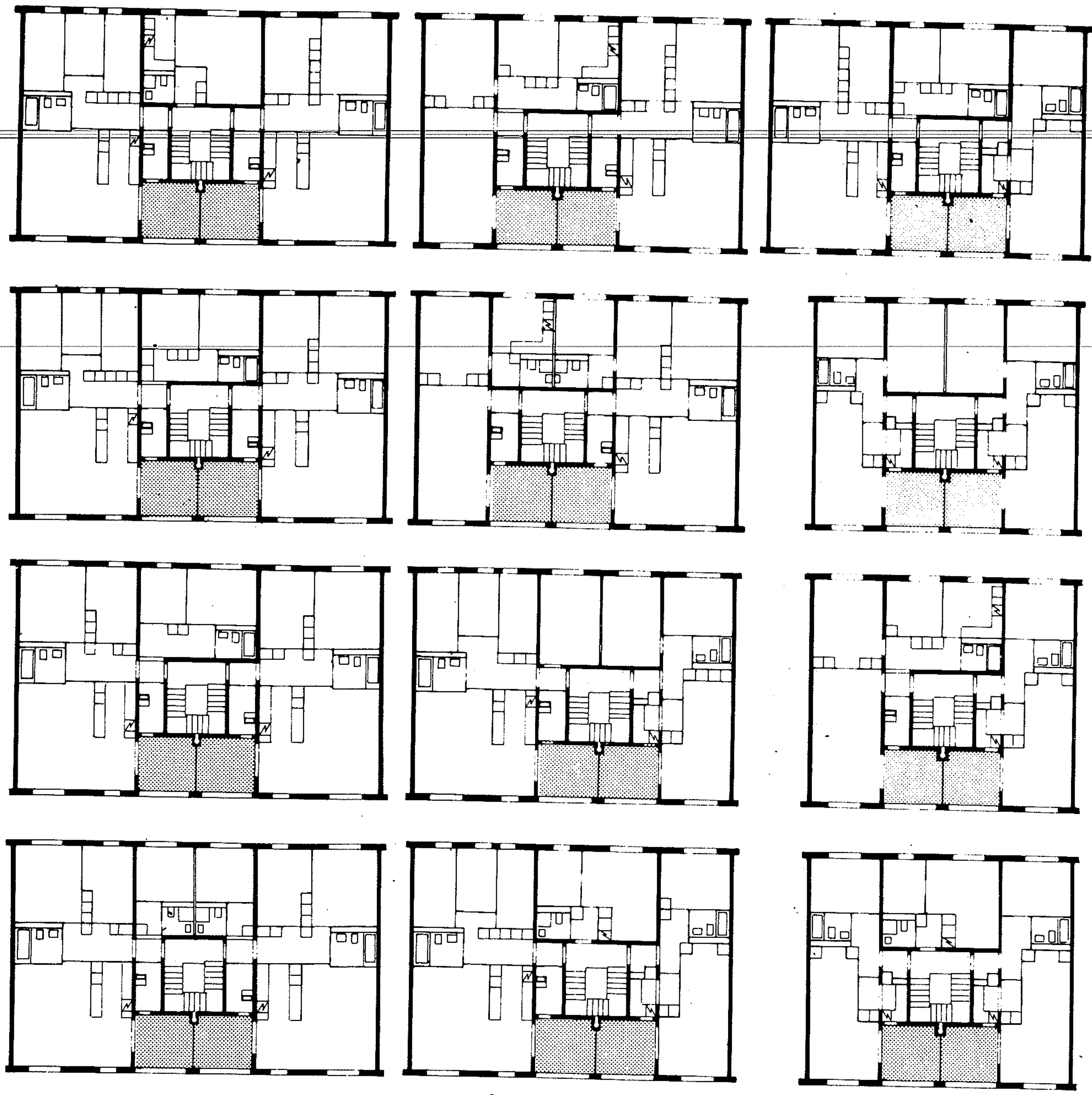


Figure 7. LOAD-CARRYING CROSS-WALLS

Possible planning variants within a given structural system. Few variants of wall components (door placing and a few joints). The apartments vary in size from 1 room ($42\ m^2$) to 6 rooms ($130\ m^2$). (LN-Nybo). See also, M.K., page 78.

Long spans

One possibility is to use floors with very long spans, so that the number of cross-walls can be reduced. However, this requires relatively thick floors since there would otherwise be a risk of creep phenomena. The joints between floors and lightweight walls/lightweight facades must be designed to take account of these possible movements.

"Extra" door openings

One possibility for conversion that can be incorporated from the start is to equip a certain number of load-carrying cross-walls with door openings and brick these up or seal them in another (sound-proof) way, so that rooms or apartments can later be joined together.

Variable door placing in given wall geometry

This principle can be used - within a given wall pattern - to establish, say, two 3-room apartments on one floor and one 4-room apartment plus one 2-room apartment on the floor above or below it, whereby the selection of types of apartments can be widened despite (almost) identical component solutions.

L&N's type housing is an example of this solution. Here, however, the flexibility only extends to the planning stage, since only door openings decided before production are made (figure 7).

"Supplementary rooms"

Another possibility is to place a 1-room flat with toilet and, possibly, kitchenette between two "normal" apartments. There will thus be two big apartments and one small one per landing. The 1-room flat can be leased separately or in connection with a bigger apartment (on the same or a nearby landing), as a supplement to a family apartment - for example, as semi-separate accommodation for an (almost) adult son or daughter.

The staircase

It makes no difference to the system whether a two-flight or a three-flight staircase is used, or whether this is placed at the facade or in the middle of the building. If the system is used in an earthquake zone, however, the staircase should be placed in the latter position so as not to weaken the floor diaphragm more than absolutely necessary and to facilitate the execution of the longitudinal reinforcement.

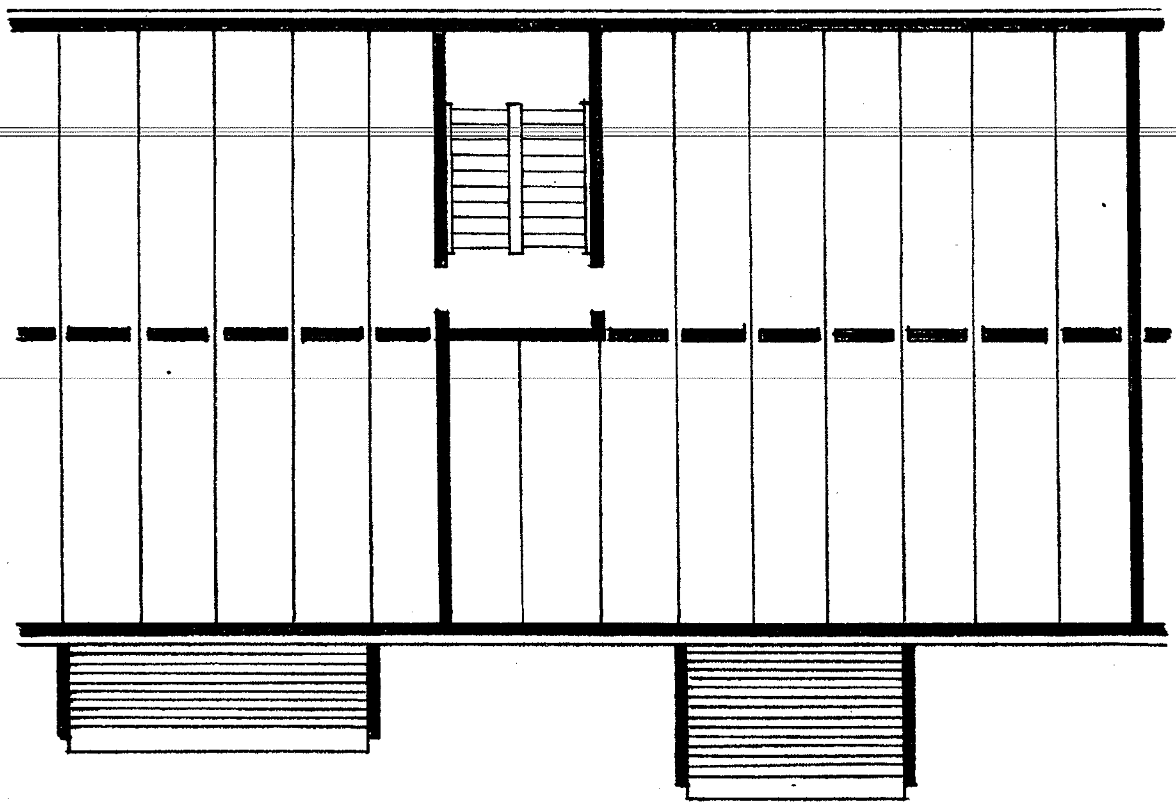


Figure 8. LOAD-CARRYING FACADES (POSSIBLY SUPPLEMENTED BY LOAD-CARRYING LONGITUDINAL, CENTRAL WALL).

An example is the Ishøj Plan on the outskirts of Copenhagen. (Kooperativ Byggeindustri A/S).

See also M.K., page 86, and SLN, project C.

The system can give rise to some difficulties if, for example, balconies are placed up against staircases or in the corner at the gable, as the (horizontal) structural stability of the walls requires some special connections.

Figures 9, 10, 12 and 13 show variants of the system with load-carrying cross-walls - variants that can also be used with modern requirements to facade design.

Another limitation of this system is the fact that it may be difficult to incorporate different types of apartments on the various floors. Generally speaking, the load-carrying walls must continue uniformly through all floors unless costly column-beam solutions are to be introduced. Figures 9 to 13 show how variation can be achieved. The possibility of flexibility through varying door-opening placings is described above.

Load-carrying facades

Load-carrying facades, possibly supplemented by a longitudinal central wall offer advantages with regard to layout flexibility, see figure 8. From the concrete components manufacturer's point of view, this system differs very little from the system with load-carrying cross-walls.

Party walls - lightweight/heavy ?

Balconies special

The limitations of this system include the fact that the cheapest solution for the party walls is presumably to use heavy cross-walls, since party walls in the form of double, lightweight walls are relatively costly. Moreover, balconies cannot be directly incorporated in the structural system because the floors cannot be cantilevered on account of the problem of condensation. The balconies therefore require a special solution.

Restrictions on facade

The design of the facade is also rather restricted. Since the facade is a load-carrying facade there are limits to how much it can be staggered, limits to how sculptural it can be made and limits to how the windows can be placed. In multi-storey buildings, the facade must be made with heavy components.

Some flexibility

The advantages offered by this system are that, in the longitudinal direction of the building, partition walls can be placed relatively freely - with the above-mentioned limitation as far as party walls are concerned.

Movable party walls increase flexibility

If double, lightweight and thus movable party walls can be afforded, the system will allow plenty of possibilities for later conversions, for example, for joining small flats together to form big apartments and for splitting up apartments designed for communes into smaller, one-family homes, etc., etc.

It should, perhaps, be added that if this system is used in countries with a hot climate, it may be regarded as an advantage that the balconies can simply be designed as cantilevered parts of the floor components (which must, however, in such case be special compontns, since they will then require reinforcement at the top).

Diaphragm buildings

Systems with load-carrying cross-walls and load-carrying longitudinal walls are relatively simple, statically speaking. As both systems include a certain number of load-carrying longitudinal walls as well as load-carrying cross-walls, the buildings can always be designed as diaphragm buildings.

Load-carrying central wall

It should be added that if the building can be designed so that the longitudinal central wall can be omitted, far greater planning flexibility will be achieved. A load-carrying longitudinal wall (like a load-carrying facade) cannot have openings of unlimited size. Without a central wall, the only design restrictions are the load-carrying facades and a few bracing cross-walls (party walls ?). The floor components span from facade to facade. If the floor components are not to have too great a span, the building must have only a small depth. That makes the cost per square metre relatively high, since the expensive facade components now make a disproportionately big contribution to the price per square metre.

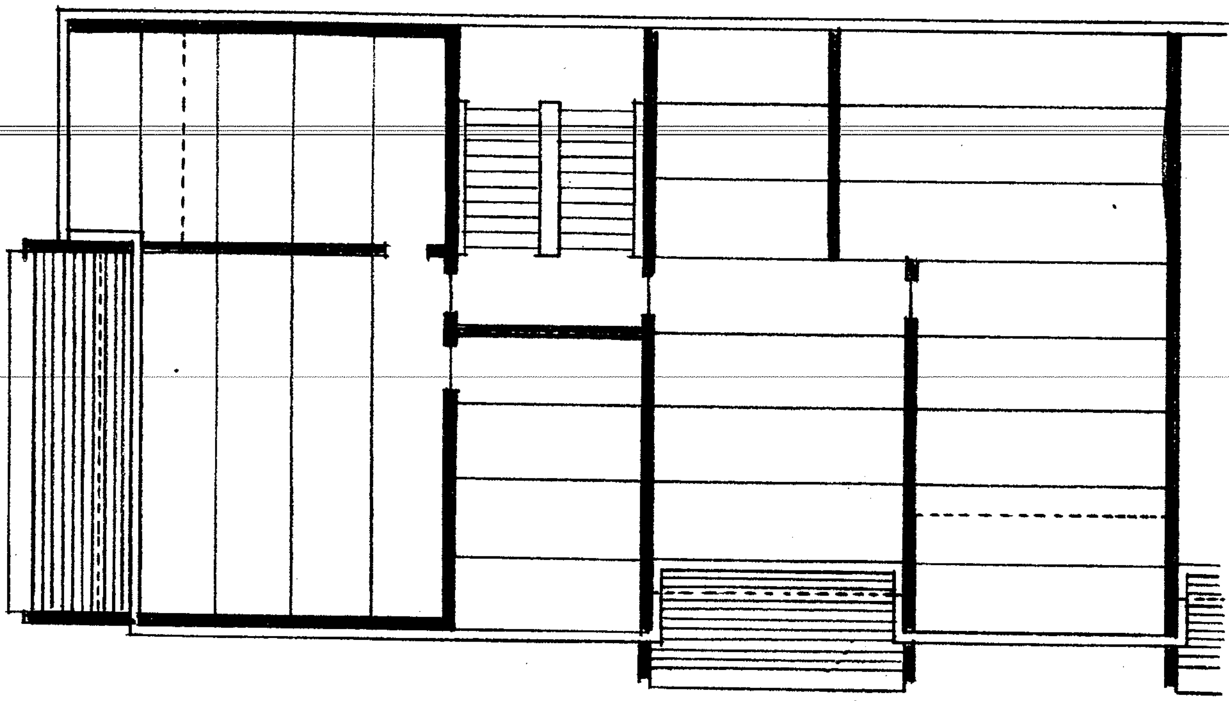


FIGURE 9. VARIANT OF LOAD-CARRYING CROSS-WALLS, cf. figure 10.

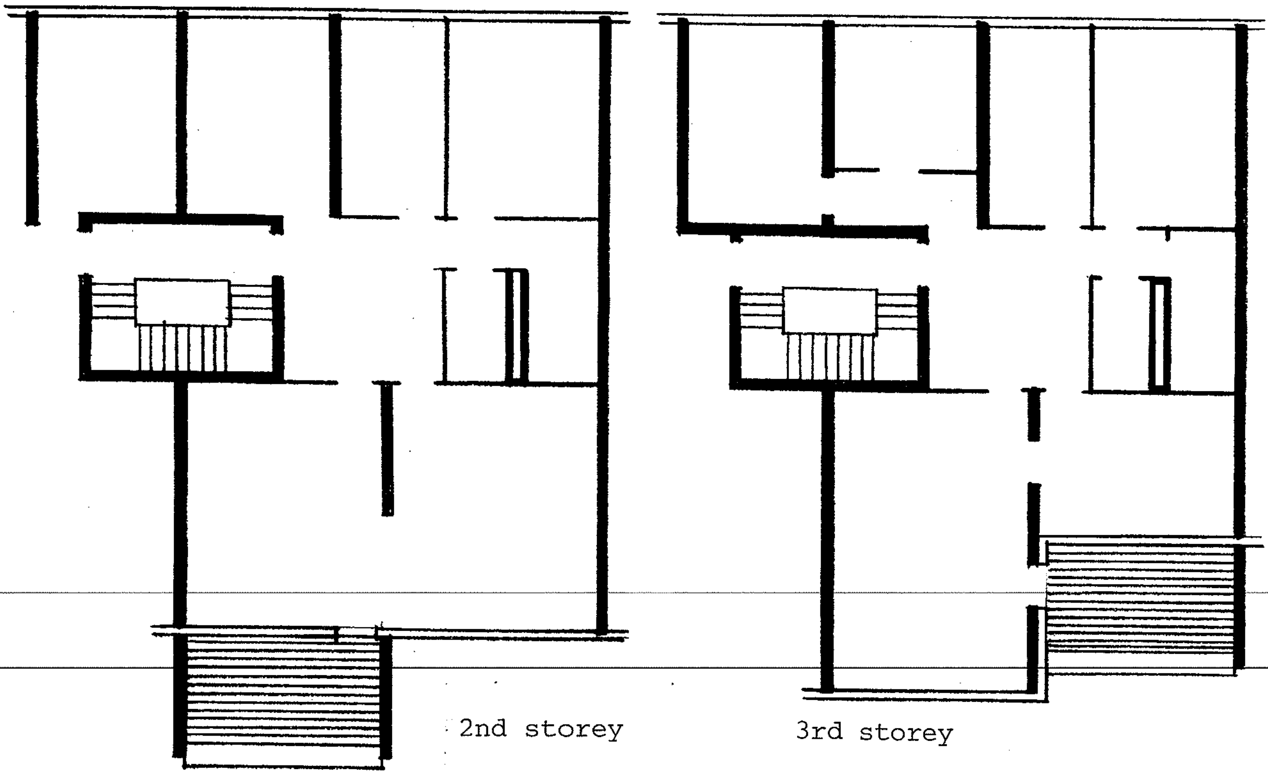


Figure 10. LOAD-CARRYING CROSS-WALLS, variant used at Brøndby Strand

Note that the solutions around the bathroom-staircase-entrance-bedroom are identical. Here, two possible solutions are shown, in which two two flats (not shown) on the left of the staircase have 2 or 3 bedrooms, while those shown on the right of the staircase have 4 or 3 bedrooms. The difference is achieved by a simple rearrangement of walls. The balcony-sitting-room solutions, on the other hand, vary considerably from floor to floor.

See also M.K., page 18, and SLN project B.

Variant of load-carrying cross-walls

Figure 9 shows a variant of the principle with load-carrying cross-walls. At the gables, the building has load-carrying facades and load-carrying longitudinal wall, so that the balconies can be placed in the gables. Such a building is considerably more exciting to look at than one with load-carrying cross-walls, as shown in figure 6, where the gable is often a big, plane face, possibly with a few small windows inserted in it.

Brøndby Strand

The system has, for example, been used at Brøndby Strand, where it is the heavily terraced facade that gives the strongest visual effect, figure 11.

Mutual placing of the balconies

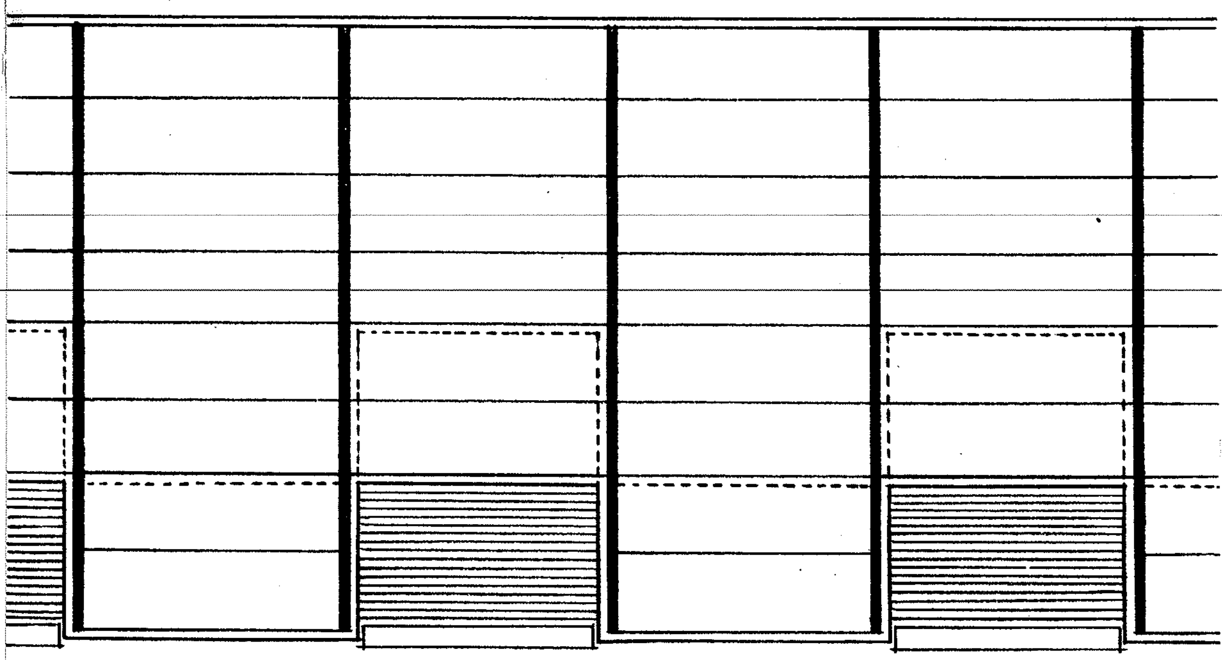
Figure 9 shows a theoretical possibility for placing the balconies, and figure 10 shows the placing actually adopted at Brøndby Strand.

In the Ballerup Plan, the balconies were aligned vertically, separated by vertical bands of ordinary facade. In figures 9, 10 and 11, the balconies and ordinary facades alternate both vertically and horizontally. The fronts of the balconies and the facades project out or are recessed on the various floors.

The variations in the facade plan are governed by a 600 mm module in the transverse direction of the building, so that a few of the floor components have a width that deviates from the "completely normal" width (although one that complies with the Danish code requirement of a 300 mm planning module).

The balconies in the Ballerup Plan were completely covered and it was impossible to look from one balcony to another unless one had suicidal tendencies. At Brøndby Strand, the balconies are partly covered, and this part is therefore "private", while the other part is not quite as protected, although the side walls and very wide flower boxes along the fronts of the balconies restrict the view of other balconies. The idea was to let this part of the balcony act as an open terrace, with a view of the sky. Theory and practice are two different things,

Figure 11. BRØNDBY STRAND. See text and figures 9-10.
Svend Høgsbro, Architect, M.A.A., A/S Dominia, Larsen & Nielsen A/S.



however, as demonstrated by the fact that some of the occupants have more or less "roofed" this area in and equipped it with radiant heat and similar.

In the Danish climate, a completely open balcony - a terrace - can hardly be used for more than one month out of the twelve, whereas a covered and - especially - a heated terrace can be used for many months. On some projects, consideration has been given to providing protection against the weather in the form of an arrangement with a movable glass covering for balconies, which should give a sub-tropical climate and thus allow almost all-year use.

← Figure 12.A SECOND VARIANT OF LOAD-CARRYING CROSS-WALLS

Figure 12 shows another variant of the system with load-carrying cross-walls. The balconies are placed one above the other, but are recessed on the top floors, which gives the building the character of a terrace building. See also figure 13.

Figur 13. LOAD-CARRYING CROSS-WALLS

Variant as used in Farum Midtpunkt.

See also M.K., page 110, SLN project A.

Farum Midtpunkt

An example from practice is Farum Midtpunkt, a section and plans of which are shown in figure 13. (Fællestegnestuen and Dominia A/S).

Each building is an elongated, north-south-oriented building, the facades of which, especially those on the west side, are clearly inspired by Southern European terraced houses.

Reasonable layouts are achieved by a number of unusual measures: the access route, two-storey apartments, and small flats facing east.

The interior, continuous access corridor connects up with the parking floor under the building (stairs); with paths and gardens at ground-floor level (doors in gables); and with the various apartments (doors, and open lobbies, and staircases to 2nd floor flats). Lumber-rooms are also placed along the main corridor.

The apartments

For each two cross-walls, the three storeys of the building contain the following apartments:

Two identical 4-room apartments, facing west, built in an L-shape around a terrace, placed on the 1st and 2nd floor. The 2nd floor apartment is recessed 7.2m in relation to the 1st floor (A, figure 13).

Two laterally reversed 1-room flats facing east on the 1st floor, with ordinary balconies (C, figure 13).

Two laterally reversed, 2-storey, 5-room apartments on the 2nd and 3rd floors with terrace facing west and balcony facing east (B, figure 13).

In this project, the buildings have load-carrying cross-walls, which are, however, replaced on the lowest floor - the parking floor - by beams on rows of columns. The cross-walls of the upper storeys consist of wall components with many openings, to suit the requirements of each floor. As usual, the staircase walls brace the buildings longitudinally. The installations for the kitchen-bathroom-laundry are placed in an oblong niche between these rooms and the cross-

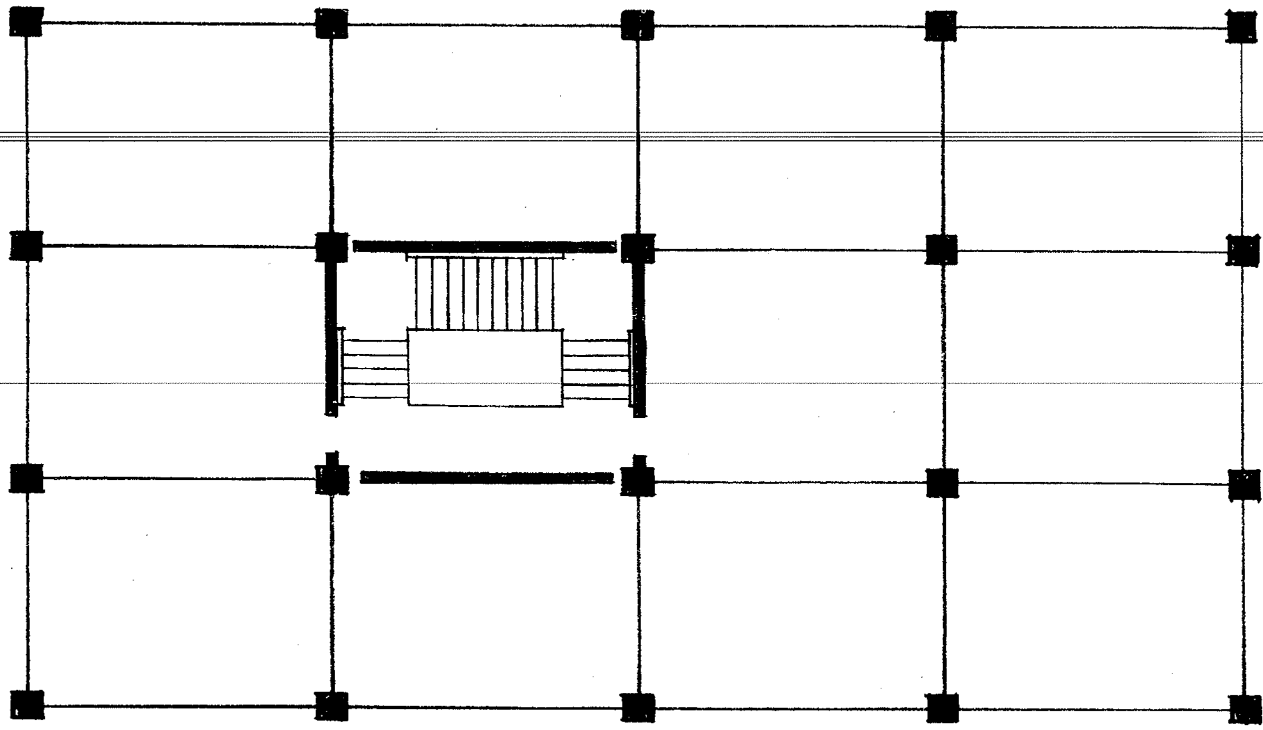


Figure 14. COLUMN-BEAM SYSTEM

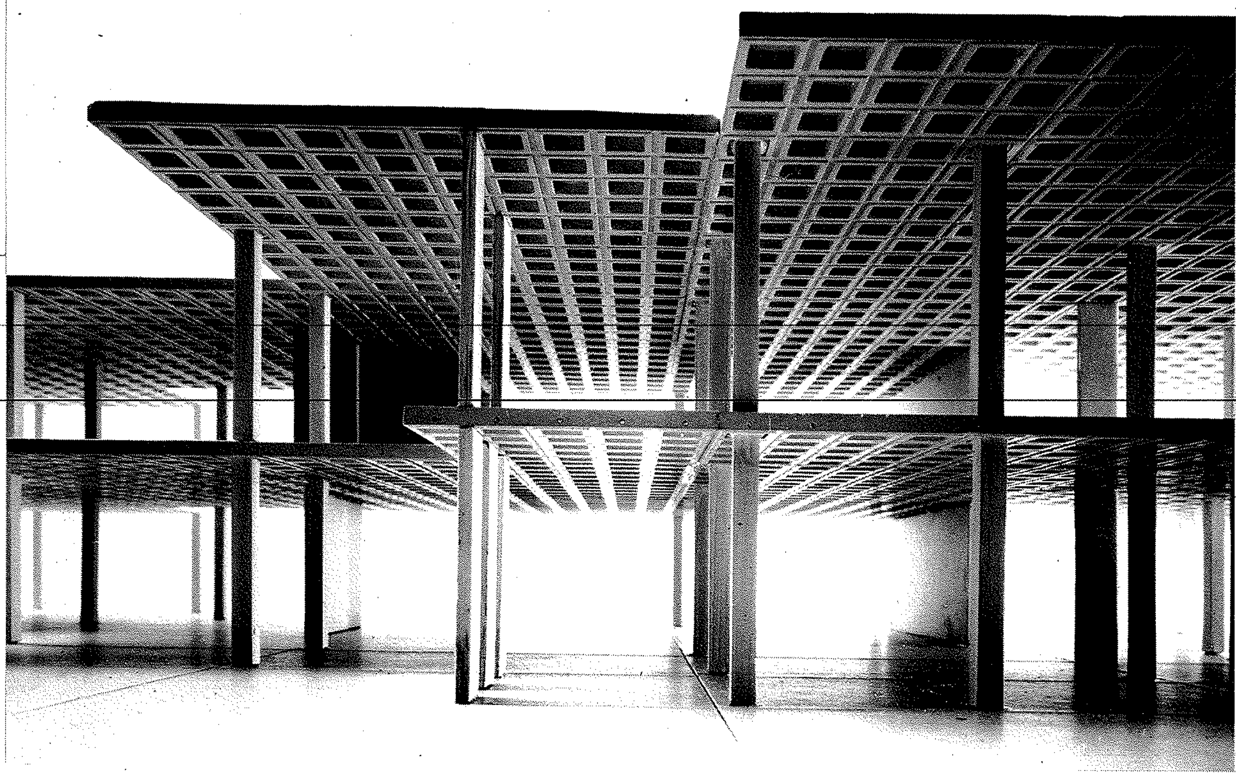


Figure 15. THE RIB CROSS SYSTEM

(Lemming & Eriksson A/S). See also M.K., page 134.

wall. The niches on the individual floors are relatively staggered, although they overlap enough to allow vertical piping. The pipe recesses, the staircase towers and the practical/statical possibilities for the placing of door openings restrict layout flexibility.

Column-slab

Figure 14 shows a structural system composed of columns and floor components. The system can only resist vertical forces and must be supplemented by bracing components (in figure 14 in the form of the staircase tower with concrete component walls).

Such a system gives quite extensive planning flexibility and convertibility and is therefore suitable for office buildings, where conversion is a common occurrence.

The system's planning module results in some stiffness in the building design, and the solution described below is therefore a more desirable variant of this system.

The floor components are supported on columns at the four corners, and they must therefore be reinforced in two directions, so that the load on and from the floors can be transmitted to the columns. It is then reasonable to consider making the floors as rib-cross floors (cf. figure 15).

Rib cross system

The rib cross system illustrated in figure 15 is shown in Marius Kjeldsen, page 134. All the floor components are of the same size, and the joints between them can transmit bending moments. It is therefore possible to place the supports (columns and walls) rather freely in relation to the system lines of the floors (joints) and to use cantilevered floors.

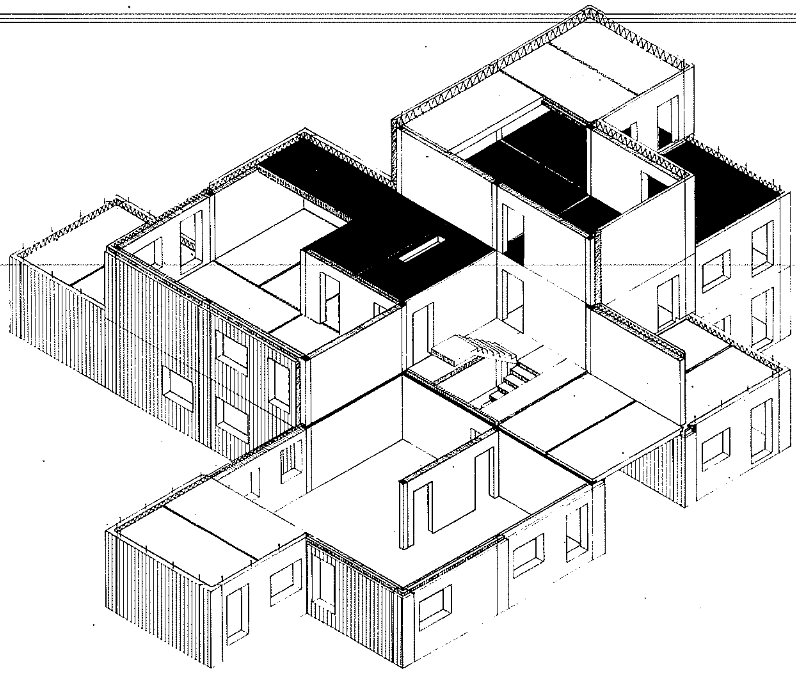


Figure 16. ISOMETRIC PROJECTION OF "TERRAFORM" SYSTEM
(I-68 K/S, Consulting engineers, Copenhagen).
(See also M.K., page 116.)

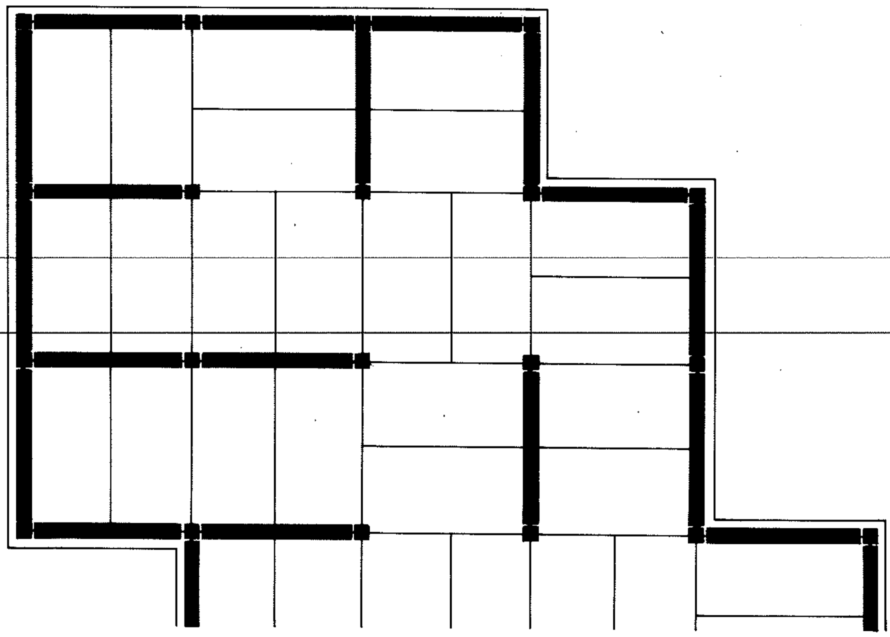


Figure 17. PRINCIPLE OF THE "TERRAFORM SYSTEM"

Variant of the column-slab system

The system shown in figures 16 to 21, Terraform, has been developed by Svend Høgsbro's tegnestue, the consulting engineering firm I-68 K/S and the contractors Rasmussen & Schiøtz A/S. It is a variant of the column-slab system, here with variable utilization of walls and facades as bracing members.

The Terraform System

The columns are placed in a square grid, for example, 4800 x 4800 mm. Each of these squares is covered by two floor components (4800 x 2400 mm). Walls are positioned between two columns where needed in the layout and/or for statical reasons (cf. figures 17 and 18).

Floors

The floor components are simply supported at both ends, either on a wall or on another floor component, spanning orthogonally in the adjacent square (support along the edge, see figure 19).

Walls

Eventually, dead and live loads from the floors are carried to the walls. The wall components are suspended from the columns (see figure 21) and transmit their own dead load and the loads from the floor components to the columns but not to a subjacent wall (there may not be any subjacent wall).

Column-slab system
The "walls" are actually
- beams for the floors
- bracing members

The system is consequently a column-slab system with beams added: the walls are, in fact, beams, not load-carrying walls in the normal sense of the term. The walls also function as bracing members.

With this system, the load-carrying walls on the various floors need not be in line vertically, which means that the layouts on the various floors need not be identical. The floor area naturally usually decreases from floor 1 to floor 3 or 4.

In practice, the architect usually works within the square grid determined by the columns, designing his layouts floor by floor.

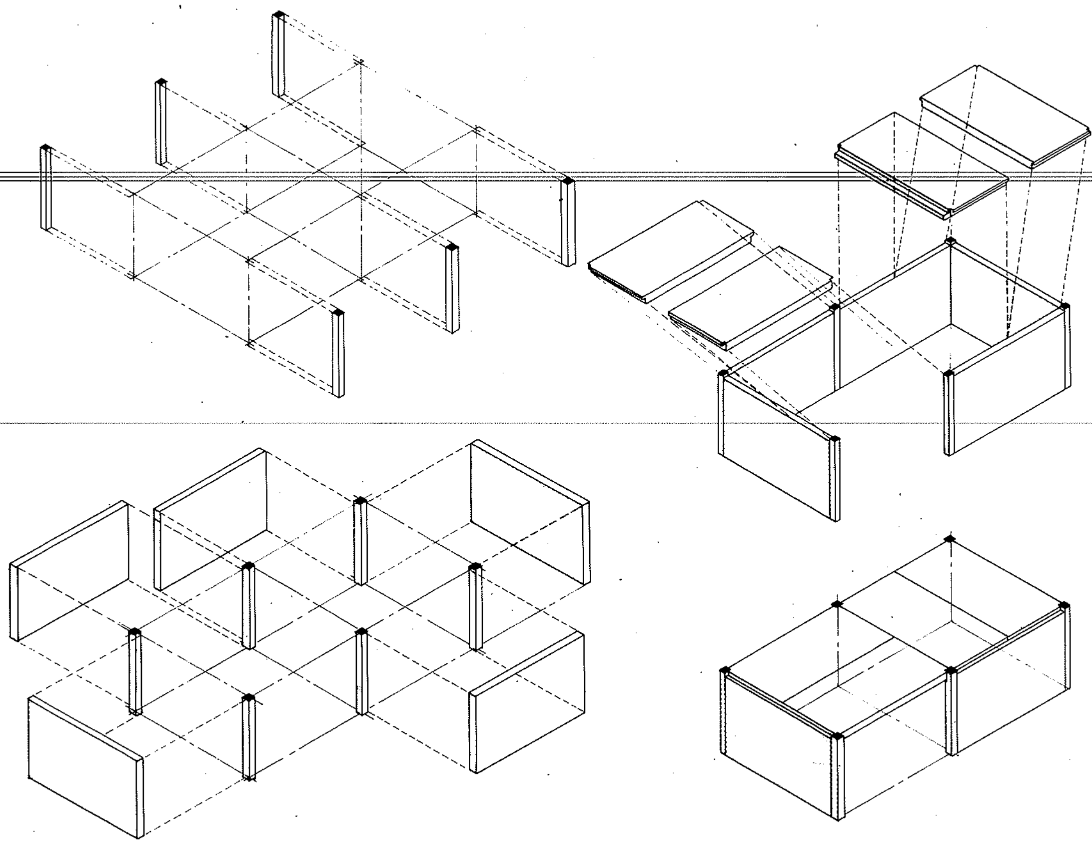


Figure 18. ERECTION SEQUENCE IN THE "TERRAFORM" SYSTEM

A. The columns are erected at the intersections of the modular lines.
B. The heavy walls (and facades) are suspended between columns, where such components are required. The walls (and facades) act as bracing members and as beams for the superjacent floor components. The vertical forces are transmitted (only) through the columns.
C. The floor components are laid, supported on walls or along the edges of adjacent components.
D. Finished (part) of building.

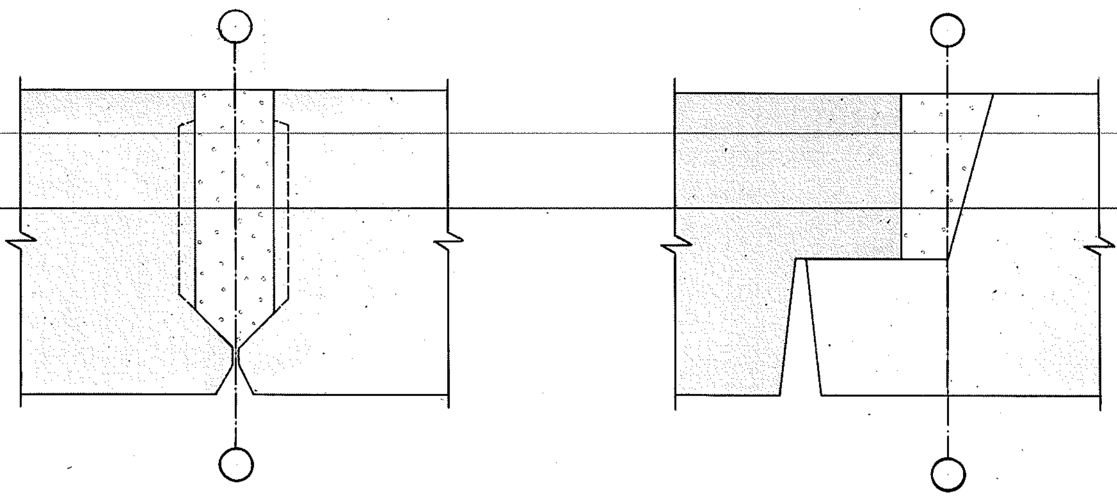


Figure 19. FLOOR-FLOOR JOINTS IN THE "TERRAFORM" SYSTEM, 1:5.

As it is natural to let some walls run from column to column, there are a lot of obvious possibilities for making a wall a heavy wall that can participate in the bracing system. Experience has shown that it is hardly possible to design normal layouts where there are not enough bracing walls placed naturally within this system.

An analysis of feasible layouts has also shown that the system need not necessarily include heavy facades. Even if lightweight facades are used, there will usually be sufficient bracing walls placed "at random" on each floor for the system to be stable.

The system gives great flexibility as regards both layouts and the sculptural design of the facade. It offers only very limited flexibility with regard to later conversions, unless some of the bracing walls are equipped with door openings that are bricked up in the initial stage - door openings that do not reduce the bracing effect of the walls.

The Terraform system's components

The system has - at any rate today - concrete sandwich facades. The inner concrete leaf of the facade components has the same dimensions as the wall components and, like these, is suspended from the columns via the same joints, with shear-keys and U-stirrup connections.

Columns

The columns are therefore made in just a few variants, depending on the number of walls to be suspended from the column in question, cf. figure 20, left side.

Floors

The floor components come as "normally" loaded slabs or as components also subjected to loading along the edges from other floors. Figure 19 shows the two main floor-floor joints.

Walls

The walls vary only as a result of door openings and electrical installations, but are otherwise identical, the columns being erected in a square grid, and the joints between walls and columns being as shown in figure 21 (apart from insulation and outer concrete leaves).

If the walls were arranged in a rectangular grid, as on the left in figure 20, it would have been necessary to have two widths.

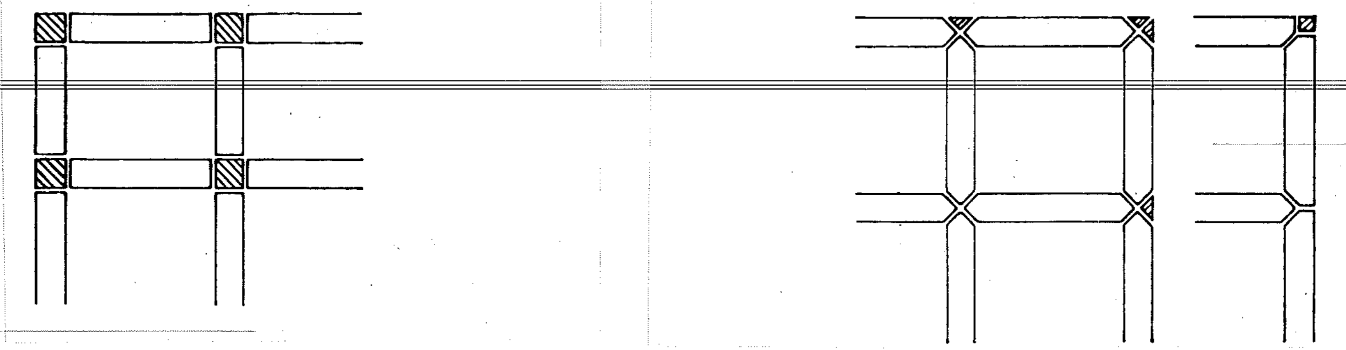
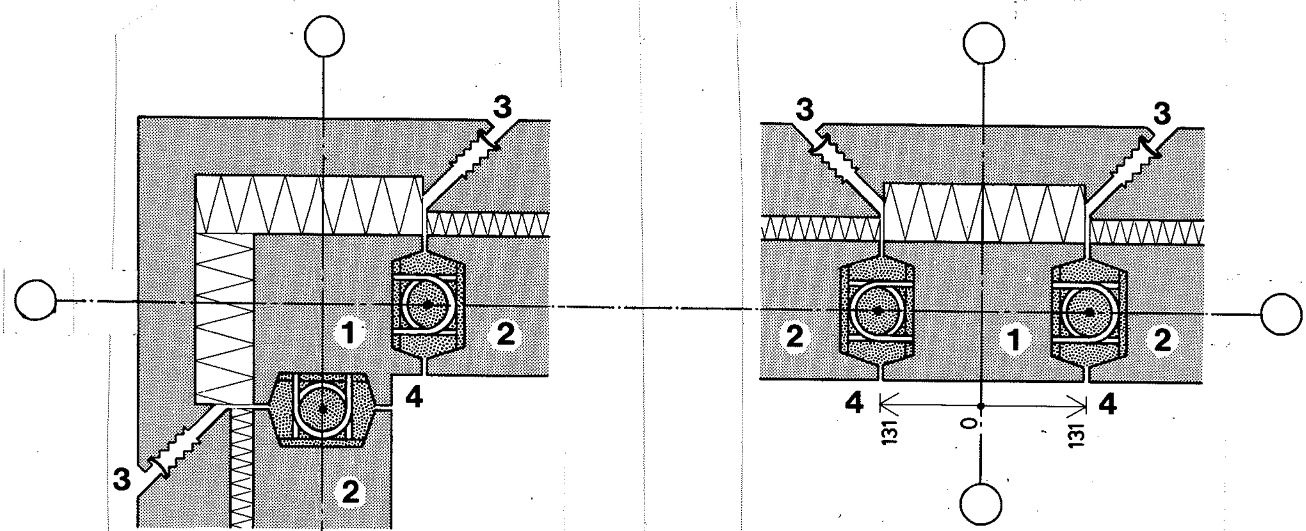
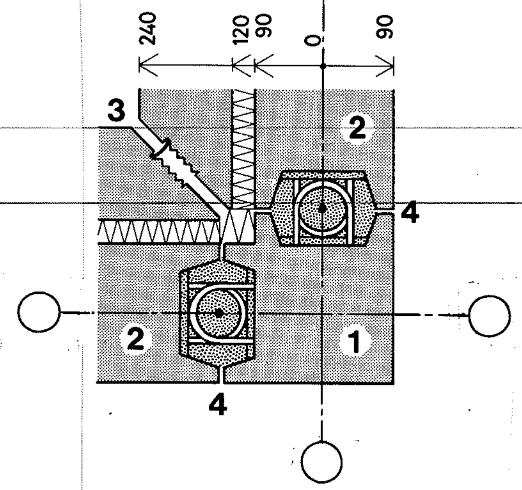


Figure 20. Two theoretical possibilities - with a logical simplification - of combining facade components in a plane facade, and at inwards and outwards corners.





1. Columns
2. Facade components
3. Two-stage joint with neoprene gasket, "washboard" and drained, ventilated cavity
4. Joint with shear-keys and (shear-)reinforcement

Figure 21. FACADE-COLUMN JOINTS IN THE "TERRAFORM" SYSTEM, 1:10.

Facades

When, as mentioned, the inner concrete leaf of the facade component is identical with a wall component (i.e. a component with given exterior geometry and variations only as a result of inside factors such as openings and installations), it is desirable for the exterior dimensions of the outer concrete leaf and of the insulation to be identical as well.

The geometrical problems arise when the vertical edge geometry of the facade component is to be designed so that the component can meet another component both in a plane facade and at an inward or outward corner.

Even if one were prepared to accommodate the plane solution together with the two corner solutions in a number of variants, it would still be difficult to achieve a reasonable solution for this case in which the inner leaves of the sandwich components follow the grid lines.
All building systems have solved the plane case and the outward corner, but few have managed the inward corner in a rational manner.

The Terraform system shows an interesting geometry that solves the two corners and the plane case elegantly. (In this system, too, there are variants where the facades meet the roof and terrace along the horizontal edges).

Facade joints

Figure 21 shows that all the facade components have the same geometry along the vertical facade joint, the outer concrete leaf being held back at an angle of 45^{o} and equipped with the usual "wash-board" and neoprene gasket*. In the inward corner (bottom left), the joint works out all right, but in the other two cases, something is missing, and that something is tacked onto the columns. The columns thus get yet another couple of variants for use in the facades.

All "specialities" are located in the columns

Thus, the columns are complex, whereas the floors, walls and facades have uniform, simple overall dimensions and edge geometries.

*cf. the normal Danish facade joint, shown in Munch-Petersen: Typical Danish Prefab Floors, Walls and Facades.

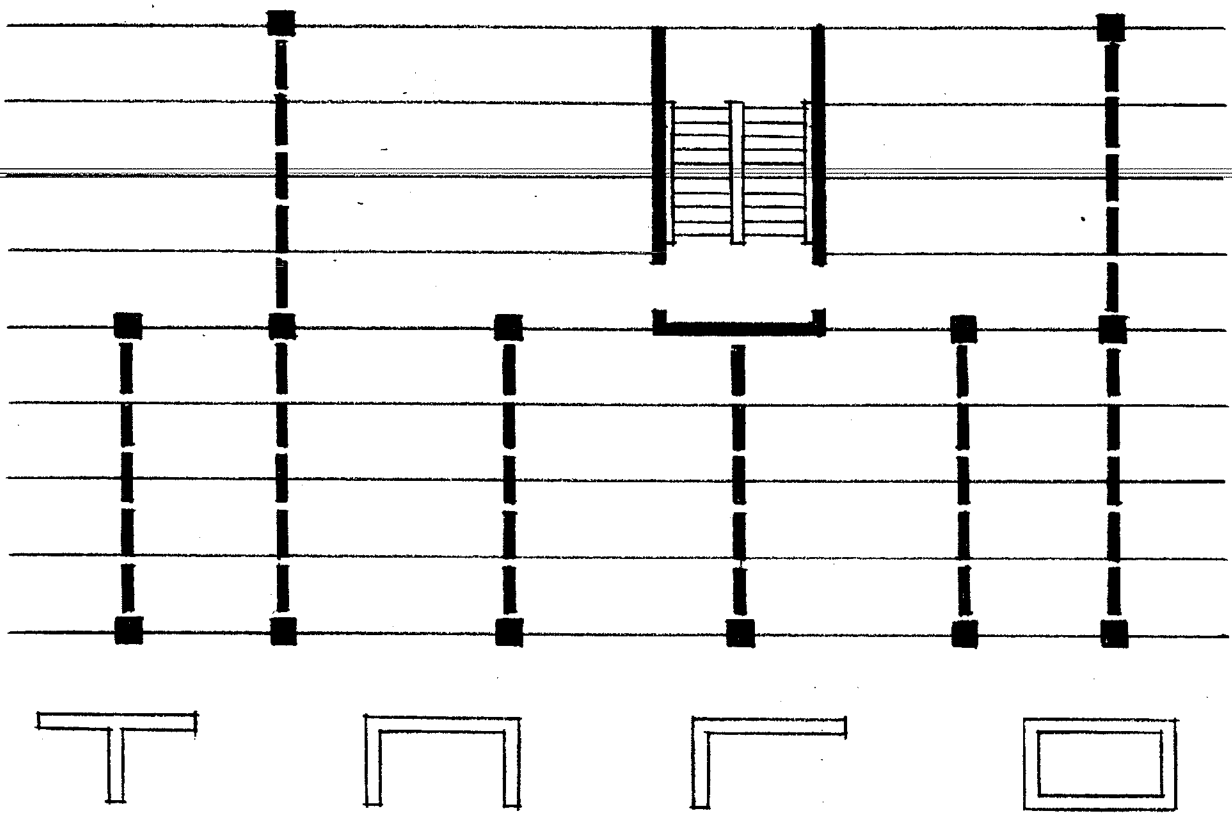


Figure 22. COLUMN-BEAM-SLAB SYSTEM, with simply supported slabs. Frames of T-, L-, U-, or O-form can be utilized instead of columns and beams.

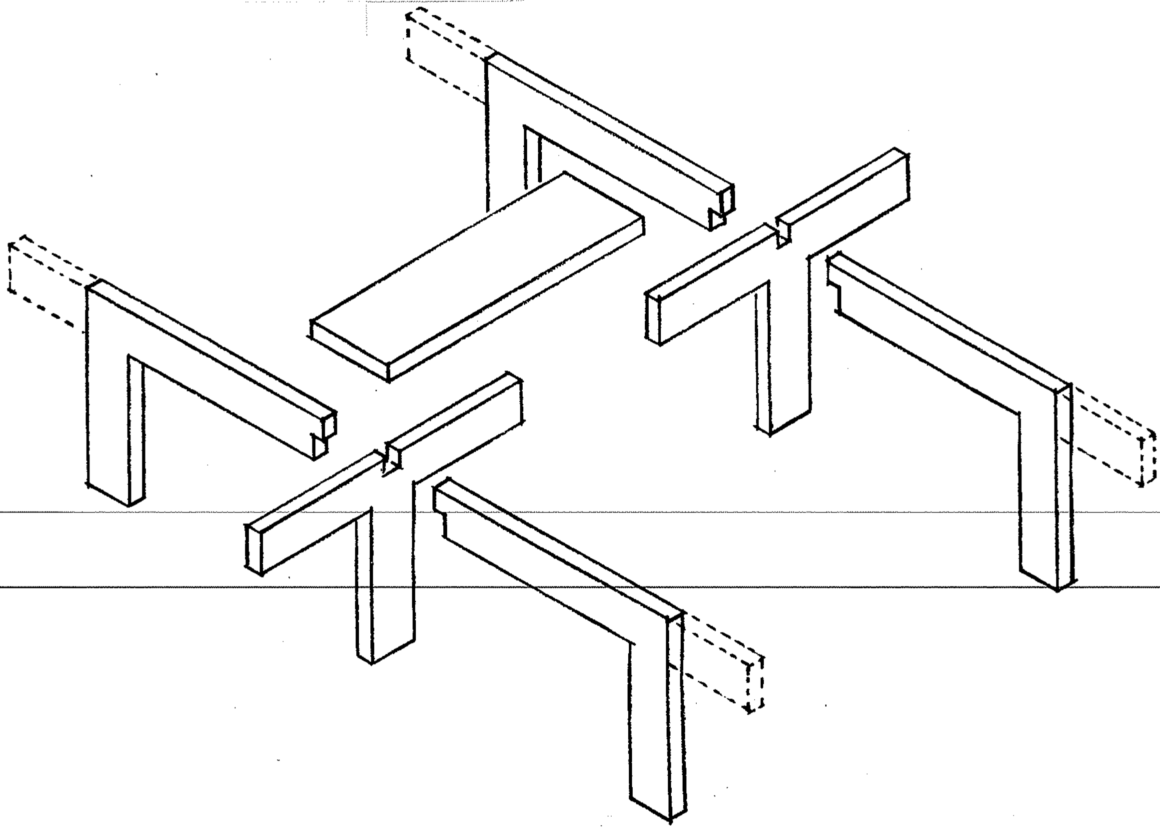


Figure 23. TVP-SYSTEM, composed of slabs (P) and T- or L- (V-) shaped frames.
(J. K. Schmidt, Kaj Schmidt, H. Nygaard-Andersen and Poul Bigum & Hans Steenfos A/S).

See also M.K., page 105.

Slab-beam-column or slab-frame

Figure 22 shows a development of the load-carrying cross-wall system, in which the load-carrying walls are replaced by columns and beams or by frames.

Such a system naturally affords greater planning flexibility and greater convertibility, but beams or frames will show in the ceiling, which is now no longer plane, and this - for purely visual reasons - restricts the placing of the walls.

The system is thus relatively flexible, but is restricted by traditional ideas about how a ceiling should look. The system also means that party walls cannot be made in the cheapest way - viz., as concrete walls - but must be double, lightweight walls, which cost 50-80 per cent more than a concrete wall with the same sound-insulating characteristics.

The system is known in Denmark, for example in the form of the TVP-system, in which the structural frame consists of T-shaped and L-shaped frame components, together with floor components, i.e., slabs (TVP), see figure 23.

Box systems

A natural consequence of the wish to shift manpower from the worksite to the factory is to design the building system with boxes, each of which constitutes a whole room. This means that each room in a flat can be totally finished ex factory, including wallpaper etc.

In practice, of course, a box of reasonable size sometimes happens to contain several rooms, and in other cases, it is too small to accommodate a whole room. A bathroom, for instance, takes up no more than half a box, while a sitting room should perhaps comprise two to three boxes. Consequently, the boxes are no longer regular boxes, but boxes with several cross-walls or boxes that are open on one or more sides.

In practice, the box system gives rise to various connection problems, with quite considerable dimensional deviations.

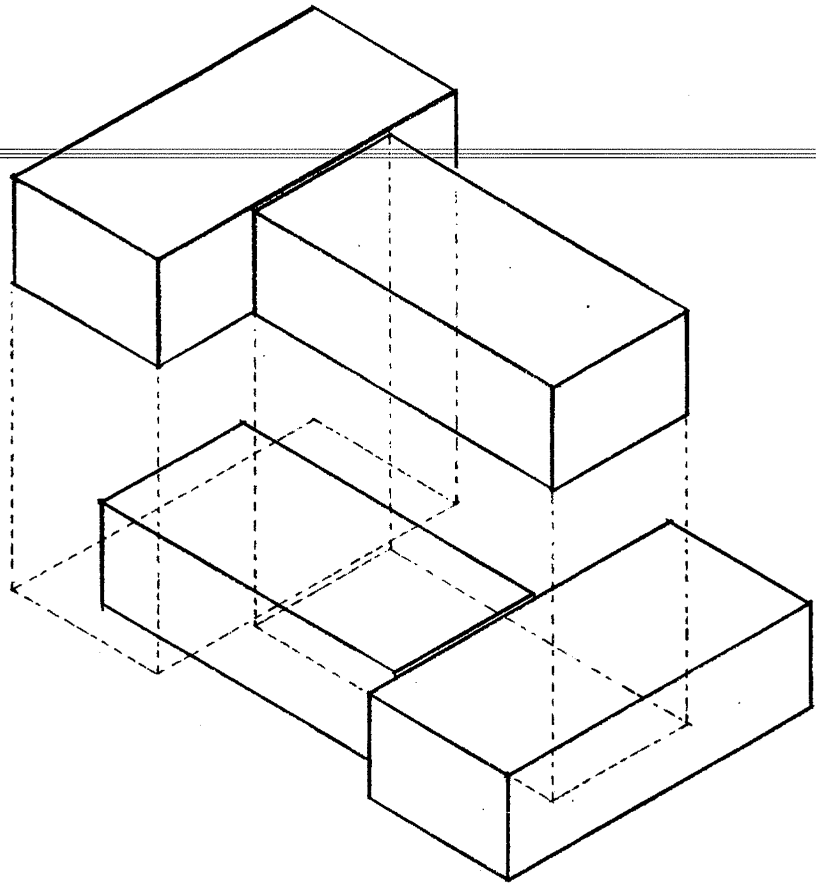


Figure 24. BOX SYSTEM WITH SELF-SUPPORTING BOXES

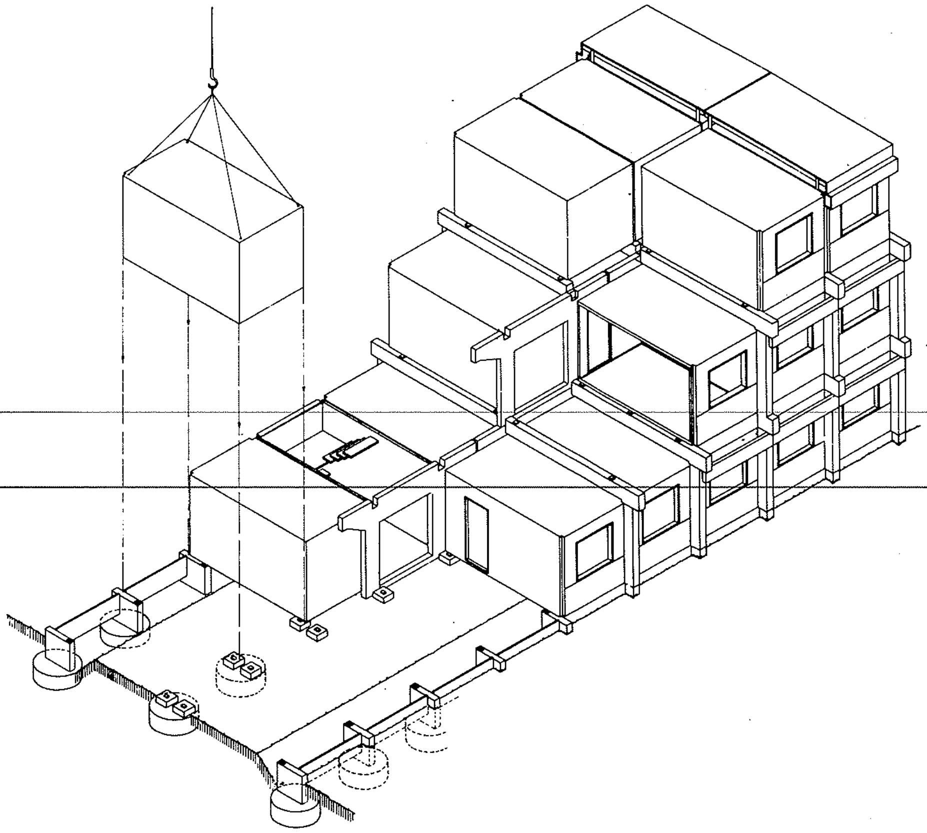


Figure 25. BOX SYSTEM WITH BOXES SUPPORTED ON FRAMES

(The Conbox-system). See also M.K., page 105.

The box-size becomes a "room module"

Furthermore, the box system is very inflexible. All rooms should be planned with sizes equivalent to 1/2, 1/1, 1-1/2 or 2 boxes, there is little design freedom with regard to facades, and the possibilities for conversion are extremely limited.

Box production

The box system is not particularly attractive on the production side either. The individual components have a large volume and therefore require an exceedingly big factory building, in which the components stay for a disproportionately long time. Transportation is also a problem, at any rate under normal conditions, because the Traffic Act only permits the transportation of components with a maximum width of 2500 mm, with certain exceptions for components up to 3600 mm. Larger components, which would be more reasonable if the box system were to be utilized, may only be transported on the public roads with special permission and under police escort and can thus not form the basis for a generally usable system.

A box system can be based on each individual box constituting part of the structural system (figure 24), or it can be designed so that the boxes are lightweight components that are inserted in (supported on) a frame system developed for this purpose (figure 25).

FLEXIBILITY

In this review of building systems, the word flexibility has been used again and again. The word is an integrating thread in the discussion on the future of construction and should therefore be discussed separately, even though this will mean repeating views expressed earlier.

Technologically, many of the changes proposed can be grouped under the requirement of flexibility, but flexibility covers many different factors.

External flexibility, visual environment

The demand for a more varied and friendly environment leads to a number of requirements, including, especially, a requirement to external flexibility - in the design of the project plan, in the storey height in the individual buildings and in the shape, appearance and mutual placing of the facade components - requirements that can only be satisfied by further development, and/or combination, of known building systems. This may some day lead to new systems and will make increased requirements to production and planning. It is apparently directly at variance with the technologically ideal prefabricated construction method, in which identical components are erected in accordance with a tight time schedule, making efficient use of the repetition factor. Nevertheless, the same choice of words can be made to cover an extremely flexible project provided the deliveries are carefully organized - or provided the individual processes are separated and spread out over a longer period.

The requirements to flexible aparment plans can be divided into three separate requirements.

Flexibility during design

The first of these is a requirement to the building system's outer framework around the apartment, so that a number of different designs and sizes can easily be fitted in during the design phase.

Tenants' influence when moving in

The second is a requirement of adaptability of individual flats to meet the wishes of the tenants - or the owner's wishes regarding variation within the area of each type of apartment. This requirement may also, to a certain extent, satisfy the first requirement if the flexibility not only covers possibilities for varying room division (erection of lightweight partition walls), but also enables certain party walls to be placed in several positions.

Alterations in area/ movable party walls

A variant of the possibilities is walls (possible party walls) with more door openings than necessary, so that rooms (or two flats) can be joined together or separated in several ways by mounting doors or sealing openings.

"Independent" teen-agers

Something similar applies to plans in which small, 1-room flats are arranged in connection with (beside) bigger apartments, for leasing to students, pensioners, etc. These small flats could, perhaps, also be leased together with - and possibly even connected with - bigger apartments, whereby parents could give an almost grown-up son or daughter an "independent attachment" to the family apartment.

Tenants' influence in the future

The third requirement is a requirement to future flexibility - here, thinking especially in terms of giving the occupants of an apartment the possibility of moving, lightweight partition walls - either by themselves or with assistance - to suit the changing needs of the family.

Such a flexible system as this could mean that the occupants actually simply lease an "area", which they then arrange and change as they wish.

Economy and technical consequences

The higher the degree of "occupant-flexibility", the more important it becomes to solve the questions of economy and administration, including the question of the "value" of improvements, and to consider fully all the technical consequences. Can the occupants erect walls anywhere - or must the walls be erected in accordance with certain "modular" rules ? Are there going to be rules regarding the use of specific wall and floor materials or regarding jointing methods ?

Flexibility of water, heating and sanitary installations

The water, heating and sanitary installations present an important technical problem in connection with flexible plans. The heating system must allow light walls to be moved. Moreover, the water, heating and sanitary installations will often imply serious restrictions. Flexibility in these installations will normally result in a considerably heavier initial investment, but some account of this can, for example, be combined with the possibility of complete replacement of, say, a bathroom unit (dismantlable facade ?), so that the future standard of the building can be increased in step with technological development.

Flexibility of electrical systems

Electrical installations designed in the traditional way put great difficulties in the way of movable, lightweight partition walls. Terminal strips and skirting systems etc. are only half a solution, since, with current legislation, trained electricians will be needed every time a wall is moved. Theoretically, one can envisage an electricity supply system that is independent of the lightweight partition walls in an apartment or house, in other words a system tied to ceilings or floors. One can also envisage a system in which the 220V/380V installation is restricted to permanent walls etc., and the electricity supply for lighting purposes is left to the occupants themselves - within certain limits and with a well developed overload protection system. This is not allowed either today, but it should not be impossible to elaborate instructions based on foolproof components.

Sound problems

The use of lightweight, movable walls would, at any rate in multi-storey buildings, give rise to sound problems. The apartments would have to have few, heavy party walls, which means long spans. These would result in flexible floors with consequent risk of deflections, which would, moreover, vary when the "lightweight" walls were moved, so that the connections of these latter walls would also be difficult to solve from a sound insulation point of view.

A real column-beam system (or frame system) with shorter spans - or much thicker floor components might help to produce a solution to these problems.

The relationship between the floor structure and the lightweight walls is another - and presumably more serious - problem.

Reasonable sound insulation in the vertical direction requires floating floors or similar. A floating floor cannot always withstand the weight of lightweight walls along every conceivable erection line. Even if the weight problem could be solved, a sound problem would still remain; when lightweight walls are erected on top of a floating floor, there will be nothing to prevent sound from being transmitted under the floors. The requirement regarding movable, lightweight walls is at variance with the development towards increased sound insulation between individual rooms of a flat - and presents an even greater problem if movable party walls are also desired.

Some degree of "modular co-ordination" of the erection options for lightweight walls may result in the development of a floor structure that permits the erection of lightweight walls in an aesthetically acceptable way and with reasonable room insulation, in a reasonably flexible "modular system".

The problem is analogous to that encountered in office buildings with movable partition walls: the sound insulation between the individual offices is determined by the (complicated) structures established over walls, in the space between the floor slab and the suspended ceiling.

Facade flexibility

Really extensive facade flexibility - for example, possibilities for extensions - is hardly feasible in anything but low-rise buildings. The windproofing and waterproofing of the facades would put almost insuperable difficulties in the way of "do-it-yourself" solutions.

Flexibility must be planned and "product"-developed

Flexibility is a natural requirement for many reasons: it allows for future modernization of the building; it permits fulfilment of the occupants' wish for co-determination and enables adaptation for varying family size; new family patterns can be accommodated, etc. Flexibility will cost money, but with a view to being able to cope with new - and unknown - requirements, the money may be very well spent.

Flexibility for the occupants requires advanced planning of the structure, but not necessarily a prohibitive additional expense if for no other reason than the fact that whole of the wage cost (and part of the actual investment) in connection with, for example, lightweight partition walls will be borne by the occupants themselves. If the present trend towards ever shorter working hours continues, and if the occupants want to - and can - "refurnish" their flats themselves, financial objections can hardly be made to the totally flexible apartment plan when all the advantages are taken into account. One can visualize an entirely new "timberyard industry" arising, offering small building components on the "do-it-yourself" principle. In collective projects - "communes" - which must be assumed to include many sort of "experts", this principle would definitely be able to function.

Flexibility is industrializable

Flexible construction is also industrializable. The products, the methods, the organization and the planning (and possibly also the distribution of the non-load-carrying components) would be different, but still analogous to the principles we know today.

The requirement of flexibility in building systems is not just a consequence of requirements to housing project plans and layouts, but also a consequence of the desire for "integrated" projects, in which institutions, shops, etc. are a natural constituent.

<u>Low-rise/ high-density projects</u>

In the one-family housing sector, there is a very clear tendency towards increased flexibility, even in "type houses". In addition, we have the trend towards new forms of housing, for example, the "low-rise/high-density" concept. Without the restrictions which the load-carrying structures and sound insulation requirements impose in medium-/high-rise housing, there are far greater and wider possibilities for flexibility and for building-kit and semi-building-kit activities, provided the installation systems are suitable.

The designs can be based on lightweight components that are easy to erect, extend and enlarge. Steel, wood and plastic offer great possibilities. In this connection, it should be noted that extensive use can be made of prefabricated bathroom and kitchen units in an otherwise flexible house. Such units are undergoing rapid development and will soon be available for all forms of residential building. Moreover, in view of the high price per m^2 they will be an excellent export product for the industry.

Bathroom and kitchen units

It is asserted that, unlike medium-rise housing, low-rise/high-density housing can provide a better (more friendly) environment, supplying the need for human contact and providing the possibility of flexible adaptation to different living patterns. It is also stated that, with the low-rise/high-density form of construction, it is easier to achieve co-determination for the occupants and to involve these in the actual construction process. Finally, it is stressed that this principle offers a high degree of planning flexibility.

Technologically, low-rise/high-density is, perhaps, based on industrially produced components assembled by the occupants, or on co-operative projects, which are constructed in the normal way, but in the design of which the occupants have had a say, - or on combinations of these principles.

Mixed-rise housing projects

But just as the virtues of the low-rise/high-density housing estate have been romantically compared to those of the traditional village, so might the latest mixed-rise housing projects - developed in the last eight years - be likened to the environmentally rich mediaeval town !

Both low-rise/high density and higher level building projects with varied facade and internal flexibility will make new - and big - requirements to the industry. One could mass-produce variants, or perhaps, rather, mass-produce richly varied collections of components.

A large number of examples of these new building forms are shown in Marius Kjeldsen: "Industrialized Housing in Denmark" (Danish Building Centre, 1975).