NON-TECTONIC SYSTEMS

BUILDING METHODS OF TECHNOLOGICAL RELEVANCE FOR HOT ARID TROPICAL AREAS*

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Prefatory Note

General problems of building in developing countries

Before expounding our proposition for a building technology for mass-housing in subtropical or arid tropical areas it seems important to concentrate here as a preliminary on one topic, *the problem of building in developing countries*. This theme has been dealt with many times at different international congresses and symposia. Almost twenty years ago at a congress in Copenhagen Gunnar *Myrdal* in his opening address, entitled "Needs Versus Capacity", stated: "We need more and better shelter. This is the challenge of humanity to building research and the industry." Then, later he continues: "All this now adds up to an enormous demand for construction, a demand that is constantly rising and tends to overwhelm any rise in building capacity".

These are clear words and nothing can be added to them. As we all know the situation so far in many developing countries has even grown worse and one cannot help feeling a sort of uneasiness, that we may witness again to a new decade of frustration.

We think it is an important task of integrated technological, economic and social research to reanalyse in its really complex interdepenence the fundamental inherent contradiction of building in developing countries, which has been very often and misleadingly simplified to the cliché "capital-intensiveness versus labour-intensiveness".

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The theme was elaborated partly in Aden (P. D. R. of Yemen) and in Budapest (Hungary) between 1980—84 by *M. Párkányi* D. Sci and his co-workers *Dr. L. Hajdu* architect, *J. Barcza* mechanical engineer, *Z. Szirmai* architect and *L. Varga* architect.

Consultants were *Prof. L. Gábor* architect academician (†1982), *L. Garai* C. Sci. Structural engineer.

We all know that, considered from the social and economic points of view, the type and extent of building necessary in developing countries create a fundamentally new technological problem, a problem really unprecedented in history of mankind, the solution of which cannot be directly derived from the experience of developed nations. The recognition of this fact, however, can by no means be equivalent to our accepting the view that traditional methods can ever show us a way out, it is also not equivalent to accepting the view that technology — despite its predominant role in the world of today — is not appropriate to the needs of developing countries. It is our firm conviction that the major breakthrough in mass-production of housing will come from the technological field.

We completely know that research, in itself, is not a solution to these problems, and that there is no solution in transplantation of research and technology and existing ready-made solutions from one group of countries to the other, but we definitely doubt the view — proclaimed by so many today — that the adequate housing situation can only and exclusively be solved by an *economic revolution*, firstly because it may transplant the search for a solution into an unknown, perhaps distant future and may tend, as a result of our subsequent frustrations, to a loss of faith in engineering ingenuity, and secondly because we think that the *technological possibilities* in this particular field have not yet been exhausted at all.

Considerations: Analysis of requirements

The reason why the situation in the field of construction has grown so much worse in course of these years, why the challenge ever since remained an almost insoluble problem, becomes immediately evident if we try to analyse at least the most important requirements to be satisfied by a building technology if it is really supposed to be applicable to conditions in developing areas, both from technological and from social, economic points of view.

From the *technological* point of view, it is extremely important that the technology to be applied, on the one hand, be industrialized to be able to cope with problems of mass-construction; on the other hand, be built on the existing foundations; be based on the use of local materials; be adaptable to extremely various architectural and functional requirements including housing, schools, community centres, industrial workshops etc. in urban and rural areas as well; be applicable to very different natural, geographic and climatic conditions ranging from earthquake safeness up to advantageous building physical properties; etc. in one word: be as open as possible, that is to establish an open system industrialization.

From the *social* point of view, when introducing the technology it is equally important that due attention be paid to the use of relatively unskilled labor, that only a few engineers and technicians be needed; to help the worker to leave the backward world of traditional building thus making new hands get used to new tools and acquire the reflexes and mentality, which help them to enter the world of today; to stimulate growth of centres other than cities; etc. to create fields where even self-help can be applied as one of the means of solving problems of mass-housing on the spot; etc, etc.

From the *economic* point of view, it is almost a precondition that the technology should not be bound to a built out infrastructure, in other words: to avoid requiring huge concentrated planted factories; to be able to eliminate, if necessary, the use of heavy transportation facilities, trailers, cranes and other sophisticated equipments; to promote an easy transition from present traditional methods to future building industrialization through aiming at decentralization of industry by applying transplantable, mobile factories; to stimulate new methods also for the organization of building activity in developing countries; and, last but not least, to achieve an extremely significant reduction of costs in each field, starting from investment costs up to the very cost of building, etc.

Conclusion: Outline of problem-solving

To postulate requirements of a building technology is always a relatively "simpler" task, the basic difficulty in technology spells problem-solving, that is to reply the question of how to reach the aim requested, what we have to do to call into being at least the preconditions of applicability of a building technology. Bearing in mind that the adaptability of a building technology to developing countries can only be scaled by the degree with which it satisfies the manifold and often contrasting demands enumerated above, we set out from a thorough analysis of the contemporary building technologies. This has led to interesting results. The analysis of the existing industrialized technologies namely, clearly proved that there is none among them, which could meet in itself at least the majority of the demands, and this conspicuous lack of technological relevance was actually the main reason that called our attention many years ago to looking for *basically new* building methods for solving problems of mass-housing in these areas.

Now, in order to establish a fundamentally new building technology of high degree of technological relevance capable of meeting all the requirements, we started out from a fundamental law in technology according to which establishing a real revolutionary, that is qualitative change in technology is always equivalent to creating an *axiomatic change*, characterized, in turn, by the principle of doing "*the same thing in a different way*". Thus it became clear from the very beginning, that it was not the further development but the transformation of the old, that would characterize the axiomatic change. The Gutenberg typography, the printing from movable types is no more a further development of handwriting just as a gun is no further development of the arrow, and — accordingly — the fundamentally new building method, *the non-tectonic system is not a further development but a transformation of industrialization of building*, as will be expounded on the forthcoming pages.

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First a brief description of the non-tectonic systems will be given and then, in very broad lines the problems of technological relevance in the industrialized building will be introduced, in other words the theoretical outline of the so-called technological irreversibility will be expounded (Section 1). The next few pages are devoted to the description of the nature and scope of the research 1980 to 1984 (Section 2). This is followed by a detailed analysis of two building methods: the "box-frame unit" method (Section 3) and the "closed cellular" method (Section 4). Both technologies introduce an adaptation of non-tectonic systems to hot-arid tropical areas and have been designed to give an optimum solution for the actual social-sociological, technical-economic, climatic-geographic architectural-constructional etc. requirements prevalent today in the People's Democratic Republic of Yemen. These latter sections are each subdivided into three parts corresponding to the main — design, manufacture, assembly — aspects of the subject. Verbal description of the sequence of operations is illustrated by drawings. The final section is a summary of the advantages and inherent possibilities of the non-tectonic systems reprinted from UNIDO Newsletter 132 (1979) April pp. 2—3 Vienna, Austria.

Section 1

Technological relevance in the industrialized building: theoretical outline of technological irreversibility

Introduction. Short description of non-tectonic systems

The theme — *non-tectonic systems* — has been treated in detail many times in our Periodica* therefore, here only a short description will be given.

The non-tectonic systems are open, lightweight, silicate-based building systems.

In the non-tectonic systems, building is a *complementary operation*, that is, a process in which we combine the *factory-production of surface elements with some kind of technology of pouring in of concrete either in the factory or on the building site*, whereby we produce structural units (in the factory) or call into being the structures themselves (on the building site). Thus:

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The non-tectonic systems break with the axiom of tectonics and substitute it for the *principle of surface*. This simply means that instead of working with structural elements they work primarily with surface elements.

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The surface elements of the loadbearing structure are of low specific gravity (they are mostly made of gypsum) consequently they have *no carrying capacity;* they are very thin, after all they are skin construction, consequently they have *no immediate stability* either. In brief: they are non-loadbearing, *non-tectonic* elements to be kept in position by simple regainable or unregainable *auxiliary* structures during concreting.

As a consequence of the moisture absorptivity of gypsum, the concrete — poured into the very thin cavities and channels arising between the surface elements — becomes stabilized almost immediately: it "freezes" on the gypsum.

The new — non-tectonic — construction arising as a result of this process is a *lightweight, silicate-based, rigid, monolithic, frozen reinforced concrete structure* and as such it is really unique in the industrialized building.

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* See: References.

The principle of building with non-loadbearing surface elements, in other words: the simple principle of vertical and horizontal alignment (addition) of non-loadbearing — i.e. *non-tectonic* — *surface* elements next to one another (according to a certain order, of course) and uniting them into a monolithic structure (through pouring concrete into the cavities and channels arising between, within or on top of these surface elements) — this is the essence of every *non-tectonic* structure be it done by handicraft forms of production or realized at any higher level of industrialization.

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The change over from the present tectonic methods to non-tectonic systems is a real axiomatic change, which completely transforms every principle of design, manufacture and construction, and thereby — as we shall see — it transforms at the same time the very structure of building industry as well. The principle of building with non-loadbearing surface elements, namely, fundamentally changes the *architectural* and *technological* aspects of industrialization of building. The elements of the finished surface namely are absolutely *neutral* both from aesthetic (architectural) and from technological (production) points of view. The non-tectonic surface elements with their glass-smooth surface on their final visible side never "betray" what they are the surface of. You never can tell from this surface whether it will become a surface of a wall, or that of a floor, the *surface being the same in either case.*

This fact is very important because this kind of aesthetic and technological neutrality is extremely favourable from points of view of architectural and technological design. The neutrality of the elements, namely, almost "calls" for creating real *open systems of construction* and this in turn is the fundamental *architectural* precondition of *planning for change* and the *technological* precondition of *producing for change.*

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We have thus seen that in the non-tectonic systems the surface elements are *semantically meaningless* since they are not bound to any particular location in any particular building. This, however, means that the non-tectonic building method actually transplants the well-known *Gutenberg-principle* to the industrialized building.

Similarly to the letters of the phonetic alphabet, or more accurately: the types of the printed alphabet which in themselves have no meaning yet allow any kind of texts to be printed;

the surface elements of the non-tectonic system — the non-tectonic bricks — are no structures themselves yet they permit to assemble any kind of buildings.

The non-tectonic bricks are actually nothing else but letters of a structural system and as such they can equally be used for housing, schools, communal buildings, industrial halls, etc.

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The Gutenberg principled building, thus, operates with open systems of lightweight non-tectonic bricks. Here the building is undetermined since — as opposed to the practice of the well-known housing factories — the knowledge of the final product is not a precondition of *manufacture.* All you have to know is the system of grids on plan and in section, since the non-tectonic elements (these undetermined *surface* elements to undetermined *locations* in undetermined buildings) will fit into that grid system anyway. The factories do not need to see the final product.

This type of manufacture, however, is of a completely different character. This is *blind manufacture.*

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Now, in order to be able to combine workability of structure (a precondition of planning for change) with the convertibility of machine (in turn, a precondition of producing for change) the non-tectonic systems relate the variable *modular parameters* (spans, heights etc.) to variable *submodular thicknesses* (structural thicknesses, thicknesses of elements, etc.) and thereby the non-tectonic systems establish on the one hand a *modular* reference between the *elements* and the *modular (parameter) grids* on the building site, and on the other hand a *submodular* reference between the *thicknesses* and the *submodular (micro) grid* built into the manufacturing apparatus.

The ratio of modular to submodular grids can be expressed in a simple mathematical form. In the actual case this *formula of double co-ordination* is $3\ M = 8\ mc$.

This formula (which appears later in this study on Figs 9, 10, 20, 21) means that 3 basic module grid units (M = module = 10 cm) within the structural system correspond to 8 micro grid units (mc = microcell = 37.5 mm) within the manufacturing apparatus. This unique double-reference system, which cannot be realized in any closed tectonic system, results in an *optimum structural engineering performance* in which the variable loads and all the variable modular and submodular dimensions of the loadbearing, frozen reinforced concrete structure are strictly related to one another.

In the non-tectonic systems, blind manufacture is founded on the system of double co-ordination.

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In short:

The non-tectonic systems — classed among the complementary building technologies — are based on the Gutenberg principled fragmentation and call into being open, lightweight, silicate based building methods through double co-ordination.

In the non-tectonic building method the final product (that is the building) is realized in such a specific building process where additivity (that is the axiom of building) is founded on the simultaneous non-loadbearing (non-tectonic) capacity and temporary or incidental instability of semantically meaningless (Gutenberg-principled) surface elements. In this building method the immediate product of manufacture is not the load-bearing structure but its surface and therefore alignment of surface elements of vertical and horizontal structures does not lead to immediately load-supporting — load-transferring (that is: tectonic) junctions between these surface elements.

Technological relevance and its degree in the industrialized building, in general

In the industrialized building *technological relevance* is defined as an immanent (inherent) quality of manufactured structural systems by means of which these building — structural — technological systems can most favourably satisfy a system of concretely determined requirements in a concretely determined particular case.

The system of requirements of industrialized building, however, is extremely composite and complex not only because quite a series of technological, economical and social constituents have to be taken into consideration but first of all, because this system of requirements keeps constantly changing in space and in time. *A technology satisfying a system of determined requirements possibly most favourably in a given space and in a given time inevitably loses its validity — its relevance — if applied at another time or in another place.*

From this it clearly follows that when evaluating the adaptability of manufactured structural systems to some particular case varying in space and in time, their efficacy from a technological point of view can only be scaled on the possibilities offered by the system to create various adaptations, in other words, by *the capacity of the system for self-adaptation.*

This adaptability, this capacity for self-adaptation — which renders it possible for manufactured structural systems to adjust themselves to requirements varying in space and in time — is what we call the *degree of technological relevance*, and this in turn is again an immediate function of the combinatorial qualities of the structural system.

Technological relevance and its degree in the non-tectonic systems

The lightweight, silicate-based non-tectonic systems — as proven by our whole work — are expressedly open systems. This in other words, means, that in these systems the solution of any building task is theoretically completely open both from design and from manufacture-assembly points of view:

— from *design* point of view, because their *architectural and technological efficacy is equally maximum*, since in the non-tectonic systems variability is not only a function of the combinatorial qualities of the structural system and the system of auxiliary structures, but beyond this and at the same time it is also a function of the convertibility of machines, transplantability of the factory and the degree of complementarity, that is, the expediently choosable ratio of operations in the factory and on the building site;

— from *manufacture-assembly* points of view because *their degree of technological relevance is theoretically maximum* since in the non-tectonic systems it is not the building task — characterized by different levels of quantity or quality — which is subordinated to manufacture but on the contrary, it is the manufacture-assembly that is adjusted to the prevailing social-sociological, technical-economic, geographic-climatic, architectural-building etc. requirements and possibilities.

The degree of technological relevance in the industrialized building reaches its maximum in the non-tectonic systems. The combinatorial qualities of these systems, namely, offer almost unlimited possibilities for adaptation to requirements varying in space and in time and actually it is this circumstance which also renders it possible for the system to create a series of products ranging from individually manufactured individual products through individual products produced by mass-production methods up to mass-products produced by mass-production methods.

The fact that in the non-tectonic systems technological relevance reaches a maximum degree is of crucial importance from building industrialization point of view because it makes something possible that we could never realize in the mechanization-principled technologies, that is an equally optimum solution of *building tasks characterized by the most different levels of quantity or quality.*

Levels of technological relevance

The non-tectonic systems, thus, may enforce technological relevance on very different levels:

- in case of *low-level (ad hoc) relevance* (individual—incidental technological validity) the designing architect may reasonably apply an in-situ building method of low or medium degree of complementarity; may conceive the building as an expressly individual product and solves the task (eg.: detached family house etc.) in such a way as to be able to simplify manufacturing apparatuses to such a degree that they may be "amortized" even after one building; aims at using possibly unregainable auxiliary structures and applies possibly medium-sized elements, so that in the process of building they may be manipulated by hand;
- in case of *medium-level relevance* (occasional-areal technological validity) the designer-architect works with planted workshop and applied mass-production methods for manufacturing individual products; for this reason he applies the choosable building method with a medium or high degree of complementarity and aims at breaking up the building into components small enough to remain transportable and complex enough to benefit from factory production conditions;
- in case of *high-level relevance* (geographic-zonal technological validity) the designer-architect — theoretically — may equally work with planted or transplantable factory and his fundamental effort is to be equally able to produce individual or mass-products by means of mass-production methods; for this purpose he uses the selectable building methods with medium or high degree of complementarity; chooses the reasonably largest sizes for the components and — in case of working with transplantable factory — aims at maximum or even total elimination of transportations.

Technological irreversibility in general and in the non-tectonic systems

If in the industrialized building in general, we succeed in satisfying a system of unambiguously determined requirements as favourably as possible in a given space and in a given time by means of a given building-structural-technological system, then — exactly as a consequence of the technological relevance — we unavoidably (confessedly or unconfessedly) call into being an *irreversible technology*, that is a technology definitely and exclusively bound to that particular place and that can not be transferred from there to another place without alteration. *The irreversibility of the technology, consequently, is nothing else then the criterion of the correctness of application.*

The fact that in the developing countries the system of requirements of mass-construction* shows extreme discrepancies, in other words, the social-sociological, technical-economic, zonal-geographic, building-architectural etc. requirements vary in a rather wide range, *brings to the fore the adaptation of building systems of high degree of technological relevance. This explains why the non-tectonic systems may set up a claim for an outstanding role in the mass-construction of developing countries particularly in hot arid tropical or subtropical areas and consequently they may chart a new course for development in the Hungarian building industrial export as well.*

Section 2

Nature and scope of the research 1980—84

Preliminaries

A Hungarian expert — dr. L. *Hajdú*, one of the authors of this study — who happened to work at the Ministry of Construction in Democratic Yemen and who had been previously participating in the research work of the non-tectonic systems was informed that — in order to overcome increasing shortage of housing in the P. D. R. of Yemen — the Ministry of Construction looked for contemporary building technologies expected to completely satisfy the system of demands analyzed in a detailed study issued by the Ministry.

Recognizing this demand Dr Hajdú asked the Chemocomplex Hungarian Trading Company to prepare an informative tender for adapting the non-tectonic system. The tender for establishing a transplantable factory producing hundred flats per annum was submitted to the Ministry of Construction in Aden and at the same time an illustrated lecture was also delivered by the expert to the Board of the Ministry. The tender and the lecture were highly appreciated. A letter dated June 1981 was sent by the Deputy Minister to the General Manager of Chemocomplex, expressing interest in a future project

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* In our prefatory note the general problems of building in developing countries could only be analysed very densely. This is why it seems particularly expedient here to mention a technical-economic consideration definitely pertinent to this theme in support of our conviction, that *the real domain of the adaptation of non-tectonic systems is mass-housing in developing countries.* The consideration goes as follows:

Whilst in developed countries the specific cost of building constructions, or rather the specific cost of the primary loadbearing structures — that is to say: that specific part of the building cost where the silicate-based, lightweight, non-tectonic systems may save a particularly considerable sum of money — does not amount to more than approximately 10—20% of the total building cost, in developing countries exactly the opposite is relevant: *in developing countries, namely, the building cost of the primary loadbearing structures in low-cost housing may reach even 80—90% of the total building cost!*

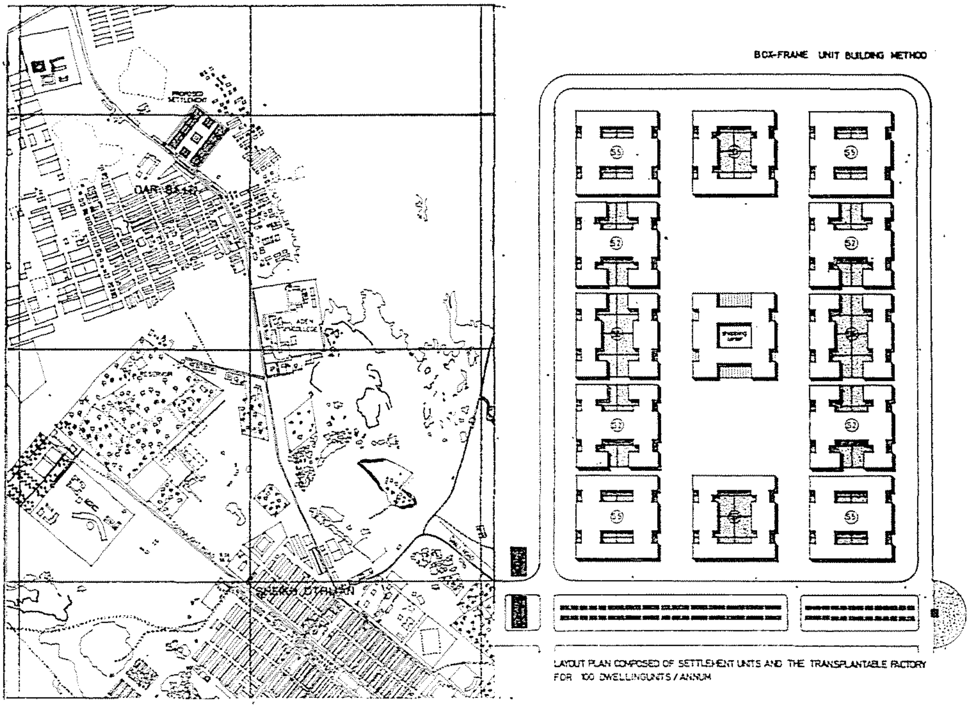

Fig. 1

introducing the non-tectonic system in P. D. R. Y. In order to promote decision on the adaptation of the system a feasibility study was requested in this letter. Furthermore a delegation was invited to collect the necessary data and information for the study in August.

In order to prepare the forthcoming negotiations a preliminary design work was started simultaneously in Aden and in Budapest. We were already acquainted on the one hand with the system of local requirements (as mentioned above) on the other hand, with the annual output of the factory required. This was enough to elaborate — of course only in a first sketchy from — quite a number of architectural variations on ground plans and settlement-variations on possible layout-plans. (In this work we could advantageously use the experiences gathered from the designs prepared for Gambia and Egypt in the previous year.)

What we could not know, of course, in this stage of the work was the actual location of the building site. We did know, however, that there can only be two essential possibilities for operating a factory of a capacity of hundred dwelling units per annum. In the first case one aims at concentrating the buildings as much as possible, in the other case one aims at building in a scattered form, that is to erect buildings at several places at the same time. And this is

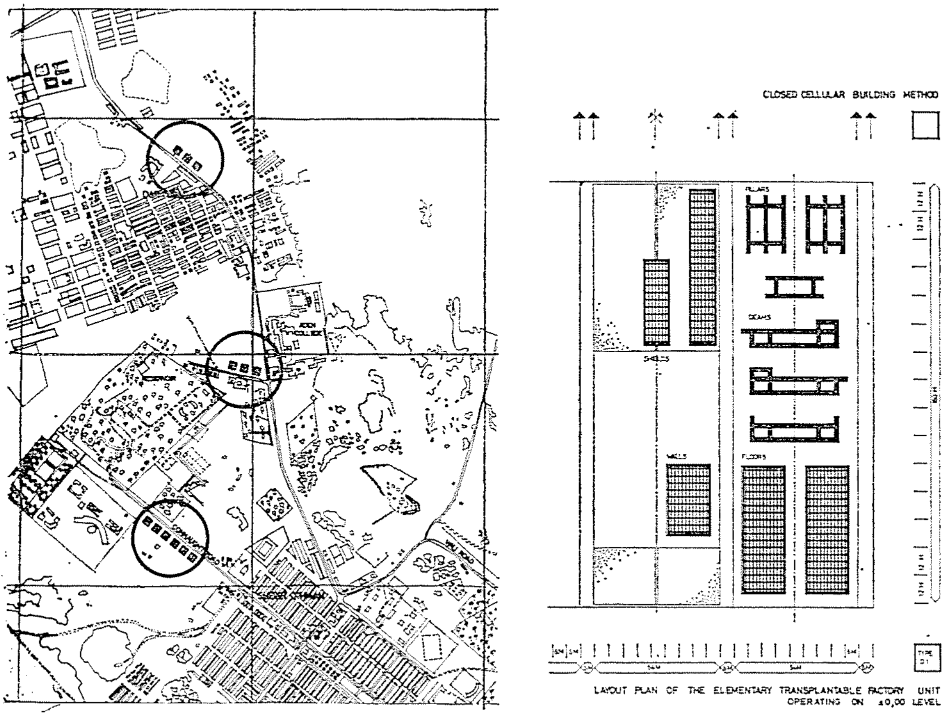

Fig. 2

how we finally came to the idea of elaborating two different technologies well in advance. For the first case the box-frame unit building method was proposed to be realized in a transplatable factory located next to the building site (Fig. 1) and for the second case, the closed-cellular building method to be realized in elementary transplantable factory units located immediately on the zero level of the individual buildings (Fig. 2).

In course of the final negotations in Aden the scope of the study was agreed on and contract was concluded between the Ministry of Construction and the Chemocomplex Company for elaborating the feasibility study with a financial calculation attached. The delegation was provided with the necessary data for calculations, the outline of the planned project was determined and the site for the buildings and the factory were finally designated in Dar Saad, so our first version (Fig 1) became actually accepted.

Let us remark here finally that in the year 1982 the actual housing cost ranged from about 300 to 450 US $ per square metre area, which was extremely high compared to the world prices. Our calculations showed that the significant reduction of weight of the buildings through reduction of materials also resulted in a significant reduction of building costs. We succeeded in reaching the 200 US $ square metre area price as requested.

Scope and field of the building project:

Propositions for building sites. Variations on settlement layout plans, building methods and transplantable factories

In order to take the first step toward the adaptation of the non-tectonic system in Democratic Yemen, the Ministry of Construction and the Chemocomplex Company came to an agreement upon preparing a proposal for a small settlement composed of about hundred low-cost dwelling units.

Three construction sites were indicated near Aden: (see map)

1. In Dar Saad (on the road to Lahej, right after leaving Sheikh Othman)
2. In Sheikh Othman (close to Connaught Road)
3. Between Sheikh Othman and the road to Mukalla (out of the map in eastern direction).

Such a determination of the construction site served two purposes; on the one hand to simulate the rural environments, that is, the desired future field of application of the non-tectonic system, on the other hand to assure comparatively suitable circumstances for the erection of the first settlement not too far from the capital, creating good possibilities also for demonstration.

The finally accepted version — the dense settlement in Dar Saad area, to be realized by the box-frame building method — is shown in Fig. 1 together with the location and arrangement of the transplantable factory unit of a capacity of 100 units per annum. The very settlement — showing an architectural concept of a closed rural community — consists of 12 units, each unit is composed of 8 houses. In the middle of the settlement an administrative and shopping centre was designed. All the 96 dwelling units are of one-level arrangement with inner courtyards.

In the second version the 96 dwelling units were to be realized in a scattered form in three different groupings in the Dar Saad and Sheikh Othman areas as shown in Fig. 2. In this case the building project is realized by the closed-cellular building method by elementary transplantable factory units. The layout plan of an elementary factory unit together with the arrangement of the apparatuses for manufacturing pillar box-frames, beam box-frames, closed-cellular wall- and floor elements, etc. is also shown in the right hand side of Fig. 2.

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Section 3

The box-frame unit building method

Introduction. General description of the method

From the point of view of principle of construction, the box-frame unit building method is actually a special case of the so called small-box-unit building methods.

The building method is characterized by a high level relevance, that is, *a high degree of technological relevance with geographic-zonal validity* and as such it is most advantageously applicable to conditions in developing countries particularly in hot arid tropical or subtropical areas and can be most expediently realized in transplantable factories.

In the box-frame unit building method we *manufacture* on a high degree of readiness. *In the transplantable factory* namely, we not only produce Gutenberg-principled non-tectonic *surface elements* for walls and floors, pillars and beams but at the same time we also begin to preassemble these surface elements into mechanization-principled tectonic *structural elements*, that is to say, we start the manufacture of tectonic wall-elements, floor-elements, pillar box-frame units, beam box-frame units, etc. as well.

On the building site the additivity is always in-situ and final, which means that these tectonic structural elements are always located immediately to their final in-situ position, in due order of course, as we shall see.

Variability of the box-frame unit building method

Amongst the non-tectonic systems the variability of the box-frame unit building method is of medium degree since the system — simultaneously founded on the slab and the box-frame as principles of construction — allows a relatively more restricted selection of sizes and increments for the elements and components as compared to the in-situ building method. At the same time the degree of complementarity (that is, the expediently choosable ratio of operations in the factory and on the building site) is the highest, since the degree of readiness achievable in the manufacture of elements and components — similarly to the box-unit building methods — may reach a reasonable maximum, consequently, the freedom of design is relatively more restricted.

The slab and the box-frame as principles of construction

The slab as principle of construction — in general — has become rather well-known through practice of the housing factories. This is why it is extremely important to note here that *in the box-frame unit building method — specifically — the slab as principle of construction completely changes both from design and from manufacture points of view:*

- from *design* point of view, because in the box-frame unit building method the tendencies towards increasing the span can not run counter the slab as principle of construction since *in this case the load of the slab is taken up by the beam-frame.* Thus, the *span-dimension* of the slab gets free, or even, it *becomes theoretically unrestricted* since the load of the tissue-structural slab is carried by the short threads at right angle to the span and transferred immediately onto the beam-frame;

- from *manufacture* point of view, because *in the box-frame unit building method — the technological relavance of which can be most expediently enforced in hot arid tropical or subtropical areas — the manufacture of the slab can be organized on a completely new basis.* Under these climatic conditions, namely, it becomes possible to apply such a method for mass-production of slabs *in a factory transplantable next to the building site,* which simply cannot be realized in an identical form under different geographic circumstances: The manufacture of the tissue structural (gypsum + reinforced concrete) floor elements, namely, is realized in this case in a determined technological order in horizontal position on a stack, above one another and in such a way, that first we manufacture the non-tectonic periodic gypsum surface element of parameter size in one direction by one single casting, then almost immediately, after setting of gypsum, we call into being the tectonic structural floor element by pouring concrete into the channels and on top of the gypsum surface element which, thus, does not require either storing, moving or any further manipulation.

The box-frame as principle of construction typically belongs to the small-box-unit building methods. The architect here uses factory-made stiffened spaceunits: box-frames. He regards this as the starting idea for mass-construction of homes, schools etc. He accepts that these small-box units — these "empty" pillar box-frames or beam box-frames — can most expediently be jointed along lines and uses, these box-frames for assembling the building. Since, however, these elements — the pillar box-frames or beam box-frames — can only be of parameter size in one direction, consequently first of all, the variability in the box-frame unit building method will — intermediately —

become a function of the additivity of manufactured tectonic small-box-units, which is very advantageous because these box-frame units — although they cannot be shaped any more in themselves — need not dispense with increments in any direction; secondly, the requirements of variability — which in the last analysis inevitably strengthen the tendencies towards increasing the sizes of the parameters — in the box-frame unit building method cannot lead to inherent contradictions so well known from the box-unit building methods. In this specific case, namely, where the slab and the box-frame as principles of construction are simultaneously applied within the system and side by side, the slab and the box-frame do not stay in the way of increments, thus, variability can be enforced within rather broad limits.

The box-frame unit building method — based on the use of non-tectonic systems — applies the slab and the box-frame as principles of construction simultaneously and side by side. This is very important because it means that the variability of the box-frame unit building method is not a direct function of the manufactured tectonic plane elements or box-frame units, but first of all, it is the direct function of the semantically meaningless, Gutenberg-principled non-tectonic surface elements, consequently demands of variability are relatively easily met. All in all:

The box-frame unit building method is founded on the simultaneous application of the slab and the box-frame as principles of construction. The architect here uses slab-elements and box-frame units of parameter-size always only in one direction. The shape of these units is always determined by the gypsum surface elements. He regards this as the starting idea for manufactured buildings. The plane elements (the wall- and floor-elements) are actually anisotropic, tissue-structural reinforced concrete slabs stiffened by ribs and a membrane arising through pouring concrete into and on top of the two-way channel system of the gypsum surface elements, whereas the small-box units (the pillar box-frames and beam box-frames) are actually empty monolitic boxes, more accurately: frozen reinforced concrete folded shells arising through pouring concrete in between the plane or profiled gypsum surface elements aligned properly in two directions. He accepts that these small-box units that is the box-frames can only be jointed — heterogeneously or homogeneously — along lines and assembles his buildings — through a proper additivity of these box-frames and slabs — on the building site.

Since the architectural solutions of the buildings — ground plans, sections, details etc. — can immediately be reduced to the additivity of semantically meaningless Gutenberg-principled surface elements, therefore in the box-frame unit building method wide possibilities arise for flexibly changing the parameters of the buildings in three directions without having this tendency run counter the slab and the box-frame as simultaneously applied principles of construction.

The box-frame unit building method — characterized by a high degree of technological relevance — is realized in a transplantable factory located next to the building site.

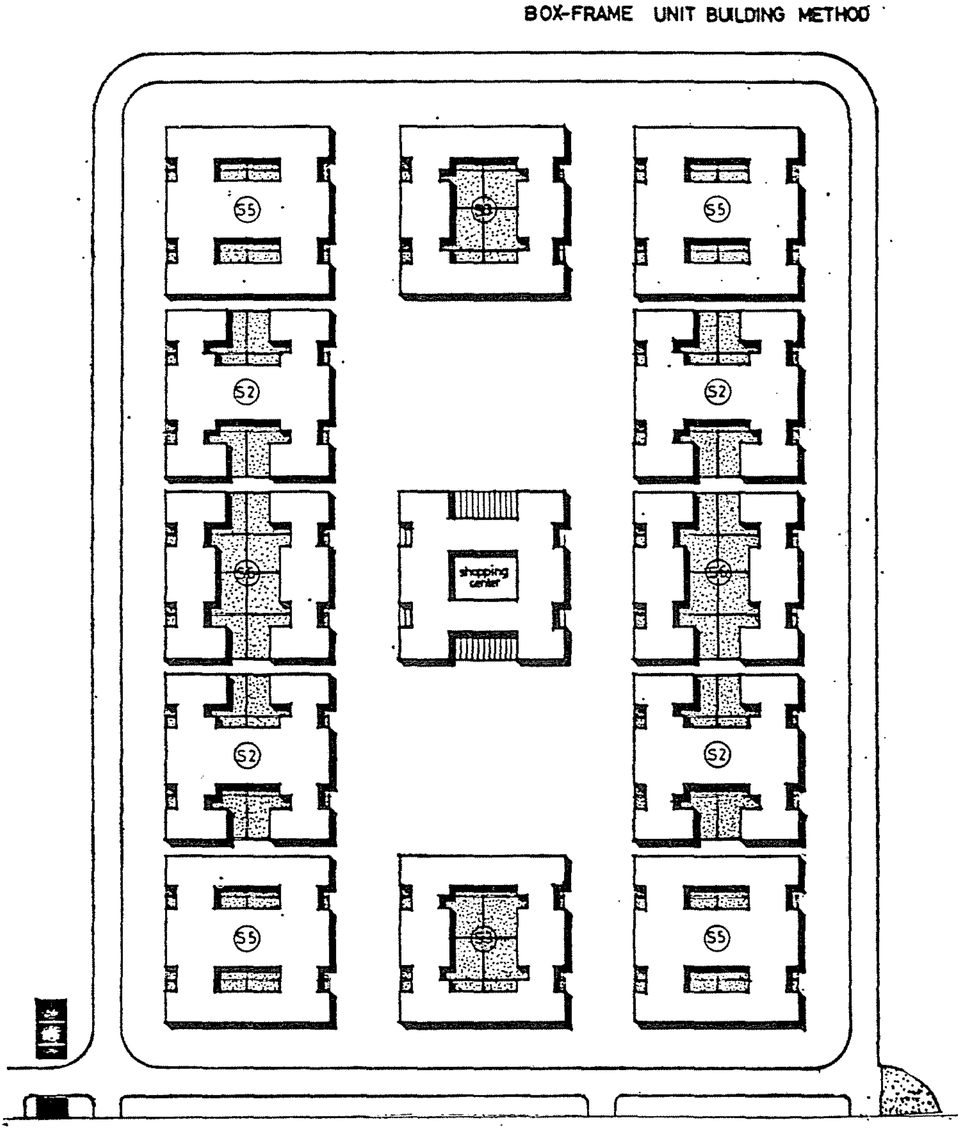


Fig. 3

An adaptation of the box-frame unit building method to the People's Democratic Republic of Yemen

Design

Settlement. Layout plan

A possible layout of the settlement to be realized in Dar Saad (Fig. 1.) is shown enlarged in Fig. 3. Codes S2, S3, S5, S6 indicate different settlement units. These *settlement units* — each composed of eight houses — are seen in Fig. 4. Further settlement units can of course be designed with different arrangements of the dwelling units, this drawing shows only some symmetrical variations.

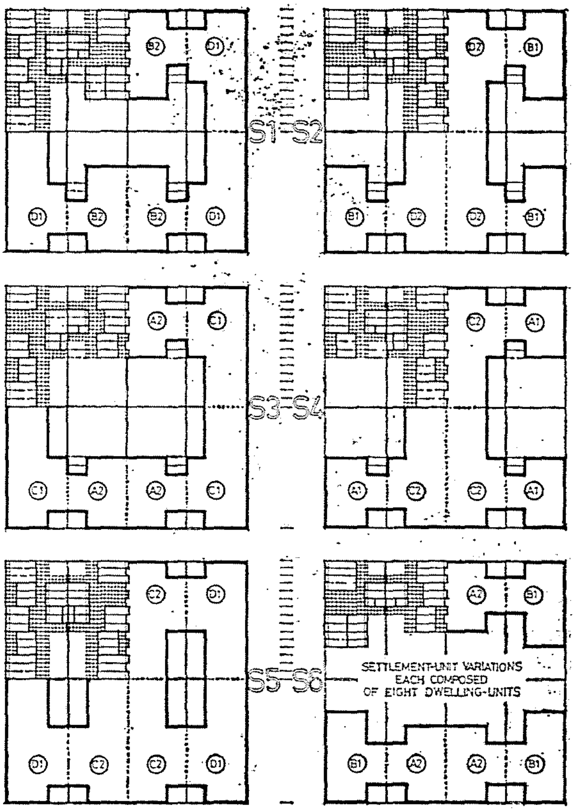


Fig. 4

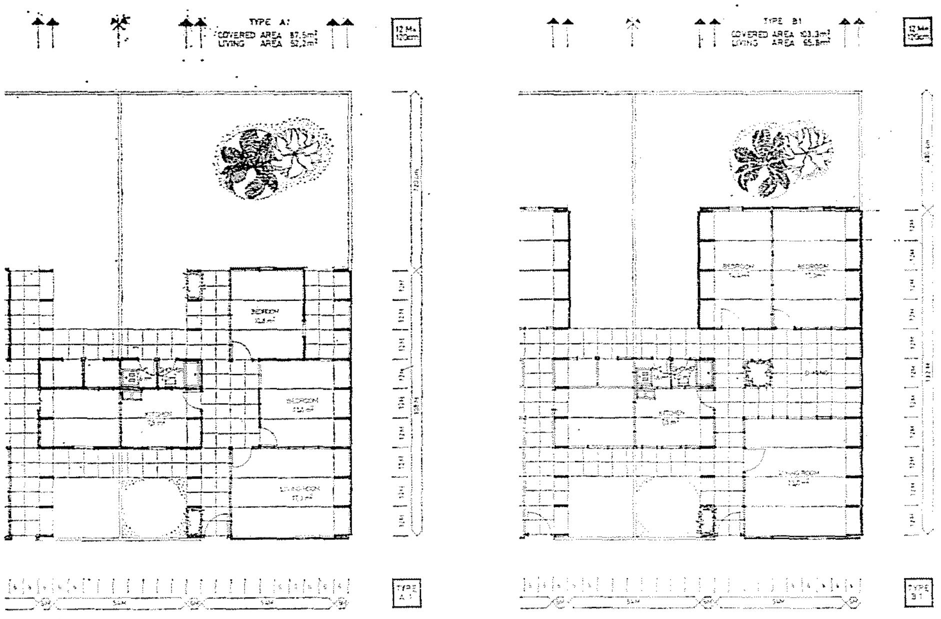


Fig. 5

Types of dwelling units

The component parts of these settlement units, that is the *types of dwelling units* are shown in Figs 5 and 6. In accordance with the negotiations between the Ministry of Construction and the Chemocomplex Company four different types of dwelling units were designed. The dwelling units are all based on the *box-frame as principle of construction*, consequently, structurally they are identical, but vary in floor areas and ground plans.

It is very important to note here that the adjacent — not necessarily twin — dwelling units are constructed in such a way that always three spans "make" two dwelling units. The span — distance between two opposite box-frames — is always bigger than room-size.

In course of the design of the dwelling units special attention was paid to the following aspects:

1. Since the area of the proposed settlement belongs to the costal region, all the dwelling units were provided on the one hand with double roofs, all the walls with sun-shields and all the rooms and passages with natural cross-ventilation; on the other hand — considering the recommendations based on a climatic analysis elaborated by a Swedish institute for the Yemeni Ministry of Construction — there was no reason to pay any particular attention to the insulation of the walls (excepted shading of course) because of the limited diurnal temperature range and due to the permanently open windows serving cross-ventilation.

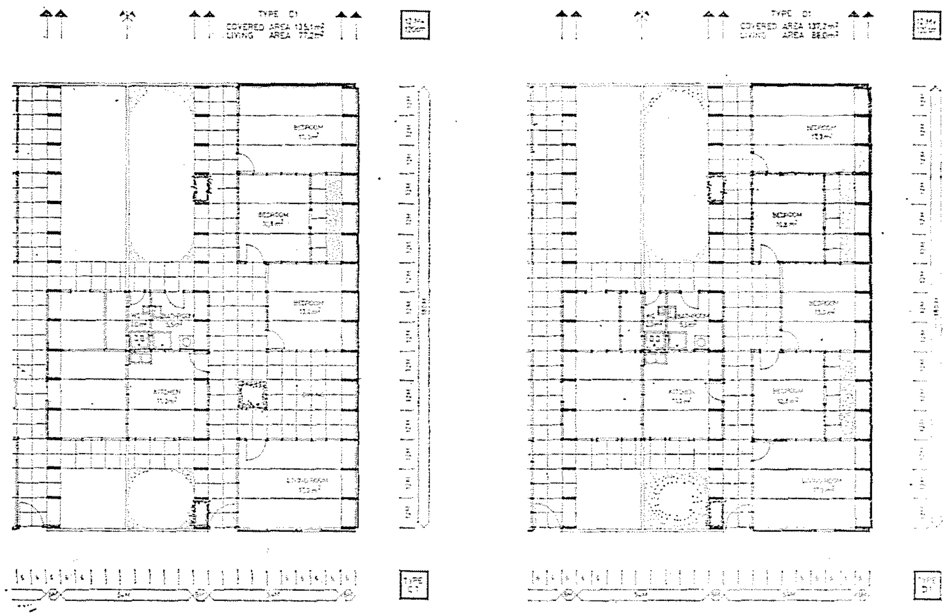


Fig. 6

2. Because of hygienic and economic considerations all the rooms supplied with water were separated and adjoined by pairs.

3. Taking the social traditions into consideration, both houses and yards assure perfect privacy for the residents.

Four pairs of types of dwelling units were designed (Figs. 5, 6), the pairs differ only by their position. External position is indicated by number 1, intermediate position by number 2 (See also Fig. 4). The area of dwelling units of intermediate position is reduced by sharing the common pillar-zone.

In the following chart the living and covered areas of the different types of dwelling units with the number of rooms have been tabulated:

	A1	A2	B1	B2
Living area m²	52.2	50.7	65.8	62.9
Covered area m²	87.5	84.3	103.3	99.3
Number of rooms	3	3	3	3

	C1	C2	D1	D2
Living area m²	77.2	73.6	88.0	84.4
Covered area m²	135.1	129.7	135.1	129.7
Number of rooms	4	4	5	5

The four pairs of dwelling units are semi-detached single-storey arrangements (Figs. 5, 6), each type of dwelling unit has about the same built-in area (18.0 m × 9.3 m or 18.0 m × 9.0 m), but the covered areas are different at the expense of the yard areas. Each dwelling unit is provided with an entrance garden and an inner yard as well.

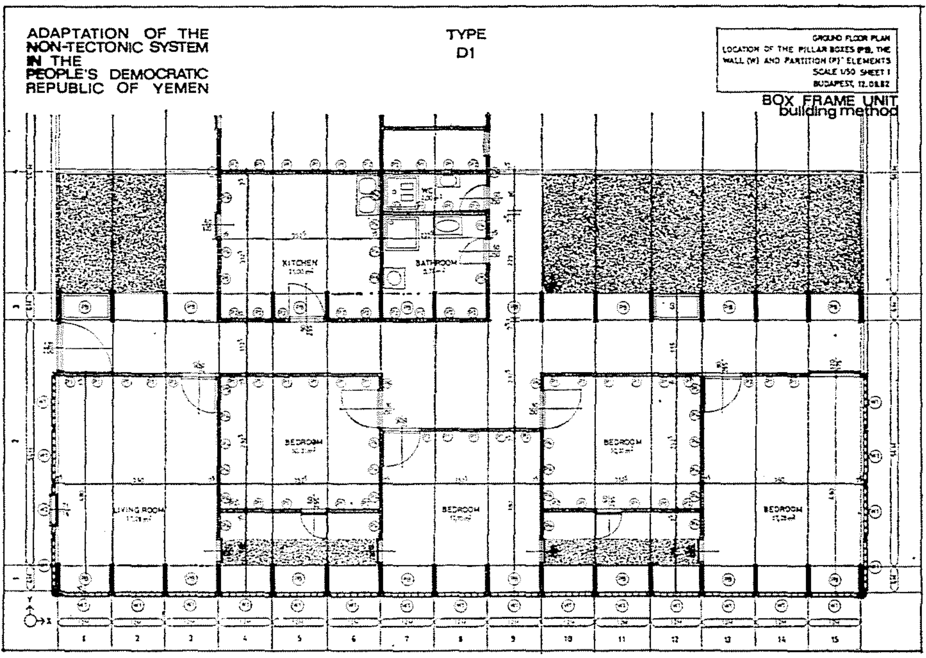


Fig. 7

As it was mentioned in Section 1 the non-tectonic systems always operate with double co-ordination. The *formula of double co-ordination* in our case was: *3 M = 8 mc.* (M = 10 cm; mc = 37.5 mm)

The characteristic dimensions of the dwellings are the following:

Primary grid dimensions on plan:	6 M (pillar-zone)
	54 M (span-zone)
Secondary grid dimension on plan:	12 M (axial dimension of pillar box-frames)
Primary grid dimensions in section:	25.5 M (pillar box-frame-zone)
	4.5 M (beam box-frame-zone)

Overall dimensions on plan:

A1 total width: 27 M + 6 M + 54 M + 6 M + 2 mc = 93 M + 2 mc = 9.375 m
total length: 3 mc + 9×12 M + 3 mc = 108 M + 6 mc = 11.02 m

B1 total width: same as A1 (see Fig. 5)
total length: 3 mc + 11×12 M + 3 mc = 132 M + 6 mc = 13.42 m

C1 total width: same as A1 (see: Fig. 6)
total length: 3 mc + 15×12 M + 3 mc = 180 M + 6 mc = 18.22 m

D1 total width: same as A1 (see Figs. 6, 7)
total length: same as C1

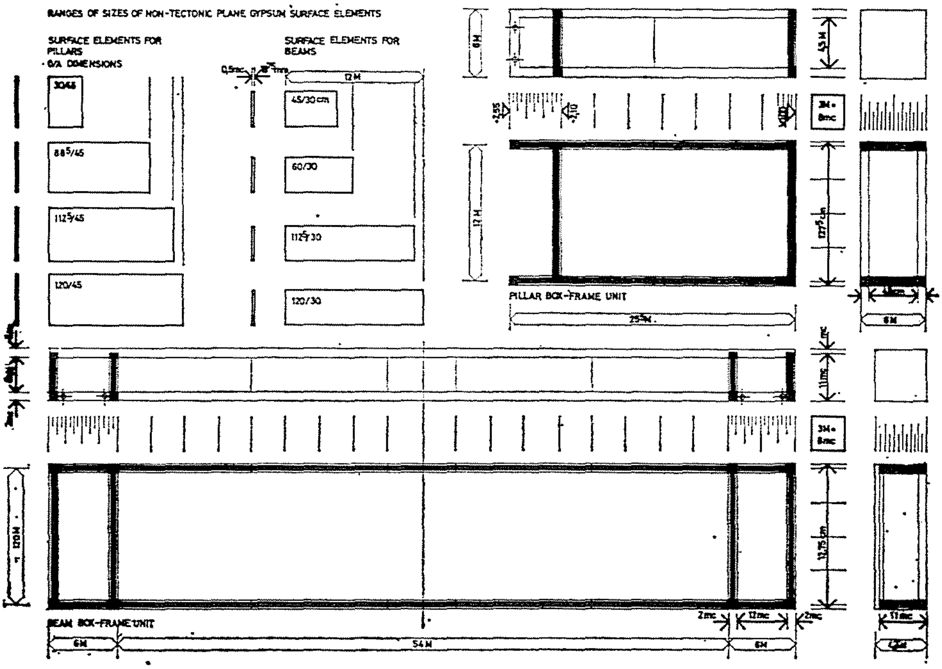


Fig. 8

In case of A2, B2, C2, D2 the total width is reduced by 3 M (i.e. half of the pillar-zone) whereas the respective total lengths are the same (see Fig. 4).

Micro-grid dimensions on plan and in section: mc × mc = 37.5 × 37.5 mm. The grid of structural — microstructural — details is shown in Figs. 9, 11.

The Gutenberg-principled non-tectonic surface elements with their respective variable and constant dimensions are illustrated by the following figures:

— plane gypsum surface elements for pillar box-frames and beam box-frames (Fig. 8);

— periodic gypsum surface elements for walls and floors (Fig. 9).

The mechanization-principled tectonic structural elements with their respective dimensions are shown by the following figures:

— reinforced concrete folded shell pillar box-frame units and beam box-frame units (Fig. 8);

— reinforced concrete tissue-structural wall and floor elements (Fig. 9).

Details

Each structural detail is elaborated in the mc = 37.5 mm microgrid system. These detailed drawings show location and junction of the elements

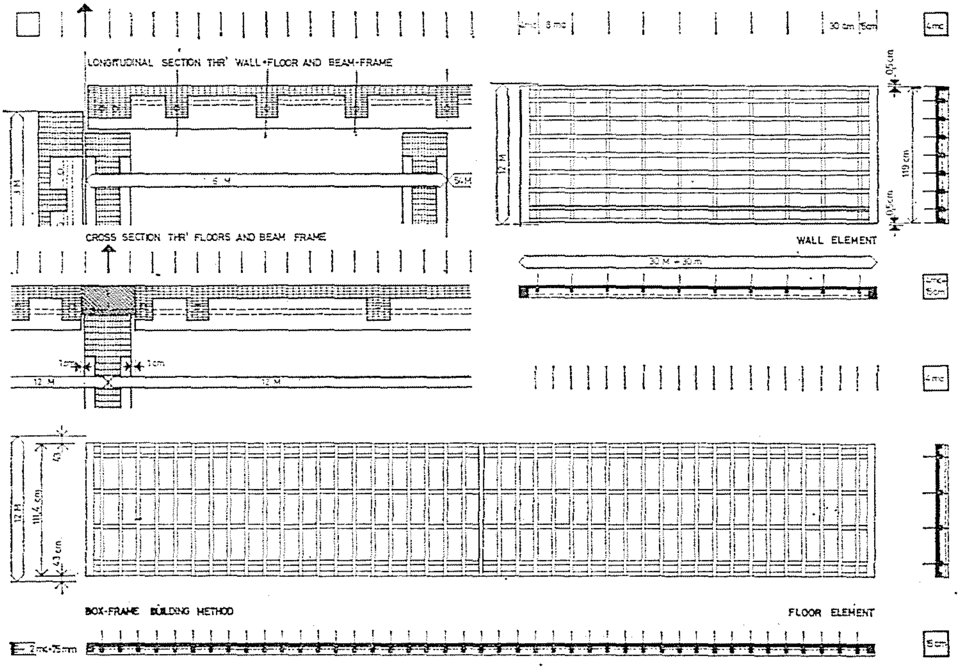


Fig. 9

in the modular and submodular grids on plan and in section. Some characteristic microcellular details are seen in Figs 9 and 11.

Mechanization-principled shield and double roof elements together with their location in the modular grid system is shown in Fig. 10. For further microcellular details see also Fig. 11.

The principle of construction

In order to show both the structural system and the process of construction simultaneously the axonometric view shown in Fig. 12 introduces the building method through the very principle of construction.

Let us remind the Reader here that in the adaptation of the box-frame unit building method the span — i.e. the primary distance (54 M = 5.40 m) between the opposing box-frames — and the axial dimension — i.e. the secondary distance (12 M = 1.20 m) between the "walls" of the pillar box-frame — are kept constant throughout the settlement. The span in this arrangement is always bigger than room-size.

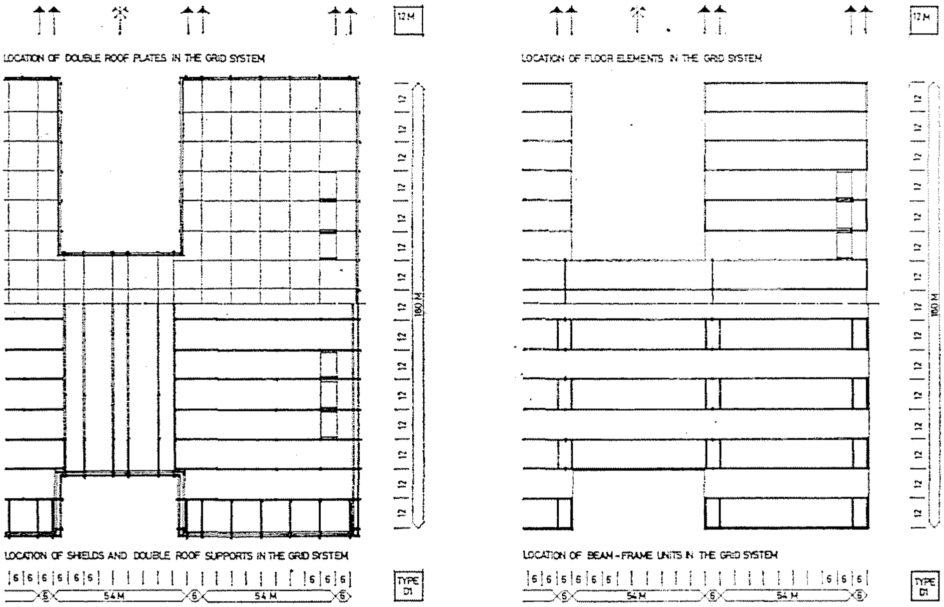

12M
LOCATION OF DOUBLE ROOF PLATES IN THE GRID SYSTEM
LOCATION OF FLOOR ELEMENTS IN THE GRID SYSTEM
12
180 M
LOCATION OF SHIELDS AND DOUBLE ROOF SUPPORTS IN THE GRID SYSTEM
LOCATION OF BEAM-FRAME UNITS IN THE GRID SYSTEM
6
54 M
TYPE D1

Fig. 10

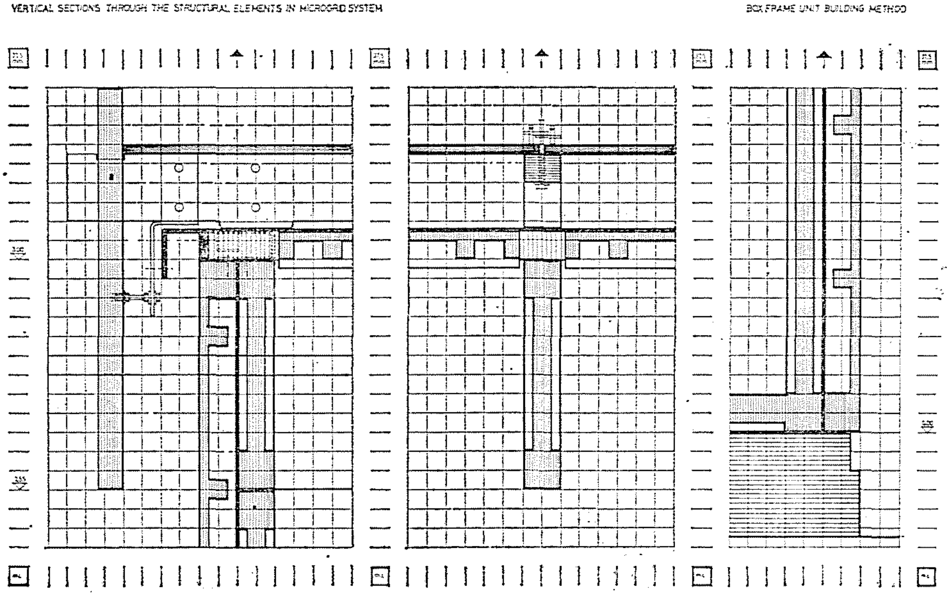

VERTICAL SECTIONS THROUGH THE STRUCTURAL ELEMENTS IN MICROGRID SYSTEM
BOX FRAME UNIT BUILDING METHOD

Fig. 11

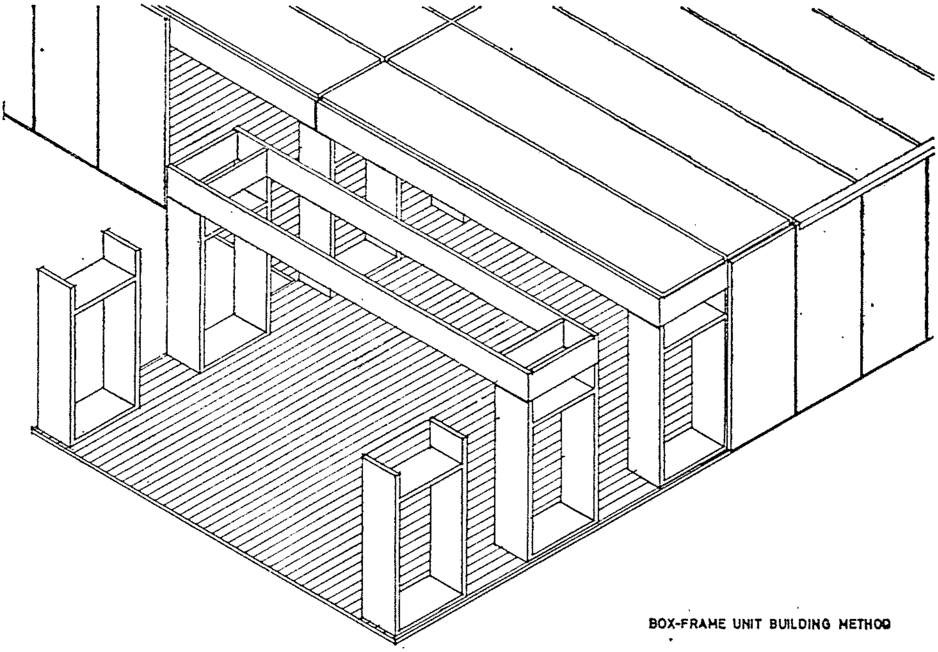


Fig. 12

Manufacture

Layout plan of the transplantable factory

The layout plan of the factory for producing hundred dwelling units per annum is shown in Fig. 13. The factory itself is located next to the building site surrounded by a road (see also Fig. 1) not necessarily built out previously. (If built out however, the manufacturing apparatuses can be expediently located immediately on the finished road surface and after completing the construction of the settlement the factory shifted will leave a useful road behind.)

The factory itself is composed of the following parts:

- a covered shed for manufacturing gypsum surface elements (including battery casting apparatuses, place for storing gypsum and surface elements etc.);
- service units (offices, laboratory, lavatories, maintenance and repair shop, stores for fittings etc.);
- fenced open-air place for manufacturing reinforcements, jointing points, and storing auxiliary structures;

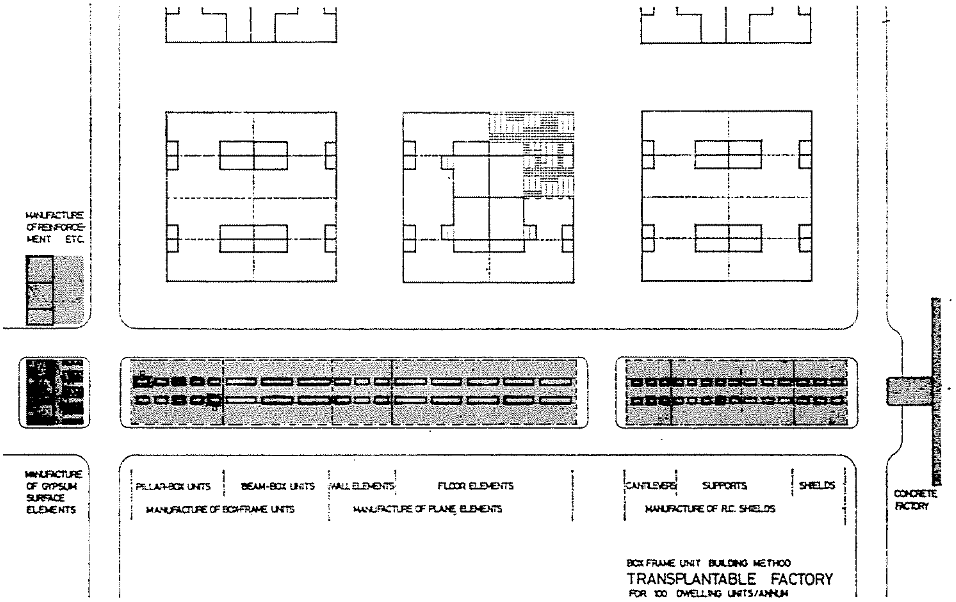


Fig. 13

— area for open-air manufacture of box-frame units (pillar box-units and beam box-units);
— area for open-air manufacture of plane elements (wall elements and floor elements);
— area for open-air manufacture of double roof elements (cantilevers, supports, sun-shields);
— transplantable concrete factory (including concrete mixer, storage for aggregates and cement).

Factory operations

In the non-tectonic systems there are two basic factory operations: 1. Manufacture of Gutenberg-principled surface elements; 2. Manufacture of mechanization-principled structural elements.

Manufacturing apparatuses and processes of manufacture

In the box-frame unit building method the transplantable factory is provided with the following apparatuses:

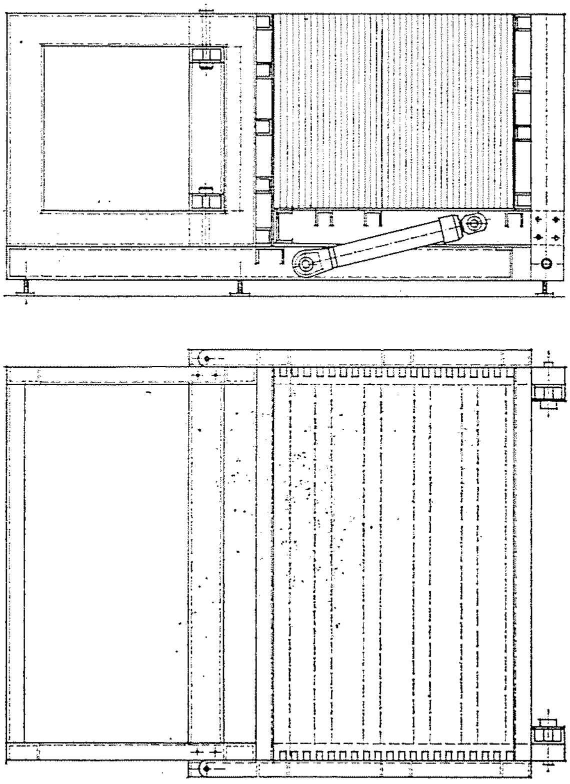


Fig. 14

— *Casting battery:* apparatus for manufacturing plane gypsum surface elements for pillar box-frames and beam box-frames (Fig. 14). With this apparatus twenty gypsum elements can be simultaneously produced in vertical position. The very battery is a mould constructed of linear bars and plates and closed perfectly by side doors. The main component parts are the following: horizontal pouring board, fixed back plate, side doors, partition plates, inserts to make the apparatus convertible, closing frame, and a small built-in hydraulic equipment. The attached unit of the battery is a special trolley for the removal of the gypsum elements. The process of manufacture involves the following cycles: 1. Assembly: closing the side doors, placing the partitions and inserts; 2. Pouring in of gypsum; 3. Hardening; 4. Opening and cleaning of doors; 5. Tilting hydraulically the pouring board, the closing frame, the partitions and the elements into vertical position; 6. Removal of the elements, cleaning the partitions; 7. Turning back the pouring board and the closing frame.

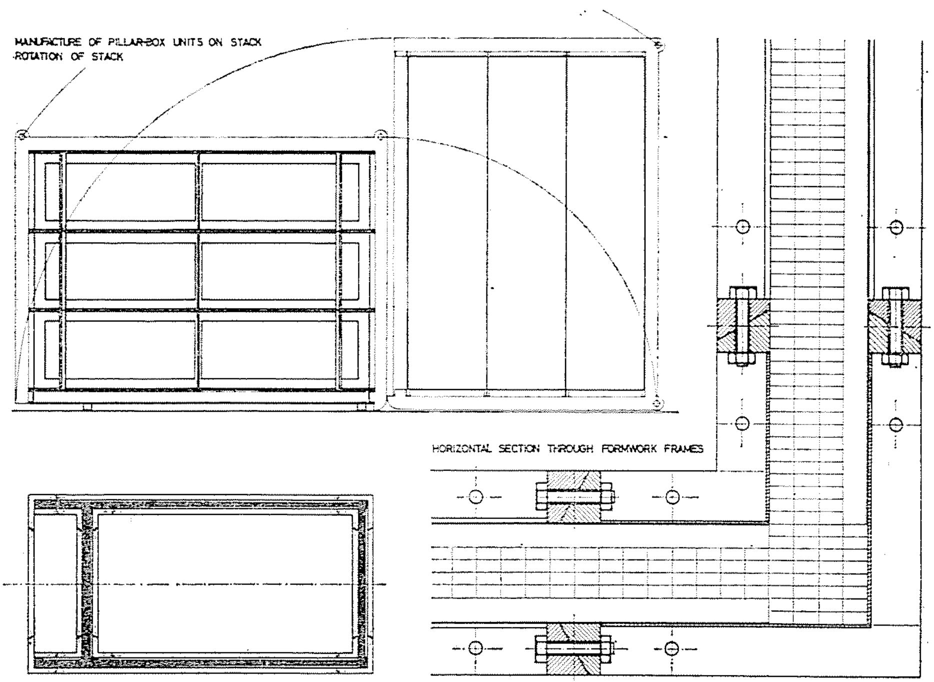


Fig. 15

— *Stack-frame:* apparatus for manufacturing tectonic structural box-units — pillar box-frames and beam box-frames — in the factory. With this apparatus three frozen shell pillar box-frames or four frozen shell beam box-frames can be produced on top of each other in horizontal position. The apparatus shown in Fig. 15 serves for manufacturing pillar box-frame units. The apparatus itself is composed of two main parts: the horizontal bottom frame (empty steel frame constructed of linear U-profiles with periodic holes for fixing the forming frames); three sets of vertical forming frames (each set is composed of rectangular corner elements and intermediate plane elements, both are empty steel frames constructed of linear steel bars and provided with periodic holes for jointing as shown by the structural detail drawing).

The process of manufacture starts with the assembly of the interior forming frames in the first row and jointing them to the bottom frame and to one another. This is followed by positioning of the interior plane gypsum surface elements and the reinforcement. The next step is the assembly of the exterior forming frames and the repetitive cycle is concluded by positioning of the exterior gypsum surface elements, so concrete can be

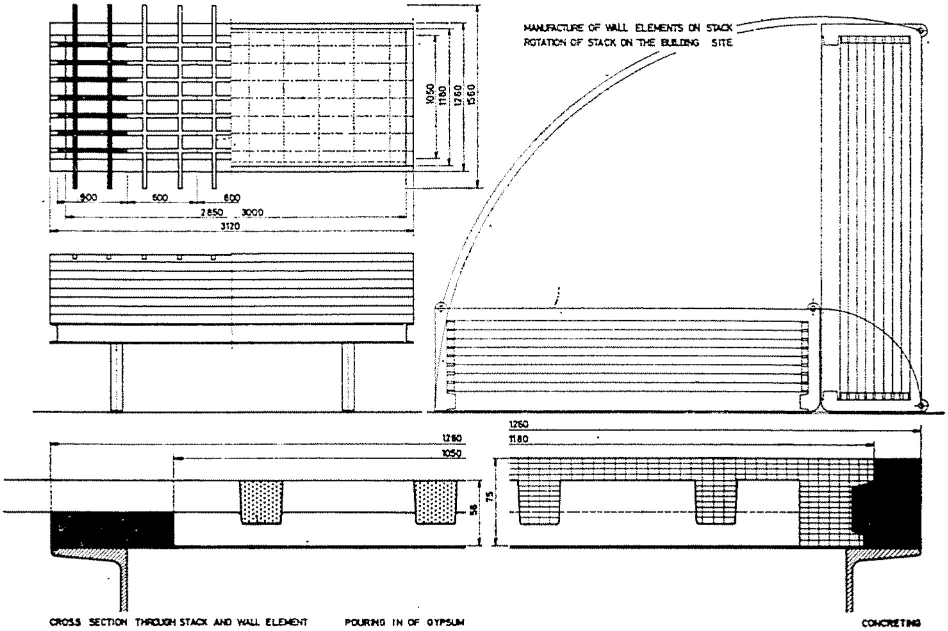


Fig. 16

poured in. For separating the rows a thin polyethylene or steel strip can be used. After finishing the third row, the three sets of forming frames can be regained immediately. The three pillar box-frame units are stored and transported in horizontal position on the bottom frame. For lifting the stack a special lifting frame is used. Before positioning the pillar box-frame units on the building site the whole stack is tilted into vertical position to ensure most favourable manipulation for the pillar units (Fig. 15).

— *Stack-plate:* apparatus for manufacturing plane tectonic tissue-structural wall and floor elements in the factory, in such a way that first the non-tectonic periodic gypsum surface element is produced by one single casting and then the tectonic tissue-structural element is made by pouring in of concrete. With this apparatus four to six tissue-structural wall or floor elements can be produced on top of each other in horizontal position. The apparatus shown in Fig. 16 serves for manufacturing wall elements. It is composed of three main parts; the horizontal bottom plate (steel frame constructed of linear U-profiles covered with a steel plate and provided with periodic holes); two different types of side forming bars (each composed of 4—6 sets) for shaping the gypsum or concrete on the perimeters; and forming grids for shaping the two-way channel system of the gypsum elements.

The process of manufacture starts with the assembly of the forming bars of the gypsum elements in the first row, this is followed by the positioning of the forming grids, then gypsum is poured in. After hardening, forming grids and bars are removed, the side forming bars to shape reinforced concrete on the perimeters are assembled, steel reinforcement is located and finally concrete is poured in. For separating the rows a thin plastic foil can be used. After finishing the last row the sets of side forming bars can be regained immediately. The tectonic wall elements are stored and transported in horizontal position on the bottom plate. For lifting the stack a special lifting frame is used. Before positioning the wall elements on the site the whole stack is tilted into almost vertical position to ensure further manipulation.

Assembly

The sequence of operations on the building site

The process of assembly in the box-frame unit building method is shown in Fig. 17. The axonometric drawings always represent the operations completed. In the text to follow all the necessary working processes are enumerated in due order:

1. *Creating the zero level of co-ordination:* soil preparation; foundation for pillars and walls; positioning of heterogeneous jointing points to be embedded into foundation through use of regainable auxiliary structures.
2. *Location of pillars:* lifting the pillar box-frame units into in-situ position by means of a mobile crane; fixing the pillars: creating heterogeneous junction between the respective jointing points manufactured on the one hand into the pillar box-frame units, and embedded on the other hand into the foundation.
3. *Location of beams:* lifting the beam box-frame units into in-situ position by mobile crane; creating heterogeneous junction by connecting the pillars and the beams with adequate jointing points.
4. *Location of floors:* lifting the tissue-structural floor elements into in-situ position by mobile crane; the floor elements first rest on the protruding reinforcing wires; creating homogeneous junction: the channels arising between the adjacent floor elements are filled out with concrete whereby the tissue becomes a continuous structure.

5. *Location of walls:* lifting the tissue-structural wall elements into in-situ position by mobile crane; creating heterogeneous junction between the respective jointing points manufactured on the one hand into the wall elements, and embedded on the other hand into the foundation and the beam box-frames; concreting the channels arising between the adjacent wall elements. Waterproofing by layers of bituminous felt.
6. *Roofing I.:* location of manufactured linear — intermediate and cantilevered — support elements and jointing them on the one hand to one another, on the other hand to the heterogeneous jointing points embedded into the perimeter channels (see also Fig. 11).
7. *Roofing II.:* location of cover elements; fixing them by heterogeneous jointing points to the supports and cantilevers (see also Fig. 11).
8. *Location of sun-shields:* lifting the reinforced concrete membrane shield elements into in-situ position; first hanging them on the cantilevers and then fixing them by heterogeneous jointing points in correct vertical position (see also Fig. 11).

The sequence of operations is finally completed by the finishing works: making the screed on zero level; location of door frames; erecting partitions; electrical wiring and plumbing; painting, etc.

* * *

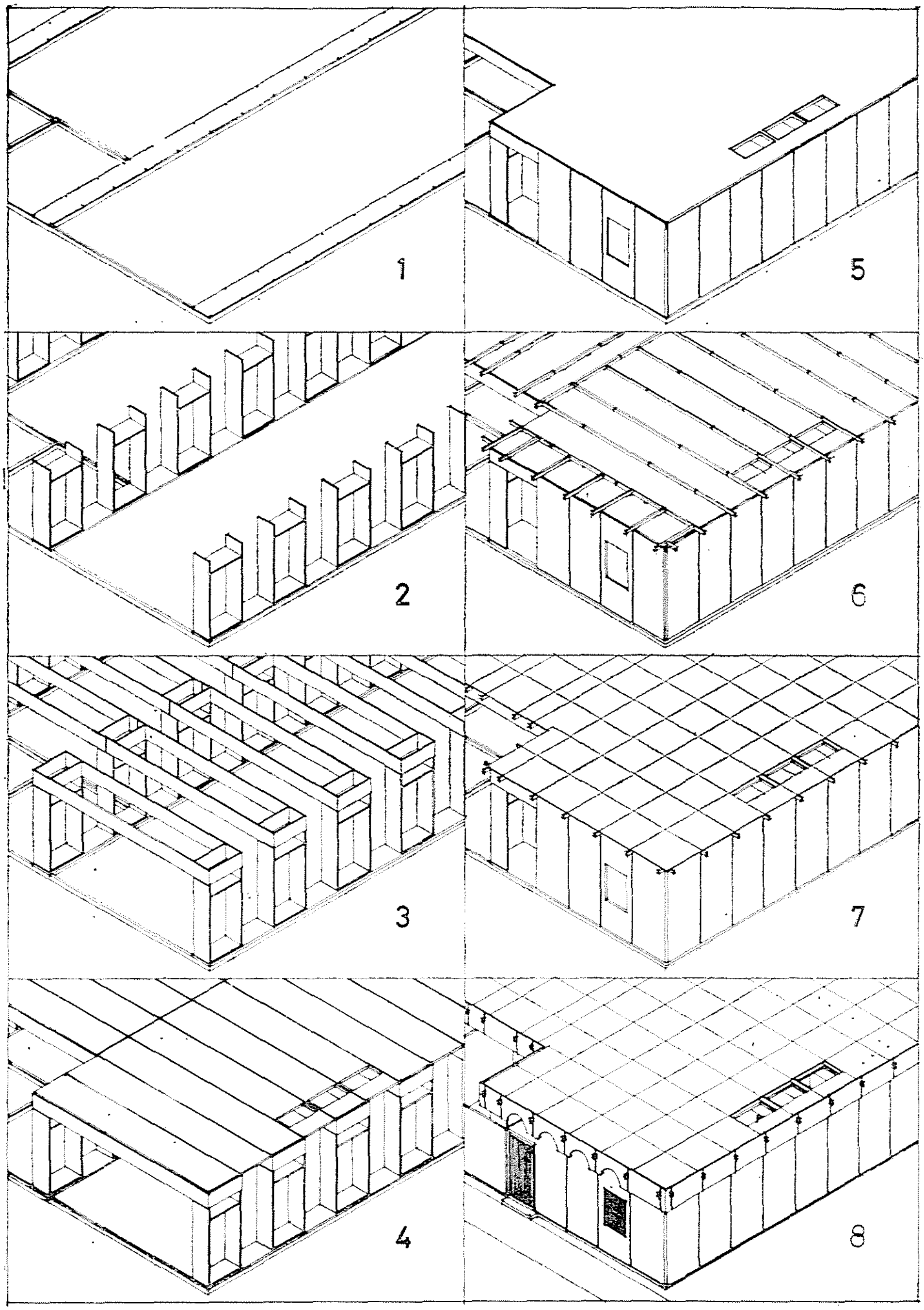


Fig. 17

Section 4

The closed-cellular building method

Introduction. General description of the method

The closed-cellular building method is characterized by a special structural form, more accurately: by the *anisotropic slab** containing internal cells.

The building method can both be realized on a low and on a high degree of complementarity. In any case, however, the structures called into being by this building method are composed of two materials; gypsum and reinforced concrete.

*

If the *degree of complementarity* (that is, the ratio of operations in the factory to those on the building site) is *low*, then we can only work with the *surface as principle of construction* since in the factory we only manufacture Gutenberg-principled non-tectonic surface elements for walls and floors;

If, however, the *degree of complementarity* is *high* then there are even two different possibilities for the building method, namely:

- — either the *anisotropic slab as principle of construction*, a special case of the in-situ building method where the building is realized through the additivity of manufactured tectonic anisotropic slabs;
- — or, *combination of the anisotropic slab and the box-frame as principles of construction*, a special case of the box-frame unit building method where the building is realized through the additivity of manufactured box-frames and anisotropic slabs.

*

The closed cellular building method — if applied on a high degree of complementarity — is at the same time also characterized by the *high degree of technological relevance with geographic-zonal validity* and as such it is again

---

* As opposed to the *traditional reinforced concrete* structures representing *homogeneous, isotropic, monolithic* constructions, the *frozen reinforced concrete* constructions created by the non-tectonic systems are inhomogeneous, anisotropic, monolithic constructions. They are:

inhomogeneous, in so far as the final structure is composed mostly of two materials (reinforced concrete stabilized between, within or on top of surface elements of low specific gravity;

anisotropic, since the physical property of the final reinforced concrete structure varies with the direction in the body;

monolithic, because the additivity of surface elements leads to creating continuous structures.

most advantageously applicable to conditions in developing countries, particularly in hot arid tropical or subtropical areas and can both be realized through using transplantable factories or elementary transplantable factory units.

*

The analysis of the actual conditions and requirements prevalent today in the P. D. R. of *Yemen* led us to choose the closed-cellular building method as an alternative technology more accurately that particular building method which combines the anisotropic slab and the box-frame as principles of construction. On the forthcoming pages only this case will be demonstrated in detail.

Variability of the closed-cellular building method

Amongst the non-tectonic systems the variability of the closed-cellular building method is of high degree since the anisotropic slab as principle of construction stands closest to the surface as principle of construction; since the sizes and increments of the elements and components — including their thicknesses as well — can be selected within very broad limits; finally because in the closed-cellular systems the degree of complementarity can reach a reasonably high level without seriously retsricting the freedom of planning.

The anisotropic slab as principle of conrtruction

The slab as principle of construction has partly been dealt with in Section 3. Now, it is important to note here as an addition that the *anisotropic slab* — the characteristic structural form of the closed-cellular building method — again *endows the technology with completely new features both from design and from manufacture points of view:*

— From *design* point of view, because in the closed-cellular building method the architect works with inhomogeneous, anisotropic, monolithic slabs composed of two materials: gypsum and reinforced concrete, supplied by a two-way r.c. rib system stiffened by a reinforced concrete membrane and reduced in weight by a periodic system of closed internal cells. These "slabs" not only can be loadbearing but also of parameter size in two directions, consequently the tendency towards increasing the span does not run counter serious obstacles (as would be the case with the traditional — i.e.: homogeneous, isotropic, monolithic — reinforced concrete slabs);

- from *manufacture* point of view, because in the closed-cellular building method — the technological relevance of which can again be most expediently enforced in hot arid tropical or subtropical areas — the manufacture of these large-size anisotropic slabs can also be organized on a completely new basis. Under these climatic conditions, namely, the production of anisotropic slabs in horizontal position and above one another not only can be realized in a factory transplantable next to the building site but also in elementary factory units located immediately on the zero level of co-ordination of the individual buildings.

The non-tectonic closed-cellular building method can completely extend the anisotropic slab as principle of construction to the primary walls and loadbearing floors. This is of crucial importance from the point of view of variability of the building method. In case of working on a high degree of complementarity, namely, the large-size two-way periodic surface elements do not arise any more as a result of the additivity of surface elements but are produced by one single casting which in turn means that variability here becomes an immediate function of the convertibility of the manufacturing apparatus, thus, variability can be enforced within rather wide limits. All in all:

The closed-cellular building method — chosen for adaptation in Aden, and to be presented on the pages to follow — *is founded on the simultaneous application of the closed-cellular anisotropic slab and the box-frame as principles of construction.* The architect here uses tectonic box-frame units of parameter-size always only in one direction (as already described in Section 3) and anisotropic slabs of parameter size in one or two directions containing closed internal cells, composed of gypsum and reinforced concrete, supplied with a two-way r.c. rib system stiffened by a r.c. membrane. He regards this as the starting idea for manufactured buildings. He accepts that these box-frame units (pillar box-frames and beam box-frames) can only be jointed heterogeneously along lines and accepts at the same time that the anisotropic slabs (the wall and floor elements) can only be jointed homogeneously and along lines; he finally accepts that the large-size anisotropic slabs — when placed on the vertical loadbearing structures — first always rest on their reinforcement protruding from the ribs until the homogeneous junction is created by the concrete poured in.

Since in the closed-cellular building method — if realized on a high degree of complementarity — the largesize gypsum surface elements are produced through continuous casting and not through additive alignment of manufactured surface elements, therefore the architectural solutions of the buildings (i.e.: ground plans, sections, details etc.) can be immediately derived from the convertibility of the manufacturing apparatuses, consequently quite a number

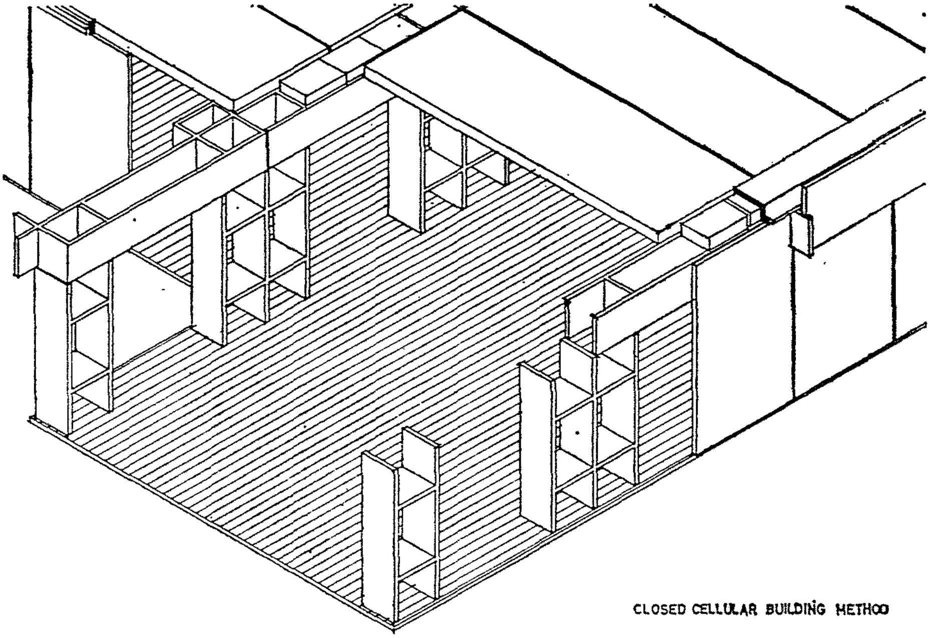


Fig. 18

of possibilities may again arise for flexibly changing the parameters of the buildings in three directions without having this tendency run counter the anisotropic slab and the box-frame as simultaneously applied principles of construction.

The closed-cellular building method described above is characterized by a high degree of technological relevance and is realized in elementary transplantable factory units located immediately on the completed zero level of the individual buildings.

An adaptation of the closed cellular building method to the People's Democratic Republic of Yemen

Design

Settlement. Layout plan

A possible layout of the 96 dwelling units to be realized in a scattered form in three different groupings in the Dar Saad and Sheikh Othman districts has already been presented (see Fig. 2). The settlement units were again composed of eight houses.

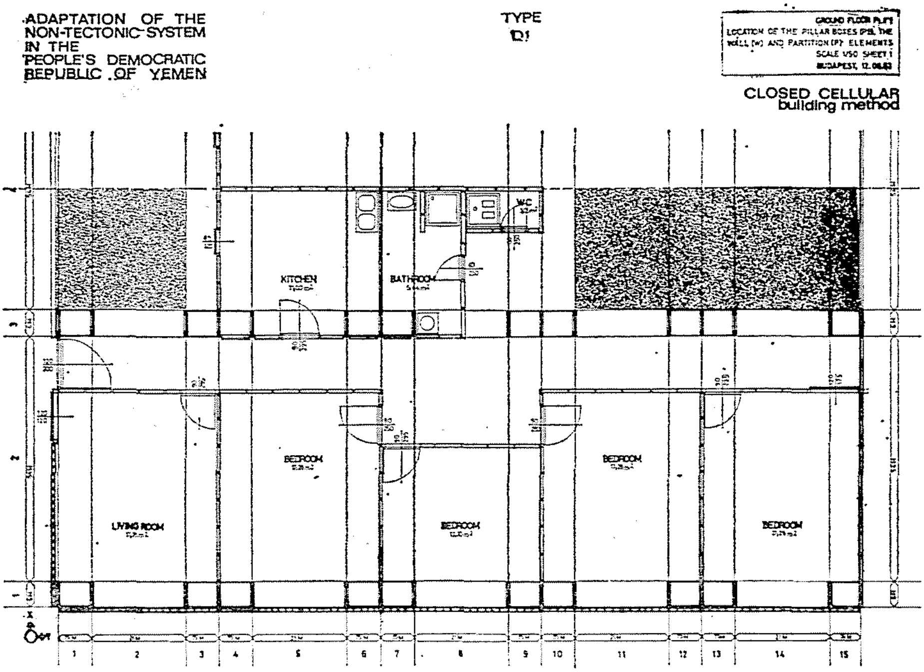


Fig. 19

The principle of construction

The structural system and the process of construction are simultaneously seen in the axonometric view in Fig. 18 presenting the closed cellular building method through the very principle of construction of the anisotropic slab. Let us call the attention of the Reader that in this arrangement the span again exceeds room-size.

Types of dwelling units

Types of the individual dwelling units follow exactly the same arrangement as shown in Figs 5 and 6. The necessary modifications are due to the change in the principle of construction. These modifications become immediately evident by comparing Fig. 7 with Fig. 19.

The characteristic dimensions of the dwellings are the following:

Primary grid dimensions on plan: 6 M (pillar-zone)
54 M (span-zone)

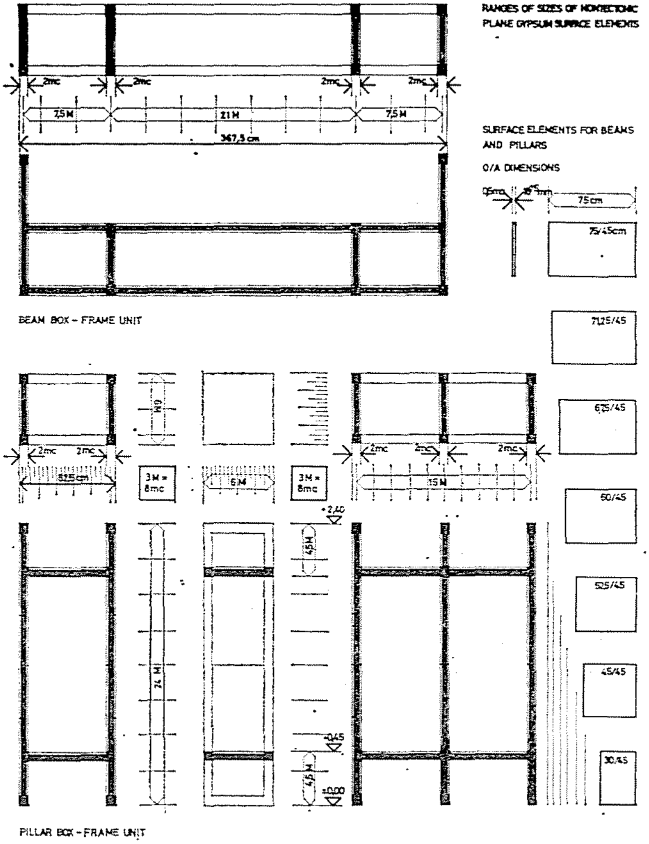


Fig. 20

Secondary grid dimensions on plan: 7.5 M — 21 M — 7.5 M (axial dimensions of pillar box-frames)
Primary grid dimensions in section: 24 M (pillar box-frame zone)
6 M (beam box-frame zone)
Micro-grid dimensions on plan and in section: mc × mc = 37.5 × 37.5 mm.
The grid of structural — microstructural — details is shown in Figs 21 and 23.

The Gutenberg-principled non-tectonic surface elements with their respective variable and constant dimensions are illustrated in the following figures:
— plane gypsum surface elements for pillar box-frames and beam box-frames (Fig. 20);

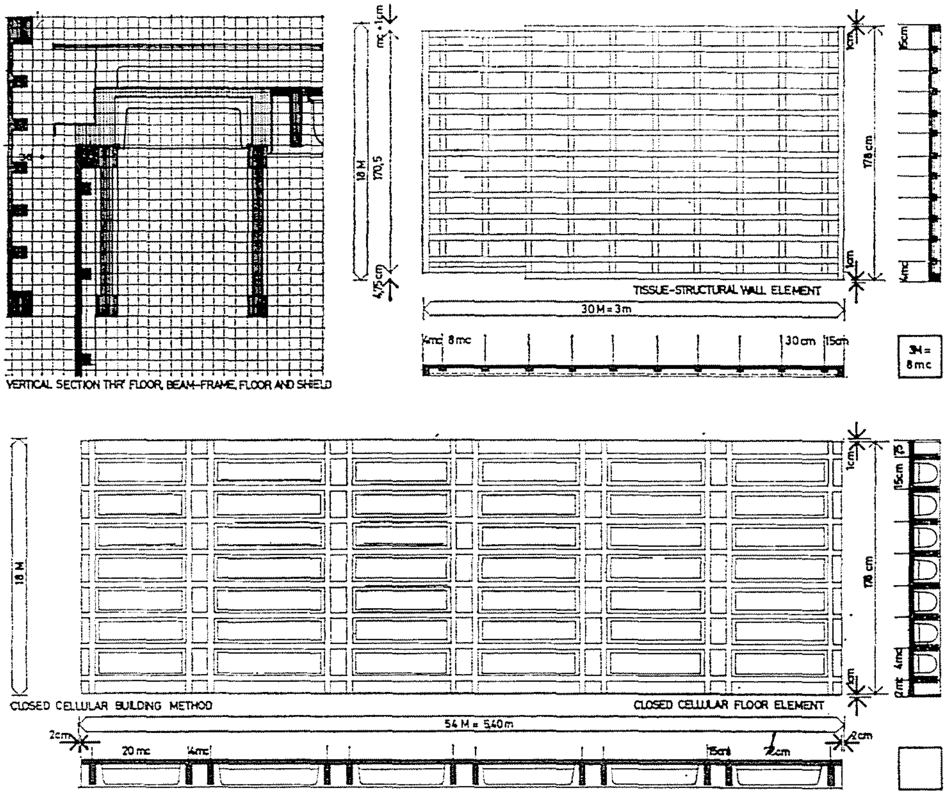


Fig. 21

- periodic gypsum surface elements for walls and periodic closed cellular gypsum surface elements for floors (Fig. 21).

The mechanization-principled tectonic structural elements with their characteristic dimensions are shown in the following figures:

- reinforced concrete folded shell pillar box-frame units and beam box-frame units (Fig. 20);
- reinforced concrete tissue-structural wall elements and reinforced concrete anisotropic floor slabs (Fig. 21).

The mechanization-principled shield and double-roof elements, their location in the modular grid system on plan is shown in Fig. 22.

Details

The individual structural details were again elaborated in the mc = 37.5 mm microgrid system. Characteristic examples are shown in Figs 21. and 23.

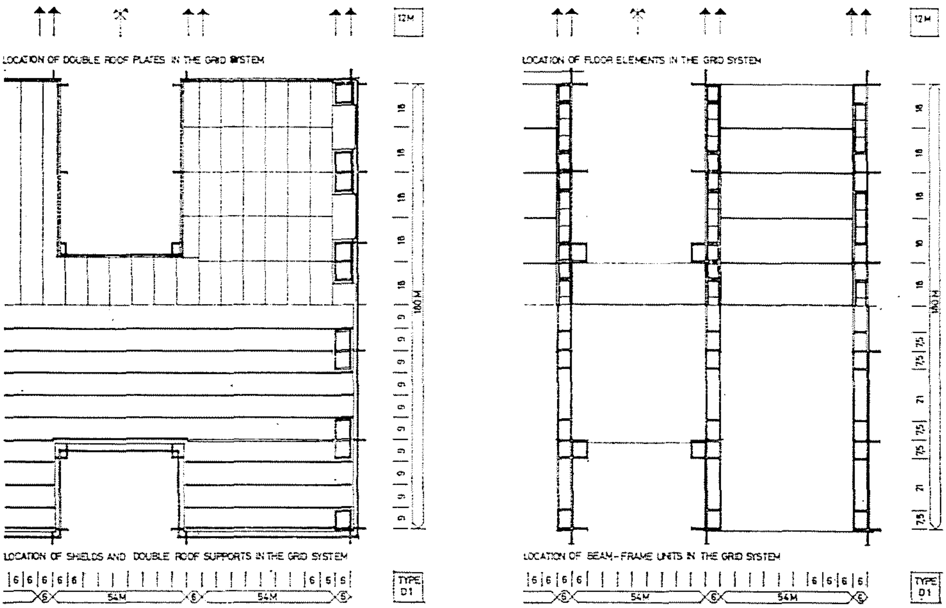

12M
LOCATION OF DOUBLE ROOF PLATES IN THE GRID SYSTEM
LOCATION OF FLOOR ELEMENTS IN THE GRID SYSTEM
18
9
180 M
7,5
21
LOCATION OF SHIELDS AND DOUBLE ROOF SUPPORTS IN THE GRID SYSTEM
LOCATION OF BEAM-FRAME UNITS IN THE GRID SYSTEM
6
54M
TYPE D1

Fig. 22

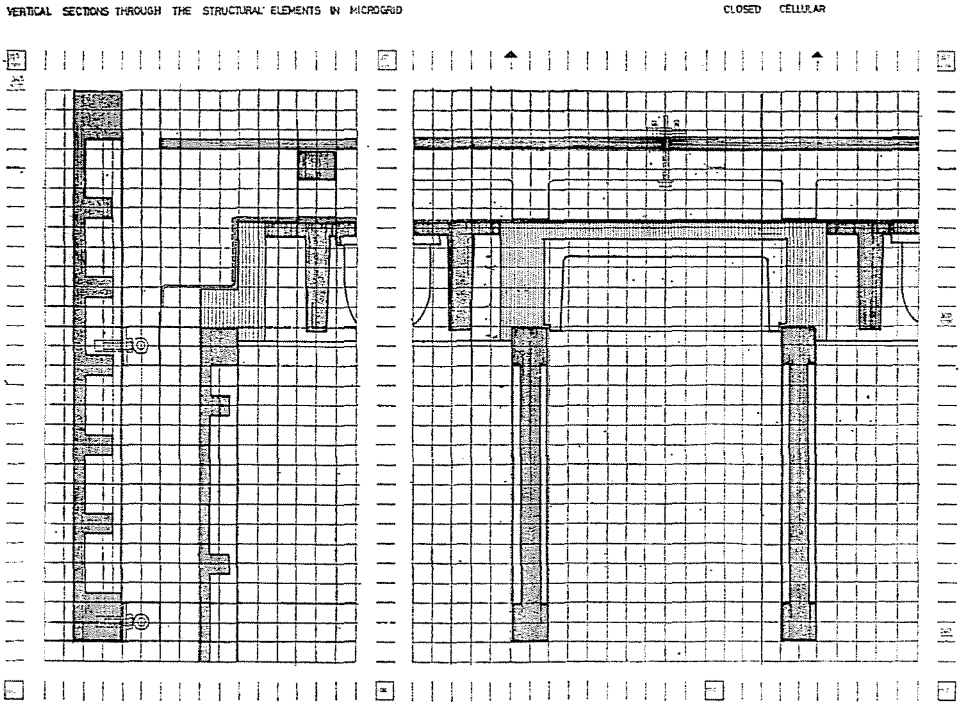

VERTICAL SECTIONS THROUGH THE STRUCTURAL ELEMENTS IN MICROGRID
CLOSED CELLULAR

Fig. 23

Manufacture

Layout plan of the elementary transplatable factory unit

The layout plan of the elementary transplantable factory unit located immediately on the very zero-level is shown by Fig. 24. The transplantable elementary unit is composed of the following parts:

- stacks for manufacturing pillar box-frames and beam box-frames on the finished zero level;
- stacks for manufacturing tissue-structural wall elements and anisotropic floor slabs on the finished zero level;
- stacks for manufacturing mechanization principled reinforced concrete sun-shields on stack plates next to the finished zero level.

Factory operations

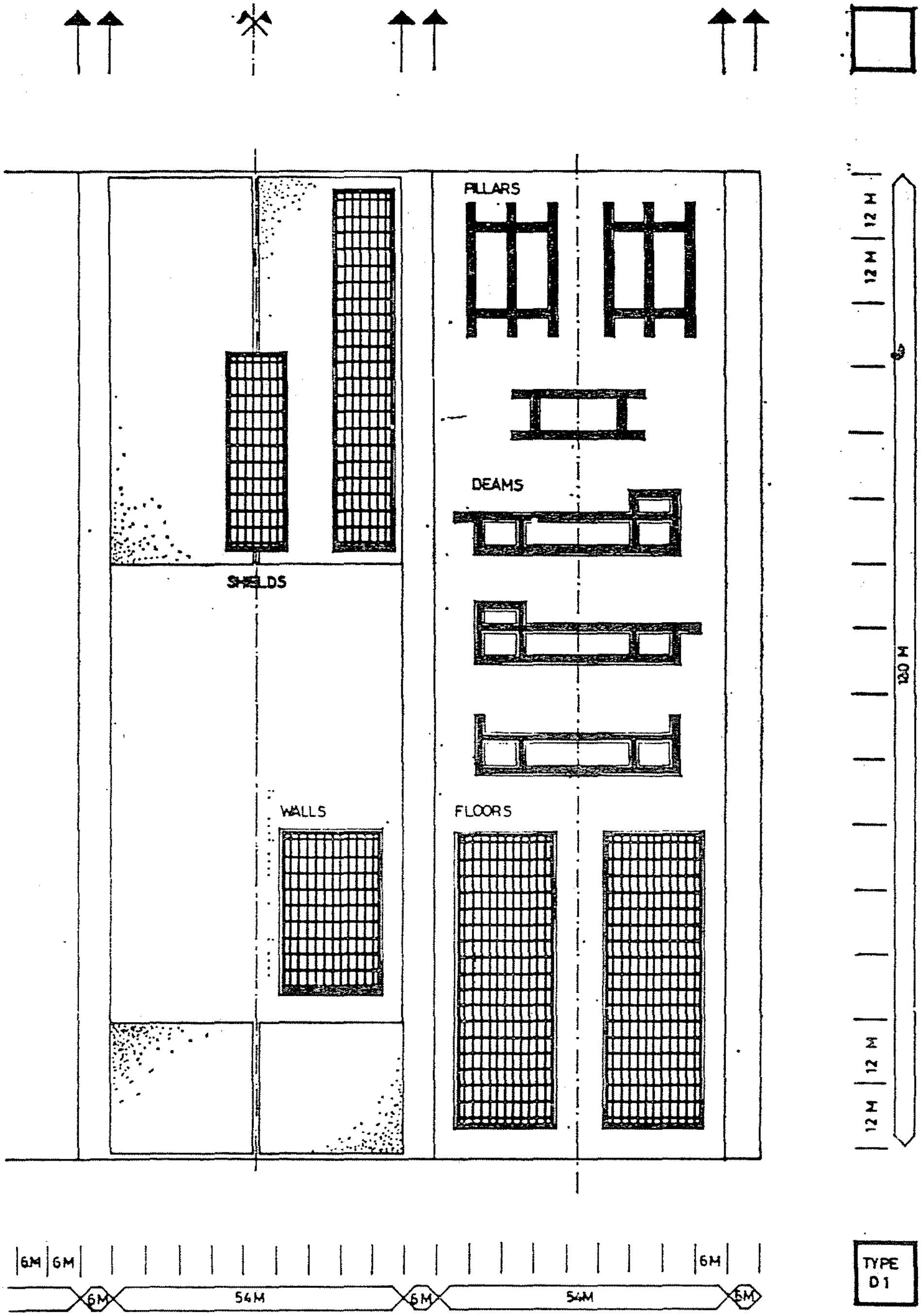
In case of the closed cellular building method the manufacture of the Gutenberg-principled plane gypsum surface elements for the pillar box-frames and beam box-frames is organized in a central workshop. The required elements are transported to each building site in containers. The manufacture of the mechanization-principled reinforced concrete linear double-roof supports is again organized in a central workshop, close to a central concrete factory. The same applies to the production of reinforcements. A small mobile concrete mixer provides for all the concrete used on the building sites.

Manufacturing apparatuses and processes of manufacture

In the closed cellular building method a part of the factory operations as mentioned above is organized in a central workshop. This includes amongst others the same *casting battery* as described in Section 3 and shown in Fig. 14. The other part of factory operations is organized by the transplantable elementary factory unit located on the very zero level of the individual building sites. This unit is provided with the following apparatuses:

- *Stack-frame:* apparatus for manufacturing tectonic structural box-units — pillar box-frames and beam box-frames — immediately on the zero level of each building site. With this apparatus three frozen shell pillar box-frames or four beam box-frames can be produced on top of each other in horizontal position. The apparatus shown in Fig. 25 serves for manufacturing beam box-frame units. In this case the horizontal bottom frame (shown in Fig. 15) is substituted for horizontal steel strips by means of which the exact projection of the beam and its formworks is unambiguously determined on the zero level. The apparatus itself is constructed of four

CLOSED CELLULAR BUILDING METHOD



LAYOUT PLAN OF THE ELEMENTARY TRANSPLANTABLE FACTORY UNIT
OPERATING ON ±0,00 LEVEL

Fig. 24

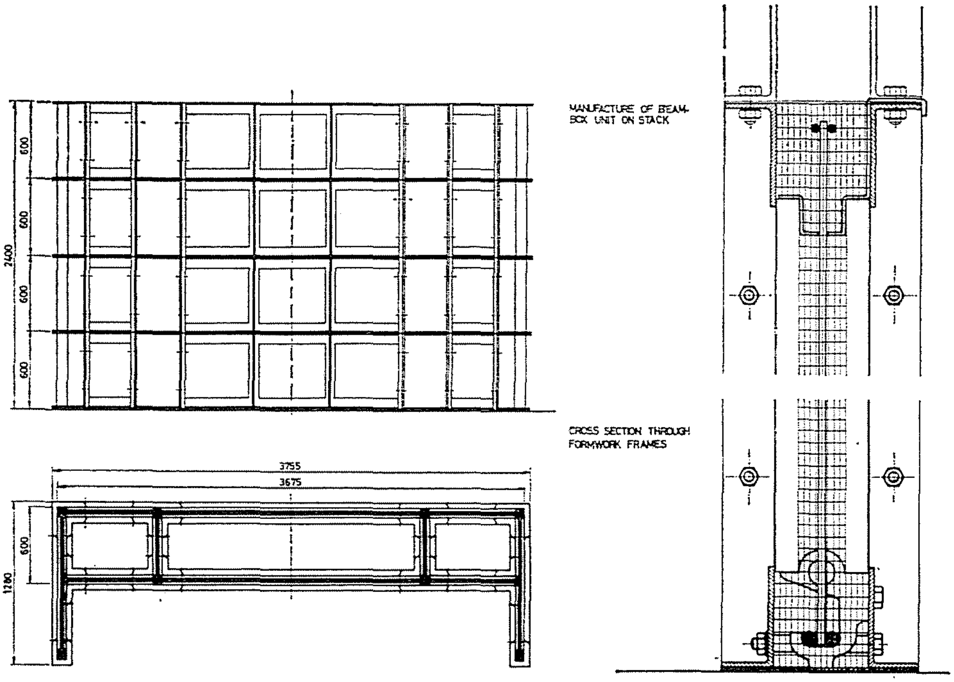


Fig. 25

sets of vertical forming frames (each set is composed of rectangular corner elements and intermediate plane formwork frames, they are both empty steel frames constructed of linear steel bars and L-profiles and provided with periodic holes for jointing as shown by the structural detail drawing). The process of manufacture starts with the assembly of the horizontal bottom steel strips, this is followed by the assembly of the interior forming frames in the first row, and jointing them to one another. The next step is the positioning of the interior plane gypsum surface elements and the reinforcement. This is followed by the assembly of the exterior forming frames and the repetitive cycle is concluded by the positioning of the exterior gypsum surface elements, so concrete can be poured in. For separating the rows again steel strips are used. After finishing the fourth row the four sets of forming frames can be regained immediately. After the necessary hardening period the beam box-frames are lifted one by one into in-situ position by mobile crane.

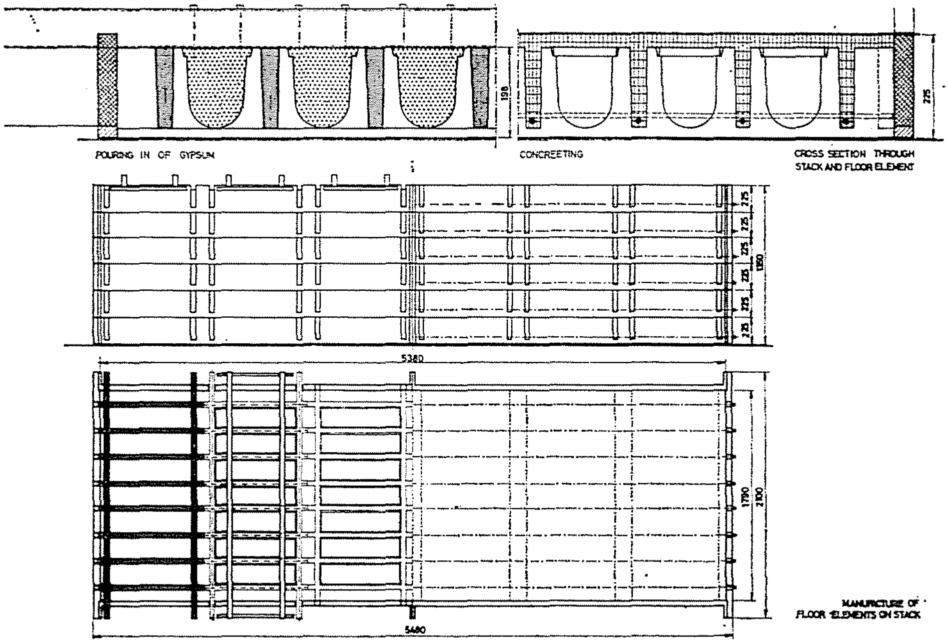


Fig. 26

— *Stack-plate:* apparatus for manufacturing plane tectonic tissue-structural wall elements and closed cellular anisotropic floor slabs on the building site in such a way that first the non-tectonic periodic gypsum surface elements are produced by one single casting and then the tectonic structural plane elements are made by pouring in of concrete. With this apparatus ten to fourteen tissue-structural wall elements or six to eight anisotropic floor slabs can be produced on top of each other in horizontal position. The apparatus shown in Fig. 26 serves for manufacturing closed cellular anisotropic floor slabs. The apparatus itself is composed of the following parts: a horizontal bottom steel plate by means of which the exact outline of the slab and its formwork in unambiguously determined on the zero level (in case of the closed cellular building method this simple steel plate substitutes for the bottom stack-frame shown in Fig. 16); two different forming sets for shaping the gypsum or concrete on the perimeters; and finally two different types of forming grids for shaping, on the one hand, the two-way channel system of the gypsum element, on the other hand the cells in the gypsum surface elements.

The process of manufacture starts with the positioning of the bottom steel plate, and is followed by the assembly of the forming bars of the gypsum elementin the first row. The next step is the positioning of the different forming grids, then gypsum is poured in. After hardening of gypsum the forming grids are all removed, the plane gypsum surface elements to cover the open cells are placed, steel reinforcement is located and finally, concrete is poured in. For separating the rows a thin plastic sheet can be used. After finishing the last row the sets of side forming bars can be regained immediately. After the necessary hardening period the anisotropic floor slabs are lifted one by one into in-situ position by mobile crane.

— *Stack-plate:* the apparatus for manufacturing mechanization-principled tissue-structural reinforced concrete sunshields (see Fig. 23) is located next to the finished zero level. The apparatus itself and the process of manufacture basically follow the case described in the box-frame unit building method in Section 3 and illustrated in Fig. 16.

Assembly

The sequence of operations on the building site

The process of assembly in the closed cellular building method is shown in Fig. 27. The axonometric drawings again represent the operations completed. In the text to follow all the necessary working processes are enumerated in in due order:

1. *Creating the zero level of co-ordination:* soil preparation; foundation for pillars and walls; positioning of heterogeneous jointing points to be embedded into the foundation through use of regainable auxiliary structures; location of the elementary transplantable factory unit (as shown in Fig. 24.) and manufacture of all the necessary structural elements.
2. *Location of pillars:* lifting the pillar box-frame units into in-situ position by means of a mobile crane and fixing them in the usual way.
3. *Location of beams:* lifting the beam box-frame units into in-situ position by mobile crane; creating heterogeneous junction by connecting the pillars and beams with adequate jointing points.
4. *Location of floors:* lifting the closed cellular anisotropic floor slabs in due order into in-situ position and placing them on top of the beams, letting them first rest on their protruding longitudinal reinforcement; location of gypsum top-of-cell elements in the beam frame zones; creating homogeneous junction: the channels arising between the butt-end of the floor slabs and the top-of-floor elements are filled out with concrete.
5. *Location of walls:* lifting the tissue-structural wall elements into in-situ position by mobile crane; creating heterogeneous junction between the respective jointing points, manufactured on the one hand into the wall

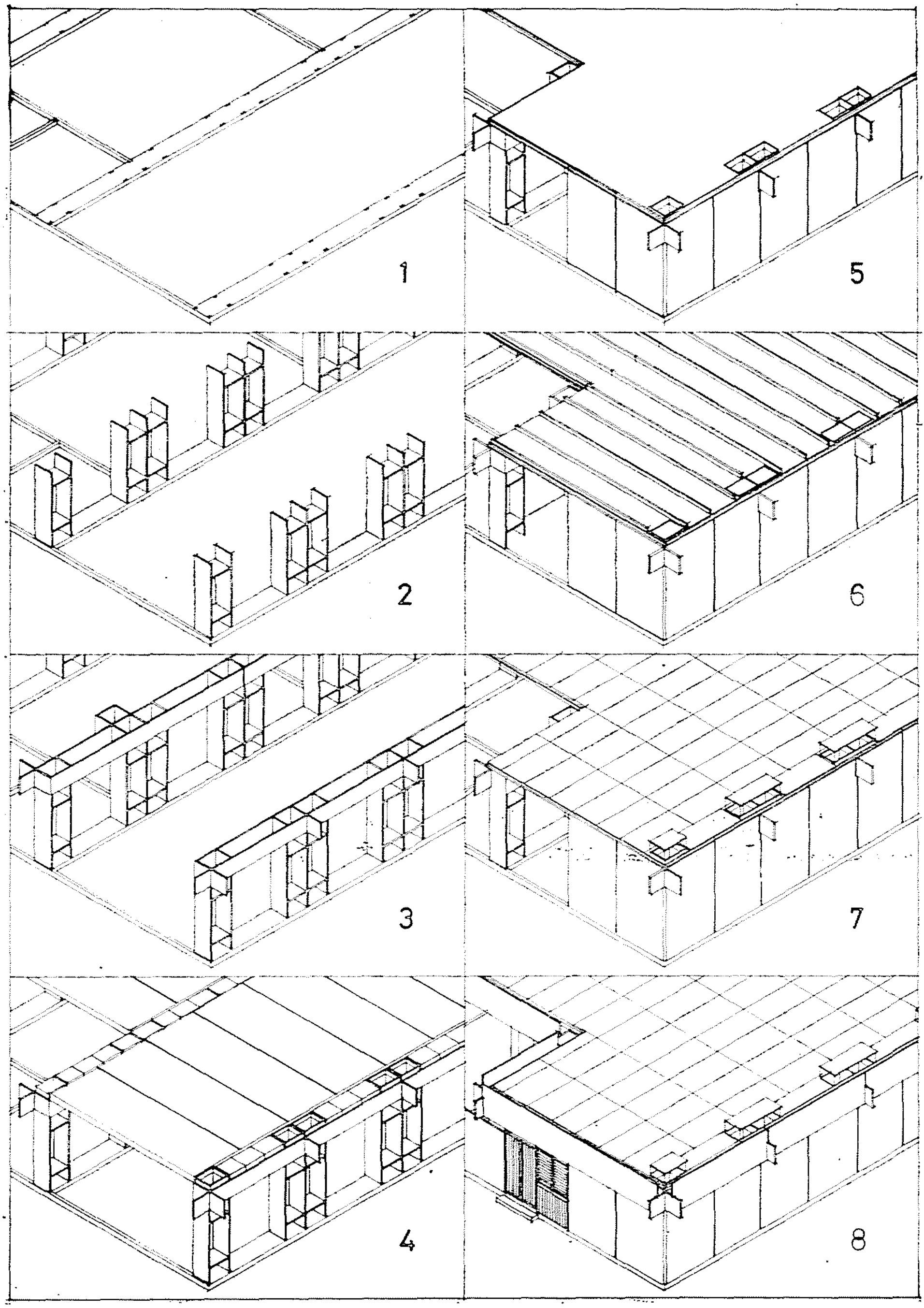


Fig. 27

elements and embedded on the other hand into the foundation and the beam box-frames or into the perimeter channels of the floor elements; concreting the channels arising between the adjacent wall elements, and finally creating homogeneous junction between the walls and beam-frames or floors by pouring concrete on top of the wall elements and beam-frames, or on top of the wall elements next to the perimeter channel of the floor slab (as shown in Fig. 23). Waterproofing by layers of bituminous felt.

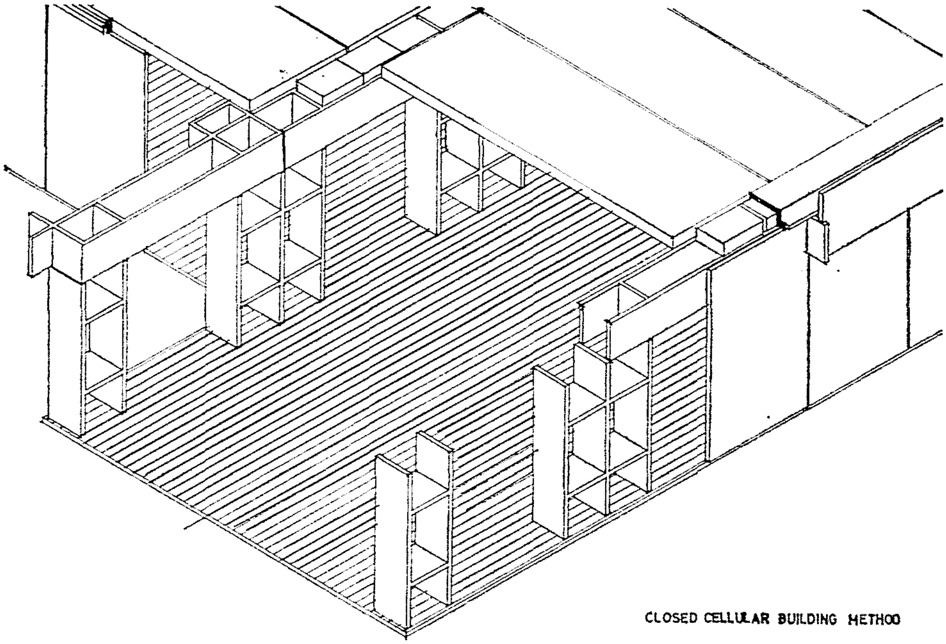
6. *Roofing I:* location of manufactured linear support elements and jointing them to one another.
7. *Roofing II:* location of cover elements; fixing them by heterogeneous jointing points to the supports (see also Fig. 23).
8. *Location of sun-shields:* lifting the tissue-structural shield elements into in-situ position; first hanging them on the cantilevers of the beam box-frames and then fixing them by heterogeneous jointing points in correct vertical position (see also Fig. 23.).

The sequence of operations is again completed by the finishing works: location of door frames; erecting partitions; making the screed in the pillar zones; electrical wiring and plumbing; painting, etc.

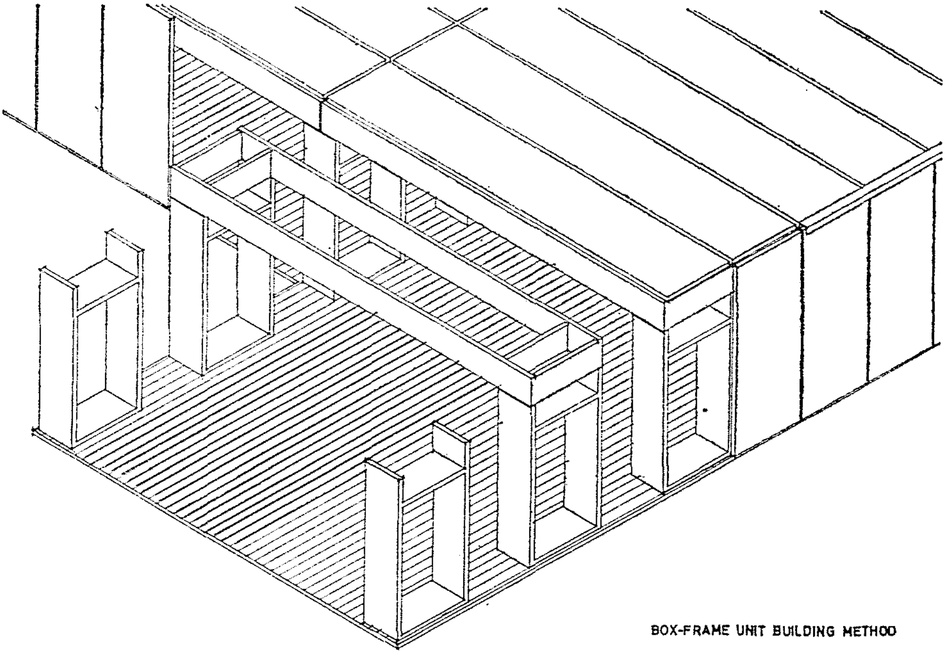
*

Finally, in order to show the two structural systems and the two processes of construction simultaneously the axonometric view in Fig. 28 presents the box-frame unit building method and the closed cellular building method next to each other to facilitate comparison.

* * *



CLOSED CELLULAR BUILDING METHOD



BOX-FRAME UNIT BUILDING METHOD

Fig. 28

Section 5

Conclusion

Advantages and inherent possibilities of the non-tectonic building methods in developing countries*

Considering the results achieved hitherto, the system seems to be very promising for use in hot arid countries (where gypsum is available) for low-cost housing, community centres, industrial workshops, rural health centres for many reasons:

1. because the system which calls into being the lightweight, silicate-based constructions is an open system, it is equally applicable to various types of buildings: the ground plans, arrangements, functions, formation of the buildings, namely, can be freely chosen since all characteristic dimensions (such as spans, heights, structural thicknesses, overall dimensions of the elements, thicknesses of elements, etc.) can be variable without giving up any principle of design, manufacture and construction;
2. because the materials applied are traditional hydraulic silicate materials which can be found in abundance in these areas;
3. because the very significant reduction in weight of buildings through reductions in material absolutely eliminates heavy transportation and lifting equipments; non-tectonic systems are not bound to a built out infrastructure;
4. because instead of requiring huge factories, the investment costs of which are large, the structure of the building industry can be founded on a system of transplantable elementary factories, with simple equipment that can be operated even by unskilled workers and last but not least because, site work does not require skilled labor either.

Summary

Two fundamentally new building methods of technological relevance for hot arid tropical areas are expounded in detail. Both technologies — the "box-frame unit" building method and the "closed cellular" building method — introduce an adaptation of the non-tectonic systems for solving problems of masshousing in developing countries and have been designed in such a way as to give an optimum solution for the social-sociological, technical-economic, climatic-geographic, architectural-constructional requirements prevalent today in the P. D. R. of Yemen.

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* Quoted from UNIDO Newsletter 132 (1979) April.

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