UP-TO-DATE DESIGN METHODS FOR OUTER WALLS

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The changed process of architectural design

The widespread use of industrialized building methods has altered — besides the character of the building process split now into the stages of plant production and site assembly — necessarily, that of architectural design as well. The latter has also been divided into two parts: basic design (the design of units) and adapting design. Adaptation consists in selecting and applying unit varieties featured to suite the designed building, it being considerably influenced by the efficiency and the limitations of these units.

By analyzing the building practice of many years, it has been attempted to establish a method enhancing efficiency of basic design. Of course, the two design stages cannot be separated rigidly, they are in a close complex interaction, interdependence, since tasks and part of information needed for the adapting design issue from the basic design.

Motivations of new methods of design

A fundamental and obvious requirement is to mass-produce the units for the industrialized building. Units have to be designed possibly to perfectness, since even the slightest error is multiplied in mass-production. Design requires all factors to be considered much more carefully than for traditional buildings, because industrialized building units do not dispose of safety reserves to resist peak stresses from unexpected effects. Therefore not only all possible effects, but also their peak values and even their coincidence must be reckoned with.

The advent of industrialized building is accompanied by that of great many new materials and structures unknown to the architect before, who thus lacks experience in their application.

This is why various new, more efficient methods have to be found for designing industrialized building units, to compensate the architect for the missing experience and routine.

Both special literature and everyday practice are increasingly interested in computer methods of design.

Two different tendencies are manifest in computerized architectural design. One of them, of technical aid character, applies stockpiling models, makes consignations, cost estimates, traces designs for units and buildings, etc. It does purely mechanical work for man but faster and more precisely.

The other is an extension of the mental capacity of man. Computerized solution problems include e.g. design of certain load-bearing structures.

The method to be presented is concerned with the least developed field falling into the scope of the second tendency. As a matter of fact, even the first, cautious steps taken in this direction have raised widespread debates around the subject "design optimization".

Systems theory considerations in architectural design

The new methods of architectural design profit most from operation research.

To make the process of architectural activity accessible to operation research, it is necessary to explain what a system means, i.e., how to apply the considerations of systems theory in architecture. The system consists of elements (objects, components) of given properties, with their interactions of a high density.

The functioning of the system can be described mathematically, by means of the general systems theory.

The technical development of our days has produced a great variety of building materials and technologies, their variations allowing to obtain an infinite number of solutions. Approach on the side of systems theory is meant to find correct and reasonable (optimal) variations. Rather than to impose restrictions, utilization of possibilities offered by modern technical development is aimed at.

This conception does not identify the notion of element with that of prefabricated unit, and architectural system does not mean the exclusive application of prefabricated units, though this is, of course, not impossible. The element is meant here as a part of the building, with a definite function and a given property (e.g. price).

In relation to the systems theory, architectural system means the entity of a building, with co-ordinated subsystems such as foundation, structure, outer walls, partitions, heating system etc. To constitute a system, these subsystems must be co-ordinated and must permit a standard connection. The subsystems are complete systems in themselves.

Now, what is meant by closed or open system in the building industry?

In a closed building system a subsystem permits a single combination, thus each component becomes a determined part of the building; and nothing but the designed building can be built with them.

The subsystems of an open building system are interchangeable and so are the units. Their application in the building is not confined to certain parts. This requirement entails the mass-production of so-called anonymous units on a high technological level, to be stockpiled and used in different combinations.

The possibility of producing interchangeable units — in independent sites, under different technical conditions — supposes
— a different process of designing units,
— an adequate modular co-ordination and a possibility of using great many "anonymous" units,
— new, up-to-date methods of adapting design.

Operation research in architectural design

Application of this computer-aided method in architecture is preconditioned by the mathematical formulation of the design process. To this aim, the sequence and the inner progress of designing operations have to be known. This process is divided into three stages (Table 1) such as data specification,

Table 1

Application of Alexander's model in architectural design

TRADITIONAL DESIGN PROCESS

data specification	analysis		decision making
↓	↓		↓

DESIGN ACCORDING TO ALEXANDER'S MODEL

<table>
<tr><td rowspan="2">data specification</td><td colspan="2">decomposition</td><td rowspan="2">decision making</td></tr>
<tr><td>relating data</td><td>establishment of subsystems</td></tr>
</table>

assembly of design requirements; analysis of data; and finally — as a result of this analysis — decision, resulting in design, an operation having to do also with arts.

Analysis of the design process marks out the confines and methods of operation research.

The first stage, specifying the requirements, needs no special analysis. The second stage, however, that of analysis and evaluation of requirements, imposes a mental activity, too burdensome in view of the numerous data involved, that is why a mathematical method is not only justified, but so to say indispensable.

The third stage is the creative process containing the most intuitive elements; its mechanization — especially in architectural design — cannot be spoken of at present.

The universally known and much disputed model allowing the formulation of architectural design for computer treatment is due to the British architect CHRISTOPHER ALEXANDER.

To ease handling of the system of requirements, Alexander suggests the architect not to deal with the whole design simultaneously, but part-wise, treating each group of requirements separately. This requires, however, to decompose the complex of requirements into subcomplexes.

The decomposition of the structure must be carried out adequately, i.e., the highest possible degree of information about the connection between the subsystems should be maintained and the least possible amount of information should be lost. The groups of requirements obtained by decomposition can be planned simultaneously.

Application of the method for planning outer walls

The first step consisted in collecting information and formulating the task. It seemed expedient to derive requirements from external and internal influences affecting the wall (Table 2).

The second step was to relate the requirements.

The difficulties of the task were obvious already at the time of establishing the design information system, the information basis containing relatively few units at a great density of relations.

Let us examine the four subsystems of the system obtained by applying the HIDECS computer program (Table 3). The first subsystem "A" contains the requirements for the skin. The second subsystem "B" refers to the joints. The subsystem "C" includes the requirements for layer structure, the one marked "D" comprises aspects of outer appearance and dimensioning. Analysis of relations between the subsystems within the system leads to the following conclusions:

In traditional planning, design of an outer wall unit for a definite building involves the structure of layers and skin as well as of the respective joints in consideration of the architectural requirements (Fig. 1a). If the model is to be used for designing an element that will be applied on a building still

Table 2

External influences	Requirements for outer walls	Internal influences
Shock	1 outside shockproofness	
Burglary	2 burglary protection	
	3 inside shockproofness	shock
Fire	4 fire protection	fire
Mech. influences of weather	5 resistance to mech. infl. of weather	
Wind	6 airtightness	
Driving rain	7 impermeability	
Light	8 lighting, outlook	outlook
Noise	9 sound damping	
and/or thermal load	10 heat damping	room temperature
	11 elim. of condensation	inside surface temp.
	12 elim. of condensation inside the structure	moisture load
Sunshine	13 radiation protection	
Dust, snow, insects	14 elim. of dust, snow, insects	
	15 pleasant aspect	
	16 easy upkeep	
	17 economicalness	
	18 appropriate dimensions	

unknown, i.e. an alienated element, the group of standard requirements for the skin and layers has to be met first, while the details and outer aspect can only be designed subsequently (Fig. 1b).

The computer program is essential by establishing categories for the diverging requirements to point out their interrelations, thus the joint handling of the requirement categories yields a reliable basis for the design.

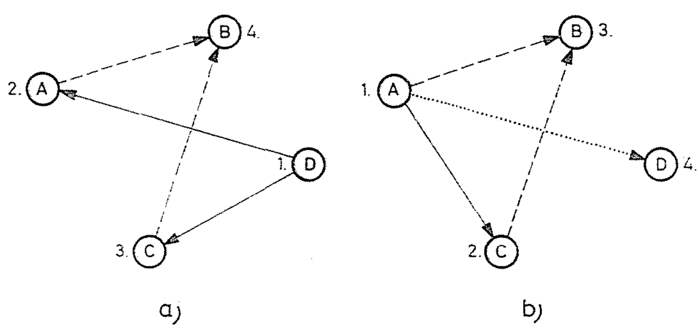

Fig. 1a) Traditional design process; *b)* Process of designing an alienated unit

Table 3

Requirement subsystems

A	1	safety to outside shocks
	2	burglary protection
	3	safety to inside shocks
	4	fire protection
B	5	resistance to mech. infl. of weather
	16	aspects of upkeep
	6	airtightness
	7	impermeability
	14	elim. of dust, snow, insects
C	11	elim. of condensation
	12	elim. of condensation inside the structure
	10	thermal insulation
	9	sound insulation
D	18	proper dimensions
	13	sunshine protection
	15	outer aspect
	8	lighting, outlook
	17	economicalness

Application of the method for the design of plastic outer walls

This method was adopted first for the design of a plastic wall panel. Chemical Building Materials Co. ordered to design versatile, so-called "alienated" wall units adaptable to the existing structural systems.

The design started by satisfying the requirements for the skin, completed by the specification to apply some plastic material. The choice fell on polyester reinforced with fibreglass, of favourable properties.

This material is characterized by a low density and a relatively high strength little impaired by ageing. It is sufficiently weatherproof. The binder is polyester resin. The panels are produced by the so-called low-pressure laminating process.

Reinforced polyester acts like reinforced concrete, tensile stresses in the unit being taken by the glass fibers, incorporated in form of glass fabric or quilt. The strength characteristics of the unit can be improved up to a certain limit by increasing the fibreglass percentage by weight. For quilts and glass fabric this limit is at 50, and 75 per cent by weight, respectively.

The system of glass reinforcement determines the strength of the reinforced polyester unit in different directions. The tensile strength of the glass wool reinforced material is 700 to 1400 kp/sq.cm, that of glass fabric reinforcement 2800 to 3200 kp/sq.cm, moduli of elasticity in tension being $1.1 \cdot 10^5$, and $1.8 \cdot 2.8 \cdot 10^5$ kp/sq. cm, respectively.

Glass-wool quilt reinforced plastics have a bending strength of 3500 to 4000 kp/sq.cm.

The design has to take into account the heterogeneity of the material and the inherent unevenness of the cross-section.

The material is featured by the following length change characteristics: up to + 50°C the material expands, from + 50 to + 100°C it contracts, from + 100°C to +300°C it expands again, then it softens and starts to decompose. Its heat expansion coefficient in the domain important for actual use is $1 = 40 \cdot 10^{-6}$. (Analysis of Hungarian and foreign-made reinforced polyester sheets showed values of 12.2 to $31.1 \cdot 10^{6}$.)

Besides its high heat expansion coefficient, another disadvantage is combustibility, strictly confining its use. There exist self-quenching glass reinforced polyesters, these are, however, even more expensive, although reinforced polyesters are rather costly themselves, narrowing their field of application and decisive for the design.

From a confrontation between the requirements for the outer skin of the designed panel and the material properties, the following conclusions could be drawn:

— since the material is expensive, it is advisable to apply only one layer of the least possible thickness in the form of a plate stiffened by ribs;
— by virtue of its above-mentioned qualities — pleasant aspect and weatherproofness — it has to be applied outside;
— its favourable strength characteristics should be made use of, the panel has to be provided with a load-bearing skin of fibreglass-reinforced polyester, to take all the stresses due to dead load and wind load.

Selection of the material for the inner lining skin was governed by shockproofness and fireproofness requirements best coped with by 5 mm thick flat asbestos cement sheeting, surfaced either by painting or by wallpapering. Also some other inner lining may be convenient, such as veneered fibreboard or plasterboard (Fig. 2).

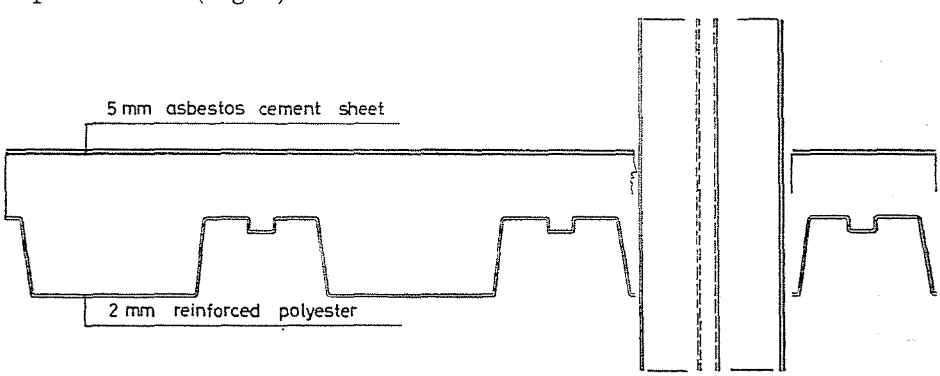

Fig. 2. 5 mm asbestos-cement sheet; 2 mm fibreglass reinforced polyester

Once the outer and the inner skin have been determined, the next step is to meet requirements for the layer composition, responsible for winter and summer thermal comfort and moisture protection. The heat-insulating materials suggested are plastic foam insulation of a designed thickness, polystyrene or polyurethane foam. Even two or three panels with different effectivities may be realized, according to the climatic conditions of the protected space, to the useful life and function of the designed building. Panel layer composition has to be checked for exemptness of surface or inside condensation. Vertical channels of the structural ribbed plate may be relied on for shading and aerating. If also acoustic requirements prevail, the panel must be examined for its response to sound loads and admissible noise level (Fig. 3).

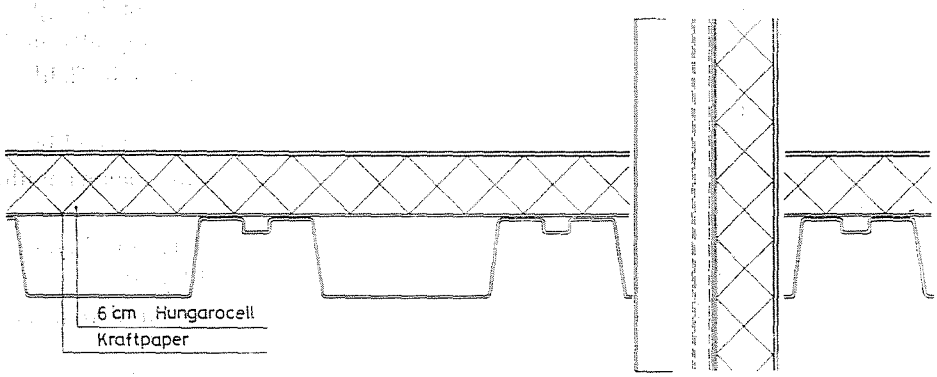

Fig. 3. 6 cm Hungarocell kraft paper

The third group of requirements contains those for panel joints. Resistance against weathering effects means freedom from damage. The structural element of the panel is a 2-mm ribbed polyester plate joining the panel structure along the floor line to act structurally as on two or three supports. Support spacing can be selected at will within the range of the design load capacity of the ribbed plate.

As for the way of fixation, the panels can be either supported or suspended. The fixation of supported panels is cheaper and more economical, the top edge needs strengthening against horizontal displacement alone, on the other hand, there is a risk of warping. Thus, it is advisable to suspend storey-high panels and to support parapet wall panels.

As concerns panel joints, connection of vertical edges to ensure interaction, rainwater protection is provided by a cover strip fastened by screws. Airtightness may be provided by a bithurane sealing inserted in the inner cover strip. Protection of horizontal joints against rainwater is provided by 6-cm overlappings of the polyester ribbed plates. Airtightness is again due to a bithurane sealing strip inserted in the "J" section connecting the panel to the structure. Thus, about equivalent joints are realized in any direction. In case of an adequate construction, the unit needs no particular upkeep during its lifetime (Fig. 4).

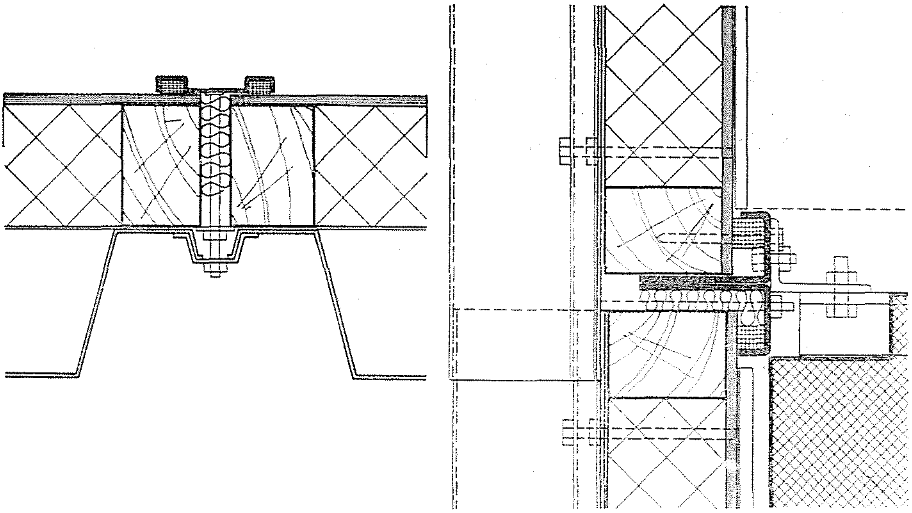

Fig. 4

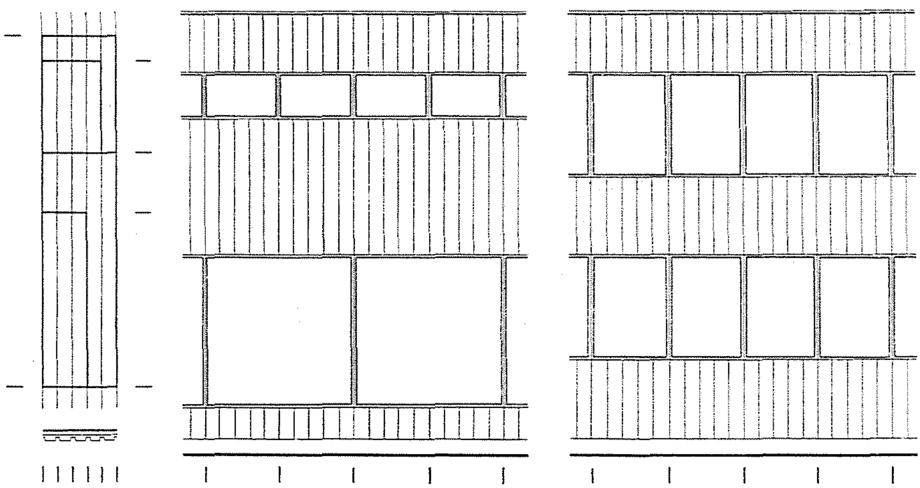

Fig. 5

The design process ends by meeting the fourth subsystem of requirements. Once data relevant to a structurally and technologically justified modular system for the unit have been established, and appreciated that a so-called commercial product rather than a panel adapted to a definite structure was ordered, obviously, the fibreglass-reinforced polyester unit has to be produced with the technologically possible largest dimensions, horizontally cut according to the multiples of *M*, and vertically, according to the carpet principle, modelled by mould inserts. Architecturally, unobtrusive joints are of decisive importance. Window sizes depend on the needed light intensity, their construction must be in accordance with that of the panel. Panels are matched in character by strip windows (Fig. 5).

The unit must always be examined from economy aspects for the given case. Its application may possibly call for modifications to be economically efficient.

Applications of external plastic wall structures

The possible fields of application are definitely limited by the characteristics of synthetic resin panels, such as:
— insensitivity to corrosion,
— freedom from upkeep,
— arbitrary thermal characteristics,
— suitability for mass-production for standard requirements . . . etc.
Negative features affecting the application are:
— confined lifetime,
— restricted fireproofness,
— sensitivity to high temperatures . . . etc.

		A		B
		Skin		Layer construction
		External	Internal	
Design aspects		Expensive material→thin plate →bracing	Increased fireproofness	Aspects of thermal, moisture and fire protection
Suggested units	1. Framed aluminium panel	V = 0.8 mm thick framed alum. plate	Plasterboard (asbestos cement) fixed on frame and post	Slag wool thermal insulation of a due thickness, vapour barrier inside
	2. Wall unit made of flanged plate	V = 0.8 mm heat insulation both sides braced	Horizontal plasterboard (asbestos cement) on assembly ribs on the site	Hard polyurethane foam
	3. Sandwich panel made of pasted alum. plate	V = 0.6 mm alum. plate pasted on plaster-board providing hard skin		Slag wool heat insulation of designed thickness
	4. Close-ribbed alum. panel made of strip units	V = 0.8 mm alum. strip flanged and braced by ribs and vertical folding	Plasterboard (asbestos cement) fixed on ribs	Due thickness of slag wool heat insulation, inside vapour barrier

As a conclusion, plastic panels can be used in conditions of
— increased risk or corrosion,
— difficulty of systematic upkeep,
— high heat insulation requirements,
on the other hand,
— on structures of moderate durability since plastic panels are liable to ageing;
— under conditions of moderate fire safety demand.

From among mass-buildings, the application of plastic panels is suggested for the following:

Agricultural buildings:
— freezing stores,
— poultry-houses.

Industrial buildings:
— wet-process buildings.

Service buildings:
— kiosks of sale,
— minor shop buildings,
— motels,
— office blocks.
— materials and technologies for an adequate surfacing, such as heat-treated synthetic resin coating or anodization.

C		D		
Joints		Modular system		Aesthetic quality, economicalness
Vertical	Horizontal	Width	Height	
On the principle of equivalence		Adjustment to structure and prime materials		Adjustment to requirements
Provided by frame of unit, intermediating cover strips		4 $\overline{M}$ 5 $\overline{M}$ 6 $\overline{M}$	Cut according to carpet principle 3000 to 4000 mm	Resulting from the process Supervision is indispensable Correction expected (feedback)
Intermediating cover strips on vertical ribs	Obtained by folding of unit	4 $\overline{M}$ 5 $\overline{M}$ 6 $\overline{M}$	$\overline{M}$ 2 $\overline{M}$ 3 $\overline{M}$	
Joint with cover strip in line with wall post	Flange of unit	8 to 12 $\overline{M}$	2 $\overline{M}$ 3 $\overline{M}$ 4 $\overline{M}$	
Flange of unit	Lintel, intermediating cover strip	$\overline{M}$ 3 $\overline{M}$ 4 $\overline{M}$	Cut according to carpet principle, max. 3000 mm	

The method of constructing outer walls of aluminium is largely affected by material properties, the most important being:
— Because of its low modulus of elasticity, aluminium is prone to deformation and buckling. Hence, the selected reasonable thickness values govern length and width of aluminium panels, possibly suspended rather than supported. Because of its high thermal expansion coefficient (22 to 24 $\cdot 10^{-6}$), the units have to be assembled and built in so as not to oppose the expected thermal movements.
— Aluminium has a high heat conductivity, thus great care should be taken of thermal bridges, unless they can be eliminated by construction.
— Aluminium, of a low melting point, is sensitive to fire, thus the wall structure must not contain any combustible material and must possibly be protected by fireproof materials.
— The specific consumption of aluminium of high unit cost largely affects the cost of the wall construction.

A stepwise description of the design process is felt to be needless. Instead of it, the varieties obtained by the above method will be tabulated according to unit kinds and requirement categories, together with the design aspects and illustrated by a typical structural joint each (Table 4, Figs 6 to 9).

The use of plastic panels is little affected by structural aspects; they can be applied on any structure designed in the same modular system as the panels (30 cm).

Application of the method for the design of aluminium external wall panels

This method has also been adopted for the design of outer wall structures made of aluminium. The design procedure was the same as described above, but decisions were affected by changed initial conditions — aluminium for the skin of the unit — and so was the outcome, although panels with ribbed aluminium skin and of the same structural solution as the above-mentioned plastic panel are not only possible but even have been realized. Four various types were designed by this method, as a proof of the fact that this method is not a hindrance but a help for the designing architect.

Thus, the task was to design panels made of aluminium. Initial assumptions were the availability of
— adequate aluminium alloy in the required plate or strip size;
— technological equipment for modelling the plates or strips as needed in panel construction, i.e. high-precision bending, chasing and corrugating;
— cold-worked and extruded sections necessary for the construction of panels; connections (rivets, different screw types), fittings and adhesives for the assembly of panels;

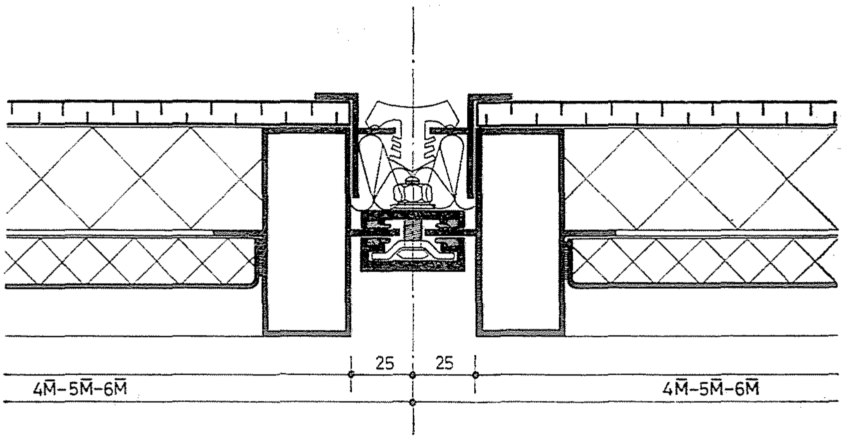

Fig. 6

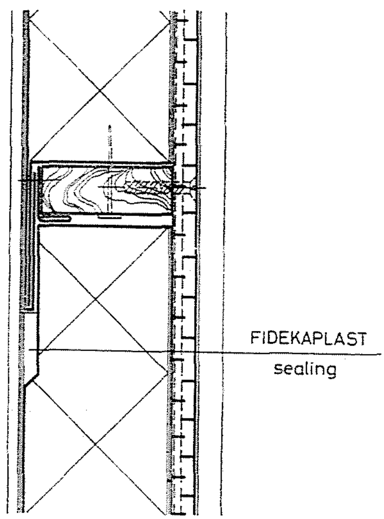

Fig. 7. **55/20-mm timber lath inserted in horizontal joint during assembly supports Neoprene sealing and can support inner skin. Fidekaplast jointing at the plastic bordering joint**

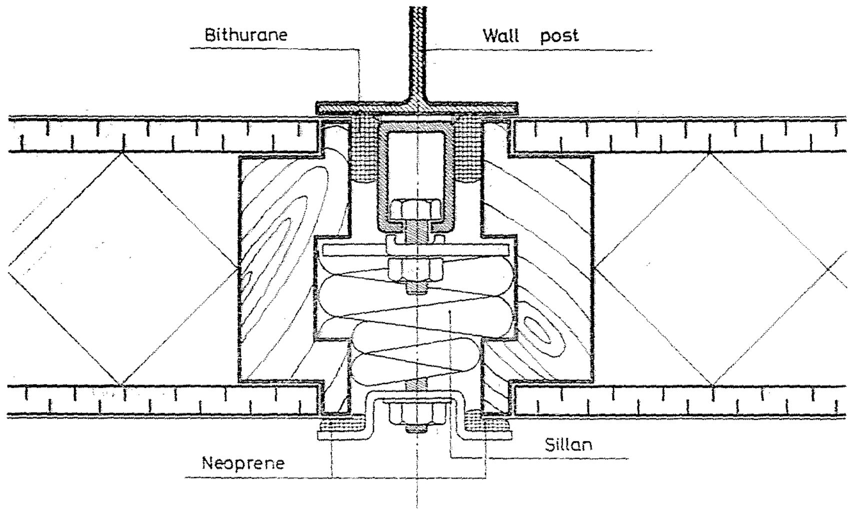
Bithurane
Wall post
Neoprene
Sillan

Fig. 8

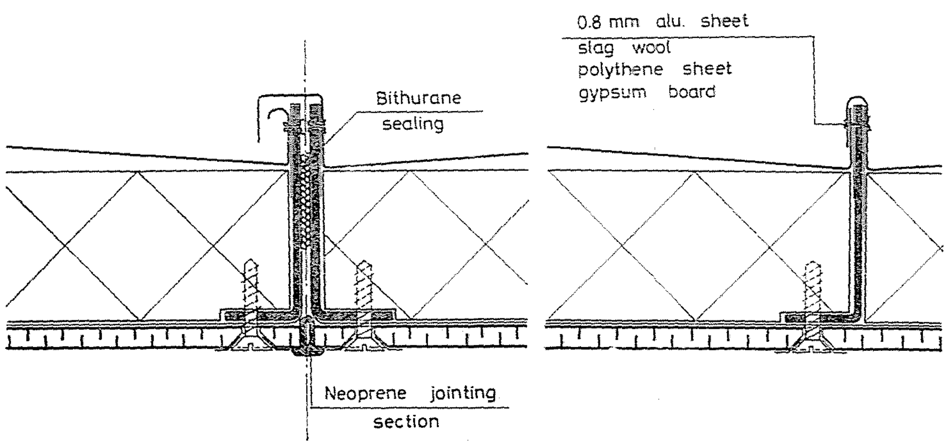
0.8 mm alu. sheet
slag wool
polythene sheet
gypsum board
Bithurane
sealing
Neoprene jointing
section

Fig. 9

Applications of outer wall structures of aluminium

The possibilities of use of aluminium panels depend on, and are limited partly by architectural demands, partly by the supporting structures and partly by restrictions imposed upon outer walls in lightweight constructions. These factors, together with the actual technical level in this country, codes and regulations in force (sometimes exaggerated) as well as the increased complex structural and functional requirements sharply confine their field of application.

Thus, aluminium outer wall structures can be used for low-requirement buildings such as
— industrial halls,
— agricultural (animal husbandry) buildings,
— buildings of transport.

Aluminium panels can be applied on civic buildings for complex structural functions. The same is true for storehouses of high thermal insulation requirement. Buildings with complex requirements include
— nurseries,
— schools,
— office buildings,
— shelters,
— shop buildings,
— service buildings,
— storehouses (for high thermal requirements).

Rather than by the function of the building alone, the use of aluminium outer wall structures is governed by the structural system, first of all, the framework. The design involved the following frameworks:

Single-storey frameworks:

— avialable lightweight structures like FÉM-TIP, Poliacélváz, GFT-III, etc.

Multistorey frameworks:

— ÉGT-framework,
— precast reinforced concrete frameworks,
— cast in-situ reinforced concrete frameworks, designed according to the COMECON modular system,
— buildings with cast in-situ walls.

We have adopted this method for the design of outer wall structures alone. It is obvious, however, that this method can be applied to design all subsystems considered as independent (e.g. partitions, floors).

Summary

Architectural design increasingly relies on the use of computers. Recent special literature contains several publications on attempts, analysis of possibilities and goals of application. An experiment is described, made at this Department on the design of components of building systems, adapting the Ch. Alexander design model. It has been applied for designing an external wall system as a sub-system of two different materials (polyester and aluminium). Relevant research seems to be justified.

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