CONDITIONS OF APPLYING LIGHTWEIGHT SURGICAL UNIT STRUCTURES

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Complex conditions of the large-scale hospital building program in this country include in the first place the development and enforcement of up-to-date principles of hygieny. To meet public health requirements depends on several factors preconditioned by epidemiologic regulations, organized hierarchy of qualified personnel, etc. All these remain ineffective without a correct design of wards and surgical theatres, what is more, without a quite novel building technology enforced as engineering parameters.

Novel features are based on up-to-date building materials and design principles, hence attempts to isolate reservoirs of infection can be combined with that to introduce lightweight structure technologies, however experimental in character they are, from several aspects.

Within the hospital ensemble, surgical theatres are the most affected by the outlined requirement and possibility. Partly, because operating theatres may be a centre of wound infection, and partly, because of their isolability, they can be treated as functional and constructional units both for projects and for existing hospitals. To mention *existing* beside *project* is of importance since structures composed of lightweight materials and units are quite advantageous for up-to-date surgical units fitted ulteriorly to a conventional ensemble. Thus, requirement and possibility are integrated, realizing aims of asepsis by new methods and materials, excluding the majority of conventional building materials counteracting progress in the fight to sepsis, to iatrogen infections.

Lightweight structures with their advantages — modular co-ordination, exchangeability, rapid building and assembly — offer possibilities but also raise constructional problems by virtue of their crudeness, special requirements (long-term behaviour of newly developed materials, tolerances, highly organized production and construction etc.).

Of course, rather than the operating theatre alone, the one or more operating theatres and the servicing, accessory rooms are meant by prefabricated lightweight surgical units. Most of post-operative purulences originate not from the operation theatre proper but of the surgical complex as a whole. In surgical unit systems, importance of up-to-date installation (illumination, ventilation) and servicing units — easy to connect to, and to disconnect from the light-weight structure, and accessible to checking, — outgrows that of the separation of septic from aseptic regions.

Surgical units should contain as little mobile equipment as sources of infection as possible (Fig. 1), and as much of the equipment and devices has to be recessed as possible, in the wall, behind the cladding of wall and ceiling.

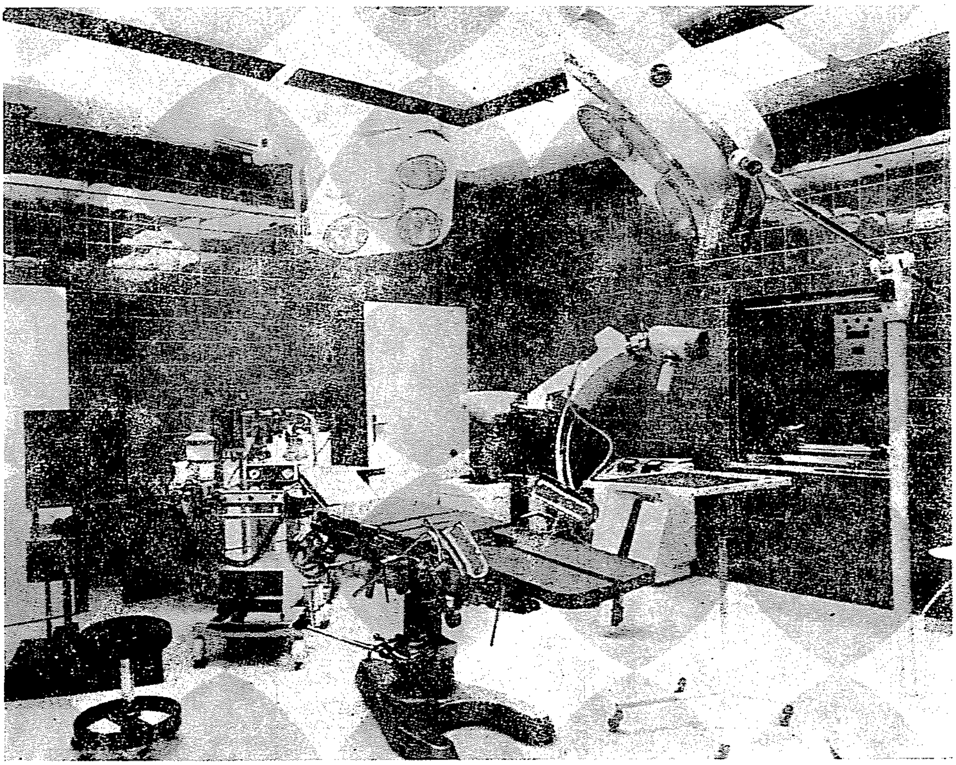

Fig. 1. Interior of a traditional operating theatre. Medical equipment inside the operating space is a reservoir of infection. After Arch. ČSSR. 1975.

In spite of the world-wide validity of the outlined requirements and modernization attempts, realization lags behind, and is restricted to, marketing aspects of development of certain companies in industrially developed countries. Responsibility for the development in this country rests with the Medicor Works striving to meet up-to-date Hungarian and export demands for an organic unity of medical instruments and surgical units. In 1974, Research and Development Institute of Medicor Works charged the Department of Building Construction, Faculty of Civil Engineering, Technical University, Budapest, to do research on modular surgical units. First stage of this research program, in particular, structural considerations of surgical unit design, will be described below.

Functional and structural requirements for surgical units

Research program on surgical units has been based on a carefully outlined system of requirements from interlacing factors of function, structure and air conditioning. Functional requirements were essentially those for conventional operating theatres, however, with certain reductions in relation to the surgical unit. The starting basis was a functional group of four or five units, of the following room types:

operating theatre	(30 to 45 sq.m)
disinfection room	(10 to 12 sq.m)
room for anaesthesia	(20 sq.m)
sterile storage room	(15 sq.m)
storage room for used materials with instruments washer	(10 sq.m).

These rooms meet the common function of operating theatres provided they can be completed or units exchanged — if needed — by other rooms of a different function, according to the building box principle. Functional demand may be simplified, and the system condensed by omitting some rooms not mentioned here (dressing room, X-radiography, special surgical rooms) from the prefabricated surgical unit, accommodating them instead in surrounding, conventionally built sections. Specification to multiply, align rooms of the surgical unit or to range them along access and service corridors may vary from design to design. Sterile storage room involves the need for the surgical unit to be supplied from a central sterilizer.

A peculiarity of the surgical unit layout is to have the operating theatre as a central core surrounded by satellite (mobile) servicing cells — depending on local features. Floor plan layout of units incorporated in an existing (masonry or framework) building has to fit the vertical structural system. In such cases, the need to have a rear access to servicing units may impose to pierce and trim masonry sections, or to conceal framework columns.

Structural requirements for surgical units can be recapitulated as:

1. Self-supporting connection between operating and accessory rooms, independent of the load-bearing structural system of the building.

2. Walls and ceilings of possibly large units (panels) with well cleanable inner linings, to minimize joint lengths.

3. While thermal requirements are lower than for external walls, adequate rigidity and sound damping (against resonance to airborne and impact sounds) are needed.

4. Impact resistance and insensitivity to mechanical damages for inner linings; limited reflections and specularity.

5. Suitability of surgical unit components for modular co-ordination, with sizes in any direction corresponding to multiples of a module, also principal room dimensions fitting to a spatial modular network. From economy aspects, reduction of the number of different unit types has to be aimed at.

6. Possibility of rapid assembly of wall units, as well as of ulterior dismantling and exchange.

7. Component sizes and weights permitting them to be lifted in and assembled without lifting machinery (max. 60 to 70 kg dead load).

8. Surgical accessories, indicator instruments, and similar equipment accommodated outside the operating theatre, in installation panels, with rear access and checking. Supply and intervention parts are concentrated (with telescopic or cantilever supply system), easy to handle by the surgeon and his assistance.

9. Surgical units being mostly windowless, most up-to-date air conditioning systems are needed to provide for climatic conditions (temperature, air humidity, air change and velocity, ion concentration, bacterial filtering, atmospheric overpressure etc.), and light effects. The pertaining apertures, blow and exhaust grids, lamps, switches recessed in the panels impose special structural solutions.

10. Both in the operating theatre and in accessory rooms, built-in cupboard units of various widths and heights, and doors of manual or automatic operation, causing no air motion, and transfer windows are needed.

Analysis of foreign systems and prototypes

Surgical unit research started by studying foreign designs. Informative analysis looked after the possibility of satisfaying the quoted set of requirements, in particular, prototypes of surfacing material, joints, and operating theatre shape. Of the scarcity of examples, essentially two systems are worth of mentioning, taking also modular co-ordination principles into consideration, one being the *Maquet* system (FRG), the other a British system with an octagonal operating theatre.

The Maquet system applies stainless steel panels of dull surface (Fig. 2). The twin-walled sandwich panels of steel plate and polythene foam core are braced by box-section posts. Panels join posts by means of lugs, about 10 cm vertical gaps are sealed by cover strips. The extremely narrow joints point to high dimensional accuracies, of tolerances of the tenth of mm order. Operating theatre and accessory rooms are square in floor plan. The structure is non-loadbearing, since columns and suspended ceiling are supported on floors. Registers and monitors are coherent with the panels, supply ducts can be connected to mobile distribution blocks suspended from the ceiling. Both these and the surgical lamp are suspended from the floor. Lighting switches are on the vertical

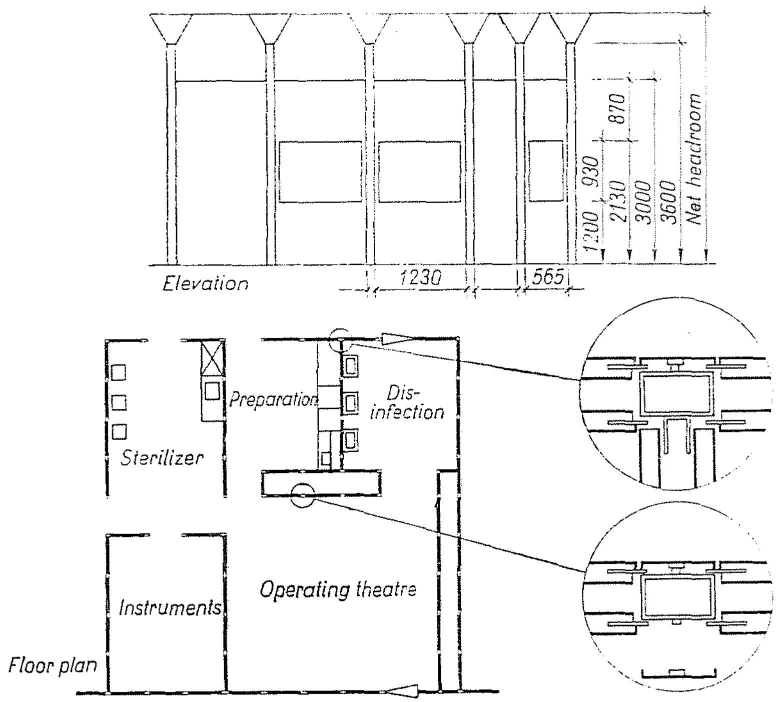

Fig. 2. Functional layout and main structural joints of a surgical unit system Maquet. By courtesy Maquet Co.

division lath. This system has several favourable features of interest for the development in Hungary, as against the disadvantage of coherence with the surrounding structural system.

Several British surgical units start from the octagonal operating theatre (*Honeywell, Venesta, Wellcome* Modular Surgical Unit, Figs 3 and 4), in six varieties of floor plan dimensions (Fig. 5), with a centrally superelevated ceiling. The self-supporting structure consists of a lightweight steel framework, walls being zinc-plated steel with PVC coating 1 mm thick, or recently with 0,8 mm PVC spray coat. Switchboards, screens and cupboards with bactericide surfacing are recessed in the panels with neoprene sealing, ventilating grids and lights are housed in the "vaulted" floor panels. Supply cantilevers (anaesthetic gas, oxigen, current, diathermic and endoscopic instrument connections) are supported on the structural columns. These surgical units are highly advantageous by the perfect independence of the heavy-weight supporting structure, and by the obtuse-angled connection between wall and ceiling planes counteracting bacterium and dust deposition, hence increasing cleaning efficiency.

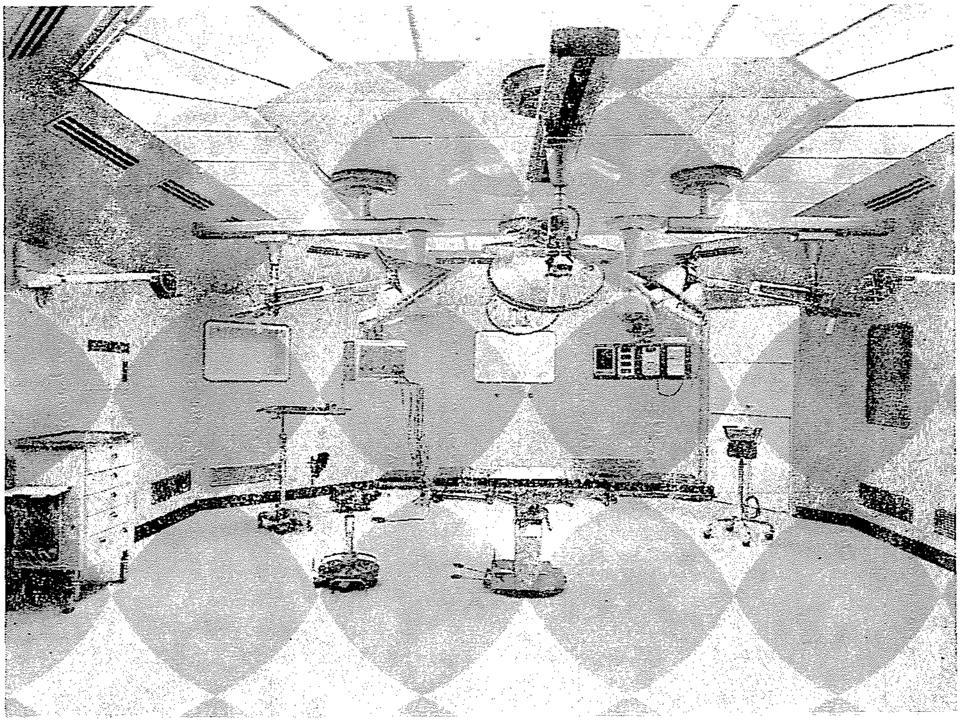

Fig. 3. Interior of a surgical unit system Wellcome (Madrid hospital). By courtesy Wellcome Medical Equipment

In spite of the relative popularity of the outlined British systems of favourable features, octagonal systems had to be abandoned in Hungarian development of surgical units

1. because of increased room demand, complicated framework and many, complex panels;

2. because the presented systems are focussed on the surgical unit, without structurally solving accessory rooms; the operating theatre is reared by acute-angled corners;

3. because of incertain technical and technological properties of plastic surfacings, especially as concerns permanent sterility; no exchangeability can be provided for PVC spray coats;

4. because of insufficient wall surface for open sashes of sliding doors of little air motion.

For surgical unit walls and floors, other sandwich panel systems with tight joints, of different destinations, may be applied. As a positive example, the *Tyler* system refrigerating chambers may be quoted. The *Refrigerator Factory, Jászberény*, has been producing sandwich panel refrigerating chambers according to a British licence, with wall, floor and ceiling panels 65 mm thick, of stove-varnished steel plates and polyurethane foam core. No special bracing is needed because of the short span (max. 3,66 m), wall units are connected and maintained by concealed fasteners, 1 to 2 mm joints are sealed by a silicon mass.

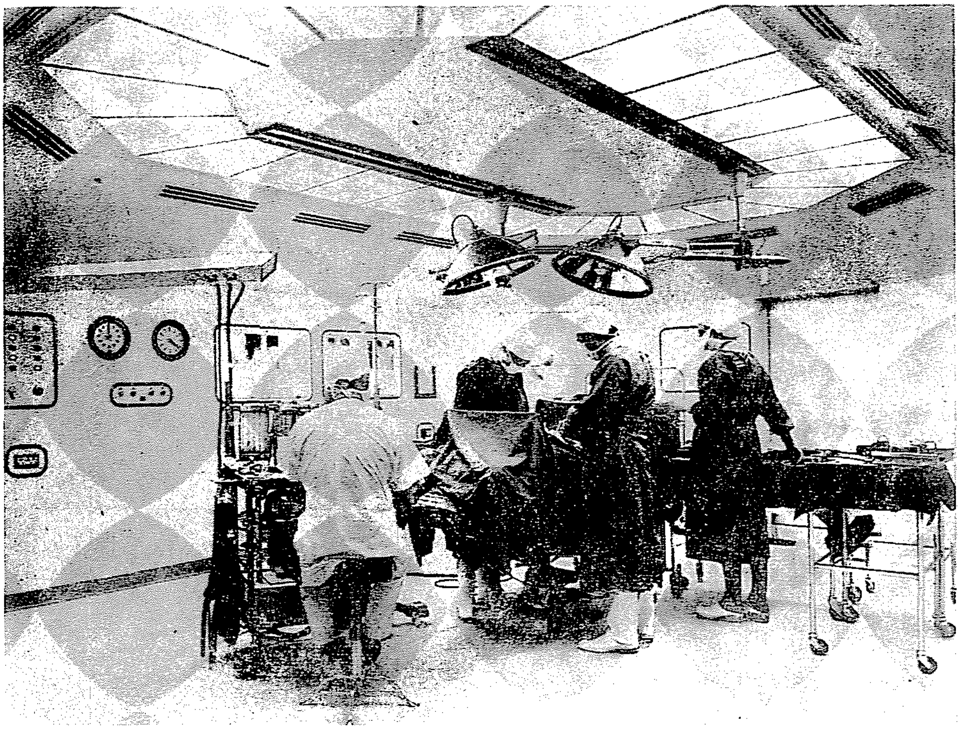

Fig. 4. Interior of a surgical unit system Wellcome (London hospital). By courtesy Wellcome Medical Equipment

Tyler panels are advantageous by being technologically affine to surgical unit panels, thus being susceptible of production in Hungarian factories. The different use would, however, require several modifications. Disadvantageous features are e.g. the excessive wall thickness, the inadequacy for spans of 6 to 7 m required for operating theatres. In lack of an assembly framework, walls

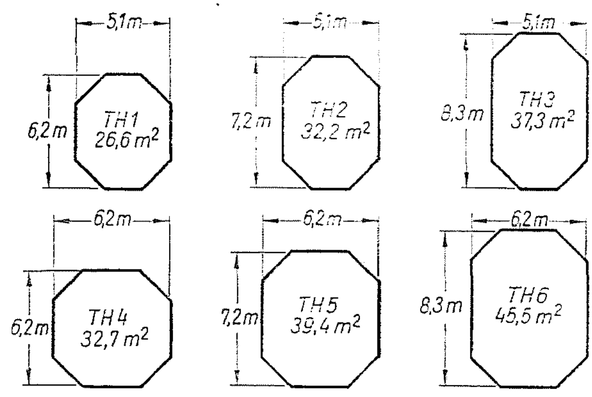

Fig. 5. Ground plan size intervals of an operating theatre system Wellcome. By courtesy Wellcome Medical Equipment

are inadequate for supporting instruments and equipment, the sensitive varnish surface has to be replaced by a better coating.

As a conclusion, all quoted foreign or imported designs have features or components susceptible of incorporation in a Hungarian development.

Studies, suggested constructional solutions

In view of the outlined requirements and foreign developments, elaboration of the Hungarian system involved the following stages of architectural and constructional design:

1. Functional sketches for a modular, flexible surgical unit of square rooms; establishment of modular co-ordination.
2. Design of a self-supporting framework incorporating installations.
3. Design of panel types, unit varieties, doors, windows and floors.
4. Study of panel materials, sandwich systems, joints and connections.

ad **1.** The operating theatre (series) and servicing rooms can be developed from square rooms according to a spatial modular system, with a functional layout (paths of patient, surgeon, material), they are rather free to develop individually as a function of local space conditions in buildings with solid walls, or with denser or sparser frameworks. Though, plans could be developed for some basic layouts to be presented in schematic floor plans. Best serial (multi-theatre) surgical units are those with servicing rooms on opposite sides of the operating theatre (Fig. 7), but in case of better layout possibilities, L-shaped bilateral systems or unilateral two-tract designs are realizable (Figs 8 and 9). From the view-point of air conditioning or installations, it is advisable to have installation ducts bilaterally, on the opposite sides of the operating theatre.

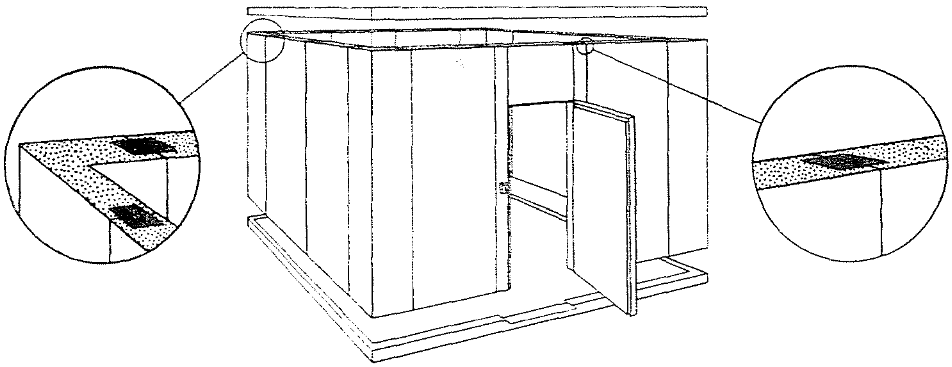

Fig. 6. Construction and joints of a refrigerating chamber system Tyler. By courtesy Refrigerator Factory, Jászberény

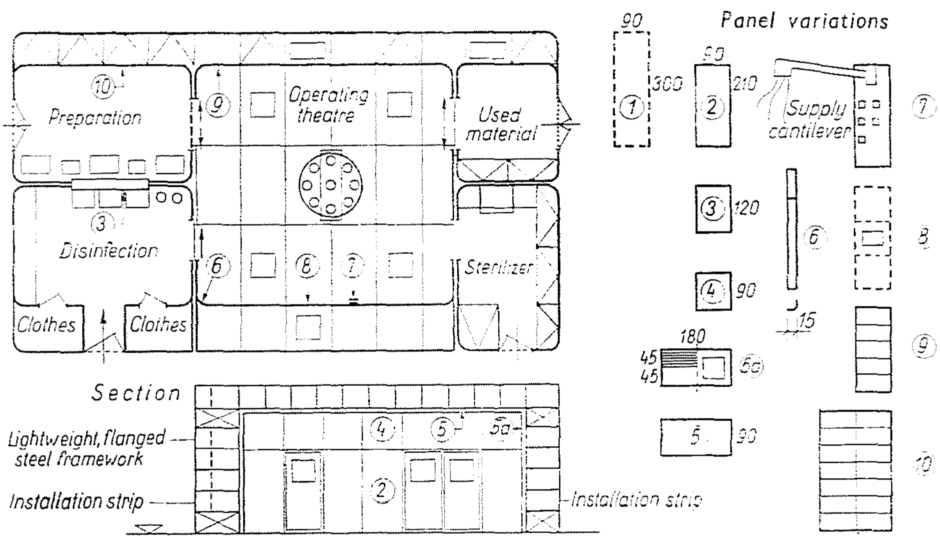

Fig. 7. Sketch and main components of a surgical unit with oppositely arranged accessory rooms

The design of the rooms is based on a 90 cm primary screen starting from the 10 cm basic module and the 30 cm increased module. Modular lines align the lightweight steel frames, joints between partitions, panels etc. Horizontally, room sizes are increased by 15 cm corner units — to simplify cleaning — and vertically, by footings 15 cm high.

ad **2.** The surgical unit is self-supporting because of Vierendeel-type frameworks of 90 cm spacing, made of surfaced, cold-rolled steel sections and steel bands. Wall panels, built-in cupboards and instruments are fastened to the columns. Horizontal installation ducts are laid between the steel bands.

Air ducts are concealed by cantilevered column units connected to the columns (installation assembly strip). Floor slabs are supported on the bottom plane of beams designed for the load of surgical lamp and supply telescope, and for handling stresses.

ad 3. The principal solid panel types have typical vertical dimensions of 210 (or 180), 120 and 90 cm resulting from modular sizes of 90 cm width and 3,00 m headroom. Accessory rooms may require units 30 and 45 cm wide. Special vertical and horizontal corner units are rounded off. Corner units may also connect floor and wall planes.

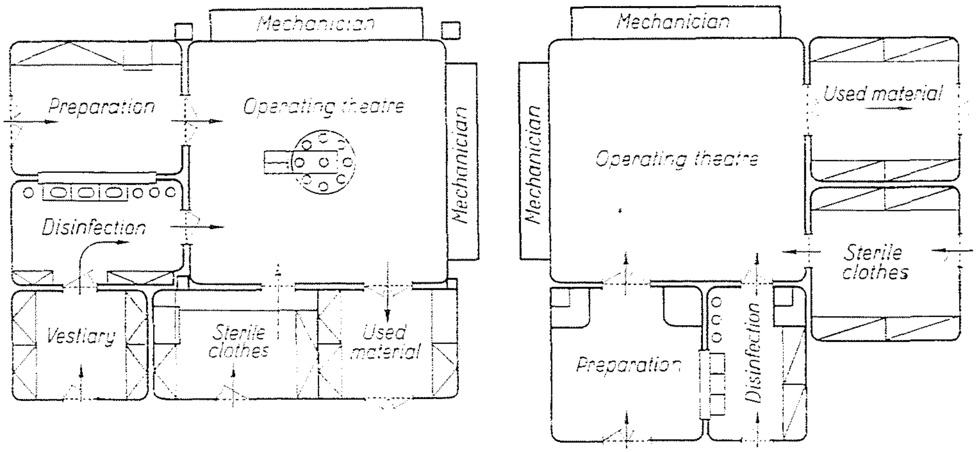

Fig. 8. Accessory rooms of L-shape arrangement

Special panels are those accommodating screens, instrument boards, supply cantilevers, and registers.

Modular and joint order of floor slabs (ceiling units) correspond to those of wall units; in addition to solid ceiling units 90 by 90 cm and 90 by 180 cm size, those pierced by air filter anemostat, lights, surgical lamp etc. are needed.

Surgical hand tools, suturing material, sterile boxes etc. are accommodated in shelved cupboards with framed glazed sashes and with sliding glazing, recessed — mostly in the installation strip, in conformity with local requirements (universal, casual, special operating theatres).

Most door structures are one- or two-sashed sliding doors fitting the wall; some actuated by a photocell. The sterile materials are passed in through a vertical sash window. Disinfection and anaesthesia rooms are separated by a window with fixed glazing. Rooms have cast (terrazzo) or spread floors bent up with rounded corners to a concrete footing 15 cm high. The top level of this footing serves as reference for exactly setting out the wall panels.

ad 4. A most important structural problem concerns material, layer system and jointing of panels. First, an inner wall lining material had to be suggested.

Cleanness tests made abroad permit up-to-date materials producible in large sheets to be ranged according to the surviving organisms found on them after being soiled with a certain impurity and then cleaned (tests by I. G. Davis and al.). This order: glass — stainless steel — vitreous enamel — polythene — polystyrene — aluminium — PVC, has to be accepted with reservation because of the possibility of rather important deviations in surface properties such as high-polished or dull metals; glossy, hard-crusted or moderately solid plastics.

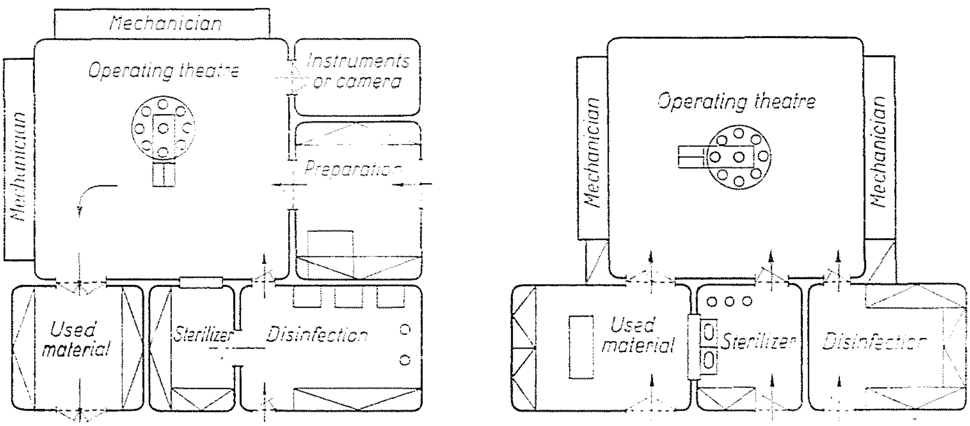

Fig. 9. Accessory rooms of L-shape or unilateral arrangement

For Hungarian needs, imported 0,8 mm stainless steel (18/8 chromium nickel steel), eventually a plastic-coated steel plate could be reckoned with, the former slightly dulled for a metallic effect, the latter coloured (blueish-greenish). Glass had to be rejected because of its sensitivity to impact, and aluminium by its softness. Enamelled steel or aluminium sheets may be applied for outer wall panels of the surgical unit facing the corridor.

Outer crust of wall and floor panels can be cut off the stainless steel sheet 100 cm wide, with an about 20 mm folding seam at the edges. Fixing lugs and zinc-plated steel frame units are connected to the folding seam, and so is the 0,5 mm back zinc-plated steel sheet. The resulting "boxes" 25 to 35 cm of overall thickness are filled out by hard polyurethane foam to produce non-rustling panels of adequate stiffness. Panels are connected to the inner flange of zinc-plated steel frames (channel or square box section) to permit ulterior dismantling and exchange, and assembly from the front side. Because of the inadmissibility of piercing the surface by screws or rivets, connections are to be made inside the joints.

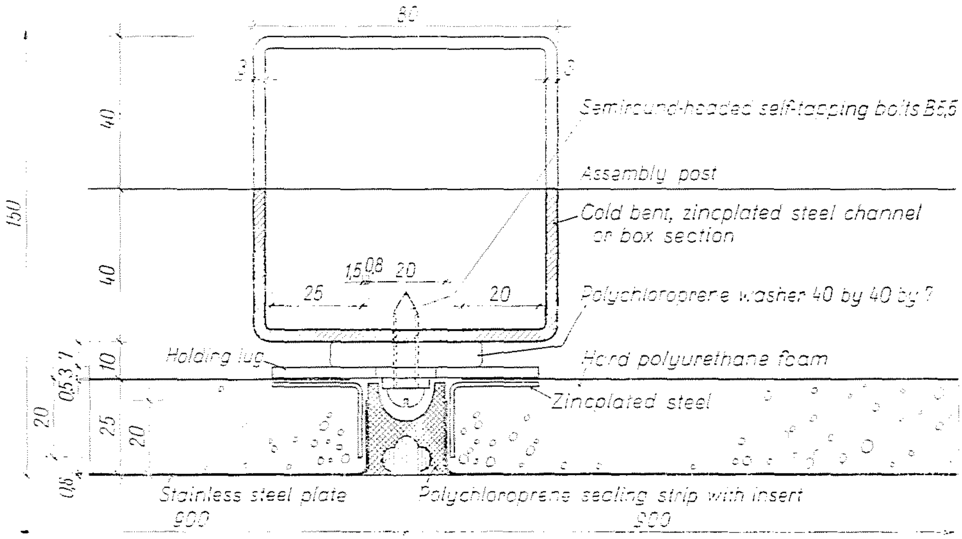

Fig. 10. Principal junction of joint A

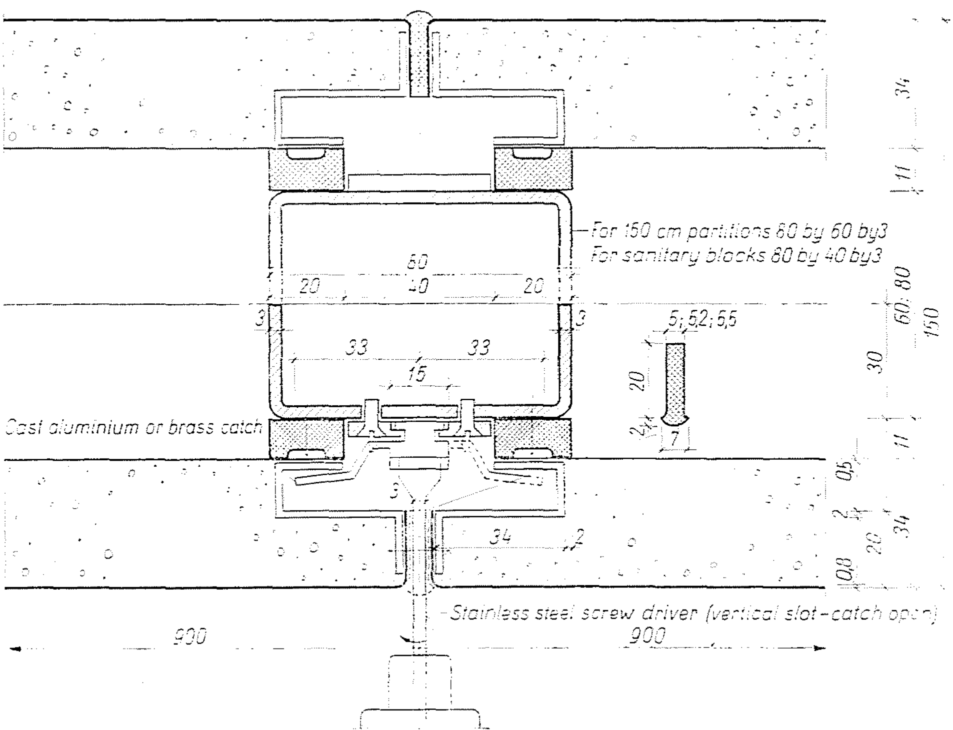

Fig. 11. Principal junction of joint B

Six different study plans of connections have been made, compared and evaluated by scoring. Main joints of system varieties A to F are seen in Figs 10 through 15.

Joint A (Fig. 10). Panel units form non-divided closed boxes connected by means of flat steel lugs castellated at a shift between two adjacent panels to be connected by screws. Joints about 20 mm wide permit easy driving of screws spaced at about 40 to 50 cm, applying polychloroprene washers. The joint is sealed by a "zipp-fastener" polychloroprene band inset.

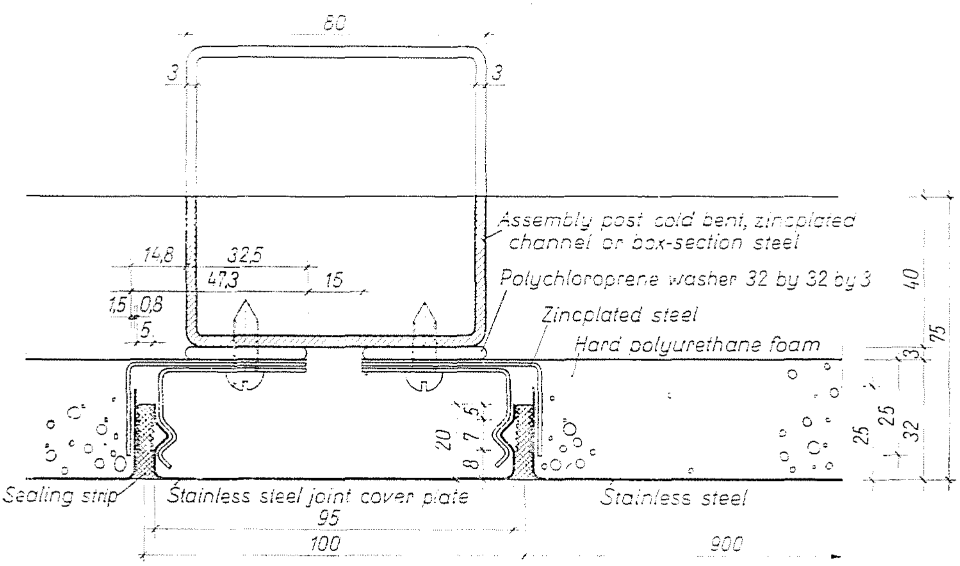

Fig. 12. Principal junction of joint C

Joint B (Fig. 11). Panel units have frames made of S-section bent steel (eventually extruded aluminium), handy grooves to house the concealed cast steel (or aluminium, brass) catches mounted on the assembly post. Panels are assembled by thrusting them against polychloroprene bands screwed onto the posts and fixed by means of catches rotated at 90° by passing a screwdriver through the 5 mm joints. Screwdriver can be taken away with edge in vertical position. The joint is sealed by a 5 mm polychloroprene band.

Joint C (Fig. 12). Panels are confined bilaterally by L-sections, shafts permitting to be screwed to the posts. 105 mm gap between each two panels is closed by snap-in joint plates of stainless steel, and two 5 mm sealing bands. This double joint system increases the primary modular net of the surgical unit to 1000 mm.

Joint D (Fig. 13). A bent 30 by 30 by 2 mm steel section bilaterally of the panels in the fixing component. Two or three flat steel hooks are screwed to it on the site, before assembly, to be superelevated for being hung on eye screws of the assembly posts, either from inside, with section outwards, or from outside, with section inwards. 5 mm joint between panels is sealed by a polychloroprene band.

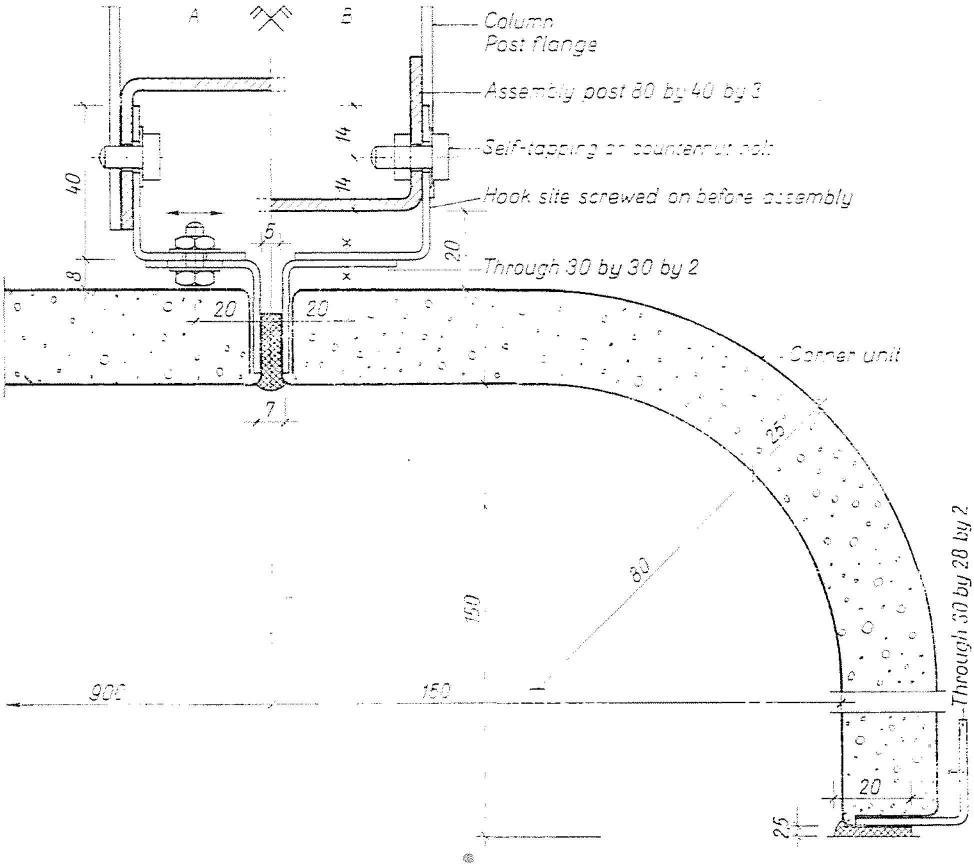

Fig. 13. Principal junction of joint D

Joint E (Fig. 14). Again, panels are hung on, but floor slabs are suspended from bent flat steel hangers. Wall panels are fixed by screws driven in the post faces through slots or holes cut in steel edges of the panel. Prestress is achieved by stainless springed button sleeves applied on the hanger screws. To maintain 20 mm spacing between panels and posts, polychloroprene spacers are attached to the posts.

Joint F (Fig. 15). Similar to C by its double joint row. But the stainless steel joint cover plate is only 26 mm wide and can be snapped on a polyamid stopper. The double joint is sealed by silicone rubber better adopting assembly

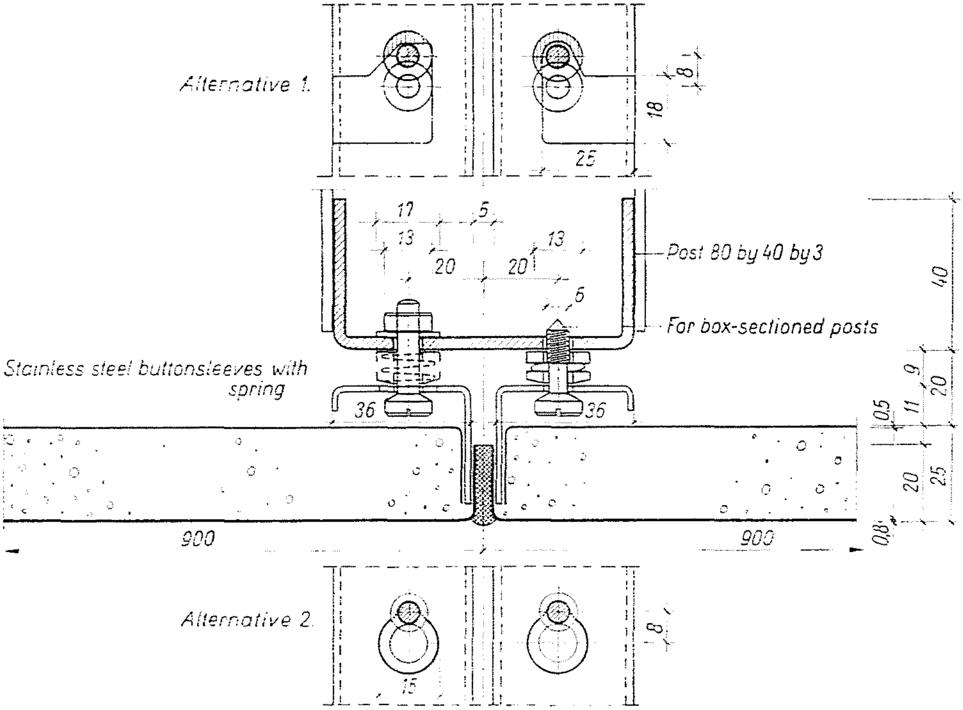

Fig. 14. **Principal junction of joint E**

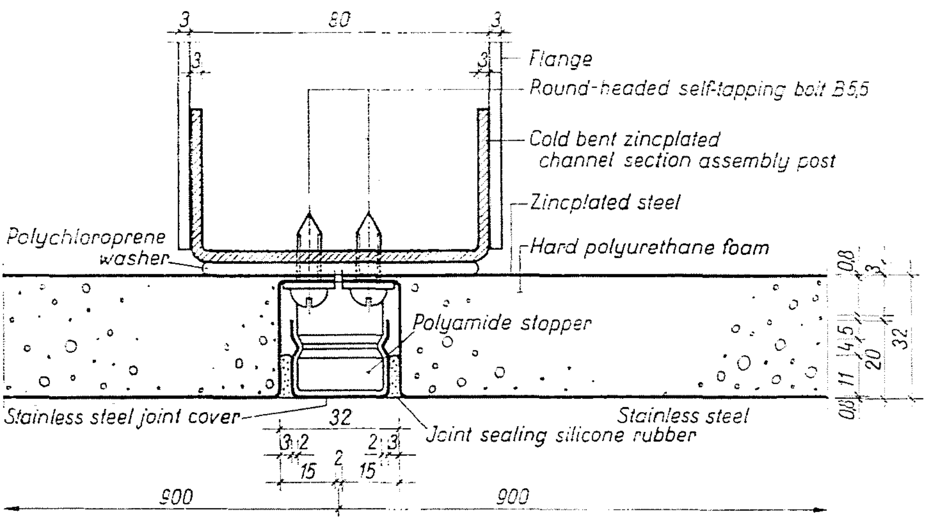

Fig. 15. **Principal junction of joint F**

tolerances but counteracting panel replacement. In these cases the paste has to be cut by a knife to lift the unit.

These six alternatives can be evaluated by establishing some fundamental requirements and the best one chosen. How criteria are met can be scored. Obviously, rather than the overall scoring alone, partial scores for certain essential criteria (such as sterility, exchangeability) are of importance. The six alternatives being identical for materials and layer system, criteria are mainly restricted to connection and jointing (Table 1):

Table I

Variety	Criterion						Overall rating
	i	ii	iii	iv	v	vi	
A	9	10	6	2	1	2	30
B	8	8	7	3	2	2	30
C	8	9	6	2	1	1	27
D	6	5	7	3	2	1	24
E	5	4	7	3	2	1	22
F	8	7	7	4	2	1	29

i Convenient design of fasteners (flush with the panel surface, simple of design, safely gripping, easy to manufacture).
Maximum rating: 10

ii Simple assembly, replaceability of panels (handling single panels without disturbing the others etc.).
Maximum rating: 10

iii Joint quality (narrow joints, sealing easy to fit and to remove, adjustment of assembly and manufacturing tolerances).
Maximum rating: 8

iv Sterility degree (primarily as concerns joint length and width).
Maximum rating: 4

v Aspect (joint layout, enhanced sealing lines).
Maximum rating: 2

vi Ease of storage, package, transport (panels easy to handle, unobtrusive fasteners etc.).
Maximum rating: 2

Overall rating recommends varieties A, B and F for manufacture, this latter being especially favourable because of its outstanding sterility. Selection work has to involve refined analysis of each item, consideration of the technological, air conditioning and other installation aspects corresponding to the features of the producing factory, manufacture of the prototype system optimum for purposes and requirements, adaptation for certain actual medical requirements.

Summary

To enhance the sterility of operating theaters in hospitals, to update those of existing hospitals, in some countries experiments have been made with up-to-date lightweight structures. Results of research done at the Department of Building Construction, Technical University, Budapest for home possibilities to introduce surgical units assembled of exchangeable panels of modular co-ordination, of rapid erection are presented, outlining functional and structural requirements for the surgical unit, analyzing systems and prototypes abroad. Finally, study plans and structural solutions are described, and structural varieties analyzed.

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* In Hungarian.