AKADÉMIAI KIADÓ

Cells and building structures. Part I. Cells – point-like, line-like and surface-like bodies – building structures

International Review of Applied Sciences and Engineering

DOI: 10.1556/1848.2020.20011

GÉZA LÁMER*

Department of Engineering Management and Enterprise, Faculty of Engineering, University of Debrecen, Ótemető u. 2-4, H-4028 Debrecen, Hungary

Received: July 8, 2019 • Accepted: February 1, 2020

ORIGINAL RESEARCH PAPER

ABSTRACT

The rooms of each building can be interpreted as three-dimensional cells. Borders (sides, edges) of rooms can be identified as the two-, one-, or zero-dimensional boundary cells of the three dimensional cell. The building structures identified as two-, one-, or zero-dimensional cells can be modeled by distinguished geometrical forms, surface-, line-, and point-like bodies. In accordance with the latter, building materials (finished products) can also be considered as surface-, line-, and point-like bodies.

The aim of the study is to create compliance between the cell elements and the building structures. It will be done at different levels:

- interpretation of relationship between building construction and cells,
- interpretation of relationship between building construction and selected bodies,
- interpretation the loadbearing's structure using cells,
- structure of the surface-construction and the cells,
- interpretation building types using cells.

In this paper (as part I) the first two items will be studied. The other three cases will be studied in another paper (as part II).

KEYWORDS

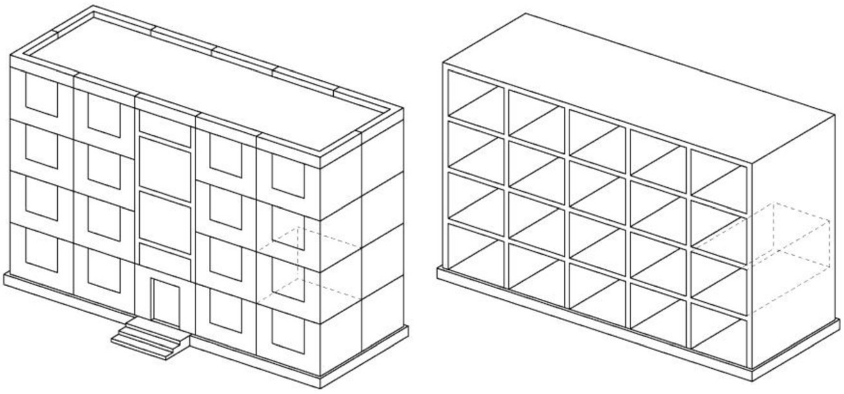
cell, boundary of cell, point-like, line-like and surface-like bodies, building structures

1. MOTIVATION

The building can be considered to be decomposed of cells adjacent and placed side by side, as well as onto each other: the sum of cells enclosed by four wall panels and two slab panels (see Fig. 1a) constitute the building. Of course, the building is more complex: each cell is divided into several smaller cells, i.e., smaller spaces, or a staircase and/or “lift shaft” is wedged between two building wings constituted by the cells. Similarly to panel buildings, in a building made with a tunnel formwork, the spaces created adjacent to and above each other can be regarded as cells; indeed, the cells at the two “ends” are not closed, they must be closed by partition walls so that they form enclosed cells (i.e., rooms) (see Fig. 1b). In a monolithic slab-pillared building, two-two slabs and four-four pillars (each relative to a corner of a rectangle) mark a cell. This is also an open cell with four open sides, its upper and lower surfaces are closed (see Fig. 1c). A unit of a frame drawn by the pillars and master beams of a three-dimensional frame structure can be also considered as a cell. This cell is only “marked” by columns and beams, and slabs and walls need to “enclose” the cells (see Fig. 1d). If you imagine a “unit” of enclosed space as a cell, you can assign cells to other building types. For example, the main walls and ceilings of the building and the partition

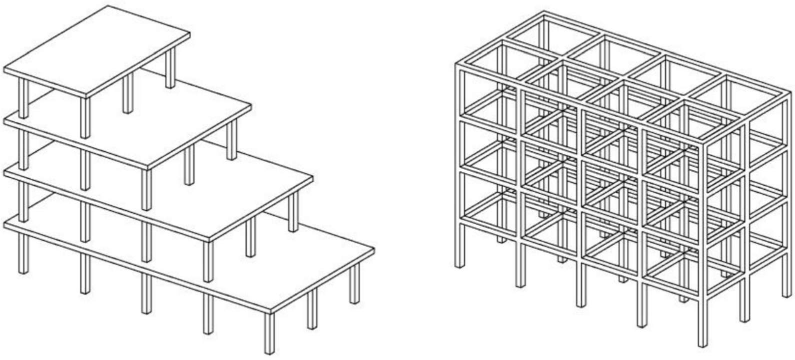
*Corresponding author.
E-mail: glamer@eng.unideb.hu

AKJournals



a) Reinforced concrete panel building

b) Building by tunnel formwork



c) Pillar frame with monolithic slab

d) Spatial frame construction

Fig. 1. Interpretation of cells in various building types

walls built between the main walls and between the ceilings define a room and a cell at the same time.

Based on examples above, the sides of a cuboid and the edges of the cuboid, *and* the individual supporting structures or space-separating constructions of the building, can be matched: the vertical sides of the cuboid are walls, the horizontal ones are slabs, and in addition, the vertical edges of the cuboid may correspond to pillars and the horizontal ones to mast beams.

Geometric forms are mainly dealt with in the field of statics, as "*selected*" geometric forms – rods, plates, discs and shells – allow for a *simplified* description of the mechanical state (see for instance Onouye–Kane [1]). The use of "*selected*" geometric forms for building constructions – column, pillar, wall, and slab – is obvious.

Building constructions are presumed to be known, at least at the level of the practicing architect. Davies–Jokiniemi [2] recommend to review some concepts. The relationship between form, structure and function is reviewed. Joedicke gives an historical outlook [3], Siegel reviews the modern forms of loadbearing structures [4]. Gilyén examines the load-bearing capacity of the support structure depending on the material and the shape of the building material used [5]. When organizing form and space, Ching systematically reviews the possible shapes of different spaces and its space-separating structures. He does not speak of a cell or a boundary, but the representation of smaller and larger volumes used in the construction of space and boundaries of it practically advance cellular modeling [6]. Onouye–Kane reviews the statics and strength of loadbearing building structures. The emphasis is on dimensioning and testing the strength of each support structure. At the same time, the representation of the frames, the trusses and the pillar frame suggest the possibility of describing them with the help of cells [1]. In his manual for structural engineers, Silver–McLean–Evens describe the strengths of the more well-known building structures during the case studies. In this, the drawings depict a relationship with cells [7]. Bajza groups the description of building structures based on building technology. For long-span spatial overlays, specific structural drawings show a close relationship with the cells [8]. Structure of the building constructions can be approached from the aspect of building materials and numerical methods, Lámer [9]. The geometric arrangement of the loadbearing structure can be modeled with the help of cells Lámer [10].

Cells are mainly dealt with in physics and crystal science. Cells are periodically repeating geometric shapes. This refers to the two-dimensional cellular structure of paving (floor tile) and surface lattice structures, in addition to the aforementioned rooms and supporting frames. Reference is made to the relevant articles in the Small Encyclopaedia of Physics [11] for some concept.

2. INTERPRETATION OF RELATIONSHIP BETWEEN BUILDING CONSTRUCTIONS AND CELLS

2.1. Introduction

To interpret the relationship between building construction and cells we will concentrate on the loadbearing and space-separating building constructions. That is why we focus our attention only on one cell.

The building is divided into three sections vertically: the base, the body and the roof. The interpretation will be given for these three kinds building part.

First, we review the concept of a cell.

2.2. Cell

The cell is basically seen as the unity of the single-layer and complete division of space. In this content the single-layer means the filling is without overlapping, the complete means the filling is without deficit. The cell can best be represented as a cuboid. It is evident that the identical cuboids in a regular arrangement fill the space without overlapping and without deficit. The spaces (i.e., rooms) in the building usually have cuboid form. Some surface divisions in architecture are triangular, quadrilateral and hexagonal. The hexagonal division is usually derived from a triangular division. Based on the above, a distinction is made between triangular and rectangular based cells. The two cell types are described separately. The emphasis is on the relationship between the cell and its boundary. The network (grid) formed by the edges of the cell will be discussed later.

The interpretation of a cell is given as a function of the number of dimensions; from the zero dimension to the three dimensions. When interpreting cells, we also specify the boundaries of cells interpreted in each dimension.

The triangular based cells are as follows (see Fig. 2).

The zero dimensional cell is the point. The boundary of a zero-dimensional cell is not interpreted.

The one-dimensional cell is the segment. The two endpoints of the segment are the cell boundary.

The two-dimensional cell is the triangle. The three sides of the triangle *and* the three endpoints are the boundaries of the triangle.

The three-dimensional cell is the tetrahedron. The four faces of the tetrahedron *and* six edges *and* four endpoints are the boundaries of the tetrahedron.

The rectangular cells are as follows (see Fig. 3).

The zero dimensional cell is the point. The boundary of a zero-dimensional cell is not interpreted.

The one-dimensional cell is the segment. The two endpoints of the segment are the cell boundary.

A two-dimensional cell is the rectangle. The four sides of the rectangle *and* the four endpoints are the boundaries of the rectangle.

The three-dimensional cell is the cuboid. The six faces of the cuboid *and* twelve edges *and* eight endpoints are the boundaries of the cuboid.

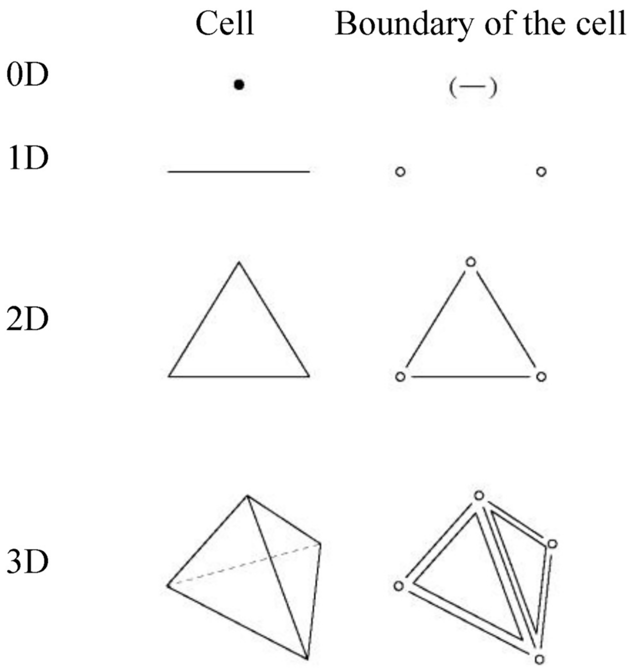


Fig. 2. Triangular based cells

The generalizations of cells can be based on the deregulation and on the modification of the straightness of the edges, and of flatness of the sides.

2.3. Cells and foundation work

Among the foundations we distinguish between shallow and deep foundations. Shallow foundations are not too high relative to the building as a whole, while deep foundations

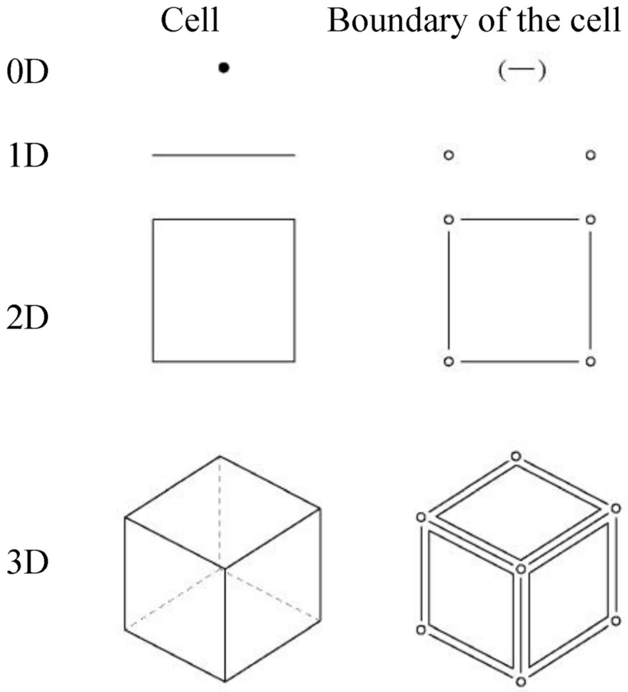


Fig. 3. Rectangular based cells

are considered as a set of building structures that height (as vertical line size) can be equal to or greater than the height of one floor. Thus, the shallow foundations correspond to the elements of a two-dimensional cell and the deep foundations to the elements of a three-dimensional cell. The relationship between the cell and the foundation is shown in Fig. 4.

The relationship between the cells and the building structure is as follows. In the case of shallow foundations:

- vertex ⇔point foundation,
- horizontal edge ⇔ strip (or beam) foundation,
- horizontal side ⇔ slab-on-grade foundation,
- curved side ⇔ shell foundation.

In the case of deep foundation:

- vertex ⇔ capital (e.g., between pile and lintel),
- horizontal edge ⇔ lintel (elements of the grid system),
- vertical edge ⇔ piles or wells,
- horizontal side ⇔ head plate of the pile or well foundation, head or bottom plate of caisson or hollow box foundation,
- vertical side ⇔ slurry wall, and side wall of caisson or hollow box foundation,
- curved side ⇔ “bottom shell” (the so-called inverted arch) of caisson or hollow box foundation.

2.4. Cell and the building structure in the body of the building

One unit (one cell) in the body of the building refers to the three-dimensional cell; which matched the main supporting structures and partition structures. The relationship between the building structure and the cells in the case of a square and circle plan is illustrated in Fig. 5.

The relationship between cells and building structures is as follows:

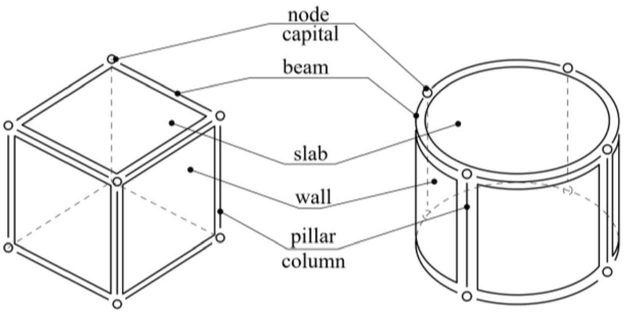


Fig. 5. Cell and the building structure

- vertex ⇔ capital or base of pillar, and node of supporting fixture,
- horizontal edge ⇔mast beam,
- vertical edge ⇔ pillar (column),
- horizontal side ⇔ slab,
- vertical side ⇔ wall.

2.5. Cell and roof (space cover) structure

We also intend to interpret the roof (space cover) structure as a cell. Generally speaking, the roof (space cover) structure is a convex surface.

Figure 6 illustrates the relationship between the cell and a roof (space cover) structure using two common roof elements.

The relationship between the cells and the building structure is as follows:

- vertex ⇔ roof peak, intersection of edges and eaves-line,
- horizontal edge ⇔ support line of roof structure (top edge of wall),
- oblique edge ⇔ roof edge (hip),
- [horizontal side ⇔ sheet of roof slab],
- oblique side ⇔ roof (board timbering, reinforced concrete sheet),

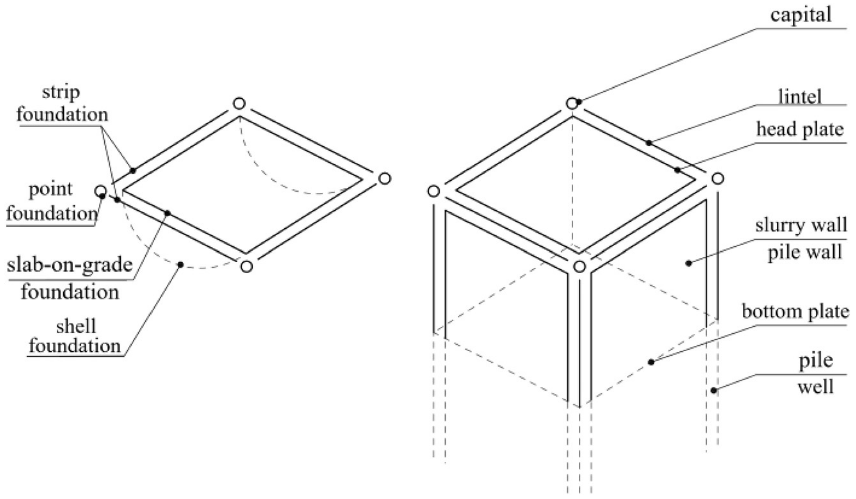


Fig. 4. Cell and the foundation

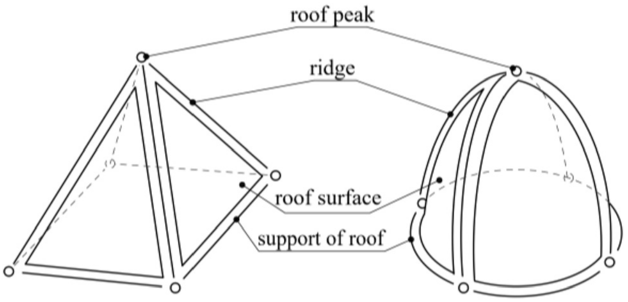


Fig. 6. Cell and the roof (space cover) structure

- curved side ⇔ roof surface (curved board timbering, vault, dome, reinforced concrete shell).

3. INTERPRETATION OF RELATIONSHIP BETWEEN BUILDING CONSTRUCTION AND SELECTED BODIES

3.1. Introduction

The elements of the cells are the three-dimensional enclosed space itself, the two-dimensional geometric figures as sides of the cells, the one-dimensional segments as edges of the cells, and the zero-dimensional points as vertices of the cell. These are geometric objects. Building structures are three-dimensional bodies, so they cannot be directly identified with two-, one, and zero-dimensional geometric objects. To interpret boundary element of a cell as a building construction we have to introduce special geometric forms. Namely point-like, line-like, and surface-like bodies or structures. These bodies will be referred to as selected bodies.

3.2. Concepts

To interpret point-like, line-like and surface-like bodies we will apply the concept of negligible quantity. A negligible quantity can be negligible relative to some "basic" quantity. In the case of building structures, the "basic" quantity, that is "basic" size is the module size used for buildings, usually 6 m.

In the relations between two quantities, the following notations are used.

If a is smaller or greater in scale than b, then it is indicated by $a << b$ or $a >> b$.

If the values of a and b are of the same scale, then this fact is indicated by $a \approx b$.

The geometrical proportions of a body are expressed by the length, width, and thickness of the body.

3.3. Point-like, line-like and surface-like bodies and structures

3.3.1. Point-like bodies and structures. *Interpretation of the point-like body*: a point-like body is a body with three linear size, a, b and c, are equal in scale, $a \approx b \approx c$, the size of which are smaller than the length (L) of, width (B) of, height (H) of dwelling unit, $a, b, c, << L, B, H$ (See Fig. 7).

Note: a point-like body can only be point-like in relation to something. The proportions of the body in themselves are irrelevant, as a "cube house" (a cottage with a 10 × 10 m floor space and an interior height of 3.5 m built in the 60s and 70s in Hungary), as well as 80 × 80 × 40 cm small wall block, or the $6^5 \times 12 \times 25$ cm brick (as a rectangular block or cuboid) would all be point-like. The benchmark is the *building* we build. The dimensions of the building are very different; besides the aforementioned detached house category, the height of the ten-storey building is approx. 30 m, its width is 6–10 m, its length is 30–40 m up to hundreds of meters. The height of skyscrapers is 100–200 m, but there are already 5–600 and even 800 m tall buildings, their floor area is multiples of the sizes of the family house. Due to the large "deviation" of the sizes, we choose the sizes of a unit of a residential building – the room. We choose 6 m as the "default value." As for height, 4.5 m is chosen as the "default."

The following building materials (finished products) are regarded as point-like bodies:

- pillar caps carved from stone, pillar base, corbels, column drums,
- fired brick and lime-sand brick, fired clay, limestone and porous concrete wall block,
- formwork block, ceramic and concrete lining,
- wooden cube, small and large stone cube for pavement,
- concrete paving element.

In the case of surface formation, the ceramic roof tilers, concrete roof tilers, the (rhombus) roof slaters and the ceramic floor tiles are considered point-like. At the same time, each one is too tinny by itself and are similar to a surface figure rather than a point-like body.

The following structures can be mentioned as a point-like building construction:

- column capitals and bases,
- the nodes in the trussed and rod structure,
- point foundation (block and sleeve foundation form),
- wood, stone-brick and steel bases to support structural elements.

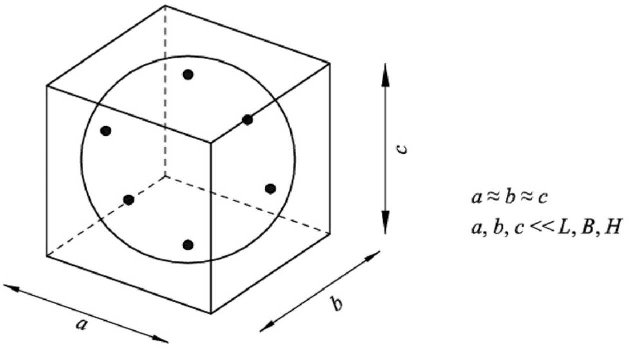


Fig. 7. Interpretation of the point-like body

3.3.2. Line-like bodies and structures. *Interpretation of line-like body:* we call the body, which can be described as a set of plane figures passed through a line section selected on a base curve *line-like* under the following conditions. The linear sizes of the plane figures (cross-sections), a and b, are similar in size to each other, $a \approx b$, and are smaller in size than the length (L) of the line section selected on the base curve, a, $b << L$.

It is implicitly assumed that length L is (at least) comparable to 6 m.

We will also use the term line-structure as a synonym of line-like structure.

The “first” and the “last” plane figure are the bottom and top base of the line-like body, respectively. The (topological) sum of the boundaries (perimeters) of the plane figures gives the lateral surface of the line-like body. The three surfaces together form the surface (or the boundary from the topological point of view) of the line-like body (See Fig. 8).

The base curve is commonly referred to as the axis of the line-like body or structure. Depending on the geometrical position of the axis relative to the plane figures, the axis is commonly referred to as a symmetry axis, median (weight axis), or axis of torsion: the axis passes through the symmetry points, centroids, or midpoints of rotation of the plane figures.

The plane figures are cross-sections of the line-like structure.

The intersection of the axis and the cross-section refers to the angle between the two geometric objects. In practice, the angle of intersection is usually 90°. *Note:* in principle, the angle of intersection can be different from 90°. There are bodies for which it is *advisable* to accept the oblique intersection and keep it in the model creation. Such a case may be an oblique (reinforced concrete) bridge track.

For the intersection of the axis and the cross-section, the point of intersection of axis and cross-section must be given. The intersection points can be *selected*, such as the center of gravity of the plane figure, or the center of rotation of cross-section in sense of bending. But it may be any point of the plane carrying the plane figure inside, or even outside of plane figure.

A plane figure can be “freely” rotated around the tangent vector of the curve. Consequently, “free rotation” must be specified. In practice, we interpret the Frenet–Serret frame of the curve [12] and the directions of the main inertia of the plane figure [1] at the intersection point. We use the position of the latter in the normal plane of the curve to fix the plane to the curve. Usually, the larger main inertia axis is aligned with the direction of the normal vector (of the curve), the smaller main inertia axis is aligned in the direction of the binormal vector (of the curve). *Note:* the fact that in architecture the issue cannot be avoided is supported by twisted columns, wrought iron rods.

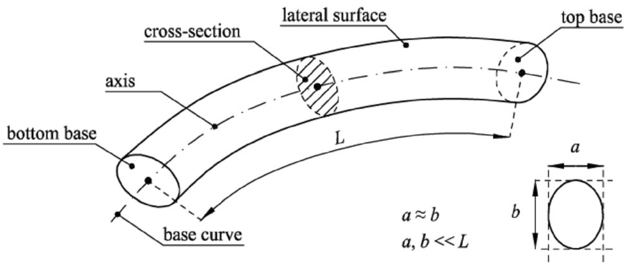


Fig. 8. Interpretation of the line-like body

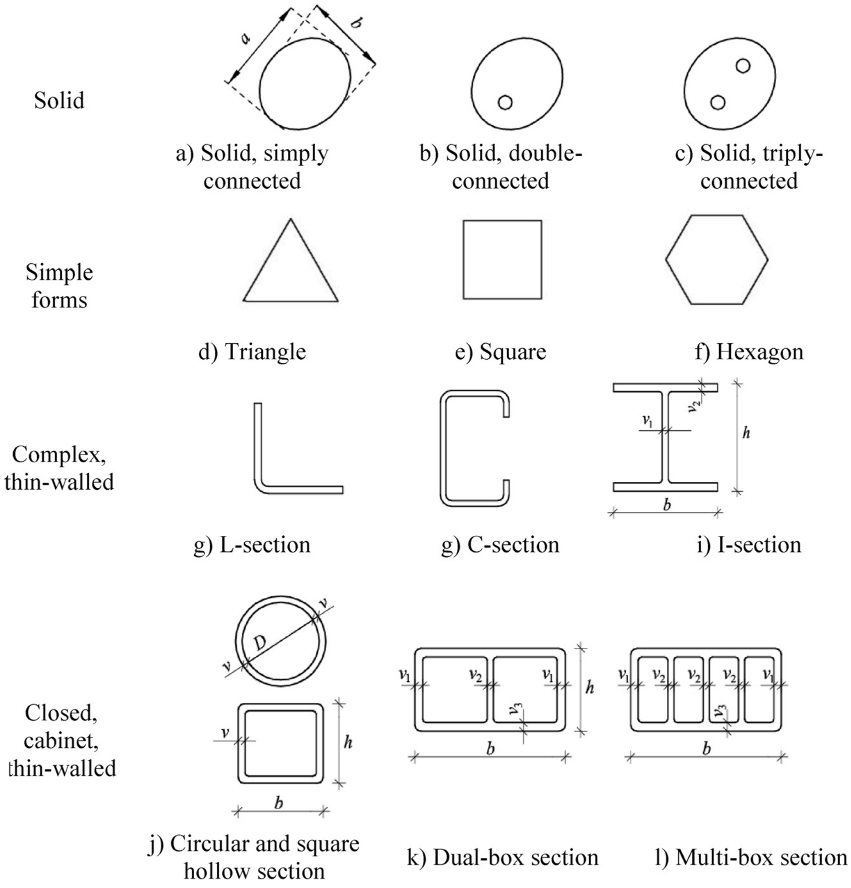
The line-like bodies and structures are divided into three major groups according to axis: straight-line, flat-curved, and space curved axis line-like bodies or structures.

The straight-line axis structure as a building material is usually called a beam. In the case of load bearing structure different terms are used depending on the position and form of the line-structure. The horizontal, line-like structure with straight-line axis is the beam, the vertical one is the pillar or the column. The line-like structure with (convex from below) vertical plane curve is arch or arch structure. The line-like structure with horizontal plane curved axis structure is the curved beam. In general, in the case of a deformable line-structure – irrespective of the figure of the axis – the term rod, while in the case of a flexible (kinematically undefined) line-structure, the term rope or cable is used.

Cross-sections are distinguished according to their connectedness, shape and relation of their sizes. If the plane figure is connected (there is no “hole” in it), then we are talking about a solid and simply connected cross-section. In the case of a few small holes, we refer to a solid, doubly, or multiply connected cross section (See first row of Fig. 9). In the case of solid cross-sections, we distinguish triangular, square and rectangular, hexagonal and circular cross-sections (see second row of Fig. 9). In the case of cross-section consisting of several simple plane figures, we refer to a complex cross-section. Such are the L-, C-, or I-sections (See third row of Fig. 9). If there are closed “planar holes” in the cross-section, we refer to a multiply connected cross-section. The circular tube and the square hollow section are doubly-connected, the dual-box section is triple-, the n-box section is $(n + 1)$-timely connected cross-sections (See fourth row of Fig. 9).

Let the linear sizes of cross-section be a and b. By default, the two linear sizes are of the same scale, $a \approx b$. If the cross-section is multiply connected and the area of inner hole makes up 10–20% of the area of the whole cross-section, then we refer to thick-walled cross section. If there is an $a >> b$ relation, then we refer to a band-like line-structure (such as a flat steel bar or a wide timber board). In the case of a compound cross-section, for example an I-section, the height h and the width b are of the same scale, $b \approx h$, the thickness of the web v_1 and the flange v_2 are of the same scale, $v_1 \approx v_2$, but the thicknesses relative to the linear sizes are smaller in scale, v_1, $v_2 << b$, h. Then we refer to a thin-walled cross-section. The hot rolled and cold formed steel sections are thin-walled.

The rod is characterized with the axis and cross-section of the line-like structure: we refer to straight, flat and space curve rods, simply, multiply connected, solid, composite, thin-walled cross-section rods.



a) Solid, simply connected

b) Solid, double-connected

c) Solid, triply-connected

d) Triangle

e) Square

f) Hexagon

g) L-section

g) C-section

i) I-section

j) Circular and square hollow section

k) Dual-box section

l) Multi-box section

Fig. 9. The cross-sections

We consider the following building materials (finished product) as a line-like body:

- hot rolled and cold formed steel sections, tubes, hollow sections,
- ribbed bars,
- battens, planks, latches, boards, beams (sawn timber),
- prefabricated reinforced concrete (flat, I-, pitched, T-, cruciform etc.,) beams,
- wire ropes, cables,
- pipes, tubes, boards.

The following line-structures can be mentioned as building constructions:

- strip, wide strip, trench-fill and pad foundations,
- pillars, columns,
- beams, lintels,
- gouged and rough arches, ribs, arch structures,
- elements of trusses and frame structures,
- elements of rope structures such as towers (or mast), edge beam, holder and tension ropes.

3.3.3. Surface-like bodies and structures. *Interpretation of a surface-like body*: we call the body, which can be described as a set of straight sections fitting to a surface figure selected on a surface *surface-like,* under the following conditions. The linear sizes of the surface figures on the given base surface, L and B, are similar in size, $L \approx B$, but are larger in size than the length of the straight section (v), $L, B >> v$.

It is implicitly assumed that L and B are (at least) comparable to 6 m.

We will also use the term surface-structure as a synonym for surface-like structure.

The “first” and the “last” surface figure are the lower and upper surface of the surface-like body, respectively. The (topological) sum of the straight segments that fit to the edge (perimeter) of the surface figure on the base surface is the lateral surface of the surface-like body. The three surfaces together form the surface (or the boundary from the topological point of view) of the surface-like body (See Fig. 10).

The base surface generally halves the thickness; then the base surface is usually called the middle surface.

The straight sections are the “cross-sections” of the surface-like body – not just one but two intersecting planes are required. The length of the cross-section is the thickness of the surface-like body.

The intersection of the base surface and the cross-section refers to the angle between the two geometric objects. In practice, the angle of intersection is usually 90°.

Surface-like bodies and structures are divided into three major groups based on the base surface: flat base-surface, developable (can be flattened onto a plane without distortion) or “simply curved” base-surface and non-developable

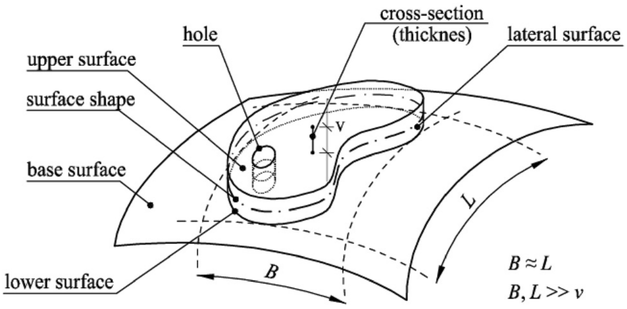


Fig. 10. Interpretation of the surface-like body

(cannot be flattened onto a plane without distortion) or "double curved" base-surface bodies or structures (See Fig. 11).

A flat base-surface structure is usually referred to as a plate or disk. The horizontal, flat base-surface structure is the bent plate, the vertical, flat base-surface structure (loaded on its own plane) is plate in plane state, as disc, wall, wall supported on a few points. The convex, viewed from below, surface-like structure, forming by a cylindrical surface with horizontal generatrix and base curve in a vertical plane is the wagon vault. In general, in the case of the deformable surface-structure, irrespective of the shape of the base surface, the term vault, dome and shell in architecture are used, and the term tarpaulin in the case of a flexible (kinematically undefined) surface-structure.

The base surfaces are distinguished according to their connectedness, shape and scale of their linear sizes. If the surface figure given on the base surface is bounded by one (not self-cutting) closed curve (there is no hole in the surface), then it is simply connected, if it is bounded by several (not self-cutting) embedded in each other closed curves (one or more holes in the surface), then it is a multiply connected surface-structure (Fig. 12).

Based on the projection on the horizontal plane of the given surface figure on the base surface, a triangular, a rectangular, different polygonal, and circular projection are distinguished (Fig. 13).

The system of plates or shells consisting of several *simple* plates or shells *and* with connections between the contact edges capable of transmitting internal forces is called *complex* or *folded* plate or shell, or *complex* or *folded* plate structure or shell structure, respectively (Fig. 14).

Let be given the linear sizes of the surface figure of the given surface L and B (see Fig. 10). By default, the two linear sizes are of the same scale, $L \approx B$. If there is a difference in scale between the two linear sizes, $L >> B$ ($>> v$), then it is referred to as band-like, or a ribbon-like structure. *Note:* this is structurally the same as the band-like line-structure. If there are only a few holes on the surface, say n number of holes, then we specify how many times, in the example, the surface-structure is $(n + 1)$-timely connected. If the holes are periodically (in a triangular, square, or hexagonal network) located in the surface-structure, then they are referred to as a perforated sheet or shell.

The base surface and the cross-section of the surface-structure is used to characterize the surface-structure: we refer to plane, developable (simple curved) and non-developable (double) curved base surface-structures, which can be simply or multiply connected, their cross-section, i.e., their thickness, can be constant and variable.

Building materials for surface-like bodies include:

- (flat) sheets and plate, trapezoidal iron sheets, corrugated iron or slate sheets,
- wooden boards (artificial wood products), drywall boards,
- prefabricated reinforced concrete wall blocks, wall panels,
- prefabricated reinforced concrete, floor panels,
- tarpaulin.

Surface-structures as a building construction can be distinguished as follows:

- walls, wall supported on a few points,
- foundation slab, foundation in form of folded plates and shells,

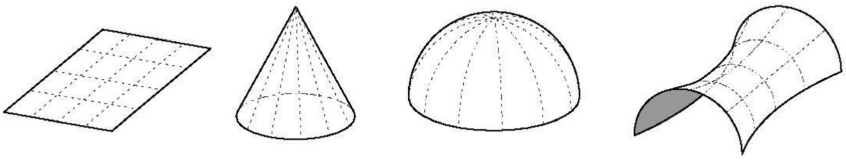
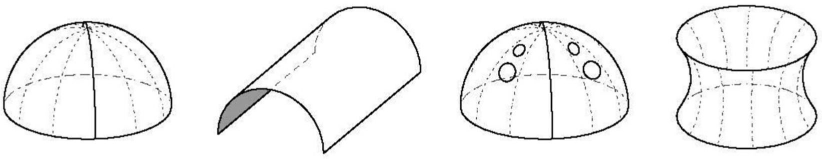


Fig. 11. Plane, developable base-surface (cone), double curved base-surfaces (spherical and saddle surface)



Simply connected

Multiply connected

Doubly connected

Fig. 12. Simply and multiply connected surfaces

Fig. 13. Projections on the horizontal plane

- slabs, and decks,
- plate, and elements of folded plate,
- shells, and elements of folded shells,
- elements of tarpaulin structures.

3.4. Constructing building constructions from point-, surface- and line-like elements

A point-like structure is a point-like support of various support structures. Three examples are mentioned; the three examples are composed of different types of elements (see Fig. 15):

- point-like structures from point-like elements: masonry block base,
- point-like structures from line-like elements: “stool” from stacked timber beams,
- point-like structures from surface-like elements: “stool” from steel plates.

Line-structures include pillars and columns, beams and arches.

Line-like structures from point-like elements (see Fig. 16):

- pillar brickwork,
- column constructed from column drums,
- arch constructed from (wedge-shaped brick or stones).

Line-like structures from line-like elements (see Fig. 17):

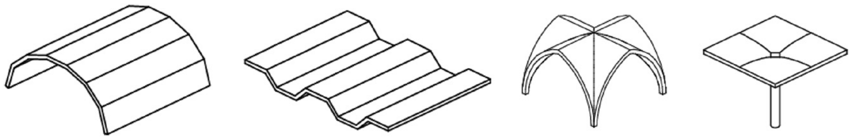
- pillar from timber beams connected with straps,
- composite section steel pillar welded from sections,
- trussed column,
- cambered composite beam,
- castellated steel beams welded from sections,
- planar truss beam or arch,
- widened beam from steel sections with pallets,
- widened beam from steel sections with welding,
- space truss beam or arch.

Note: in the cambered composite beam, there are also point-like elements, but the same time line-like elements dominate in the obtained line-like structure.

The line-like structures shown in Fig. 17 can be divided into two larger groups. The structures in the first two columns of Fig. 17 are continuous, and the ones in the third column are non-continuous and have a lattice (trussed) structure.

Line-like structures from surface-like elements (see Fig. 18):

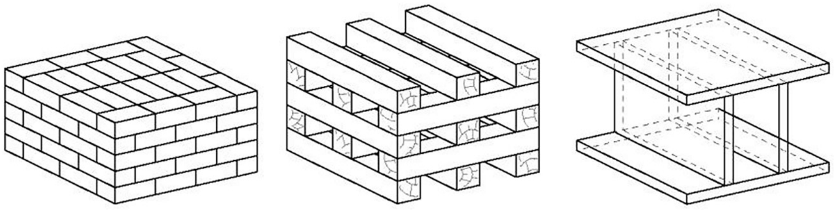
- pylons and pillars from steal sheets or plates (square cross-section, thin-walled pillar),
- box beam from steel sheets or plates (or in arch form).



Complex plate structures

Complex shell structures

Fig. 14. Plate and shell structures



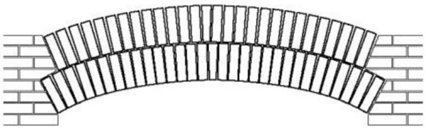
a) Masonry block base

b) “Stool” from stacked timber beams

c) “Stool” from plates

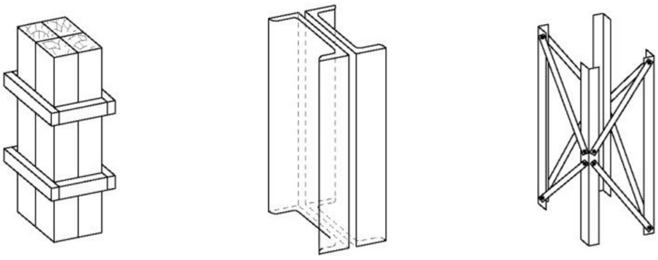
Fig. 15. Point-like structures from point-, line- and surface-like elements

a) Pillar constructed from bricks b) Column constructed from column drums

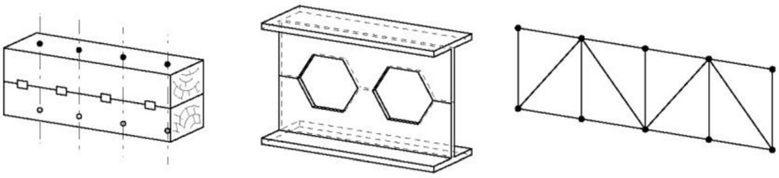


c) Arch constructed from bricks d) Arch constructed from stones

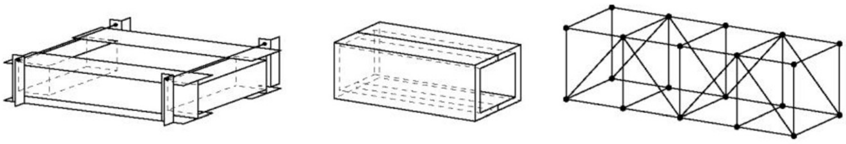
Fig. 16. Line-like structures from point-like elements



a) Pillar from timber beams b) Pillar from steel sections c) Trussed column

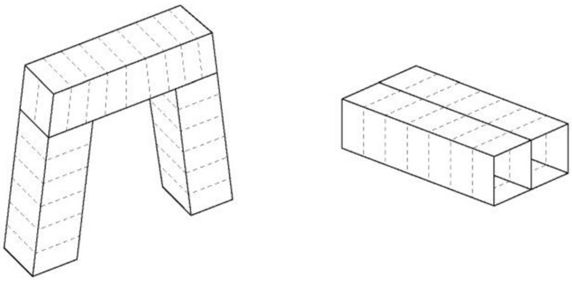


d) Cambered composite beam e) Castellated steel beam f) Trussed beam (planar)



g) Widened beam with pallets h) Widened beam with welding i) Trussed beam (space)

Fig. 17. Line-like structures from simple line-like elements



a) Pillar from sheets b) Beam from sheets

Fig. 18. Line-like structures from surface-like elements

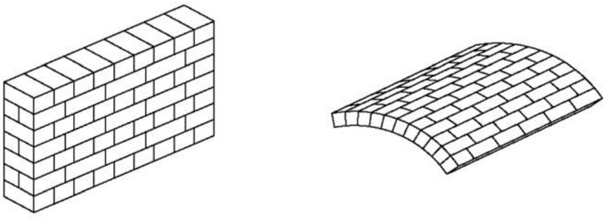
Surface-like structures are walls, slabs and decks; the latter may have plane or curved surface.

Surface-like structures from point-like elements (see Fig. 19):

- masonry wall,
- masonry vault.

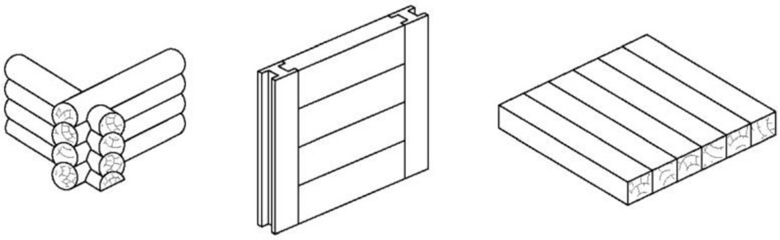
Surface-like structures from line-like elements (see Figs 20 and 21):

- log construction (primarily from logs, uniform rectangular or round cross-section beams),
- muntin and plank construction (primarily from timber, less commonly from concrete or metal),



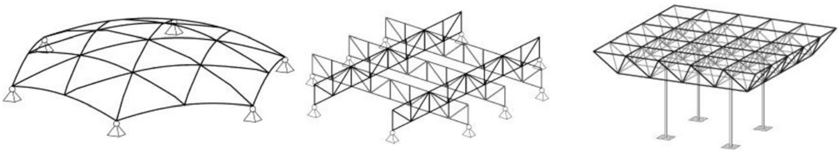
a) Masonry wall b) Masonry vault

Fig. 19. Surface-like structures from point-like elements



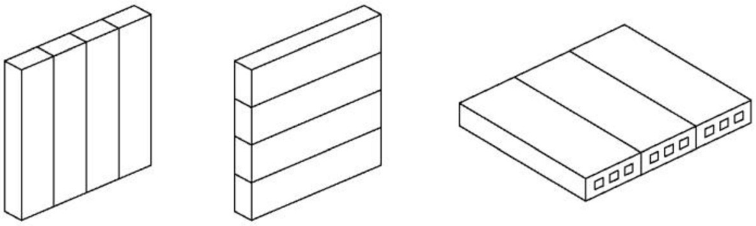
a) Boxed-lap-notch walls b) Muntin and plank wall c) Dense joins “slab”

Fig. 20. Surface-like structures from line-like elements



a) Trussed construction on surface b) Grid from trussed beams c) Two layered trussed plate construction

Fig. 21. Trussed surface-like structures



a) Wall from standing panels b) Wall from lying panels c) Hollow-core slab

Fig. 22. Surface-like structures from surface-like elements

- dense beam slabs (primarily from wooden beams, less from reinforced concrete and steel beams).

The surface-like structures shown in Fig. 20 are continuous. The lattice-like surface-structures, e.g., trussed surface-like structures are shown on Fig. 21.

Surface-like structures from surface-like elements (see Fig. 22):

- walls from wall blocks, from big board sandwich structure (plastic layer between metal plates),
- slab from reinforced concrete hollow-core slabs, or roof structures from prefabricated reinforced concrete, plastic shells elements.

4. SUMMARY

Certain types of buildings, such as the panel building or the buildings built by tunnel formwork, suggest that the building, as the sum of rooms, can be considered as a set of cells.

In this study, a cell is considered to be a finite region of space. The adjacent cells are in contact with each other along its boundary surfaces, so there is no overlapping or deficit between two boundary surfaces.

By considering the cell, especially cuboid, with a room in the building, the boundary of the cell, i.e., the sides, edges and vertices of each element of the building's supporting structure or partitioning system – walls and slabs, pillars and mast beams, pillar capitals, baseboards, and structural nodes, respectively – was corresponded.

The analogy is given for a shallow foundation:

- vertex ⇔ point foundation,
- horizontal edge ⇔ strip (or beam) foundation,
- horizontal side ⇔ slab-on-grade foundation,
- curved side ⇔ shell foundation;

and in the case of deep foundation:

- vertex ⇔ capital (e.g., between a pile and lintel),
- horizontal edge ⇔ lintel (elements of the grid system),
- vertical edge ⇔ piles or wells,
- horizontal side ⇔ head plate of the pile or well foundation, head or bottom plate of caisson or hollow box foundation,
- vertical side ⇔ slurry wall, and side wall of caisson or hollow box foundation,
- curved side ⇔ “bottom shell” (the so-called inverted arch) of caisson or hollow box foundation.

The relationship between cells and building structures for building body is as follows:

- vertex ⇔ capital or base of pillar, and node of supporting fixture,
- horizontal edge ⇔mast beam,
- vertical edge ⇔ pillars (columns),
- horizontal side ⇔ slab,
- vertical side ⇔ wall.

The following analogy can be given for the simplest roof shape (tent):

- vertex ⇔ roof peak, intersection of edges and eaves-lines,
- horizontal edge ⇔ support line of roof structure (top edge of walls),
- oblique edge ⇔ roof edge (hip),
- [horizontal side ⇔ sheet of roof slab],
- oblique side ⇔ roof (board timbering, reinforced concrete sheet),
- curved side ⇔ roof surface (curved board timbering, vault, dome, reinforced concrete shell).

The building materials and building constructions, in particular the loadbearing structures and the space-separating structures, were considered as geometric bodies and grouped according to the characteristic linear sizes. We interpreted the cross-sections of the bodies, and according to their relative proportions we introduced the concept of point-like, line-like and surface-like bodies. In the case of point-like bodies, all three linear sizes are of the same magnitude. In the case of line-like bodies, two linear sizes of cross sections are of the same magnitude, but the third one larger than the first two. In the case of surface-like bodies, two linear sizes of surface figure are also of the same magnitude, but both are larges in size than the third, the thickness.

In the study, examples were given for point-like, line-like and surface-like building materials (finished products) and building constructions. Examples were provided on how point-like, line-like and surface-like building constructions can be made from point-like, line-like and surface-like building materials (finished products).

REFERENCES

[1] B. Onouye and K. Kane, *Statics and Strength of Materials for Architecture and Building Construction*. 4th ed. Boston, Prentice Hall, 2012.

[2] N. Davies and E. Jokiniemi, *Dictionary of Architecture and Building Construction*. Amsterdam – Boston – Heidelberg, Elsevier, 2008. https://doi.org/10.4324/9780080878744.

[3] J. Joedicke, *Geschichte der Modernen Architektur*. Stutgart, Verlag Gerd Hatje, 1959.

[4] C. Siegel, *Strukturformen de Modernen Architektur*. München, Verlag Georg D. W. Caallwey, 1960.

[5] N. Gilyén, *Structure and Form in the Architecture*. Budapest, Műszaki Könyvkiadó, 1982. (In Hungarian).

[6] F.D.K. Ching, *Architecture: Form, Space, and Order*. 3rd ed. John Wiley & Sons, Inc., 2007. pp. 431.

[7] P. Silver, W. McLean, and P. Evens, *Structural Engineering for Architects: A Handbook*. London, Laurence King Publishing, 2013.

[8] J. Bajza, *Building and its Structure*. Budapest, Technical Foundation of Architecture. TERC, 2015. (In Hungarian).

[9] G. Lámer, The Relationship between Structure of the Building Constructions and Material and Numerical Methods. In *16th “Building Services, Mechanical and Building Industry Days” International Conference* 2010. (Debrecen, 2010. október hó 14–15) pp. 603–10 (In Hungarian).

[10] G. Lámer, Modelling the Structure of the Loadbearing Structure Using Cells. in *Műszaki Tudomány az Észak-kelet Magyarországi régióban. Szolnok, 2018. május hó 31. Konferencia kiadványa. Szerk.: Bodzás Sándor*. Debrecen, Debreceni Akadémiai Bizottság Műszaki Szakbizottsága, 2018. pp. 140–58 (In Hungarian).

[11] Small Encyclopaedia of Physics. Dr. Szilágyi Miklós, Ed., Műszaki Könyvkiadó. Budapest, 1977. (In Hungarian).

[12] E. Kreyszig, *Differential Geometry*. New York, Dover Publications Inc. Mineola, 1963. 1991.