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## **PRZYKŁADY ZASTOSOWANIA JĘZYKA PROGRAMOWANIA FORMIAN W KSZTAŁCENIU INŻYNIERSKIM I ARCHITEKTONICZNYM ORAZ W PRAKTYCE PROJEKTOWEJ**

*Streszczenie: W pracy przedstawiono w skrócie elementarne zasady formex algebry będące podstawą języka programowania, który służy do budowy modeli numerycznych niekiedy bardzo złożonych postaci struktur przestrzennych. Modele numeryczne mogą być definiowane w tym języku programowania za pomocą zestawu parametrów dowolnie przyjętego przez programistę, dzięki czemu modele te mogą być łatwo i szybko dostosowywane do często zmieniających się wymogów w toku całego procesu projektowania i przekształcanie oraz transportowane do innych środowisk numerycznych, w których dane struktury są następnie precyzyjnie analizowane. Zastosowanie takich modeli numerycznych znacznie usprawnia ten proces i ułatwia współpracę szczególnie między architektami oraz konstruktorami. W artykule tym autorzy przedstawiają swoje uwagi płynące z osobistych doświadczeń dotyczących nauczania i praktycznych zastosowań języka programowania Formian w Japonii i w Polsce.*

## **EXAMPLES OF APPLICATION OF PROGRAMMING LANGUAGE FORMIAN IN ENGINEERING AND ARCHITECTONIC EDUCATION AND IN PROFESSIONAL DESIGN**

*Abstract: In the paper there are briefly presented the elementary principles of formex algebra being the basis of the programming language Formian, which is applied for creating numerical models of sometimes very complex shapes of the space structures. The numerical models can be defined in this language by means of suitably sets of parameters suitably selected by a programmer, due to which these models can be easy and fast adapted to various requirements often changed during the design process. Moreover they can be transformed and transmitted to various types of software, which are suitable for the comprehensive analyses of the designed structures. Application of these type of numerical models makes the design process more effective and moreover makes easier the cooperation between architects and engineers. In the paper there are spoken remarks being results of experiences of both the authors in teaching of the programming language Formian and its practical application in Japan and in Poland.*

*Słowa kluczowe: język programowania Formian, kształcenie inżynierskie*  
*Keywords: programming language Formian, engineering education*

## 1. INTRODUCTION

Many years ago the both authors met together in the Space Structures Research Centre at the University of Surrey in UK, where the programming language Formian was invented by Prof. Hoshyar Nooshin and his team [1,2,3]. Each author gives lectures about Formian for students at their universities, the one in Japan and in the second one in Poland. Both the authors have co-operated also together during visit of Prof. K. Ishikawa at the Cracow University of Technology in beginning of October 2014, Fig. 1. In this period members of the BIM Student Scientific Circle of Numerical Design of Architectonic Structures, tutored by Prof. J. Rębielak, have had opportunity to study more carefully some specific functions of Formian.



Fig. 1. a) Professor K. Ishikawa during lecture given to students of Faculty of Architecture at Cracow University of Technology, b) both the authors during seminars with students in Cracow in the Laboratory of Numerical Modeling of Space Structures in Integrated Environment of BIM

## 2. BASIC RULES OF FORMEX ALGEBRA AND FORMIAN

*Formex algebra* has been invented for precise description of components in spaces of sometimes very complex structures and it is considered as a mathematical system especially suited for configuration processing. The programming language Formian is an interactive tool, which is a convenient medium for configuration processing by usage of *formex algebra*.

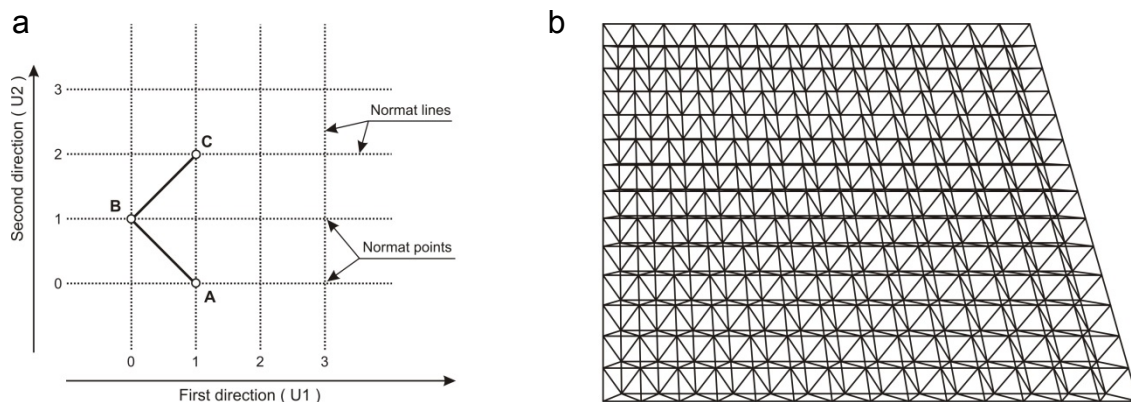


Fig. 2. a) Example of simple reference system applied in *formex algebra* for defining geometrical composition in space of a structure, b) shape of a double-layer space structure „square-on-square” determined by a numerical model defined in the programming language Formian

For instance position of node A, see Fig. 1a, in the two-dimensional space is described as:  $[1,0]$ . Member located between nodes A and B is defined as:  $[1,0;0,1]$ . The set of two members called ABC is defined as follows:

$$ABC = \{[1,0;0,1],[0,1;1,2]\};$$

First, second and third direction (U1, U2 and U3) are mostly compatible with the configuration of axes X, Y and Z in the Cartesian coordinate system. Comprehensive description of the all necessary basic rules and functions of Formian one can find e.g. in books [1, 4]. By means of them it is very easy do define numerical model of simple form of the “square-on-square” space frame, flat form of which is shown in Fig. 2b.

### 3. NUMERICAL MODEL OF SPHERICAL FORM OF SPECIFIC TYPE OF CRYSTAL SPACE STRUCTURE

Double-layer space frame created by members of the same length, which solid system consists of a tetrahedron and an octahedron, is mostly called the crystal structure. Due to big stiffness it is applied as the support structure for the double-layer lattice domes. In these cases the design processes are complicated including preparation of initial conceptual drawings. It was especially important during concept design of specific cover shaped by means of a spherical space structure, the inner the dome useful area of whose could have advantageous conditions of diffused lighting by daylight, see Fig. 3a [4, 5]. In the past process of making these drawings was toilsome and took a lot of time. Graphical presentation of structural configuration of the above mentioned dome cover is relatively very easy and considerably faster to be prepared by application of numerical model of that structure defined in programming language Formian by means of ProgramA, which is presented below.

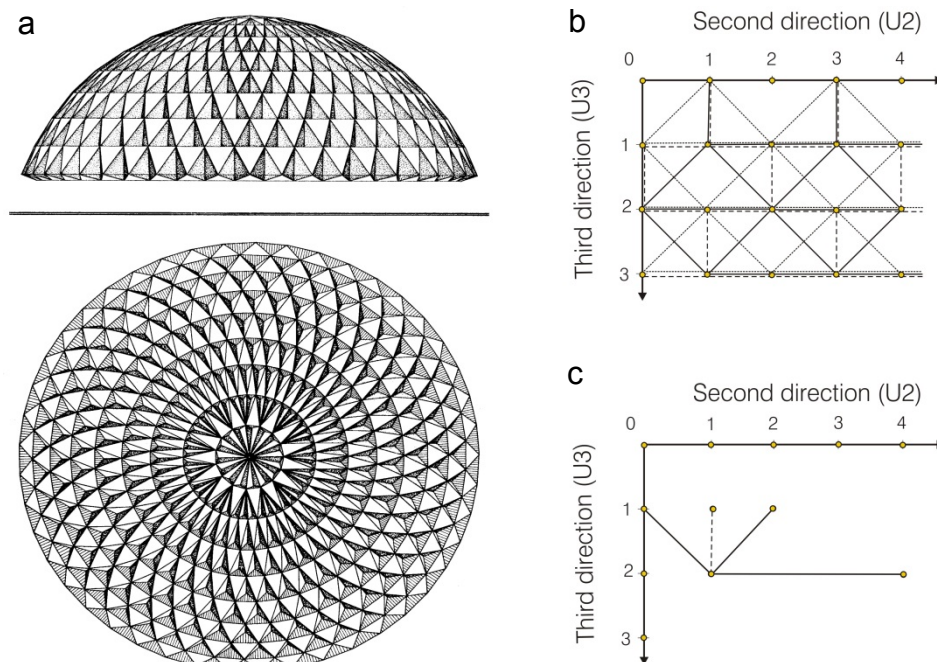


Fig. 3. a) Schemes of the architectonic view of the special spherical form of the double-layer crystal space structure, b) arrangement of component parts of flat form of the structure for the needs of preparation of ProgramA, c) arrangement of members located in the boundary, support area of the structure

The arrangement of component parts of this type of the transformed spherical form of the crystal space frame, taken into account during the preparation process of ProgramA, is shown in Fig. 3b and in Fig. 3c. The whole program is rather simple, short and it enables to create numerical models of various density of subdivisions and various rises of the dome covers. Graphical result of execution of this program is presented in Fig. 4.

### ProgramA

```

n=8;(*)Even subdivisions in the third direction U3(*)
m=38;(*)Subdivisions in the second direction U2(*)
R=18;(*)Sphere radius for the upper layer(*)
PPZ=[R,0,0;R-1,0,0];(*)Vertical post(*)
PZW=rin(2,m,2)|{[R,1,0;R,1,1],[R-1,0,0;R,1,1],[R,1,1;R-1,2,0
P1=lam(2,1)|{[R-1,0,1;R,1,1],[R,0,2;R,1,1],[R-1,0,1;R,0,2],[R,0,2;R-1,1,2],
[R-1,0,1;R-1,1,2]};(*)Modular bar set for the horizontal Band1(*)
P2={[R-1,0,1;R-1,2,1],[R,1,1;R,3,1],[R,0,2;R,2,2],[R-1,1,2;R-1,3,2
PP1=P1#P2;
np=n+1;
n2=np/2;
Band1=rinit(m,n/2,2,2)|PP1;
DDA=tran(2,1)|tran(3,1)|PP1;
Band2=rinit(m,n/2,2,2)|DDA;
EndRing=tran(2,1)|tran(3,n)|rin(2,m,2)|{[R,0,1;R,1,2],[R,1,2;R,2,1],
[R-1,1,1;R,1,2],[R,1,2;R,3,2]};
StrA=pex|PPZ#PZW#Band1#Band2#EndRing;
SX1C=bt(1,0.5,3)|StrA;
DomeCRYS=bs(1,360/m,16/n)|SX1C;
use&,vt(2),vm(2),c(1,1),vh(-200,-300,-520,0,0,0,0,0,1);
draw DomeCRYS; (*)see Fig. 4.(*).

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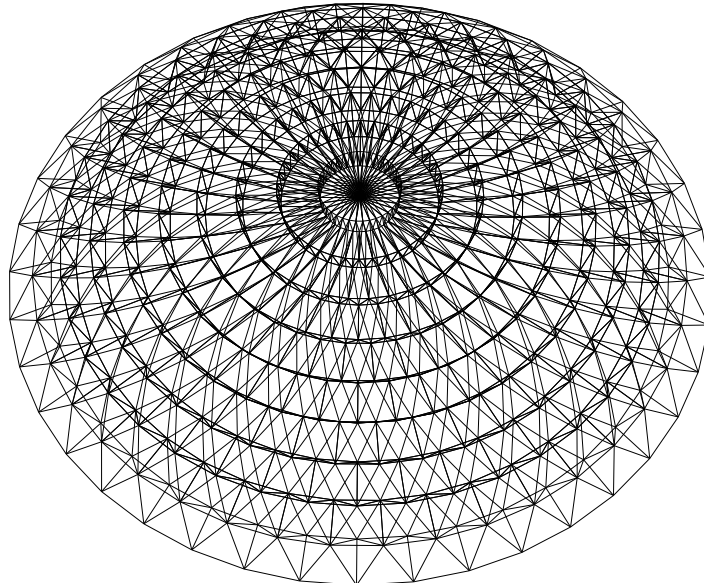


Fig. 4. Visualization of a special spherical form of the double-layer crystal space structure obtained as the result of execution of ProgramA

The spherical form of the double-layer crystal space structure shown in Fig. 4 has been subjected to some transformations carried out in order to obtain a lightweight structural system for dome covers of large spans, which at the same time can have very small rise of the cover, like for instance system of the cable domes [6]. The transformations have been done in a few stages and results of them are presented in Fig. 5. In the first stage of these transformations, the statuses of selected components were changed. After these transformations only the cross braces of the tension-strut triangular trusses, parallel to the perimeter ring, remain as rigid members. Then a suitable reduction of the number of the tension members was made and finally the way of the pre-stressing was defined. The basic structural configuration of the crystal tension-strut structure obtained in this way is presented in Fig. 5a. It can be subjected to further transformations the point of which is to remove appropriate members located in the upper layer and being parts of the concentric hoops and in Fig. 5a indicated by symbol  $U_{rc}$ . The exemplary form of the crystal tension-strut structure with a reduced number of members in the upper layer is presented Fig. 5b.

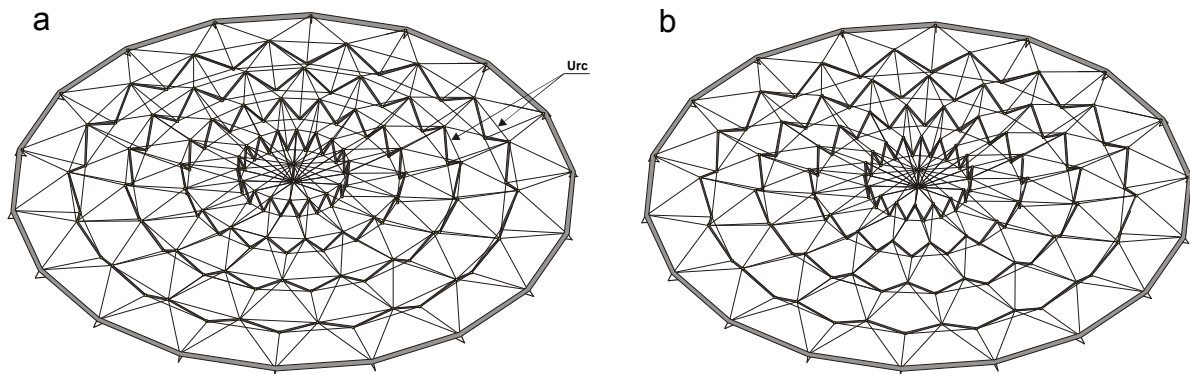


Fig. 5. Schemes of the crystal tension-strut structure; a) of the basic form, b) of the reduced number of tension members in the upper layer

Geodesic domes, invented by W. Bauersfeld and popularized by R.B. Fuller, are the very economic, efficient and spectacular forms of the roof covers designed and constructed as spatial forms of truss systems [7]. They are characterized by some advantageous features but they are of very complex geometrical configuration of components. Special functions of Formian like the *polymation function* and the *tractation function* make the design process of the complex form of geodesic domes forms, compare Fig. 6, relatively simple and fast [4].

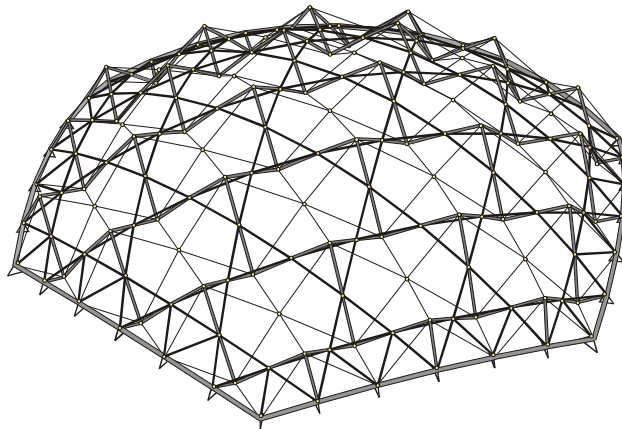


Fig. 6. Example of spherical form of the VA(TH)No2 tension-strut structure

#### 4. NUMERICAL MODEL OF PLANE AND CYLINDRICAL FORM OF SPECIFIC TYPE OF WALL AND ROOF SPACE STRUCTURE

Since earthquake resistance standards in Japan were improved, buildings which were designed on the basis of old seismic standards before 1981 need to be reinforced quickly on the basis of the exiting new ones. The aluminium braces are useful for seismic retrofitting of existing buildings, because it achieves good workability in erection site and reduces the seismic loading and additional loads on the foundations due to their light weight and aluminium alloy members owe their long-term corrosion resistance. Figure 7 shows the double-layer truss wall and roof made of aluminium alloy truss system. The wall resists in-plane shearing load in an earthquake [8]. Figure 7a is a computer graphical image of the seismic retrofit of the reinforced concrete school building using the aluminium truss system.

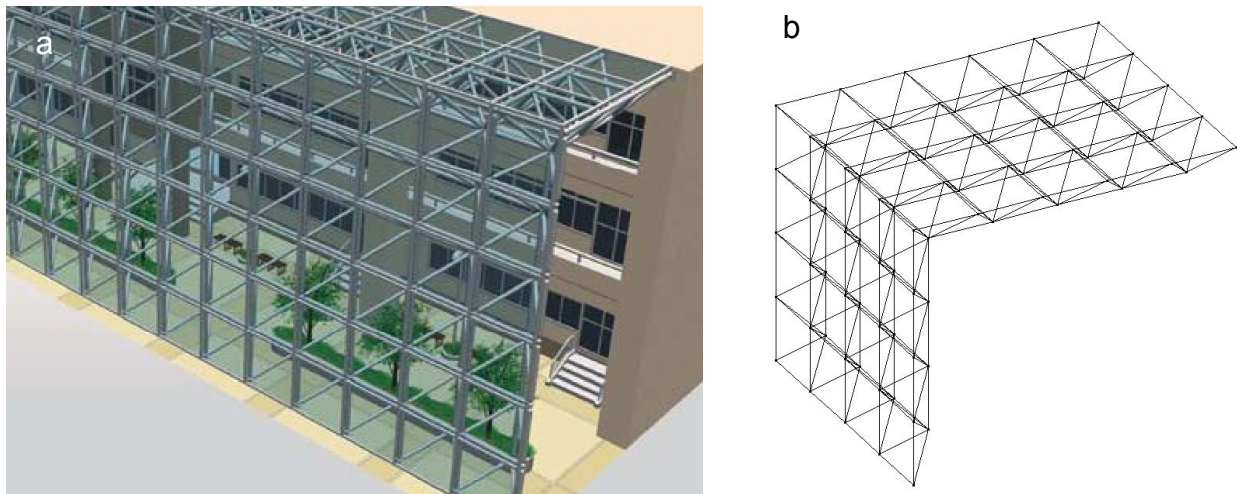


Fig. 7. a) An example of the computer graphical image using the space frame connected with the reinforced concrete building, b) visualization of a special flat plate type space frame form of the double-layer roof and wall obtained as the result of execution of Program B

It is used as a aseismic reinforcing method for existing buildings using the double-layer truss wall and the roof structure. The graphical presentation of the structural configuration, as shown in Fig. 7b of the above mentioned plane truss, is practically created by the application of a model of that structure defined in programming language Formian by means of Program B, presented below.

##### Program B

```

l = 800;      (*) Span(u1)  (*)
d = 1000;    (*) Span(u2)  (*)
h = 800;     (*) Span(u3)  (*)
i = 4;       (*) Units(u1) (*)
j = 5;       (*) Units(u2) (*)
k = 4;       (*) Units(u3) (*)
(*) Member1n=[96;78]; (*)
(*) Member2n=[96;86]; (*)
use tol(0.00001);
E1=bt(1/2/i,d/2/j,h/2/k)|pex|(rinid(i,j+1,2,2)|[0,0,2*k;2,0,2*k]
#rinid(i+1,j,2,2)|[0,0,2*k;0,2,2*k]);
E2=bt(1/2/i,d/2/j,h/2/k)|pex|rinid(i,j,2,2)|rosad(1,1)|[0,0,2*k;1,1,2*k-1];

```

```

E3=bt(1/2/i,d/2/j,h/2/k)|pex|(rinid(i-1,j,2,2)|[1,1,2*k-1;3,1,2*k-1]
#rinid(i,j-1,2,2)|[1,1,2*k-1;1,3,2*k-1]);
E4=E1#E2#E3;
Lean=E4#F4;
(*) Member1=red(Leanj)|Member1n; (*)
(*) Member2=red(Leanj)|Member2n; (*)
use c(1,1),lw(0.3),vm(3),vt(1),
vz(-100,0,0,1000,700,1000),vh(20,-40,80,0,0,0,0,1);
clear;
draw Lean;

```

Figure 8 shows cylindrical walls and roofs made of an aluminium alloy truss system. Figure 8a is a picture of the space frame structure at a square constructed in Japan.

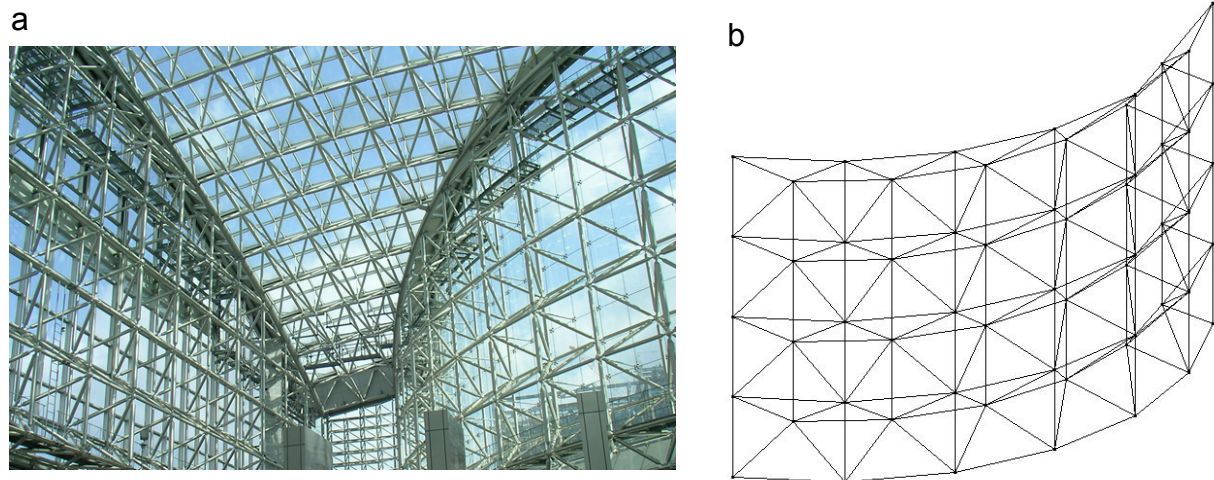


Fig. 8. a) An example of the realized space structure using the cylindrical wall and roof, b) visualization of a space frame form of the double-layer wall obtained as the result of execution of Program C

The graphical presentation of the structural configuration, as shown in Fig. 8b of the above mentioned cylindrical truss wall, is conveniently created by the application of a model of that structure defined in programming language Formian by means of Program C, presented below.

### Program C

```

l=12;
h=7.2;
m=6;
n=4;
t=0.9;
a1=50;
r1=l/2/sin(a1);
r2=r1-t;
E1=pex|rinid(m,n,2,2)|rosad(1,1,4)|{[0,0,1;2,0,1],[0,0,1;1,1,0]}
#rinid(m-1,n-1,2,2)|{[1,1,0;3,1,0],[1,1,0;1,3,0]}
#rin(1,m-1,2)|[1,2*n-1,0;3,2*n-1,0]
#rin(2,n-1,2)|[2*m-1,1,0;2*m-1,3,0];

```

```

F1=ram(sed(1,2))|E1;
G1=dic(F1)|E1;
E3=lam(1,0)|rosas(0,0,m/2,2*a1/m)|
    [0,0,r1;-r1*sin|(2*a1/m),0,r1*cos|(2*a1/m)];
E4=pex|rin(2,n+1,h/n)|E3;
E5=lam(1,0)|rosas(0,0,m/2,2*a1/m)|
    [-r2*sin|(a1/m),h/2/n,r2*cos|(a1/m);r2*sin|(a1/m),h/2/n,r2*cos|(a1/m)];
E6=pex|rin(2,n,h/n)|E5;
E7=pex|E4#E6;
F2=ram(sed(1,2))|E7;
Wall=red(F2)|G1;
use vm(2),vt(1),vh(1.5,2,3,0,0,0,1,0);
clear;
draw Wall;

```

## 5. CONCLUSIONS

Numerical models can be defined in Formian by means of assumed sets of almost optional parameters what further enables the fluent changes of geometry of the structure at any stage of the design process. Formian is intended as a very efficient tool for making the design processes easier and faster, also to facilitate the co-operation between architects, civil engineers and other designers involved in the project. The visualization of even a very complex form of the structural system is relatively simple by application of this programming language. The numeric data generated by means of Formian can be easily submitted as an input to selected analysis packages in order to carry out the comprehensive structural analyses and for preparation the graphical visualization of the designed structural systems.

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