Transactions on Information and Communications Technologies vol 5, © 1993 WIT Press, www.witpress.com, ISSN 1743-3517

Formex configuration processing

D. Hadker, D. Tzourmakliotou

Space Structures Research Centre, Department of Civil Engineering, Univeristy of Surrey, Guildford, Surrey GU2 5XH, UK

ABSTRACT

Remarkable advances in computer aided design, have made it possible to have effective techniques for organisation of graphics as well as data generation. In particular, the fields of architecture and structural engineering may greatly benefit from the concepts of formex algebra which is a mathematical system providing a convenient basis for generating and modifying configurations. Formian is the programming language of formex algebra which handles problems of data generation and computer graphics with ease and elegance.

The concepts of formex algebra have found applications in many disciplines. However, this paper describes some of the basic concepts of formex algebra in relation to a variety of space structures. Some composite transformations have been illustrated in the paper, that allow the creation and manipulation of a number of families of surfaces used for representing membranes, pneumatic structures and lattice shells.

The paper concludes by describing a convenient technique for projecting patterns on various surfaces such as spheres, ellipsoids and hyperbolic paraboloids. Also, a function is described for evolving configurations based on polyhedra. This function constitutes the kernel of the problem handling strategy for visualisation and generation of data for geodesic domes.

INTRODUCTION

In the fields of architecture and structural engineering, advancements in computer aided techniques have made it possible to design and realise more and more complicated structural forms. Especially, in the field of space structures, the role of computers for visualisation, design and analysis is becoming indispensable. The term "space structures" in this context, refers to three dimensional systems such as spaceframes as used for single and double layer grids, vaults and domes, tension structures such as prestressed cable nets and membranes, pneumatic structures and hybrid space structures.

The concepts of formex algebra and its associated programming language Formian provide a convenient tool not only for computer graphics, but also for generating data for analyzing space structures. The rudimentary ideas from which formex algebra has emerged were evolved in the early seventies. These concepts were published in 1975, Nooshin [1]. The first textbook giving a comprehensive account of the current ideas on the subject was published in 1984, Nooshin [2].

FORMEX CONFIGURATION PROCESSING

In a very broad sense, the term "configuration" is used to mean an "arrangement of objects". Although the term configuration has been used in this context to refer to assemblies of structural elements, in general, even parts that form an electrical network or a finite element idealisation of a solid medium may be regarded as a configuration. The most common usage of the term configuration is in reference to a geometric composition consisting of points and/or lines and/or surfaces. Such geometric composition may itself be the subject of study or it may represent another arrangement of objects. When digital computers are involved, the internal representation of configurations is in terms of numerical models. The term "configuration processing" is used to mean "creation and manipulation of numerical models representing configurations".

Some examples of space structure configurations commonly encountered by architects and engineers, are shown in Fig 1. Graphical visualisation of these structures and preparation of data for their analysis are very important requirements in the design process. The analysis requires information regarding various aspects of the structural system including the elements of the structure, the positions of supports, the nature of loads and the manner in which the elements are connected together.

THE BASIC APPROACH

To begin with, consider the dome shaped configuration in Fig 2. Let it be required to generate data for the

Transactions on Information and Communications Technologies vol 5, © 1993 WIT Press, www.witpress.com, ISSN 1743-3517

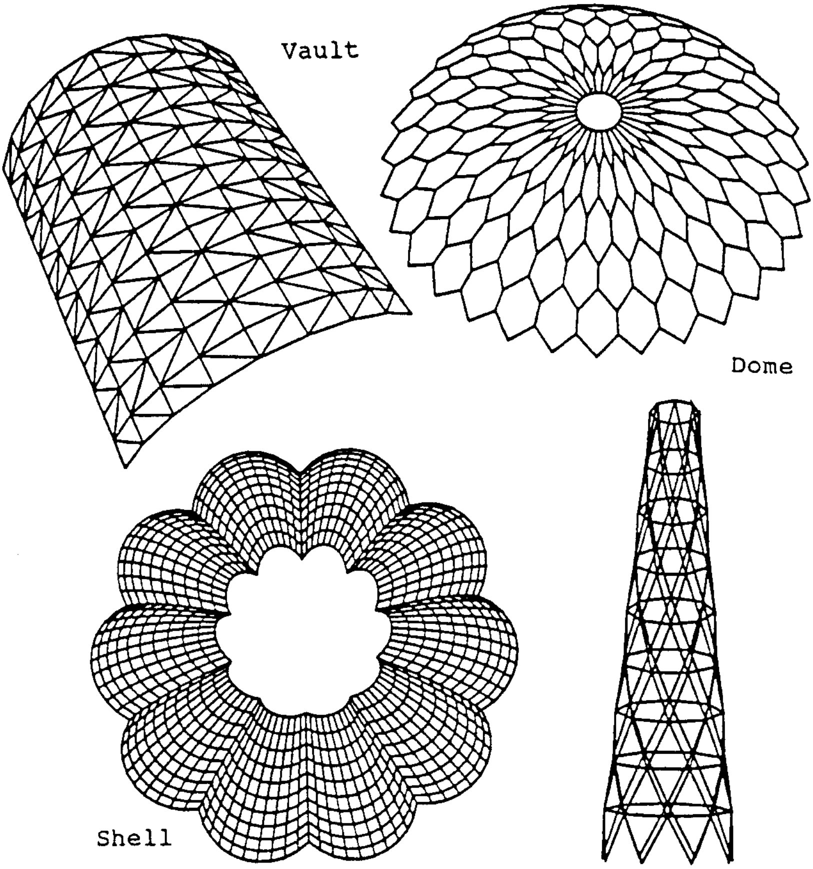


Fig. 1

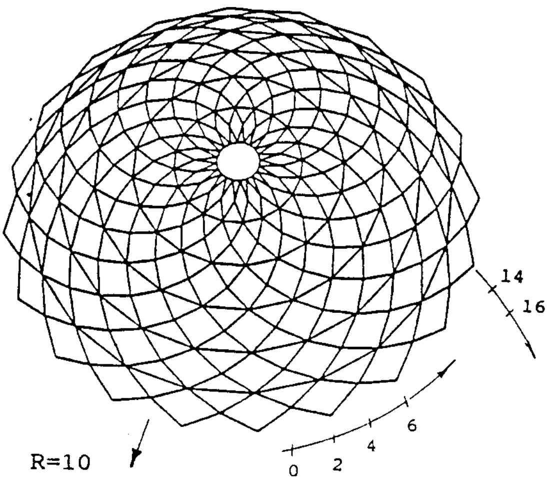


Fig. 2

analysis of this structure. The configuration may be described with the help of a formex formulation in a few lines of text as shown below

```
E1=[10,1,1; 10,3,1]#ROSAT(1,2)|[10,0,2; 10,1,3]
E2=RINIT(20,6,2,2)|E1
```

The entities E1 and E2 are referred to as "formices". A "formex" (singular) is a mathematical entity which may be used to represent a configuration. A reader encountering the above formices for the first time, is bound to find it a little confusing but once the basic principles of formex algebra are understood, the formex approach is found to be a simple way of describing a configuration.

To explain the above formulations, one may begin by describing formex E1 which represents only a small part of the configuration. The dome is formulated with respect to a suitable reference system shown in Fig 2. The radius of the dome R, is taken as 10. The construct [10,1,1; 10,3,1] represents the horizontal member near the crown of the dome and the construct [10,0,2; 10,1,3] represents the diagonal member. The "function" ROSAT implies rotational replication. This function effectively, creates a rotational replication of the diagonal member with the centre of rotation given by (1,2) to create the diamond shaped pattern. The entire configuration is generated by repeating the horizontal member and the diamond shaped pattern using another formex function. The function RINIT(20,6,2,2) is used to imply 20 replicational translations in the second direction and 6 in the third, with a step of 2 units in each direction as represented by formex E2.

The configuration may also be described relative to the x-y-z coordinate system. Such a transformation may be achieved through standard equations that relate Cartesian and spherical coordinates. This is obtained through formex E3 where

```
E3=BS(1,9,4)|E2
```

The function BS(1,9,4) is referred to as a "retronormic function" or simply as "retronorm". The general form of this function may be written as BS(b1,b2,b3) where BS stands for the "basispherical" retronorm and b1, b2, b3 are scale factors relating, respectively, to the first, second and third directions of the reference system.

In most design procedures it is often necessary to generate a number of shapes before arriving at a satisfactory configuration. By changing the scale

Transactions on Information and Communications Technologies vol 5, © 1993 WIT Press, www.witpress.com, ISSN 1743-3517

factors, one can achieve this with ease and convenience. To show the effects of changes in the scale factors, the plots of formices

E4=BS(1,9,7)|E2

and

E5=BS(1,9,2)|E2

are shown in Figs 3 and 4 respectively.

When using Formian, the formex formulation representing a configuration is typed in through a keyboard and the result is obtained as a graphical output through the VDU and/or a plotter. Formian has a number of constructs through which images may be created on the graphical output media. Depending on the viewing requirements, plans, elevations and perspective views may be obtained using different viewing specifications available in Formian, Nooshin and Disney [3]. The advantage of using the formex approach is that the same information can be used as input data for a structural analysis package.

The process of data generation is aided by a number of formex functions. Although the scope of the present paper does not allow the detailed description of all formex functions, an elaborate explanation is available in Nooshin and Disney [3]. However, some functions such as the cardinal and tendial functions which are in constant use have been described in the sequel. Cardinal functions have been described in Table 1. A brief description of each cardinal function is accompanied by a sketch showing the effects obtained by using the function.

Tendial functions are commonly used combinations of cardinal functions. For example, in formex E2, a tendial rindle function was used where

E2=RINIT(20,6,2,2)|E1

was used instead of writing

E2=RIN(3,6,2)|RIN(2,20,2)|E1

The suffix IT implies double action in the second and third directions. The suffix ID is used to imply double action in the first and second directions and the suffix IS is used to imply double action in the first and third directions.

Transactions on Information and Communications Technologies vol 5, © 1993 WIT Press, www.witpress.com, ISSN 1743-3517

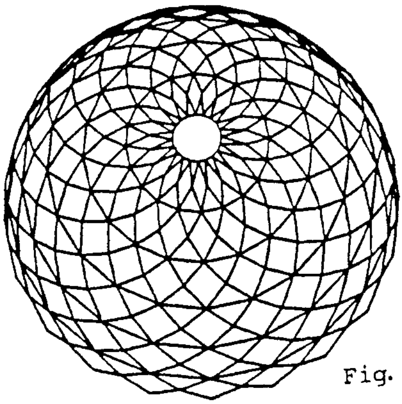


Fig. 3

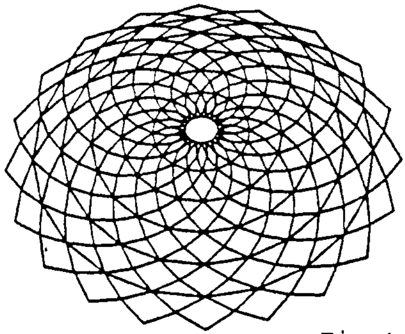


Fig. 4

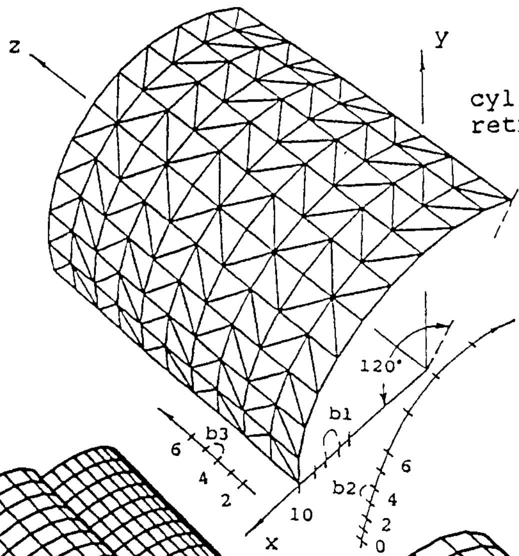


Fig. 5

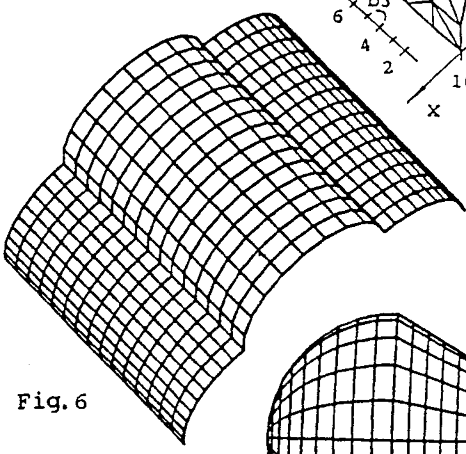


Fig. 6

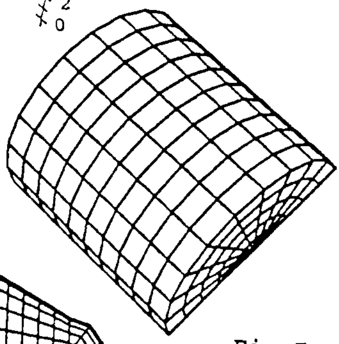


Fig. 7

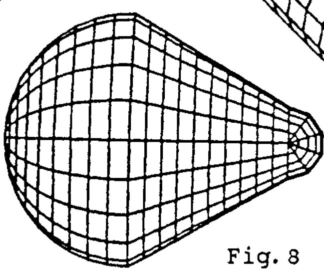
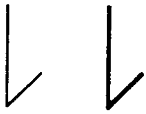
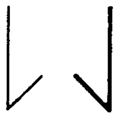
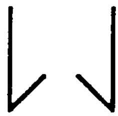
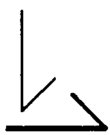
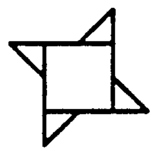
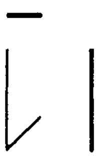


Fig. 8

Transactions on Information and Communications Technologies vol 5, © 1993 WIT Press, www.witpress.com, ISSN 1743-3517

TABLE 1 : CARDINAL FUNCTIONS

TRANSLATION G=TRAN(h,q)|E h gives direction of translation q gives amount of translation 	RINDLE G=RIN(h,s,p)|E h gives direction of replication s gives number of replications p gives amount of replications 
REFLECTION G=REF(h,q)|E h gives direction of reflection q gives position of the plane of reflection 	LAMBDA G=LAM(h,q)|E h gives direction of reflection q gives position of the plane of reflection 
VERTITION G=VER(h1,h2,q1,q2)|e h1 and h2 define the plane of rotation q1 and q2 give coordinates of the centre of rotation 	ROSETTE G=ROS(h1,h2,q1,q2)|E h1,h2 directions define plane of rotation q1,q2 give coordinates of the centre of rotation 
PROJECTION G=PROJ(h,q)|E h gives direction of projection q gives position of the plane of projection 	DILATATION G=DIL(h,q)|E h gives dilatation q gives factor of dilatation 

Transactions on Information and Communications Technologies vol 5, © 1993 WIT Press, www.witpress.com, ISSN 1743-3517

In the formulation for the dome of Fig 2, constructs were combined using an "operator". The symbol # is an operator, referred to as a "duplus symbol" which effectively combines two or more constructs or formices.

STANDARD RETRONORMS

Standard retronorms are the ones which are already available in Formian. The basispherical retronorm was discussed in the earlier sections of the paper and the "basicylindrical" retronorm is shown in Fig 5, along with a cylindrical reference system. A formex formulation for this configuration may be written as

```
D1=[10,0,0;10,2,2]#ROSAT(1,1)|[10,2,2;10,2,0]
D2=PEX|RIN(3,5,4)|LAMIT(2,10)|RIN(2,5,2)|D1
```

In the process of representing the configuration, a number of extra elements are created. Although these may not be visible in the graphical output, it is very important to eliminate them to avoid problems in the analysis of the configuration. In order to overcome this problem, the formex function PEX is used, which stands for "pexum". The function has the effect of eliminating the doubly represented members.

Formex D2 represents the whole configuration relative to the cylindrical reference system. The same configuration may be written in terms of the x-y-z coordinate system using the relation,

```
D=BC(1,120/20,1)|D2
```

The function BC stands for the "basicylindrical retronorm". The general form of the retronorm may be written as BC(b1,b2,b3), where b1, b2 and b3 are scale factors.

The retronormic functions whose names begin with "basi" imply simple scaling. There are certain retronormic functions whose names begin with "metri" and imply accelerated and decelerated scaling in accordance with a rule based on geometric progression, Nooshin [2].

Using standard retronorms, segments of basic surfaces such as spheres, cylinders and cones may be combined to generate more complex forms. Some examples of configurations obtained using combinations of parts of surfaces obtained from cylindrical and spherical retronorms are shown in Figs 6 to 8.

A number of possibilities arise when more than

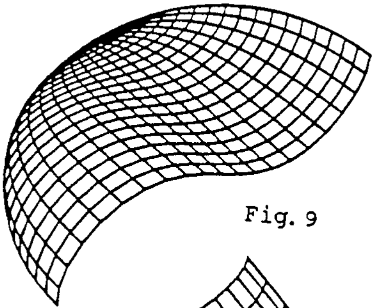


Fig. 9

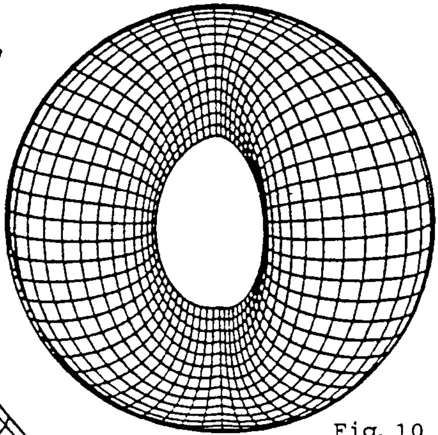


Fig. 10

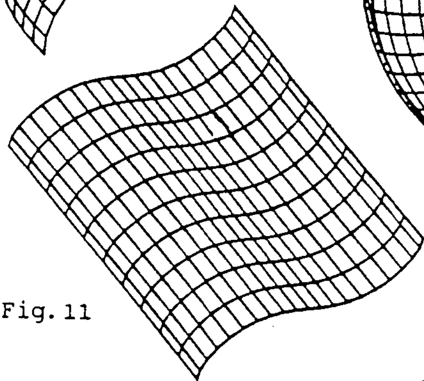
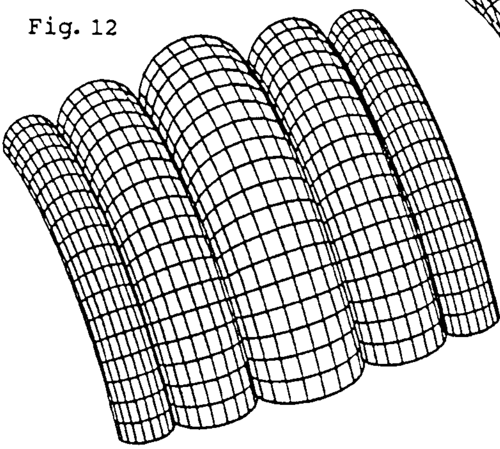


Fig. 11

Fig. 12



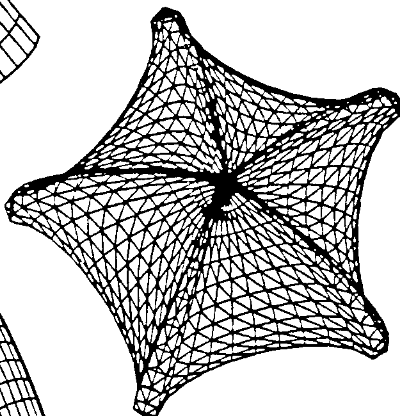
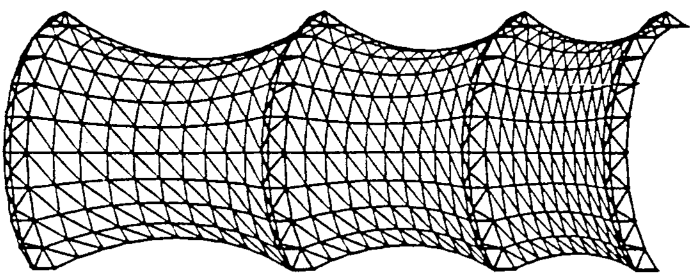


Fig. 13

Fig. 14



one type of retronormic transformation is used. For instance, one may use a composite transformation consisting of cylindrical and spherical transformations by writing

BC(1,5,1)|BS(1,6,3)

to obtain the configuration in Fig 9. Also, the constructs,

BS(1,6,3)|TRAN(1,15)|BC(1,4,1)

and

BC(1,4,1.5)|BC(1,9,1.5)

will give rise to the configurations in Figs 10 and 11 respectively. The formex which is plotted is given by

F=RINIT(m,n,1,1)|[10,0,1; 10,0,2; 10,1,2; 10,1,1]

with the values for m and n varying from case to case.

Similar composite transformations have been used to create a configuration suitable for a pneumatic structure shown in Fig 12. Figs 13 and 14 show configurations for hybrid space structures which are combinations of spaceframes and membranes, generated with the help of composite transformations.

SUPPLEMENTARY RETRONORM

During the process of data generation, a "supplementary retronorm" may be introduced through a program segment which is supplied by the user in order to use a non-standard retronorm. This program segment is linked to the body of the Formian Interpreter.

The "tractation retronorm" is a supplementary retronorm which enables configurations to be projected on different types of surfaces like spheres, ellipsoids, paraboloids, hyperbolic paraboloids, planes and cylinders.

The tractation retronorm is of the general form

TRAC(P1,P2,...,Pn)

where TRAC stands for "tractation" and P1, P2,..., Pn are parameters which describe the types of surface(s) and projection(s) to be used. If E is a formex that represents a configuration then a formex F representing the projection of the configuration on the specified surface(s) is given by an equation of

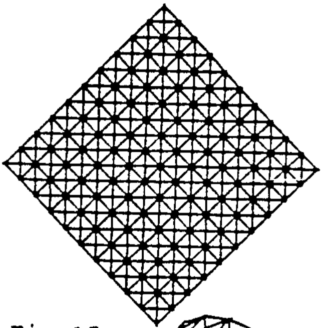


Fig. 15

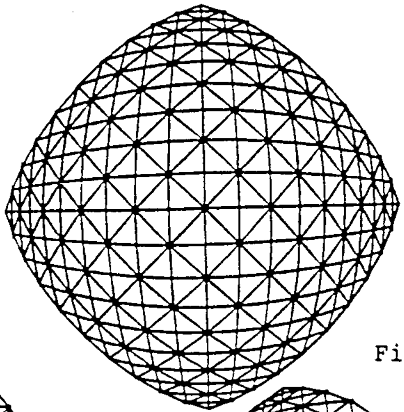


Fig. 16

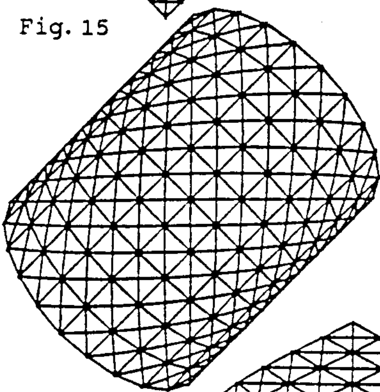


Fig. 17

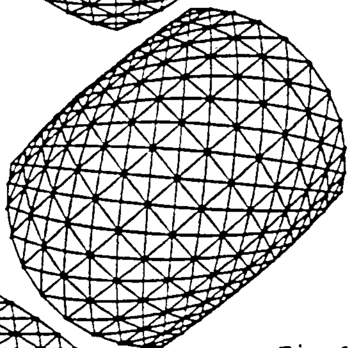


Fig. 18

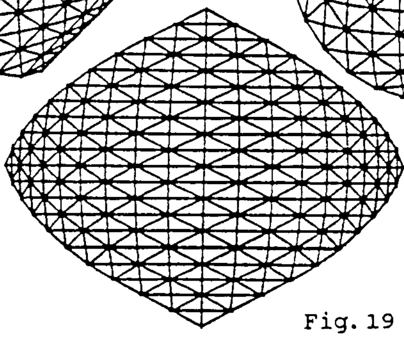


Fig. 19

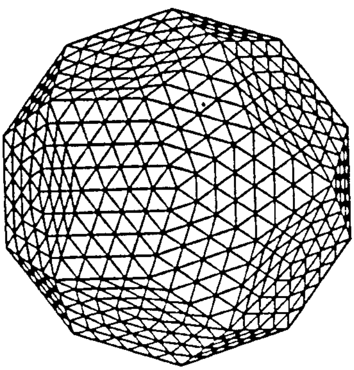


Fig. 20

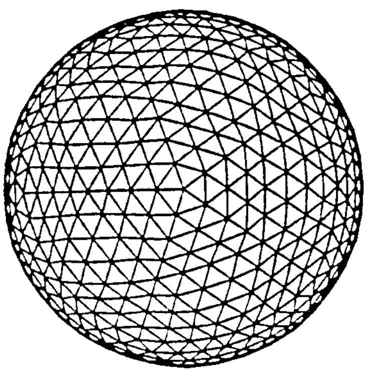


Fig. 21

the form

F=TRAC(P1,P2,...,Pn)|E

Some results obtained by applying the tractation retronorm are shown in Figs 16 to 19. Fig 15 shows the flat grid pattern which is projected on different types of surfaces using different types of projections. Figs 16, 17 and 18 show central projections of the grid on spherical, cylindrical and ellipsoidal surfaces, respectively. Fig 19 shows an axial projection of the same grid on a spherical surface.

POLYHEDRON FUNCTION

Consider a polyhedron and let its faces be replaced by a given configuration. The result is referred to as a "polyhedric" configuration. This term may also be used to refer to a portion of a polyhedric configuration.

There is a formex function called "polyhedron" function that can be used to create formices representing polyhedric configurations. If E is a formex representing the configurations that are to replace the faces of a polyhedron, the construct of the form

F=POL(P1,P2,...,Pn)|E

can be used to obtain the formex F representing the required configuration. The construct

POL(P1,P2,...,Pn)

is the "polyhedron" function, where POL stands for polyhedron and where P1, P2,..., Pr are parameters specifying the type of polyhedron, the radius of the circumsphere for each layer involved, ... , etc.

To exemplify the use of the polyhedron function, let the configuration in Fig 22 be the plot of a formex. Suppose that it is required to produce a polyhedric configuration by replacing the top four faces of a tetrahedron by the configuration of Fig 22. The polyhedron function may be used to create the formex that represents the required configuration and the plot of the formex will be as shown in Fig 23. Moreover, a similar operation applied to the top part of an octahedron produces the plot shown in Fig 24. Using the same configuration on the top half of an icosahedron produces the plot shown in Fig 25.

Transactions on Information and Communications Technologies vol 5, © 1993 WIT Press, www.witpress.com, ISSN 1743-3517

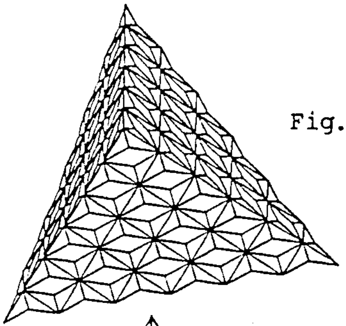


Fig. 23

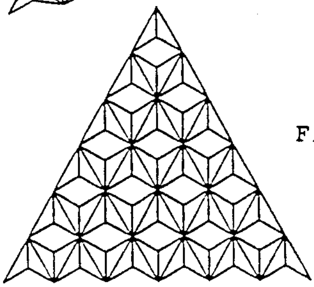


Fig. 22

Fig. 24

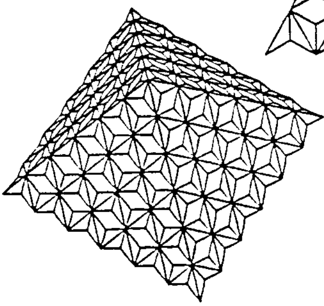
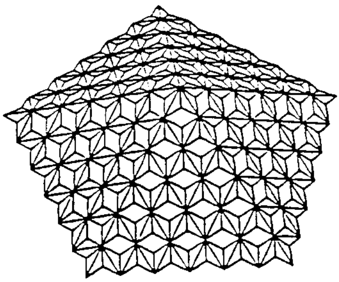


Fig. 25



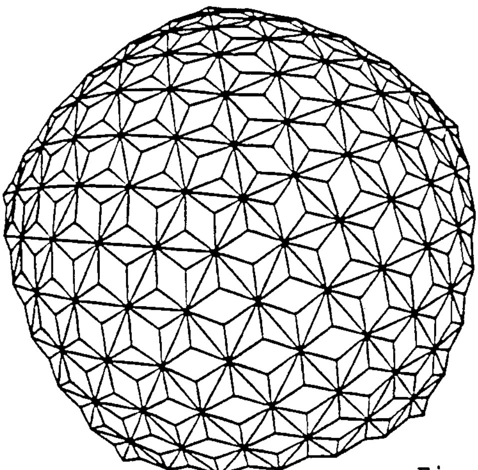


Fig. 26

If the configuration to replace the top faces of the three polyhedra is as shown in Fig 27, then the repetition of the above operations will result in the configurations shown in Figs 28 to 30.

So far, polyhedric configurations based on Platonic polyhedra have been shown. However, the configuration represented in Fig 20 is based on an Archimedean polyhedron, the icosidodecahedron.

CREATION OF GEODESIC DOMES

The combination of polyhedron function and the tractation retronorm can be used to produce a wide variety of geodesic forms. The procedure is simple. To begin with, the polyhedron function is used to create a formex representing the projection of the polyhedric configuration on a suitable surface. The above procedure has been used to produce the configurations shown in Figs 21, 26 and 31. These are based on the polyhedric configurations of Figs 20, 25 and 30 respectively. The projection surfaces are spherical and the projection type is radial.

CONCLUDING REMARKS

The material presented in the paper only covers a small subset of the concepts of formex algebra but aims at providing an appreciation of the basic principals. In practice, these concepts are used in conjunction with Formian which is a suitable computing software and a description of this is given in, Disney [5].

The concepts of formex algebra compliment the human imagination and allow mentally visualised configurations to be expressed in terms of concise numerical models. This aides in creating a versatile medium for communication between people in data generation and computer graphics.

Formex algebra, like other mathematical systems grows like a living entity in response to practical needs. It is anticipated that many new pioneers will join the present research workers to explore the exciting new possibilities that present themselves through the concepts of formex algebra.

Transactions on Information and Communications Technologies vol 5, © 1993 WIT Press, www.witpress.com, ISSN 1743-3517

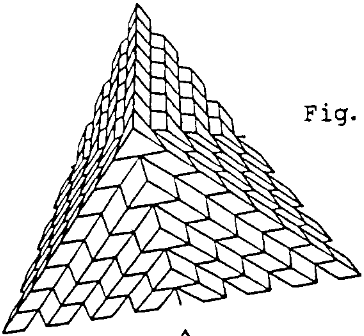


Fig. 28

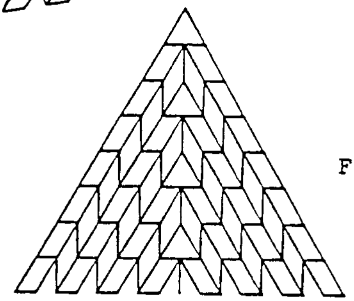


Fig. 27

Fig. 29

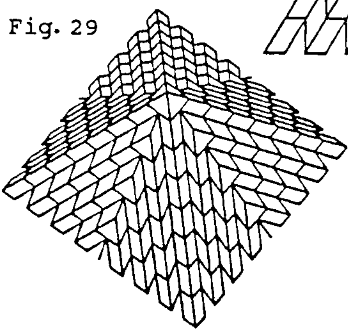
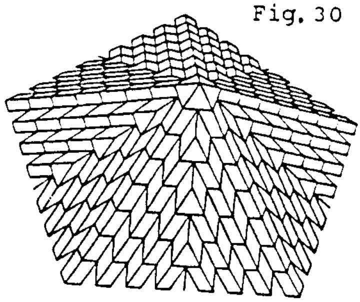


Fig. 30



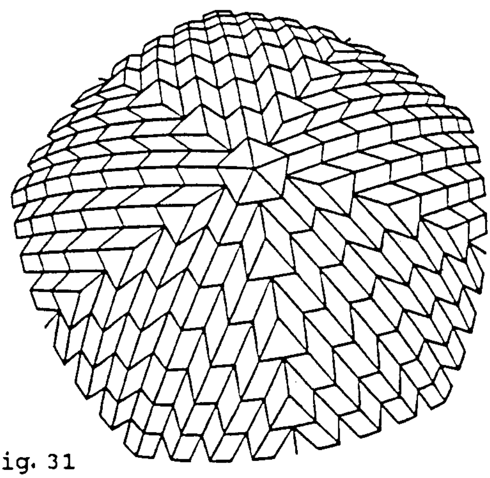


Fig. 31

REFERENCES

1. Nooshin, H. "Algebraic Representation and Processing of Structural Configurations", *International Journal of Computers and Structures*, Vol. 1, pp. 119-130, London 1975.

2. Nooshin, H. "*Formex Configuration Processing in Structural Engineering*", Elsevier Applied Science Publishers, London 1984.

3. Nooshin, H. and Disney, P. "Elements of Formian", *International Journal of Computers and Structures*", Vol. 41, No 6, pp. 1183-1215, London 1991.

4. Nooshin, H., Disney, P., Hadker, D. and Tzourmakliotou, D. "Some Aspects of Formex Configuration Processing", pp. 310-333, *Proceedings of the First International Seminar on Structural Morphology*, (Ed. Motro, R. and Wester, T.), Montpellier, France, September 1992.

5. Disney, P. "Formian : The Programming Language of Formex Algebra", *International Symposium on Membrane Structures and Space Frames*, Osaka, Japan, September 1986.