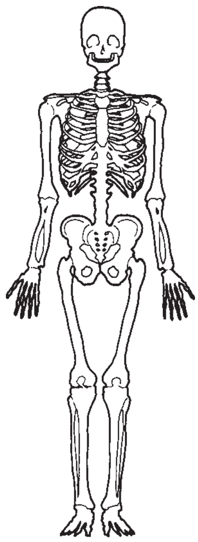
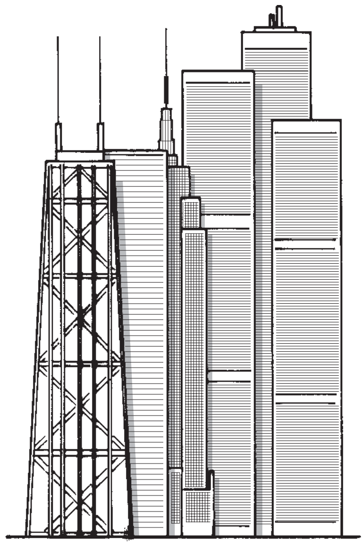
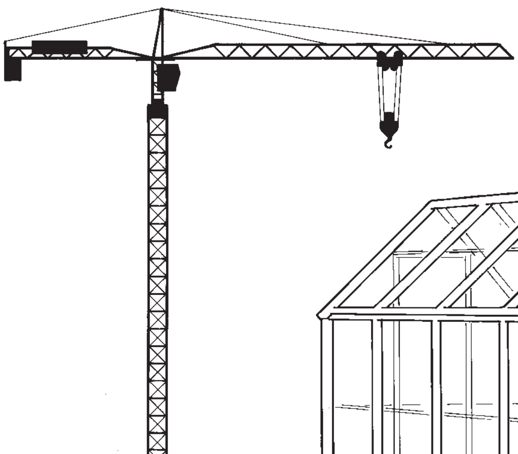
SPACE FRAME STRUCTURES

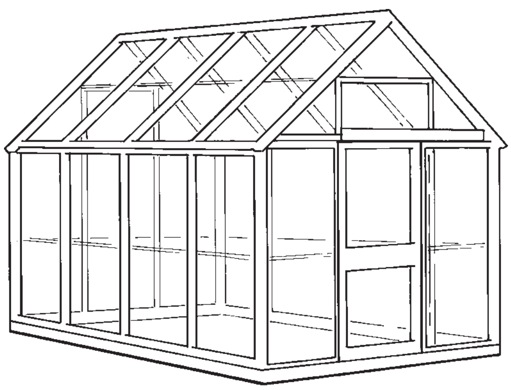
A frame structure can be defined broadly as a connected number of parts (*structural elements*) which resist *loading* (applied force). Many important categories of frame structure remain hidden from view; diverse examples include: skeletons, tall buildings, domestic architecture.



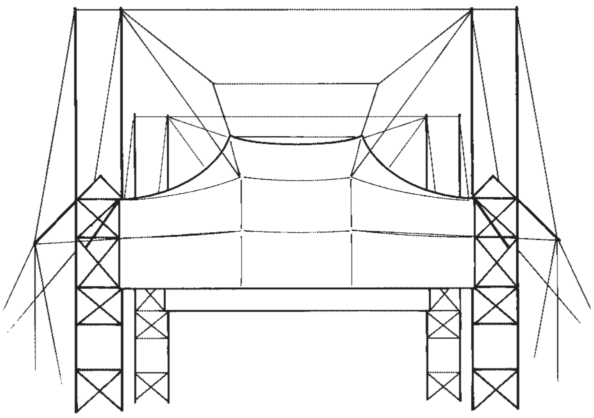


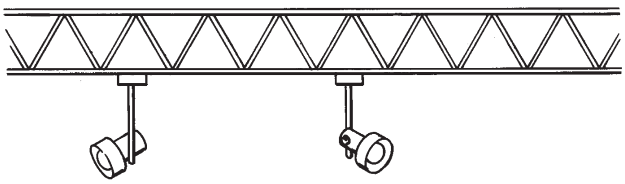
Others, such as tower cranes, some types of bridge, and domestic greenhouses clearly expose their frame structure. Increasingly, it is becoming accepted that frames should not necessarily be concealed in both buildings and other products; indeed, there are positive reasons for externalising them.





Advanced ‘high technology’ architecture offers countless examples of interesting structures exploited both for their functional and visual characteristics. Modern shop display and lighting systems increasingly use open frameworks - often finished in bright colours. A few years ago these would have been considered inappropriate as part of the visual make-up of an interior design.





Design Opportunities

Design and make a framed system for one or more of the following:

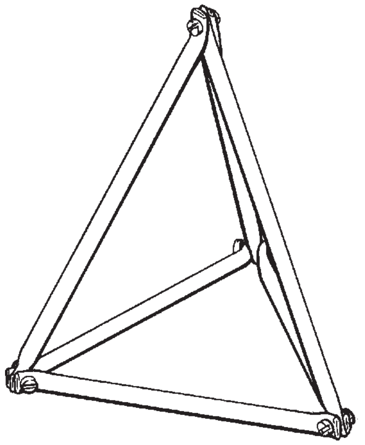
Small exhibition system
Consumer product - e.g. CD storage stack
Consumer product - floor standing lamp

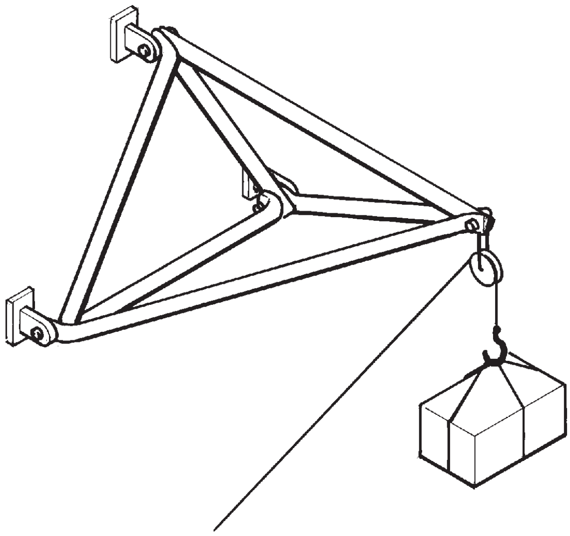
The system should conform to the opening definition of a structure and it should explore as far as possible well established geodetic design principles. Ideally, the system should also be capable of easy self-assembly so that any of the products can be sold or stored in flat packs. The development of a suitable modular system with *nodal connectors* may lend itself to application in three product contexts suggested above.

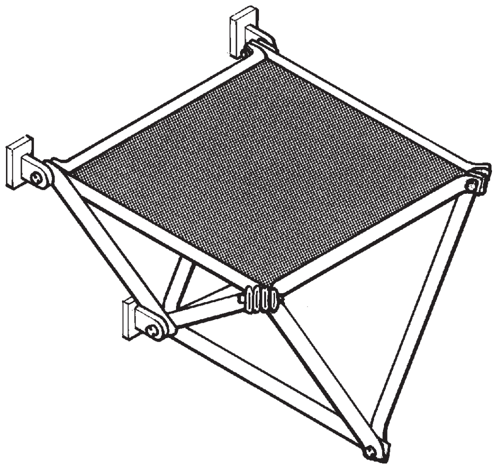
BASIC PRINCIPLES

Three Dimensional Frames
Three dimensional frames are also called space frames or space trusses. The least complex space frame is a tetrahedron made up of six components.

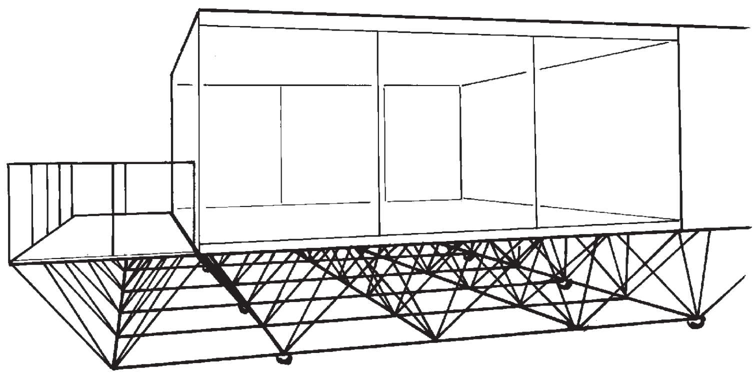
Simple space frames of this type may be used for supporting platforms or other loads on the sides of buildings. Some examples are given.



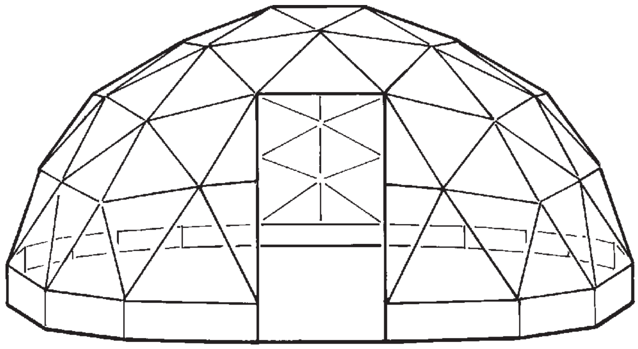




The tetrahedron can be repeated many times to provide a complex space frame (e.g. one that spans a wide gap without support at the centre). Modern buildings sometimes incorporate space frame structures to lift them off the ground or to support roofs.



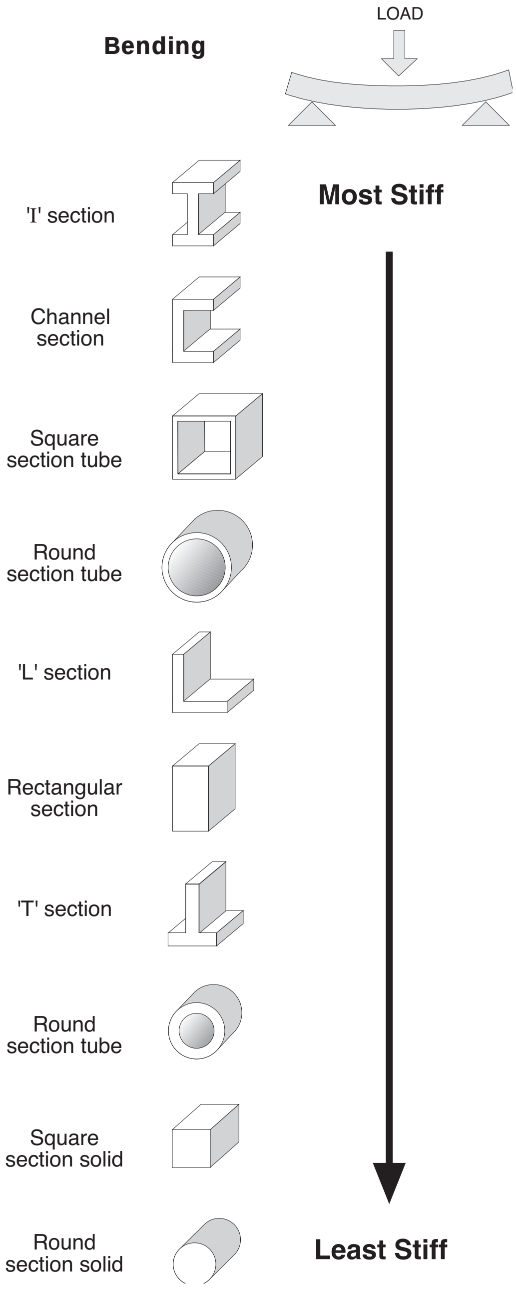
Geodetic Space Frames
The development of geodetic space frames by the American architect and inventor, R.Buckminster-Fuller, has opened up many new structural possibilities for creating framed structures whose parts fit together to enclose three dimensional space. This kind of frame is used for temporary and permanent buildings; it is also - in combination with compliant materials - for special display systems which fold down into very small storage cases for transport.

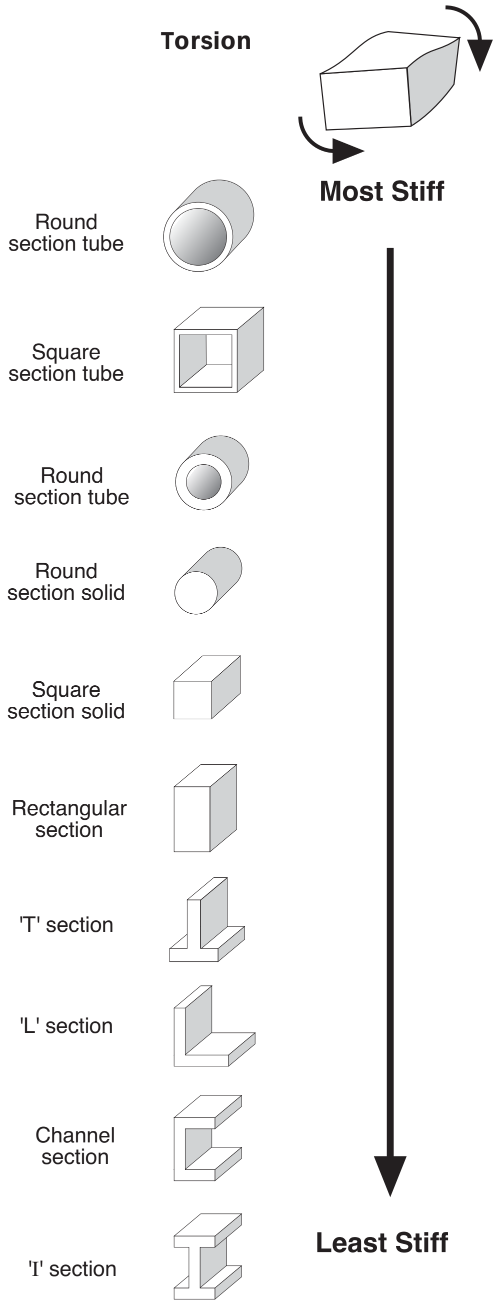


STRUCTURAL ELEMENTS

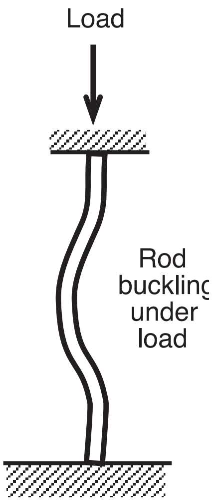
The structural elements of a frame system are normally chosen for maximum stiffness and light weight. It is unusual to find frameworks that use solid section elements because these are both heavy and less stiff. The accompanying table on the next page shows a rank ordering of the stiffness of various sections all having the same cross section area. (Notice, however, that a comparable table for resistance to torsional (twisting) forces, completely changes this order.

STIFFNESS OF SECTIONS

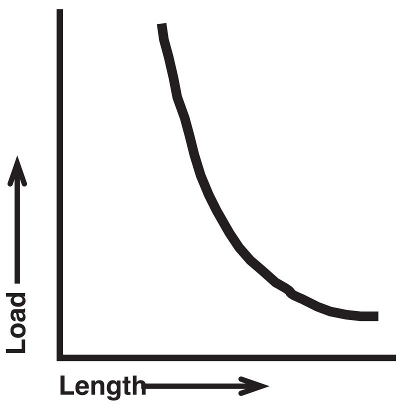




Solid rod is found at the bottom of the table, thick walled tubing is superior but thin walled *larger diameter* tubing is better than both in terms of stiffness. Larger diameter, thin walled tube also has good torsional resistance - and for this reason is also used, for example, in vehicle drive shafts. The strength of a structural element subjected to *compressive loading* will also be determined by its length. In compression, an element eventually fails by bending or *buckling*.



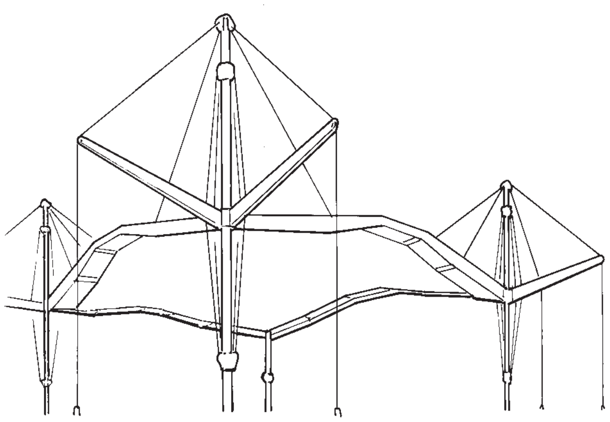
The buckling behaviour of long rods or columns was first investigated by the 18th century mathematician *Leonard Euler* who formulated an equation relating this property to length. **In brief, Euler's equation shows that a shorter column has greater resistance to buckling than a long one.** Failure against load for different column lengths can be plotted on a graph. The graph shown is a *generalised* one to *indicate* the effect of length.



It is possible to compare the behaviour of similar structural elements of different lengths by supporting them vertically, loading them and plotting performance on a graph. This is an experiment which can be performed, for example, with balsa sections or paper roll-tubes.

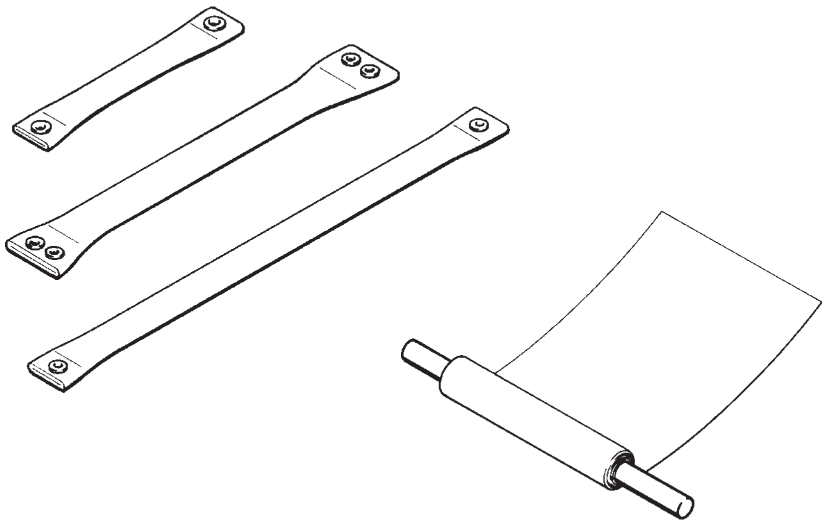
The strength of a structural element *in tension* is determined largely by the properties of the material itself. This information is available in the form of look-up tables under the heading of *UTS* or *ultimate tensile strength*. (See Study file 5). For an element such as a roll-tube the UTS is extremely high relative to its weight and for most small structures considered here is unlikely to present any problem. (It should be noted, however, that tensile failure of a roll tube will always occur at the ends where the cross-sectional area is reduced due to punching for the end connection. See below.)

In many advanced buildings and other structural systems, *flexible ties* such as steel cables and nylon lines are important elements and might be introduced into your own design. It is even possible, as Buckminster Fuller showed, to construct a geodetic form in which compressive elements are totally separated and suspended within a *mutually supportive matrix* of cable and tubular struts.



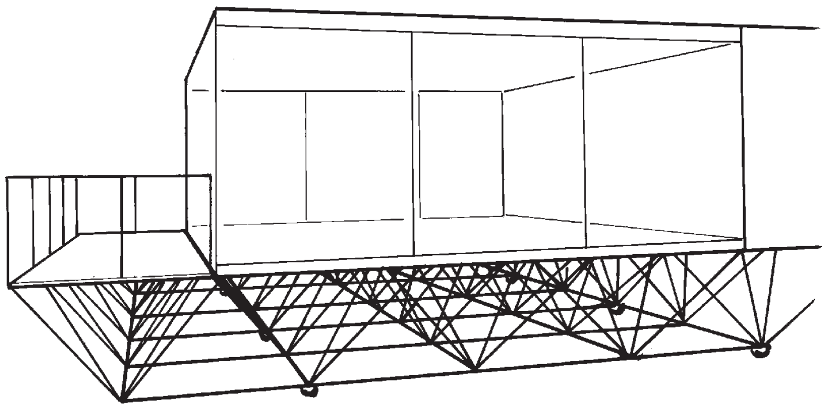
ROLL TUBES

A roll tube is a rolled paper tube whose ends are terminated to receive fastenings such as pins or bolts. They are used for modelling structures but in some situations can also be used for the "real thing". This is partly because of their potential strength and durability but partly because paper is being viewed increasingly as a versatile renewable material suitable for many consumer goods. (See study file 3 for precise guidance on making roll tubes.)

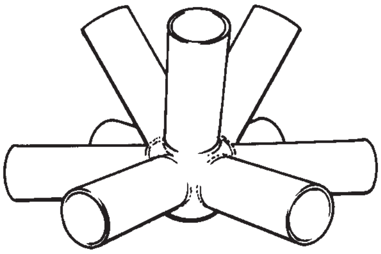


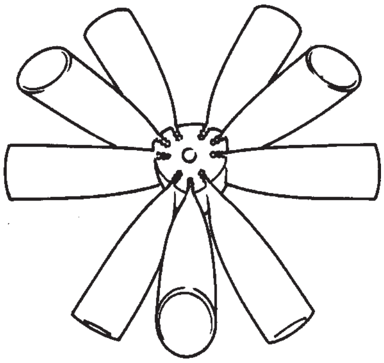
FRAME ELEMENT, JOINTS AND CONNECTORS

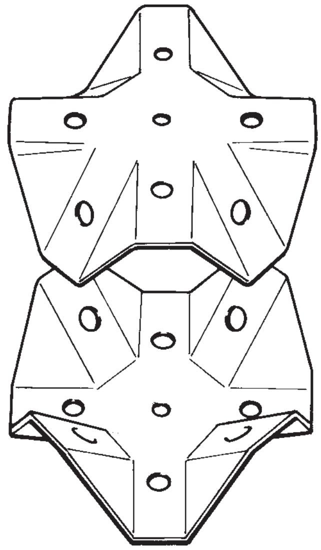
Traditional framed buildings use a variety of relatively simple joints such as riveted plates to join steel elements together. (See Study file 2.)



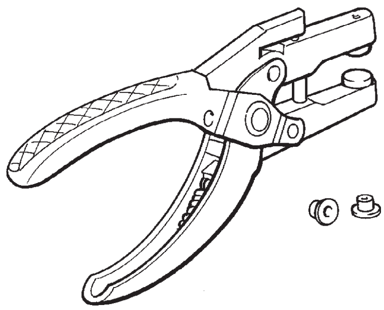
The space frames used in many new *high technology* buildings use simple structural elements that build up into a complex three dimensional *geometrical* pattern. The points at which the elements come together are called *nodes* or *nodal points* which are connectors capable of accommodating multiple elements coming together at different angles. There are many *nodal connector* systems in use, and others are being developed all the time. Three examples are illustrated, two of which are designed for tubular elements and one for elements having at least one flat face - e.g. a box section.

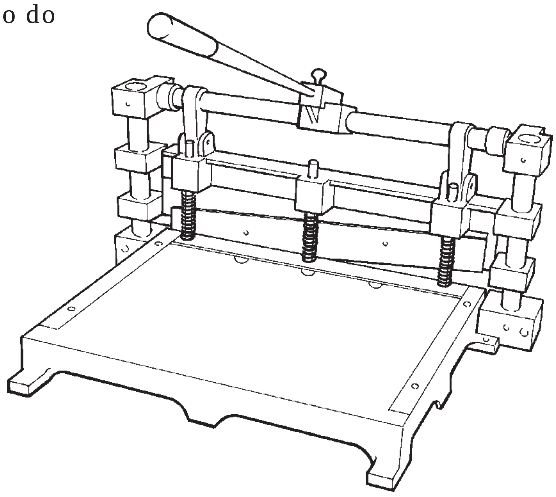




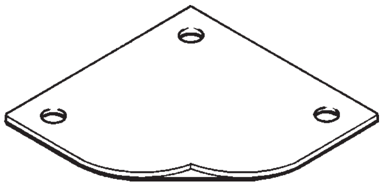


For roll tubes you can easily make large numbers of identical nodal connectors using thin gauge aluminium or plastic sheet. In fact there are so many possible design permutations, it would be surprising if you did not arrive at a unique variation ! Aluminium blanks, cut on a PCB guillotine, can be punched either using a combined eyeletter tool or the TEP punch tool. (The latter is preferable if the material is above 1mm in thickness.) The blanks can then be formed, if necessary, using a simple tooling jig. For example, to form the four corners of a square connector at an angle, the blank is held firmly on the simple MDF (medium density fibreboard) former shown and each corner folded down in turn. If many such connectors are needed, a two part MDF *tool* can easily be designed to do this in a single operation.



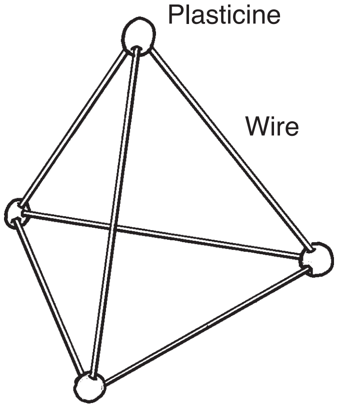


Plastic connectors - depending on the material and its thickness - can often be left flat but *flexible*. The connector will yield to the required angle. This will also accommodate changes in design which result in node angles changes.



EXPERIMENTAL METHOD

Having determined your design brief and specification, you will probably need to investigate possible frame geometries. There are commercial kits available for this work. Typically, they contain small flexible 'star' connectors for plugging into plastic straws or tubing. A cheaper alternative, for preliminary 3D 'sketching', is to use either wire or spagetti for the elements and small balls of either Plasticine or Bluetack for connectors. This can assist *visualisation* but gives no indication of structural integrity.



Because they are easy to manufacture, it might be an advantage simply to make a quantity of thin-walled roll tubes and cut them to length as required. Joining can be done by card nodal connectors - using screws and nuts to fasten everything together.

PUTTING IT ALL TOGETHER

Almost certainly an exhibition system and CD rack would need elements other than the basic frame components. Foam core board, for example, provides a lightweight sheet material which is ideal as a backing for display. Thin aluminium or plastic sheets - flat or partially formed -might be used as integral parts of a repeating stacking structure for the CDs.