Structural Forms

There are three ways to organize materials to support a load or to contain and protect something: mass structures, frame structures, and shell structures.

Structures are assemblages of elements used to support a load or contain and protect things. In many cases, the structure supports only itself (i.e., the load is the weight of the materials), and in other cases the structure supports itself and additional loads (e.g., a crane). Whether creating a museum exhibit, large sculpture, 3-D billboard, or temporary shelter, a basic understanding of structure is essential to successful design. There are three basic types of structures: mass structures, frame structures, and shell structures.\(^1\)

**Mass structures** consist of materials that are put together to form a solid structure. Their strength is a function of the weight and hardness of the materials. Examples of mass structures include dams, adobe walls, and mountains. Mass structures are robust in that small amounts of the structure can be lost with little effect on the strength of the structure, but are limited in application to relatively simple designs. Consider mass structures for barriers, walls, and small shelters—especially in primitive environments where building skills and materials are limited.

**Frame structures** consist of struts joined to form a framework. Their strength is a function of the strength of the elements and joints, and their organization. Often a cladding or skin is added to the frame, but this rarely adds strength to the structure. Examples of frame structures include most modern homes, bicycles, and skeletons. Frame structures are relatively light, flexible, and easy to construct. The most common frame configuration is the assembly of struts into triangles, which are then assembled to form larger structures. Consider frame structures for most large design applications.

**Shell structures** consist of a thin material that wraps around to contain a volume. They maintain their form and support loads without a frame or solid mass inside. Their strength is a function of their ability to distribute loads throughout the whole structure. Examples of shell structures include bottles, airplane fuselages, and domes. Shell structures are effective at resisting static forces that are applied in specific ways, but are poor at resisting dynamic forces. For example, an egg effectively resists loads that are applied to its top and bottom, but collapses quickly when the loads are applied to its sides. Shell structures are lightweight and economical with regards to material, but are complex to design and vulnerable to catastrophic failure if the structure has imperfections or is damaged. Consider shell structures for containers, small cast structures, shelters, and designs requiring very large and lightweight spans. Large shell structures should generally be reinforced by additional support elements to stabilize against buckling.\(^2\)

See also Cost-Benefit, Factor of Safety, Modularity, and Scaling Fallacy.


\(^2\) Note that shell structures can be reinforced to better withstand dynamic forces. For example, monolithic dome structures apply concrete over a rebar-reinforced foam shell structure. The resulting structural form is likely the most disaster-resistant structure available short of moving into a mountain.
Icosa Shelters exploit many intrinsic benefits of shell structures: they are inexpensive, lightweight, and strong. Designed as temporary shelters for the homeless, the Icosa Shelters are easily assembled by folding sheets of precision die cut material together and sealing with tape.

The Geocell Rapid Deployment Flood Wall is a modular plastic grid that can be quickly assembled and filled with dirt by earthmoving equipment. The resulting mass structure forms an efficient barrier to flood waters at a fraction of the time and cost of more traditional methods (e.g., sand bag walls).

The Statue of Liberty demonstrates the flexibility and strength of frame structures. Its iron frame structure supports both itself (125 tons) and its copper cladding (100 tons). Any resemblance of the frame structure to the Eiffel Tower is more than coincidence, as the designer for both structures was Gustave Eiffel.