Published: Conference Proceedings IASS Symposium 2004, Shell and Spatial Structures from Models to Realization; Montpellier France 2004

# A Morphology of Mobile Shelter Systems

N. Burford, C. Gengnagel
*Lehrstuhl für Tragwerksplanung, Fakultät für Architektur, Technische Universität München, Arcisstrasse 21, 80290 München, Germany, Phone 0049 (0)89 289 23157 Fax 289 23153*
*n.burford@lrz.tum.de, c.gengnagel@lrz.tum.de*

## 1. INTRODUCTION

This paper is concerned with the morphological classification of mobile shelter systems. The overall aim of the classification is to identify the various generic models for deploying the alternative forms of construction systems that are available. A principle objective is to identify if there are particular construction systems and forms that are more deployable than others and to define the underlying criteria for their form, construction and deployment.

## 2. DEFINITION FOR MOBILE SHELTER SYSTEMS

A comprehensive review of existing technologies revealed that mobile shelter systems are a type of building construction for which there is a vast range and diversity of forms, structural and construction solutions. They are designed to provide weather protected enclosure for a wide range of human activities. Consequently, they share many of the common characteristics of conventional buildings. Unlike conventional buildings, structures may have spans of only a few metres at one extreme, to in excess of 50 metres at the other. Additionally, the relationship of a mobile shelter to a site or location is usually limited to a defined time scale of days as opposed to decades. Common to all systems is the ability to move the construction from one location to another numerous times, which means they have to be easily deployable. Consequently, the form and design of the shelter's construction to facilitate multiple changes in location, in particular, the methods and sequences of transportation, assembly and erection are key factors in their classification. Most shelters use an incremental process of deployment relying on a series of separate operations undertaken manually or with the assistance of mechanical plant. However, transformable construction systems use mechanisms contained entirely within their construction permitting a process of transformation from a flat state at ground level, to a three-dimensional space enclosure without any significant external mechanical assistance. Constructions are normally required to enclose only a simple, singular volume or space. The physical requirements for the enclosure in terms of environmental control, and the detail and construction of the structure and building fabric, are without exception, considerably less demanding than permanently sited buildings. Specifically, floors, services and internal partitions or installations have little or no impact on the enclosure's form or its deployment.

Therefore, the enclosure can be considered to consist primarily of two principle elements:

- a supporting structural system;
- an environmental barrier or surface.

## 3. STRUCTURE AND ORGANISATION OF THE MORPHOLOGY

The morphology will be limited to the classification of Mobile Shelter Systems only. The generic parameters will address all scales, types and variations that exist within this. The first step will be to establish the basic parameters and the underlying characteristics for each parameter. The characteristics will be used to define generic groups or types within which the different kinds of systems and objects can be represented generically. A separate path for specific features in the form of matrices will be developed using the criteria for each type to produce a number of variations. The final matrices will show the principle areas and features of various methods of erection in relation to alternative construction forms and types. An appropriate level of abstraction for modelling the generic objects will be established. This will be achieved by concentrating on their physical arrangement and systems rather than their detailed design.

Three principle parameters are to be considered in parallel, namely:

- Form
- Construction
- Method of Erection

The construction of a shelter in relation to the form of the enclosure and the disposition of the elements of the construction within the form is central to the method of erection employed for the shelter system. Therefore it is necessary to consider the erection in terms of the two principle sub-parameters that make up the construction of the shelter system, namely:

- Structure
- Surface

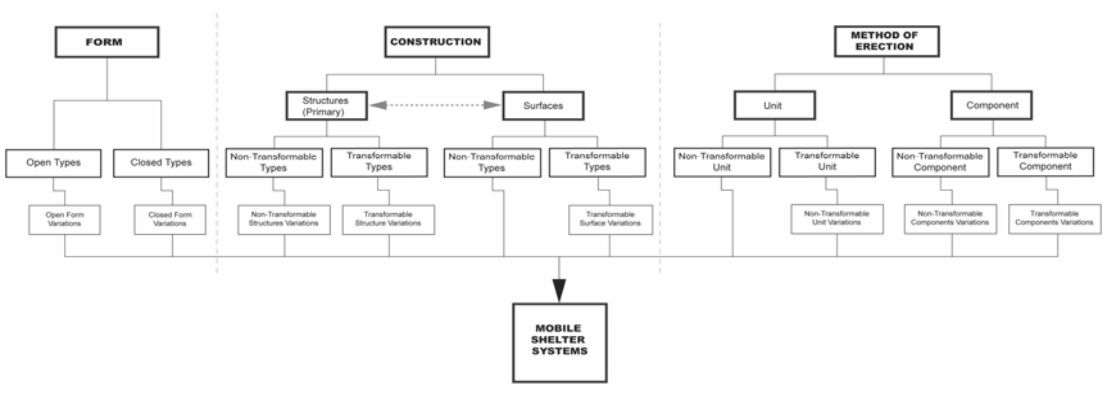


Figure 1 Structure of the morphology

## 4. FORM

The form determines the efficiency of the enclosure as a practical, usable environment and its suitability to the ergonomic requirements of different applications. Forms are governed by the geometry of the internal space or volume, the range of which can be produced by examining the relationship between the available generic plan and section geometries. Shelter system forms can be classified by the degree of enclosure given to the internal space or volume. Depending on the cross-section and its relationship to the plan, a particular form may be closed on all of its boundaries or open on one or more boundaries. It follows that certain open forms will have the ability to repeat, or extend their internal volume with an identical volume without interruption to the principle cross-sectional volume of the enclosure. The method by which a form can be extended can be described by its plan vector extension and this can be used as the basis for further classification.

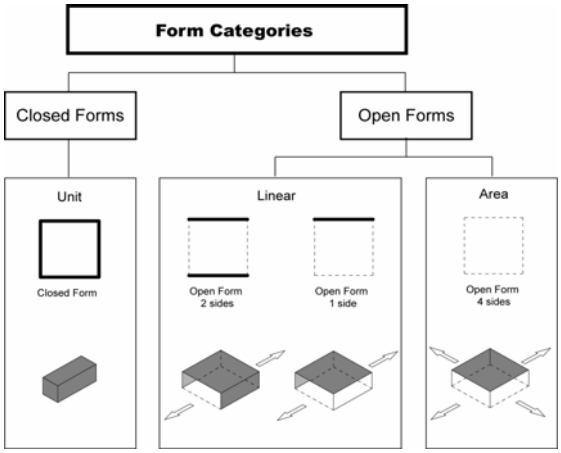


Figure 2 Categories of three-dimensional forms

## 5. CONSTRUCTION

The construction is the assembly and arrangement of all the components that provide the enclosure and support functions of the shelter system. In mobile shelters the construction comprises entirely of a *structure* and *surface*.

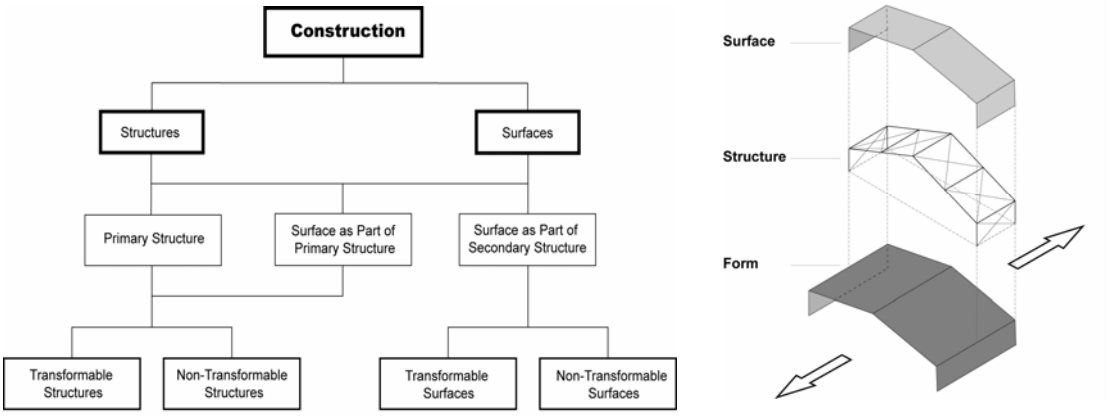


Figure 3 Categories of Construction

### 5.1. Structure

The structure encloses and protects the internal volume from large changes in shape by resisting gravity, and external applied loads such as wind and snow. The primary structure is the assemblage of all the principle elements and connected parts that are intended to sustain loads and maintain the overall stability of the construction. All other elements of the construction that are subject to external applied loads but do not have a principle role to play in the stability of the structure are termed secondary structural elements. Therefore, the primary structure may be independent from the skin of the enclosure, or it may be integrated. Where these are combined, the skin and structure act in unison to distribute the loading and will be dependant on each other to maintain their individual stability.

#### 5.1.1. Classification of Primary Structures for Mobile Shelter Systems

Three principle criteria were used to define and classify the typical primary structural systems, namely:

- Hierarchy of the primary structural system - the organization of the elements of the primary structure in terms of the main structure and subordinate structural elements and their geometrical arrangement within the construction.
- Support conditions of the primary structural system – Closed Structures only transmit forces resulting from the dead and live loads that pertain to all structures, to the supports. Open Structures transmit additional forces to the supports in addition to the dead and live load.
- Relationship between the structure and surface - whether the structure and surface are inter-dependant elements of the primary structural system or whether the surface is independent of the primary structural system.

### 5.2. Transformable Structures

A transformable structure is a primary structure that is able to change its function from a mechanism to a statical system and the geometry of its form. As a statical system it distributes the applied loads and self weight of the construction. As a mechanism it gives the construction the ability to reversibly change its form from one geometrical state to another. In mobile shelter systems this normally means that the structure will change from a largely non-space defining form into a two- or three-dimensional space enclosure In almost all transformable systems, it is the main structural element of the primary structure that is responsible for giving the construction the ability to transform. When the transformation is complete, the whole system is fixed at its supports in order to stabilise the soft or moveable components of the structure.

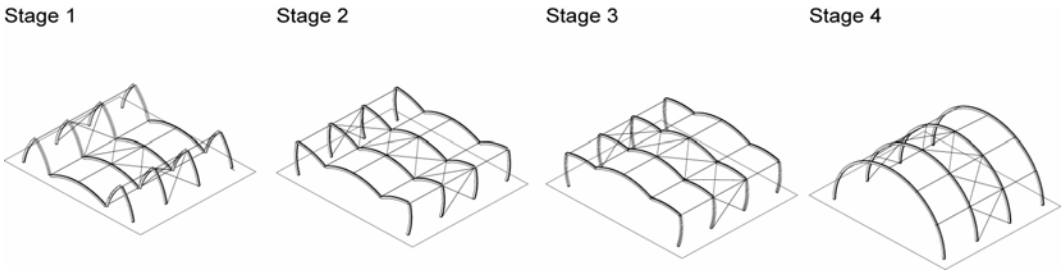


Figure 4 An example of a transformable primary structural system

Transformable structures can be classified by the process of form-change which provides two principle types. One type is a group of structures in which the elements of the structure develop internal strain as a result of geometrical changes in the form during the deployment process. The other group are structures that do not develop internal strain. To simplify the terms *non-kinematic* and *kinematic*, will be used to describe those structures that are strain-independent and strain-dependant respectively.

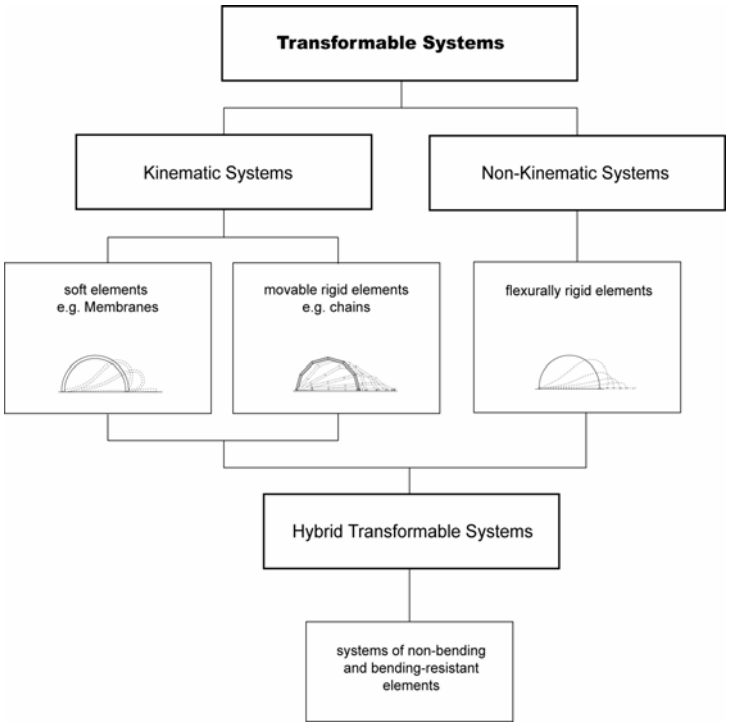


Figure 5 Categories of transformable structural systems

- Kinematic structures are transformable systems that are comprised of soft elements, rigid pin-jointed elements or sliding elements. The structural system can change its form or geometry through a mechanism which does not develop elastic strain in the individual structural elements.
- Non-Kinematic structures are transformable systems that are comprised of stiff elements without pins. The structural system can change its form or geometry through a mechanical process that changes the shape or form of the individual elements of the structure thereby producing elastic strain within the element itself.
- Hybrid transformable structures are mixed systems of soft and flexurally stiff elements or pivot-jointed rigid members or combinations of all three. The changing in the form of the structures will produce internal strain and non-strain in different individual elements depending on their role within the transformable system.

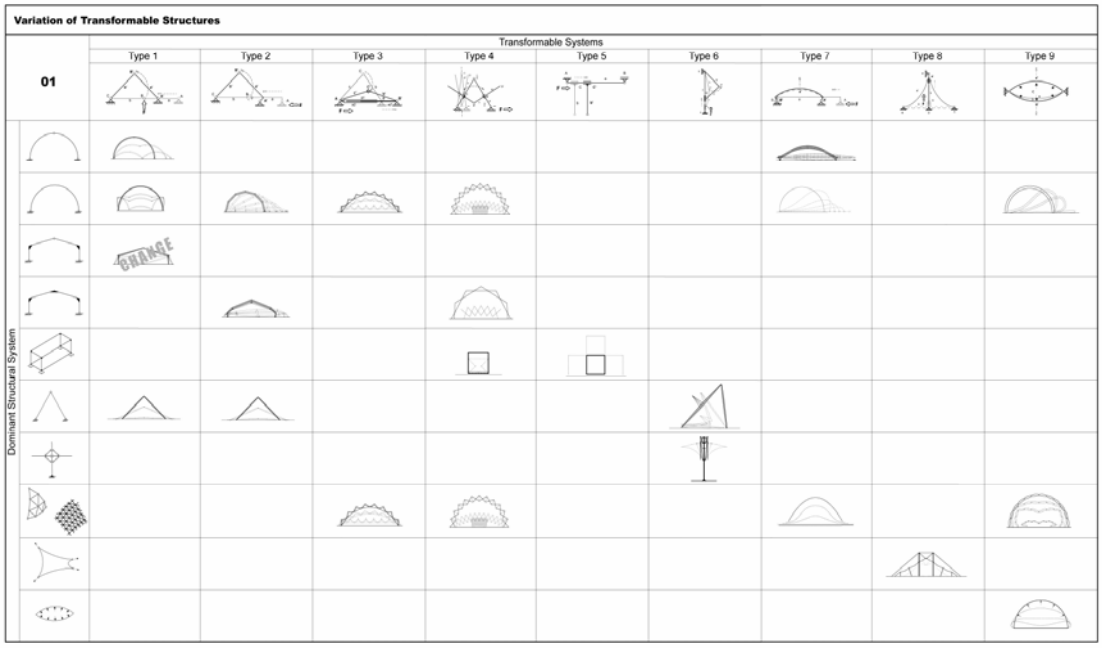


Figure 6 Variations of transformable structures

### 5.3. Surface

The surface is a skin or envelope that provides an environmental barrier to the internal space of the enclosure. The majority of surfaces are required to provide varying degrees of structural stability, load distribution, water resistance, insulation, vapour, sound and light control. All surfaces need to sustain applied loads from snow and wind and distribute these to the primary structure or supports. Surfaces can be either primary or secondary structural elements and may be stiff or soft constructions or a combination of both.

Transformable surfaces can be classified according to similar typological groups as the transformable structures, namely: *kinematic surfaces* and *non-kinematic surfaces*. All soft surfaces are inherently transformable which makes them ideally suited to mobile shelter systems. Stiff surfaces are only transformable through articulated mechanical connections, such as sliding links, pins or hinges, or by flexurally bending the surface into a curved form. Because the requirements in mobile shelter systems for highly controlled internal environmental conditions are comparatively rare there are very few examples of stiff skin constructions. Consequently, most shelter systems use soft materials and systems that are inherently deployable.

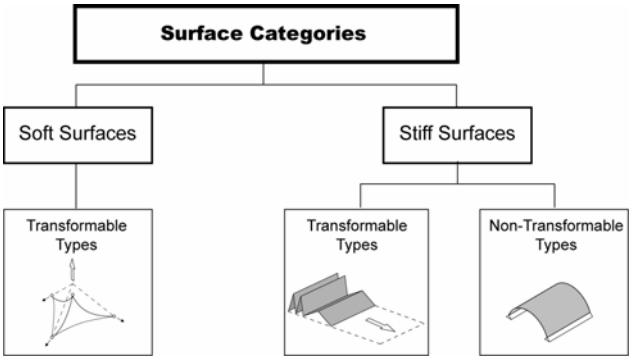


Figure 7 Categories of transformable surfaces

### 5.4. Soft Surfaces

Soft surfaces are inherently transformable because they are made up of non-bending, non-strain resistant materials that are not capable of resisting compressive forces. The basic form of a fabric is a

two-dimensional flat surface. This can be considered to have only two principle dimensions - a width and a length, with no volumetric proportions. A principle property that is common to all fabrics is the ability to reversibly transform the basic flat surface from an area to a more compact form that will be a volume having width, length and depth. The alternative ways of reducing a flat surface to a volume directly affects the process of dismounting and deployment of a three-dimensional tensile surface. There are three principle methods used for reducing a flat surface to a packed volume, namely: folding, rolling, flaking / bunching of the surface. Conventional stiff surfaces rely on internal stiffness to achieve stability and to carry loads. Soft membrane surfaces, constructed of elements that have little or no bending or shear stiffness, must rely on their form and internal tensile prestress alone to perform the same functions. Since tensile surfaces, such as fabrics, cannot develop out-of-plane stresses, loads are always resisted by planar axial forces. Therefore, the shape of a membrane surface and its prestress state are extremely important in reducing the deflection under out-of-plane loading. A membrane without double curvature and prestress will be limited to small spans in order to reduce the deflections. Consequently, membrane surfaces in mobile shelter systems can be classified by their general form of which there are four principle types, namely: flat, curved, anticlastic curved and synclastic curved.

### 5.5. Transformable Soft Surface

The different types of transformation of soft surface can be classified by the type of movement - bunched or rolled - and by the direction of the movement - linear, radial and central. The classification does not take into account the form or position of the structure or how the membrane is deployed onto the structure.

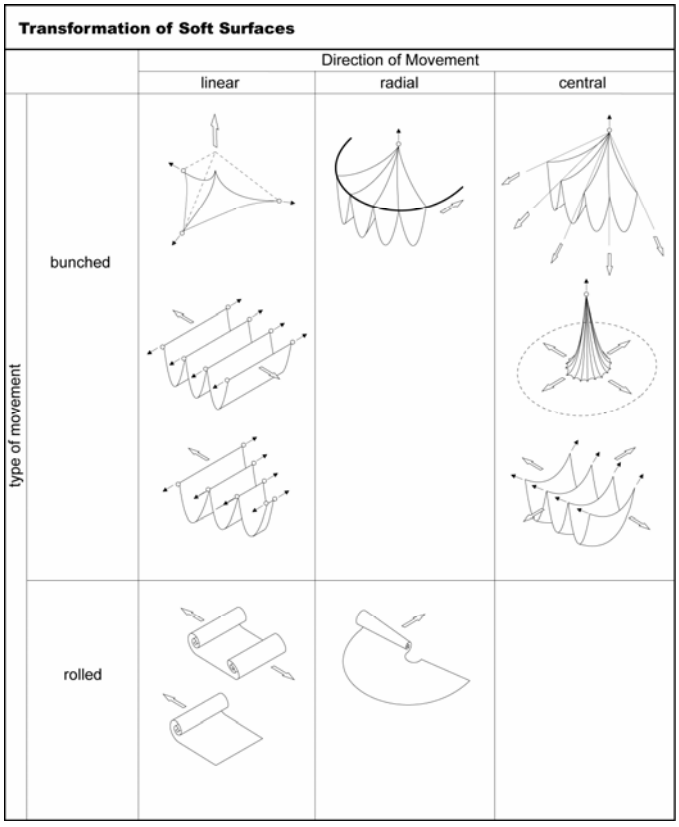


Figure 8 Types of transformation of soft surfaces

## 6. METHOD OF ERECTION

Construction systems can first of all be grouped within two broad categories, namely by: *unit* and *component*. Unit describes construction systems which are pre-assembled prior to delivery to site. Component describes construction systems that are delivered in a number of separate parts for on-site assembly. The adoption of a particular construction strategy will depend on the transportation method used and its particular restrictions and the scale of the construction in terms of its volume as this affects the size, weight and bulk of the component parts. These issues are equally relevant to both small and large enclosures.

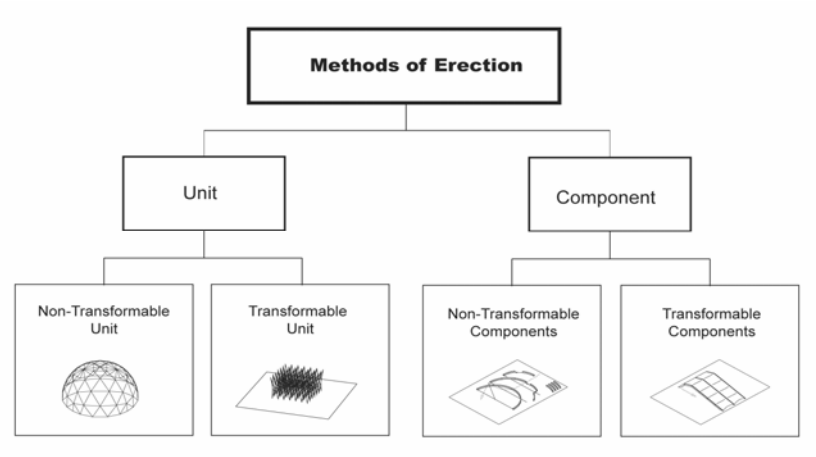


Figure 9 Categories of methods of erection

The erection of a construction may be considered in three ways, namely:

- a single process involving a prefabricated volume;
- an incremental process involving separate components;
- a process of transformation of the structure or surface or both.

The process of erection describes the distinct stages by which a construction system is assembled from its component parts to its final form. This can involve an incremental process consisting of a structured sequence of completely separate operations, or it may involve one or more processes of transformation of a transformable construction system. The latter may also involve a combination of transformable and incremental processes.

The principle aim of the classification of the construction processes is to elicit the different directions and sequences of moves required to erect the transformable construction systems. For simplicity, the prefabricated volumes and incremental components are categorized within one classification group. The transformable systems are classified within five classification groups that describe the different principle directions of move involved in the transformation of the construction.

The construction variations are generated by combining the different primary structure and transformable structures with the surface of the enclosure. Each construction arrangement can be compared with the different types of deployment process to give the range of variations of deployable constructions containing different combinations of structure, transformable structure, surface and form.

**References**

[THO00] Thompson, D.W., “On Growth and Form”. Cambridge University Press, 1942.

[BUT03] Büttner, O., Hampe, E., “Bauwerk Tragwerk Tragstruktur – Klassifizierung Tragqualität Bauwerkbeispiele”, Verlag für das Bauwesen, Berlin 1985.

[OTT05] Otto, F., IL5, “Convertible Roofs”, Institut fur Leichte Flachentragwerke (IL), Heinrich Fink KG, Stuttgart, 1972

[CLA03] Clamshell Buildings; URL: http://www.clamshell.com/ , 2003-12-01.

[LOW03] Lowland Outdoor Technology; URL:http://www.lowlandtents.com , 2003-11-11.

Published: Conference Proceedings IASS Symposium 2004, Shell and Spatial Structures from Models to Realization; Montpellier France 2004