1: INTRODUCTION.

1:1. THE INCREASING FREQUENCY OF NEW FABRIC STRUCTURES.

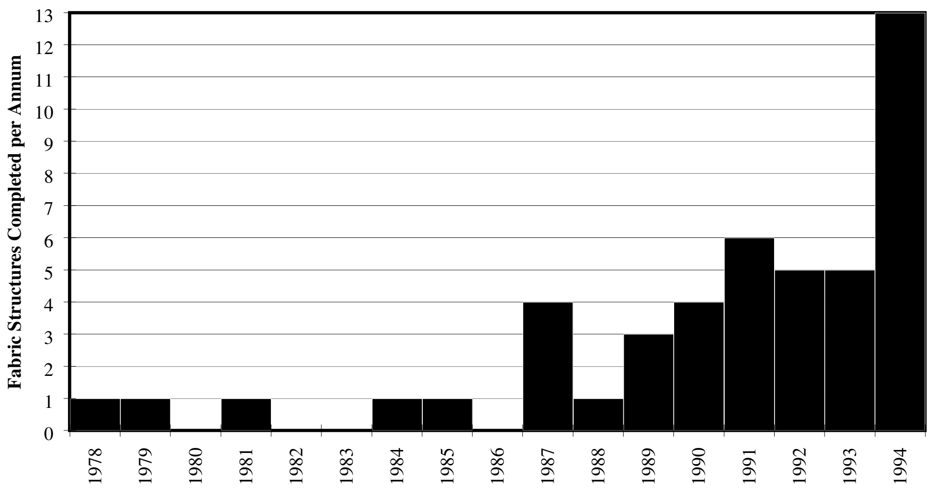
Prior to 1980 few permanent fabric structures had been built in the United Kingdom. A number of impressive large scale projects had been planned, but only a handful of small, temporary structures had actually been realised.

In 1981 The Clifton Nurseries was built in Covent Garden. This was a permanent, heated fabric enclosure formed by a long life PTFE coated glass fabric never before used in the UK[1]. The durability of this new fabric, and the obvious permanence of the Clifton Nurseries challenged the preconceptions many designers had about the word '*tent*', and seemed to herald the beginning of a new age of long life, high profile fabric structures in this country.

Since the success of the Clifton Nurseries an increasing number of permanent fabric structures have been built throughout the UK. Ever improving materials and the development of highly successful structural analysis programmes has slowly convinced even the sceptical construction industry of the durability and longevity of modern fabric structures.

Because such structures are unusual and tend to be aesthetically quite appealing, they are almost always well publicised and as a result every year their popularity seems to grow. This trend is clearly illustrated by the graph below.

Figure 1:1. The Increasing Frequency of Permanent Fabric Structures Completed / Year in the UK (see Appendix 1 for details).



The permanent buildings represented by the above graph have been supplemented by a large number of smaller scale shading structures and temporary shelters, and today fabric structures are not an uncommon sight in the UK.

The popularity of fabric structures around the rest of the world has shown a similar trend in recent years, and indeed Southern Europe, the Middle East, USA, Japan and Australia have all established a significantly larger fabric structures market than exists in the UK. In Japan for example, it is estimated that the annual demand for the fabrics used in such structures has increased from just 600m^2 in 1984 to approximately 180,000m^2 in 1994[2].

1:2. THE INCREASING SIZE AND COMPLEXITY OF NEW FABRIC STRUCTURES.

The research which facilitated the modern generation of '*architectural*' fabric structures was initially stimulated by the spanning potential of tension stabilised surfaces. With low self weight and immense tenacity, fabric structures offered a new opportunity to cover large areas with little material, doing more with less, embodying the concept of minimum surface area and maximum resource efficiency.

The development of specialist computer programmes allowed the design of one off designs from first principles, and the reliability of this approach produced an increasingly diverse and complex range of long spanning fabric structures. In the UK the largest fabric structure built to date is at Tilbury Dock. The second stage of Birth 42 was completed in 1993 and the total structure now covers nearly 20,000m^2, making it the largest single PVC coated polyester enclosure in the world[3].

Currently, the largest fabric enclosure in the world is the air supported Tokyo Dome. Completed in 1988 the PTFE coated glass fabric roof covers approximately 40,000m^2, the enclosed space is 60m high at its apex, and it can accommodate 50,000 people[4]. On an even more formidable scale, the Hajj Terminal at Jeddah Airport, whilst not strictly speaking a fabric enclosure, is composed of 210 similar units each measuring 45m square and covering a total area of approximately 470,000m^2[5].

More recently, the 17500m^2 double membrane fabric roof of the Great Hall at Denver International Airport encloses an air conditioned high occupancy space located in a predominately cold climate. The project is seen by many as a test case for the future of fabric structures [6] [7]. If a climate controlled fabric enclosure can work in Denver, it can work anywhere.

1:3. THE IMBALANCE IN THE EXISTING BODY OF KNOWLEDGE.

An initial survey of the existing body of knowledge relating to fabric structures uncovered a daunting volume of well established theory. This work however referred predominately to the structural behaviour of fabric envelopes, including detailed investigations into the structural properties of fabrics, methods for determining ideal structural forms and techniques for generating these three dimensional forms from pieces of flat fabric. It became increasingly apparent however that the environmental behaviour of fabric structures had barely been studied at all.

This imbalance in the existing body of knowledge was perhaps inevitable. The first generation of modern fabric structures tended to be temporary, or at least short term because of the limited life of the available materials. These structures were generally only required to provide shelter, not to maintain thermal comfort, and '*enclosed open space*' became the misnomer used to describe their standard of environmental performance[8]. There were so many environmental complexities inherent in enclosing a space with a thin fabric that it was easier to just assume that '*tents*' do perform comparatively badly, than it would have been to find out if this was necessarily the case.

The recent increase in demand for more complex, permanent fabric structures however has forced designers to reconsider this approach. The emerging class of permanent architectural fabric structures is beginning to compete with more conventional building types which have well established standards of environmental performance and increasingly strict legislation on energy consumption. If fabric structures are to compete successfully in this market, designers must be able to ensure that they will be both comfortable to occupy and efficient to maintain. *Enclosed open spaces* are ceasing to be acceptable.

Unfortunately, few tools are available that allow the designers of fabric structures to carry out environmental analysis, and those that there are appear to have been inappropriately cannibalised from other fields. It was in order to address this problem that the research described in this thesis was undertaken.

1:4. THE AIMS OF THIS RESEARCH.

The overall purpose of the research described by this thesis was to provide a sound theoretical base from which detailed investigations into the environmental behaviour of spaces enclosed by fabric membrane envelopes could be undertaken with confidence.

Because of the great number of topics encompassed by the general heading '*environmental behaviour*', it was decided to focus specifically on *thermal behaviour* as this in itself is a complex subject, and a great number of other environmental issues cannot be tackled unless thermal behaviour is properly understood.

Research in this area was carried out with the practical goal of identifying how the thermal behaviour of such spaces might best be predicted. This research was structured according to a series of specific aims:-

- To determine the overall stage of development of the subject.
- To review the range and appropriateness of techniques currently used for investigating the thermal behaviour of spaces enclosed by fabric membranes.
- To determine what approach is necessary in order to properly predict that behaviour.
- To assess the accuracy of such techniques compared to those adopted by previous researchers.
- To identify the overall implications of this research for the future development of the subject.

1:5 THE SCOPE OF THIS RESEARCH.

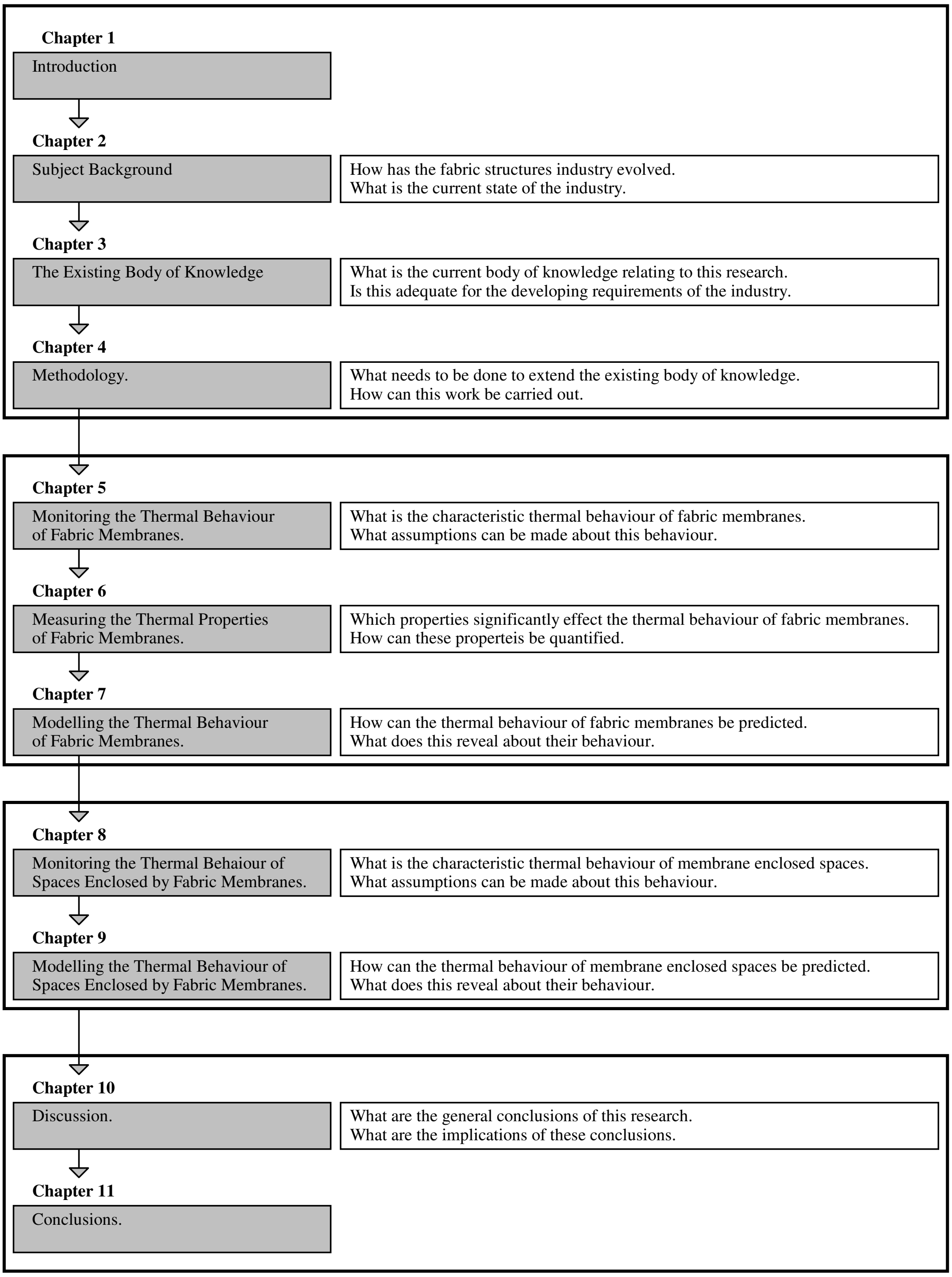
These aims posed a series of wide ranging and complex problems and in order to make these manageable, it was necessary to restrict the overall scope of the research. For this reason a number of general limitations were identified:-

- Research was limited to the study of the thermal behaviour of permanent *enclosures* whose external envelope was formed predominately by a thin fabric membrane.
- In order to ensure that this behaviour was as simple as possible, only unheated spaces were studied.
- In order to avoid the complex forced ventilation patterns found within *air supported* structures, only *frame supported* structures were investigated.

1:6 THE FORMAT OF THIS THESIS.

The specific methodology adopted for this research is discussed in detail in Chapter 4, however the overall structure of the work is illustrated overleaf in order to act as a '*map*' of the thesis.

Figure 1:6. Schematic Illustration of the Format of this Thesis.



The next chapter will look in some detail at the background to the subject as a whole, describing the historical development of fabric structures, and assessing some of the characteristic features associated with them.

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[1] Jodard, P; World Masterpiece Lightweight Classic: Terry Farrell's Covent Garden nursery building, *World Architecture Building Profile*, No.1, 1993.

[2] Taiyo Kogyo Corporation, *5:26*, unpublished paper, Messe Frankfurt, Textextil Symposium 1995.

[3] "World's largest polyester fabric structure built." *Fabrics and Architecture,* V6 No 3 May/June 1994, P57.

[4] Muramatsu, E; "Big Egg." *Japan Architect*, July 1988, P26- 29.

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[6] Usborne, D; "The Airport that refuses to take off." *Independent on Sunday*, 15 May 1994, The World, P9.

[7] *Denver International Airport Landside Terminal Complex: Final Design Analysis Report*, Birdair Inc., unpublished, April 1991.

[8] Campbell, J; "Environmental considerations of lightweight structures." *Arup Journal*, October 1980, P24.