FOUNDATION FOR THE BUILT ENVIRONMENT

RESEARCH PROGRAMME 2001/2002

PhD PROJECT PROPOSAL

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Project Title.	A generic element approach for the prediction of wind loading on fabric structures with applications to faceted continua.
Participating University.	University of Newcastle
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Statement of the **aims** of the project, the **approach** to be adopted and the **methods** by which **the aims will be achieved.**

This project is part of a long-term research programme seeking to establish comprehensive guidance on the design of fabric structures and faceted continua (e.g. cable-nets, grid-shells). The project described in this proposal has origins in doctoral research (1989-1992), with the most recent contribution to the overall programme from a Royal Society Industry Fellowship (with the Arup Partnership: “COLLIMATE – Collaborative Solutions for Membrane Structures”, 2000-2002).

The aim is to provide a simple, paper-based (consistent with BS6399-2; EC1) methodology (an object-oriented version may also be developed subsequently) to estimate the wind loading acting on non-conventional structures of arbitrary and complex geometry for use by the full spectrum of practitioners. Prestressed fabric structures will form the basis of the Ph.D. project with applications to cable-nets, grid-shells and other non-aeroelastic faceted continua. For the purposes of this project, therefore, they are assumed to be, at worst, mildly dynamic, where the dynamic component of stress does not exceed 25% of the static stress. Upon successful completion of the project, the principle that need for CFD or specially commissioned wind tunnel tests will be negated in all but the most sensitive cases will be demonstrated and design guidance provided for wind loading of geometrically complex buildings.

An approach is proposed involving industry provided data (from the collaborating organisations detailed in the next §), computational fluid dynamics (CFD) and a relatively small number of wind tunnel tests. The basis of the approach stems from the recognition that whilst curved structures of unusual shapes are obvious candidates for ad-hoc wind tunnel tests, they are composed of basic elements similar for which experimental data is available. Furthermore, components in the flow around these more complex forms are recognisable in the characteristics displayed by the simpler bodies. For example, the Olympic Coliseum at Calgary has a cable-supported roof curved in two opposite directions. Design pressures on this roof were determined from wind-tunnel tests (Davenport and Surrey, 1984) and shown to have correspondence with shallow dome and flat cylinder roof data (Cook, 1985). However, the geometry of the cited structure is characterised by only two principal curvatures over the entire surface. In the context of other cable-net (e.g. Munich Olympic Stadium) and fabric structures this is considered to be a simple form and not representative of usual geometric complexities.

The approach proposed here to fulfil the aim of the project seeks to extend this principle to more complex geometries than those available in the literature. Design pressures will be established using both wind tunnel data (established as necessary for a small number of structural forms) and CFD (the primary tool) for a number of generic families of geometries. Rules for aerodynamically joining elements within generic families will be established using the novel application of surface algebra and patches or Monte Carlo simulation, providing first-order estimates of loading on even the most unusual curved shapes. This procedure will be extended to the complete structure as a function of linked elements and wind direction. Issues of permeability may also be considered. Guidance will be established on the division of the structure, appropriate selection of elements and interpretation of the predicted wind loading.

Details of the research programme methodology (by task) and duration of individual tasks (total 36 months) are set out below. They are set in the context of a research studentship, with recognition of the importance of the training it provides to the graduate as well as the research outcomes that are generated. Therefore, activities related to establishing background information (review) are also identified.

It is expected that BRE would provide supervisory support particularly in aspects of CFD and wind tunnel modelling. The expertise of the supervising academic is in the analysis and engineering of fabric structures for which support, facilities and guidance will be provided, in addition to the contributions made by the participating organisations. A steering committee would be proposed, comprising the academic and BRE supervisors and personnel from BRE and the contributing organisations.

References

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Background to the Project.

Fabric structures (and other smooth and faceted lightweight structural continua) fulfil the requirements of changes in modern working practice, social behaviour and commercial needs. A fabric structure enables the internal environment to be modified rather than controlled and occupancy to be part-time or full-time. Construction (and subsequent repair and refurbishment) speeds are fast while unit costs are extremely competitive (frequently the minimum) with good durability and low maintenance (a feature enhanced by the introduction of self-cleaning PTFE coated glass fabrics). Architecturally dramatic forms are also intrinsically achievable. Over the last decade, the number of fabric and lightweight skeletal structures has increased significantly, with both types often leading refurbishment and regeneration projects. For example, fabric roofs have been erected at *Butlins*' Skegness, Minehead and Bognor Regis resorts, where the objective was to roof over the central open spaces as part of a revitalisation programme. In choosing this form of structure, problems associated with load transfer onto and around existing buildings of uncertain performance, budget constraints and closure limitations, were overcome, leading to architecturally striking skyline.

Fabric structures (including tents, prestressed and air supported, sails and inflatables) resist applied loads by a combination of curvature and tension (prestress). A flat fabric panel cannot resist a pressure, however much tension there is in it, until deflection of the panel gives it curvature. The lateral stiffness produced by the tension in a structure is referred to as geometric stiffness. The analysis of a fabric structure is, therefore, strongly non-linear. Curvature is introduced through the cutting pattern, support configurations and partly by the applied loads (e.g. wind and snow). It is a combination of the surface geometry, prestress and loading that determines the design and performance of a fabric structure. The appropriate determination of wind loads for design forms the basis of this proposal.

Compared with standard construction practice, it is an unusual feature of the industry surrounding the 'supply' of fabric structures, that at all stages complex analytical concepts are applied and solutions to problems sought which tend to be almost unique to each contract. This is reflected in the list of external contributors to the project that includes consulting engineers and contractors. This field of structural engineering is supported by very little published guidance.

In the 4th February 1999 issue of *New Civil Engineer* a special feature appeared under the title "Creative tension – wiring into tented structures". The main article, written in the context of the Millennium Dome construction, opened with the following - **"Are giant tents domed? Tensile fabric structures are among the most spectacular of the 20th century – and the most controversial"**. This statement was made with reference to the collapse of the new fabric roof over Montreal's Olympic Stadium in early 1999 (*NCE* 28th January 1999). The actual cause of the failure was identified as design based and not arising from accidental damage. This event, which is not unique, serves as a timely example of the need for further research in the design of fabric structures.