FELSSO - Finite Elements with Laser Scanning for mechanical analysis of Sculptural Objects

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Figure 1
Complete 3D dataset of "Large Arch" in fibreglass, sited at RHS Wisley, captured using phase-shift laser scanning.

Abstract
This poster presents an overview of current research in progress to define a viable method for the finite element analysis (FEA) of large stone sculpture. The FELSSO study aims to provide conservators with a tool to predict the mechanical behaviour of stone sculpture when subjected to typical display, handling and transit scenarios. The FEA will use 3D solid body models, derived from high-resolution 3D laser scanned datasets. The Monte Carlo method and a degradation approach will be applied to assess the impact of microscopic damage, brittleness and heterogeneity on the strength of an object. Henry Moore's "Large Arch" (1980) in Travertine is the principal test case for the study.

Introduction and background
It is difficult, even for conservation experts, to predict how large stone sculptures will react to, and whether they may be damaged by, conditions of display, handling and transit. Currently, decisions are made on the basis of experience and the "best guess" of how the sculpture might behave. It is against this background that the FELSSO project was conceived; the aim of the project is to provide museums and collections with a computer-based tool that will allow the probable outcome of proposed actions to be analytically predicted before such decisions are made.

FELSSO is a collaborative pilot research project, financially supported by the Arts and Humanities Research Council and the Henry Moore Foundation. The principal team members are Dr. Angela Geary (Senior Research Fellow in Cultural Heritage Visualisation, SCIRIA, University of the Arts London), Dr. John Harrison (Senior Lecturer in Rock Mechanics, Imperial College London) and Mr. Derek Pullen (Head of Sculpture Conservation, Tate).

Originally, it was planned to base the research on sculptures from the Tate collection. However, the Henry Moore Foundation has given permission for Moore's travertine stone "Large Arch" (1980) to be used as the principal subject for the FELSSO study. "Large Arch" — once displayed at the side of the lake in Kensington Gardens — was dismantled twelve years ago due to structural instability. To date, no method has been found to determine whether the sculpture can be safely reconstructed and, if so, how this might be best achieved. As a result, the individual blocks of travertine from which "Large Arch" is sculpted have remained in storage since that time.

3D Laser scanning and FEA are the principal analytical methods applied in the research. FEA is a mature technology that is widely used in engineering to calculate the strength of structures such as buildings, cars and aircraft (see figure 4), but with FELSSO it will be applied to sculptural artefacts in order to accurately model the probable impact that different handling or display scenarios may have.

Earlier this year, 3D laser scanning was applied to both the blocks of the dismantled "Large Arch" (see figure 3) and a fibreglass copy currently displayed at RHS Wisley (see figure 6). The resulting geometric data will allow the internal stresses, to which the reconstructed sculpture would be subject, to be modelled and assessed. In this way it will be possible to determine how the sculpture could be safely reconstructed. It is possible that reconstruction may require the use of internal reinforcing elements; the FELSSO model will be able to consider various materials for these, and determine their positions within the sculpture.

Analytical methods
3D Data Capture
The FELSSO project has used commercially available advanced 3D laser scanning technology to capture detailed 3D surface geometry data of the sculptures. A phase-shift laser scanning system was the chosen method for digitization. Phase-shift laser scanners use the principle that a wave reflected from an object will undergo a phase-shift. By using carrier waves of different wavelengths, and measuring the phase-shift induced in each, these systems are able to compute the distance from the instrument at which the reflection occurred (see figure 2). This is the distance to the object being surveyed. By making many such measurements, each separated by a small angular distance of a few seconds of arc, the systems are then able to generate a digital model of the surface of the object.

This technology has the advantage of accommodating a large capture range of up to 80m, at accuracy sufficient for the purposes of the research (approx. 3.5mm). It was possible to capture the entire "Large Arch", in fibreglass, from as few as seven scan positions, taking less than a day on site to complete (see figures 1 and 5).

The FEA method
The basic concepts of using FEA for stress analysis of irregularly-shaped objects are well known and routinely used in industry. Thus, we will be following the usual route of converting the surface data into a solid body model composed of unstructured tetrahedral elements. However, a key issue will be to determine what density of scan data should be used in the modelling, in order to capture sufficient detail of the surface texture of the sculpture whilst preventing inclusion of too large a number of elements. The texture on Arch occurs at a variety of scales (from a few millimetres to tens of centimetres), and the potential interaction between this and the heterogeneous nature of the travertine is currently unknown.

Benefits of the research and future work
The use of the "Large Arch" as the principal subject for the FELSSO project is a unique and exciting opportunity to show how modern data acquisition and numerical analysis methods can help solve the very real conservation challenges involved in redisplaying this spectacular sculpture. By working with the "Large Arch", the research project will deliver a detailed practical strategy, based on FEA, for the physical conservation and redisplay of stone sculpture. In addition, the 3D data captured from the sculpture will be available for use by the Henry Moore Foundation in a variety of ways, including the computer aided manufacture of a scaled facsimile for display and educational purposes, and 3D models for virtual display and web based access.

A robust method for the prediction of damage and stress behaviour in stone sculpture is almost certain to become an indispensable tool for conservation professionals. However, in addition to the benefits of being able to reliably pre-determine optimal transit and handling arrangements for particular objects, there is scope for the tool to be adapted to allow artists to employ FEA in the design of new work. Artists often push the boundaries of the materials they use in the creation of their work but, particularly in large scale pieces, there are real risks associated with structural instability. FEA could allow sculptors to experiment freely to the safe limits of the materials they apply, and to readily determine when such limits have been exceeded.

Subsequent to establishing a viable approach for stone, it is intended to extend the study to develop FEA techniques for a wider range of materials and composites, allowing the stress behaviour of many types of cultural heritage objects, such as panel paintings, metal and ceramic objects, to be analysed in this way. Whilst some artifacts do not present the same challenge to duplicate in a physical test as large scale stone sculpture, using FEA modeling has several advantages over physical mock-ups. Many scenarios can be modeled rapidly and a wide range of variables can be covered, including material variability, scale and environmental conditions. The time and materials expended using this approach would certainly be far lower than the physical equivalent.

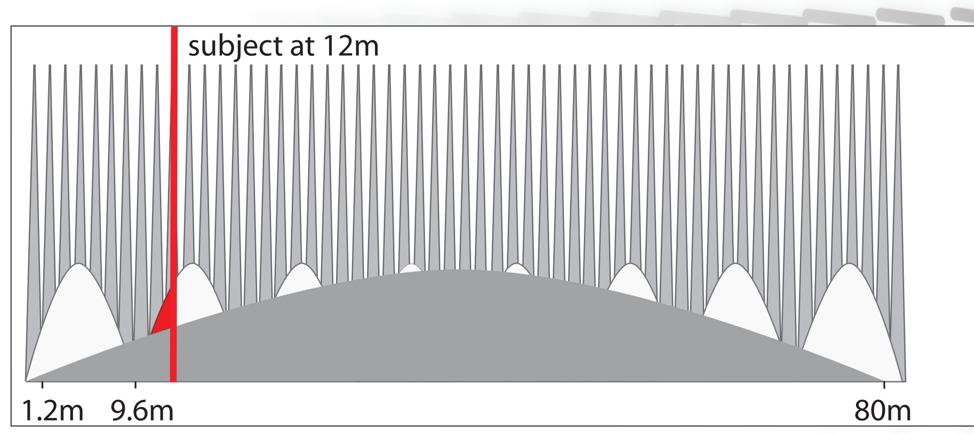

Figure 2
Three infra-red carrier waves of different wavelengths are used in the range calculations of the phase-shift 3D scanner.

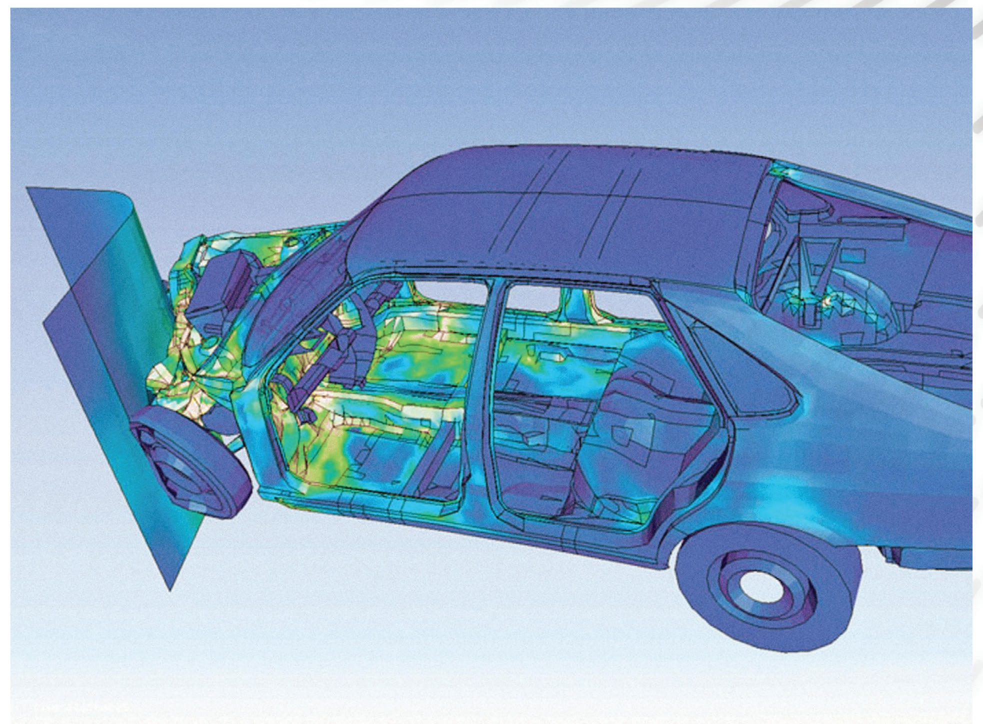

Figure 4
A visualization of an asymmetrical car collision analysis done using the finite element analysis method.

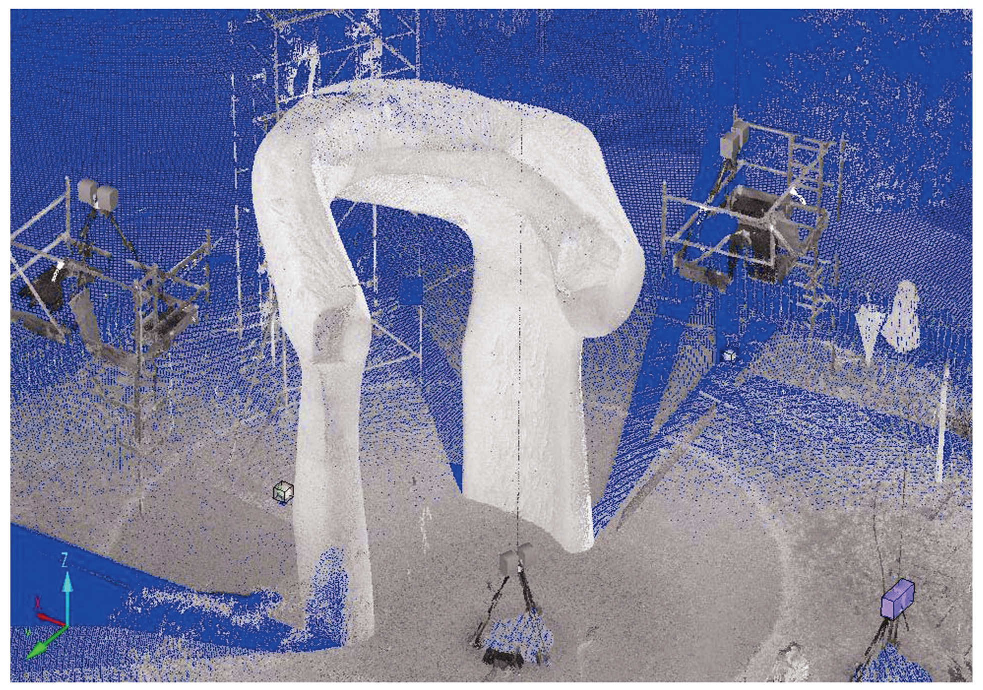

Figure 5
One set of raw 3D coordinate data of the fibre-glass "Large Arch", captured from an elevated scanning location.

Figure 3
The dismantled blocks of "Large Arch" (Henry Moore, 1980) in travertine stone during scanning sessions at Kensington Gardens, London.

Figure 6
"Large Arch" (Henry Moore, 1980). Replica in fibreglass. Currently on display at RHS Wisley.

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