Plan Overview

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Title: Beyond Nature: Luffa-Inspired Hierarchical Structural Materials through AI-Driven Design and Additive Manufacturing (BLISS)

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Project abstract:

BLISS aims to unlock new opportunities in high-performance structural materials by translating the hierarchical fibrous geometry of *Luffa cylindrica* (sponge gourd) into innovative engineered material and structural systems. Despite being composed of relatively weak, low-stiffness organic fibres, Luffa exhibits remarkable mechanical efficiency, including high specific stiffness, strength and energy absorption. Its performance arises primarily from its complex, interconnected, hierarchical architecture. *BLISS* seeks to exploit these geometric principles using the wider range of engineering materials available today, creating lightweight, resilient and multifunctional structural technologies that go beyond the capabilities of conventional solutions.

The project will address three fundamental challenges: (1) developing appropriate 3D imaging approaches to capture Luffa's complex hierarchical geometry; (2) identifying and characterising its underlying geometric patterns and structural principles; and (3) demonstrating the potential to reproduce and adapt these architectures using different engineering materials. By integrating advanced 3D imaging, AI-driven geometric analysis and design, and additive manufacturing, *BLISS* will establish a pathway for translating natural architectures into engineered structural elements. These will incorporate diverse material systems, including metals, fibre-reinforced polymers and functionalised nanocomposites.

BLISS moves beyond conventional biomimicry, which often focuses on replicating natural materials, towards understanding and exploiting the fundamental geometric principles underlying their performance. Recent advances in imaging, artificial intelligence and additive manufacturing provide unprecedented opportunities to characterise, optimise and reproduce complex natural architectures. The project will establish new fundamental understanding of hierarchical structural materials and demonstrate how these principles can be adapted to discover previously unexplored material and structural technologies.

Lightweight, resilient and resource-efficient structural technologies are essential for achieving the UK's net-zero ambitions and strengthening industrial competitiveness. *BLISS* will contribute to these priorities, particularly in offshore renewable energy and construction, by enabling structures with improved mechanical performance, reduced material consumption and lower embodied energy. Its potential applications also extend to aerospace, automotive, biomedical and defence sectors. Furthermore, integrating multifunctional capabilities, such as electromagnetic interference shielding, alongside structural performance could reduce material requirements and reliance on critical minerals.

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Beyond Nature: Luffa-Inspired Hierarchical Structural Materials through AI-Driven Design and Additive Manufacturing (BLISS)

Data Collection

What data will you collect or create?

The project will generate and use qualitative and quantitative research data through experimental investigations, 3D imaging and scanning, computational modelling, AI-driven geometric design and mechanical testing.

Data description	type	format	volume
Images of Luffa (Primary)	qualitative	.jpeg,.stl, .tiff	200 GB
Geometry data (Primary)	quantitive	.text	<1 GB
Numerical data (Primary)	quantitive	.csv	<1 GB
Experimental data (Primary)	quantitive	.csv	< 1GB
Existing experimental data (Secondary)	quantative	.csv, .text	<0.5GB

How will the data be collected or created?

Micro-CT imaging of Luffa specimens will follow established high-resolution X-ray imaging practices and the operational protocols of the Roslin Institute, University of Edinburgh.

Image datasets will be processed using ImageJ/Fiji and Bitplane Imaris 9.5 for segmentation, volumetric measurements and 3D reconstruction. Reconstructed geometries will be exported in suitable formats, including STL, for further processing using CAD software such as SolidWorks. Imaging and processing procedures will be documented to ensure reproducibility.

The reconstructed geometries will be analysed to identify characteristic structural patterns and hierarchical features. Computational algorithms and custom-built AI tools will then be developed to support geometric identification, design generation and performance optimisation. Computational work will use University of Edinburgh facilities and local research computers.

Generated designs will be fabricated as 3D-printed test specimens using University facilities and mechanically tested at FastBlade. Experimental data will be collected using appropriate measurement and data acquisition systems. Specimen details, manufacturing and testing procedures, loading conditions and data processing methods will be recorded to ensure traceability and reproducibility.

All data collection, processing and storage will follow the relevant facility protocols and University of Edinburgh research data management policies.

Secondary data will be obtained from publicly available scientific literature, including Luffa geometries and reported mechanical properties. Extracted information will be recorded in standard digital formats, with appropriate references to original publications.

Documentation and Metadata

What documentation and metadata will accompany the data?

All datasets will include appropriate documentation and metadata to support interpretation, reproducibility and reuse.

· **Imaging data:** Specimen identification, imaging parameters, acquisition conditions, image resolution, reconstruction settings and image-processing procedures. Available facility acquisition logs and quality-control reports will also be retained.

· **Geometric data:** Specimen dimensions, geometric characteristics, segmentation procedures, file formats and CAD processing steps.

· **Computational data:** Algorithms, modelling assumptions, input parameters, software versions and processing procedures.

· **Experimental data:** Specimen identification, material and manufacturing details, testing configurations, loading conditions, measurement units and data acquisition and processing methods.

A README file will accompany each major dataset, describing its contents, directory structure, file-naming conventions, associated software and instructions for accessing and interpreting the data. Data dictionaries will also be provided for numerical and experimental datasets.

Ethics and Legal Compliance

How will you manage any ethical issues?

The project will not involve human participants or personal data, and no human or animal subject data are anticipated. Primary data will be generated through imaging, computational investigations and experimental testing of Luffa specimens.

Secondary data from scientific publications will be appropriately acknowledged and referenced. Requirements relating to the collection, handling and use of biological materials will be followed in accordance with University and facility procedures.

Although no significant ethical issues are anticipated, some research outputs may have commercial value. Commercially sensitive information will therefore be managed in consultation with Edinburgh Innovations (EI), in accordance with University policies.

How will you manage copyright and Intellectual Property Rights (IPR) issues?

The dissemination and IP strategies will reflect the nature and commercial potential of individual research outputs.

Fundamental research findings, methodologies and datasets will be published open access and shared through appropriate repositories wherever possible. Where commercially valuable technologies, methodologies, software or products are developed, appropriate IP protection, including patent applications, will be considered before public disclosure.

Edinburgh Innovations will support the assessment, protection and exploitation of potentially valuable IP. Research outputs will be made publicly available in accordance with University IP policies and any applicable commercial restrictions.

Storage and Backup

How will the data be stored and backed up during the research?

Raw research data, including original micro-CT images, processed imaging datasets and experimental data, will be stored in the University of Edinburgh's Research DataStore.

DataStore provides enterprise-class storage, automatic replication to an off-site disaster recovery facility and 10 days of online file history. Off-site tape backups retain 60 days of filesystem history, supporting recovery following accidental deletion or other incidents. Sensitive data will be protected using 256-bit encryption where required by University policy.

Working datasets, including processed images, CAD models, computational files, AI development files and experimental datasets, will also be stored in the University-managed Microsoft OneDrive environment to facilitate collaboration among authorised investigators.

The Principal Lead (PL) will oversee data organisation and access to shared project folders, ensuring that important raw datasets are retained in DataStore and working files are maintained in OneDrive as appropriate.

How will you manage access and security?

Access to DataStore and OneDrive will require University authentication. The PL will manage project folder permissions, restricting access to authorised investigators and reviewing permissions when project personnel change.

Raw and commercially sensitive research data will be protected through University-managed authentication, access controls and applicable information security and data protection policies.

Selection and Preservation

Which data are of long-term value and should be retained, shared, and/or preserved?

The following datasets and outputs will be retained for their long-term research value:

- Original and processed micro-CT images, including reconstructed 3D geometries.
- Geometric models, CAD files and AI-driven computational design datasets.
- Raw and processed experimental data from mechanical testing.

· Numerical modelling results, computational algorithms, AI methodologies and associated source code.
· Documentation of experimental procedures, computational methods, data processing and model development.

These resources will support future research, independent verification of findings and further development of the proposed structural design methodologies.

Fundamental research findings, datasets and methodologies will be shared openly wherever possible. Potentially valuable IP will be assessed with Edinburgh Innovations before public dissemination.

What is the long-term preservation plan for the dataset?

The project will follow the principle of making research data as open as possible and as restricted as necessary.

Datasets with long-term research value will be deposited in DataShare, the University of Edinburgh's open-access research data repository, subject to applicable IP, commercial confidentiality and legal restrictions.

Raw and processed datasets, together with relevant documentation and computational resources, will be retained for a minimum of 10 years after project completion, in accordance with University retention policies and funder requirements. Where data cannot be made fully open, appropriate metadata and descriptions will be made available wherever possible.

Data Sharing

How will you share the data?

Datasets supporting published research findings will be deposited in DataShare wherever possible, typically alongside the associated publications or within 3–6 months of project completion, subject to IP assessment and protection.

AI methodologies, computational algorithms, geometric design data, numerical modelling results and other research tools will also be shared through appropriate open-access repositories and platforms where feasible. Relevant documentation and instructions will accompany shared datasets to facilitate reuse and reproducibility.

Potentially commercially valuable outputs will be reviewed with Edinburgh Innovations before public release. Any necessary restrictions will follow University policies and applicable legal requirements.

Are any restrictions on data sharing required?

No significant restrictions are anticipated at the outset. However, some outputs may have commercial value and require temporary restrictions to allow appropriate IP protection, including patent applications.

The project team will work with Edinburgh Innovations to establish suitable arrangements that protect IP while maximising research data availability. Restrictions will be limited to information necessary to protect the relevant interests.

Responsibilities and Resources

Who will be responsible for data management?

· **Project Lead:** Overall responsibility for data management, including collection, quality assurance, ethical and legal compliance, access management, IP considerations and timely deposition of research datasets.
· **Project Co-leads and Research and Innovation Associate:** Responsibility for generating, processing, documenting and maintaining research data in accordance with agreed procedures and University policies.
· **IT and Research Data Management Support:** Technical support for storage, backup, access management, metadata and long-term preservation, as required.

What resources will you require to deliver your plan?

The project will use existing University of Edinburgh infrastructure, including DataStore, University-managed OneDrive, computing facilities and institutional research data repositories. Imaging, 3D printing and mechanical testing will use existing facilities and data acquisition systems at the Roslin Institute, University of Edinburgh and FastBlade.

Approximately 10% FTE IT support will be allocated to data management, storage, backup and related technical requirements.

Additional advice and support will be sought from the University's Research Data Service and Edinburgh Innovations where necessary.