Digital Health Interventions for Hypertension Control in Low-and-Middle Income Countries (LMICs) – Systematic Review

Angelina Ankah Amengu, a.amengu23@imperial.ac.uk
Supervisors: Dr. Talya Porat, Dr. Weston Baxter

> "The study highlights the urgent need for research into the limited adoption of digital health interventions (DHIs) for hypertension control in LMICs."

Background & Motivation

Hypertension affects 32% of adults aged 25 and older in LMICs, contributing to heart disease, strokes, and kidney failure. However, only 14% of hypertensive patients have their condition controlled [1] (Figure 1).
While digital health interventions (DHIs) have the potential to improve hypertension management (cite), their adoption and effectiveness in LMICs is limited (cite) compared to HICs.
Despite efforts to control hypertension in LMICs, research on the effectiveness and barriers influencing DHIs in achieving blood pressure reduction, medication adherence, and healthy lifestyle modifications remains limited [2] [3] [4], highlighting the pressing need for further exploration.

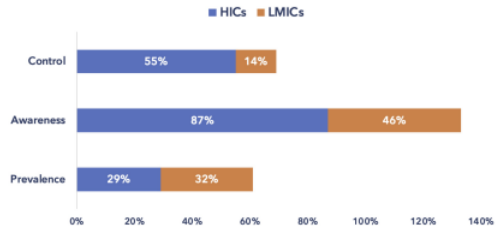


Figure 1: Hypertension prevalence, control and awareness in HICs vs LMICs

Aim & Objective

To explore the effectiveness and barriers of digital health interventions in achieving health outcomes (i.e., blood pressure control, medication adherence, and healthy lifestyle modifications) in LMICs.

Method

We conducted a systematic search of the Web of Science, PubMed, and Embase databases for articles published between January 2010 and September 2023.
The results were reported in accordance with the PRISMA search process.
The systematic review included 35 studies from LMICs, after the screening process.

Results

Results 1: Blood Pressure Control

Interventions for BP Control

SMS messages, alerts, reminders, telemonitoring, task shifting, and self-monitoring.

Blood Pressure Reduction

9%

of interventions decreased both systolic and diastolic blood pressure

Self-Blood Pressure Monitoring

14%

of interventions increased patients' self-efficacy and compliance towards self-blood pressure monitoring

Identified Barriers

Lack of personal home BP monitors
Lack of personal blood pressure
Lack of personalised interventions
Mobile phones shared among family

Results 2: Medication Adherence

Interventions for Medication Adherence

SMS messages, alerts, reminders, and follow-ups, along with clinical decision support systems in titrating medications or adjusting prescriptions.

Medication Adherence

29%

of interventions increased patients' compliance with antihypertensive medication intake

Identified Barriers

Lack of availability and accessibility of antihypertensive medications, along with legal restrictions on licensed chemical sellers and community health workers

Lack of shared decision making between patients and healthcare professionals on treatment plans, reminders and follow-up

Limited interventions focusing on patient active engagements and personalisation tailored to medication titrations, refills, and prescriptions

Results 3: Healthy Lifestyle Modification

Interventions for Healthy Lifestyle Modification

DASH diet; Reminders; Alerts; Follow-up; peer-counselling, and education.

Healthy Diet

23%

of interventions reduced salt/sodium intake and increased fruit and vegetable consumption among hypertensive patients

Physical Activity

17%

interventions increased physical activity among hypertensive patients.

Identified Barriers

Financial burden of cooking separate meals with little or no salt when sharing household meals

Limited healthy lifestyle advice from healthcare professionals

Inability of older adults, particularly obese hypertensive patients, to engage in physical activities.

Design Recommendations

- Integration of community-centred, and behaviour-centred approaches into intervention design and implementation
- Personalized and gamified applications for active user engagement, tailored to diverse cultures and contexts.
- Data visualization for mHealth apps using culturally relevant colours and symbols, with real-time feedback and recommendations.
- Provision of incentives, such as blood pressure monitors, to participants in low-resource settings.
- Cost-effective interventions tailored to diverse contexts and settings.
- Research collaborations, funding, and updates on policies and regulations.

Conclusion

Effective digital health interventions (DHIs) in LMICs primarily focus on SMS, alerts, and reminders for hypertension control. However, their effectiveness is limited by inadequate resources, lack of shared decision-making, and insufficient active engagement between patients and healthcare professionals. Future interventions should incorporate advanced DHIs, along with community-centred and behaviour-centred approaches.

Bio

Angelina Ankah Amengu is a PhD student at the Dyson School of Design Engineering. Her PhD research focuses on designing novel digital health interventions for improved self-measured blood pressure (SMBP) monitoring among hypertensive patients in LMICs, using a behaviour-centred design approach. Her research interests include behavioural design, participatory co-design, HCI and WSNs.

References

[1] K. T. Mills, A. Stefanescu, and J. He, "The global epidemiology of hypertension," Nat Rev Nephrol., vol. 16, no. 4, pp. 223–237, 2020, doi: 10.1038/s41581-019-0244-2.
[2] V. Boima, A. Doku, F. Agyekum, L. S. Tuglo, and C. Agyemang, "Effectiveness of digital health interventions on blood pressure control, lifestyle behaviours and adherence to medication in patients with hypertension in low-income and middle-income countries: a systematic review and meta-analysis of randomised controll," eClinicalMedicine, vol. 69, p. 102432, Mar. 2024, doi: 10.1016/j.eclinm.2024.102432.
[3] M. Hoffer-Hawlik, A. Moran, L. Zerihun, J. Usseglio, J. Cohn, and R. Gupta, "Telemedicine interventions for hypertension management in low- And middle-income countries: A scoping review," PLoS One, vol. 16, no. 7 July, pp. 1–15, 2021, doi: 10.1371/journal.pone.0254222.
[4] Y. Mao, W. Lin, J. Wen, and G. Chen, "Impact and efficacy of mobile health intervention in the management of diabetes and hypertension: A systematic review and meta-analysis," BMJ Open Diabetes Res. Care, vol. 8, no. 1, pp. 1–11, 2020, doi: 10.1136/bmjdrc-2020-001225.
[5] A. J. Adler et al., "Barriers and facilitators to the implementation of a community-based hypertension improvement project in Ghana: A qualitative study of ComHIP," BMC Health Serv. Res., vol. 20, no. 1, pp. 1–13, 2020, doi: 10.1186/s12913-019-4774-x.
[6] B. Bhandari, P. Nareesmitan, R. Jayasuriya, A. Vaidya, and A. E. Schutte, "Effectiveness and Acceptability of a Mobile Phone Text Messaging Intervention to Improve Blood Pressure Control (TEXT4BP) among Patients with Hypertension in Nepal: A Feasibility Randomised Controlled Trial," Glob. Heart, vol. 17, no. 1, pp. 1–16, 2022, doi: 10.5334/GH.1103.
[7] L. R. Brandt et al., "Addressing depression comorbid with diabetes or hypertension in resource-poor settings: A qualitative study about user perception of a nurse-supported smartphone app in Peru," JMIR Ment. Heal., vol. 6, no. 6, pp. 1–21, 2019, doi: 10.2196/11701.
[8] A. Bozorgi et al., "The effect of the mobile 'blood pressure management application' on hypertension self-management enhancement: a randomized controlled trial.," Trials, vol. 22, no. 1, pp. 1–10, Jun. 2021, doi: 10.1186/s13063-021-05270-0.
[9] N. P. Cecchetti, E. A. Bellei, D. Biduski, J. P. M. Rodriguez, M. K. Roman, and A. C. B. De Marchi, "Developing and implementing a gamification method to improve user engagement: A case study with an m-Health application for hypertension monitoring," Telemat. Informatics, vol. 41, no. December 2018, pp. 126–138, Aug. 2019, doi: 10.1016/j.tele.2019.04.007.
[10] L. Steinman et al., "Facilitators and barriers to chronic disease self-management and mobile health interventions for people living with diabetes and hypertension in Cambodia: Qualitative study," JMIR mHealth uHealth, vol. 8, no. 4, pp. 1–16, 2020, doi: 10.2196/13536.
[11] D. Burke et al., "Keep it simple: designing a user-centred digital information system to support chronic disease management in low/middle-income countries," BMJ Heal. care informatics, vol. 30, no. 1, pp. 1–4, 2023, doi: 101136/bmjhci-2022-100641.
[12] J. D. Piette et al., "Hypertension management using mobile technology and home blood pressure monitoring: Results of a randomized trial in two low/middle-income countries," Telemed. e-Health, vol. 18, no. 8, pp. 613–620, 2012, doi: 10.1089/tmj.2011.0271.
[13] D. Jindal et al., "Development of mWellcare: an mHealth intervention for integrated management of hypertension and diabetes in low-resource settings," Glob. Health Action, vol. 11, no. 1, pp. 1–10, 2018, doi: 10.1080/16549716.2018.1517930.

IMPERIAL Dyson School of Design Engineering

Can asking questions relieve mood disorders?: Digital phenotype platform for adolescent mental health

> “ Digital phenotype can help manage adolescent mood disorders with a **stronger sense of connection through questionings.** ”

Minseo Cho, m.cho24@imperial.ac.uk
Prof. Rafael A. Calvo

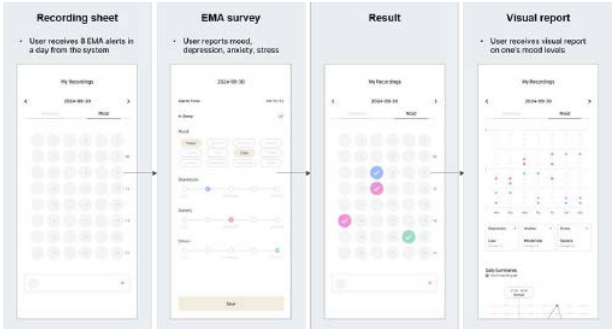
Abstract

This study is a Pre-PhD work, developing a platform that collects and tracks digital phenotypes related to the emotions and daily lives of adolescents. The study determined whether the platform positively affected mood disorder management through self-monitoring. Additionally, this study identified potential indicators to predict the development of mood disorders.

Introduction

Adolescence is the period with the highest incidence of mental disorders, half of which begin before age 18. Mental health issues during this stage of life can have extended effects into adulthood, highlighting the need for proactive interventions. Advances in technology have introduced digital phenotypes as a way to diagnose and treat mood disorders early. Despite their potential, concerns have been raised about the technical limitations of passive digital phenotypes and the limited uses of active digital phenotypes. Moreover, the effect of digital phenotype collection on managing mood disorders remains unexplored.

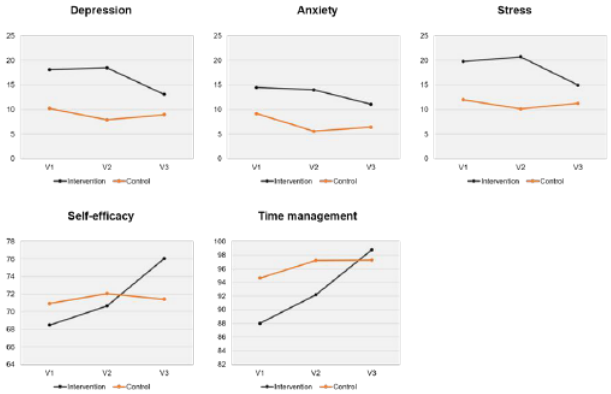
Methods



A four-week parallel, non-equivalent control group design was employed. The intervention group was instructed to install a digital phenotype collection platform on their mobile devices for 28 days. The passive control group was not required to engage in any specific task. Both groups were assessed at multiple points for mood disorders, namely depression, anxiety, and stress; self-efficacy; and time management abilities. Following the intervention, the intervention group participated in semi-structured interviews to discuss their experiences. Data was analyzed using 2×3 repeated measures ANOVAs with one between-subject factor (intervention group and control group) and one within-subject factor (pre-intervention, mid-intervention, and post-intervention).

Results

Total of 36 adolescents participated in the study. The digital phenotype collection platform significantly reduced adolescents' depression ($P = .044$) and stress ($P = .034$) and significantly increased their self-efficacy ($P = .002$) and time management abilities ($P < .001$). However, it did not result in significant changes in anxiety levels ($P = .113$). The correlational analysis revealed weak but statistically significant relationships between passive digital phenotypes and daily levels of depression, anxiety, and stress.



Discussion

Participants became more aware of their depression, anxiety, and stress levels by recording emotions and reflecting on their daily activities and behaviors. They identified emotional triggers from these records or recalled unrecorded daily events. This reflection helped them develop strategies to manage mood disorders, such as improving sleep or engaging in mood-boosting activities when triggers were controllable. When triggers were unknown or uncontrollable, participants used passive strategies such as distancing themselves from stressors.

Conclusion

The findings suggest that the digital phenotype collection platform can be used to understand and manage emotional disorders in adolescents. The study's high level of adherence, despite the extensive engagement required for active input, underscores the potential for using digital phenotyping in adolescent mental health care. The study contributes to a growing body of evidence supporting the use of digital phenotyping as a means of diagnosing and managing mood disorders in adolescents.

Bio

Minseo Cho is a PhD student at the Dyson School of Design Engineering. Her research interests include utilizing technology to improve mental health among adolescents. Her current research focuses on chatbot design for social prescribing to support the mental well-being for young people.

References

- Cho M, Park D, Choo M, Han DH, Kim J Adolescent Self-reflection Process through Self-recording on Multiple Health Metrics: Qualitative Study JMIR Preprints. 05/06/2024:62962
- Cho M, Park D, Choo M, Kim J, Han DH Development and initial evaluation of a digital phenotype collection system for adolescents: proof-of-concept study JMIR Preprints. 17/04/2024:59623

IMPERIAL Dyson School of Design Engineering

Design of a mHealth dementia screening tool in resource-limited settings

Marco Da Re, m.dare@imperial.ac.uk
Prof Rafael Calvo

"Successfully implemented in four diverse Peruvian sites; 32,000 older adults to be screened in 2025"

Abstract

Dementia impacts millions worldwide, with rural regions of Latin America facing notable challenges in diagnosis and care. Digital healthcare tools, while potentially transformative, often fail in these areas due to lack of cultural integration, usability issues, and missing features, resulting in ineffective top-down solutions. This project is about designing and implementing a mobile health dementia screening system tailored for rural Peru. For 18 months, we engaged in an iterative participatory process with local community health workers and healthcare professionals across Peru. We detail how this process directly informed our design outcomes, ensuring the solution was adapted to the specific needs of the communities.

Introduction

Latin America faces a growing dementia crisis, rising from 7.8 million in 2013 to 27 million by 2050. Early diagnosis is crucial but challenging in rural areas with inadequate health systems. As part of the *IMPACT Salud* project (NIHR150287) [1], we designed and implemented a scalable, accessible diagnostic tool for use by non-healthcare professionals (e.g., community health workers) in rural Peru.

Methods

Our 18-month mixed-methods approach, guided by the Information Systems Research framework and Human-Centered Design methods [2], involved 40 community health workers, 30 healthcare professionals, and the Peruvian Ministry of Health across four diverse sites in Peru. The process included:

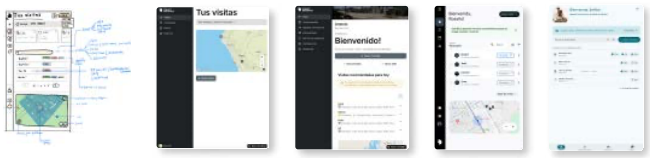
1. **`Pre-field studies`**: literature review, workshop and interviews, remote community meetings, and low-fidelity prototyping.
2. **`Field studies`**: ethnography, co-ideation workshops, and MVP testing in four diverse regions of Peru.
3. **`Post-field design:`** iterative development of a comprehensive socio-technical system based on field insights.

Outcomes

Our design process yielded a comprehensive socio-technical system for dementia screening (detailed information available via QR code down below).

1. **`An offline-first mobile app screening for community health workers`** accommodating varying literacy levels, health visit management and personalisation features enhancing autonomy and competence [3].
2. **`A web application for supervisors and researchers,`** with team performance metrics, data visualisation and editing capabilities, user-friendly questionnaire editor for system expansion.

The cognitive and physical tests in the system are suitable for remote communities and have been previously tested in Latin America.



Sketches
Concept

Iteration 1 - 3
Concept and content

Iteration 4 - 6
Content and logic

Iteration 7 - 8
Usability (Low-fi)

Iteration 9 - 15
Usability (Hi-fi)

Impact

The project has been implemented in four sites across Peru, with plans to screen 32,000 older adults in 2025. The Peruvian Ministry of Health intends to adopt and integrate the tool, with potential scaling to Colombia and Argentina. *IMPACT Salud* aims to establish a culturally appropriate mHealth intervention model applicable to various resource-constrained settings in Latin America and globally.

References

1. Lúcar MG, et al. Peru initiates the IMPACT project. Lancet Neurol. 2023;22(8):653.
2. NIHR. Community engagement and involvement. nihr.ac.uk (2024).
3. Ballou N, et al. Self-Determination Theory in HCI: Shaping a Research Agenda. CHI EA '22. ACM; 2022:1–6.

Bio

Marco is a research assistant and design lead at the Wellbeing Technologies Lab. His work focuses on community-based health, AI, and technology ethics. Marco specialises in participatory approaches with marginalised communities and the ethical implementation of technology in low-resource settings.

IMPERIAL Dyson School of Design Engineering

Read and watch more

Prediction of microstructural representativity from a single image

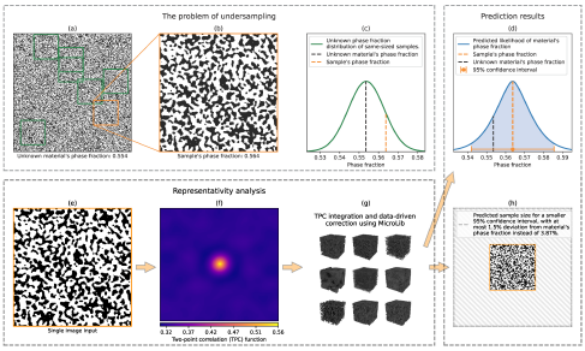
Amir Dahari (a.dahari@imperial.ac.uk), Ronan Docherty, Steve Kench, Samuel J. Cooper

> “**Single image** representativity estimation gives researchers and practitioners their **first tool** for measuring the proximity of their image properties to the material properties together with an associated confidence level”

Background and existing method

Precise control over phase-fractions is essential for optimizing materials for specific applications, ensuring optimal performance and reliability. However, usually only a small sample of the material is available, which is used to deduce the bulk material properties, such as its phase fraction. Therefore, knowing how much the image is representative of the material is crucial.

To determine image representativity, the existing traditional method require many large image samples, which are expensive, time consuming and sometimes only feasible for simulated data to obtain. Moreover, we find that when the dataset is not large enough, the existing method suffer from biased over-confident representativity predictions.



Our representativity method

In this study, we present a novel method for predicting the phase fraction of a material (the fraction of a specific phase in a material), from a single image sample, with associated confidence levels.

Our method leverages the Two-Point Correlation function (TPC) to directly estimate the variance of phase fraction, while validating the variability of our prediction using the heterogenous microlib (microstructure library) dataset. Importantly, we prove that our prediction is unbiased and is the right prediction in expectation.

User confidence level flexibility

By allowing users to input their desired confidence level, this method not only estimate the material phase fraction but also gives researchers the flexibility to choose their preferred level of confidence of the estimation.

Measuring representativity

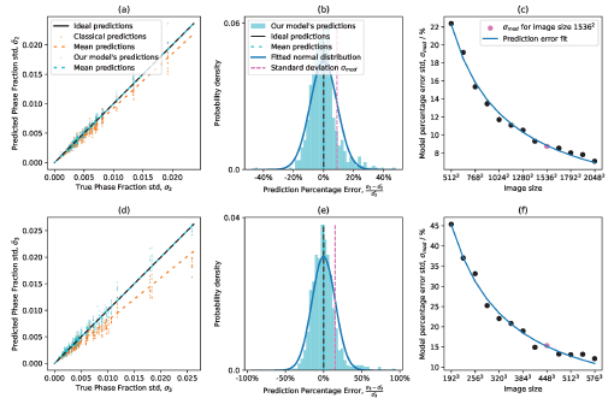
From a certain image size, the distribution of the phase fraction of a random image reaches a normal distribution centered around the phase fraction of the bulk material, which the images are sampled from.
If the standard deviation of this distribution is known, we would know, with a certain amount of confidence, the closeness of the phase fraction of the image to the phase fraction of the bulk material. So predicting how much an image is representative equals predicting the standard deviation of the distribution of phase fractions of images of the same size.

Webapp!

To make our model easily accessible, we have created a web-application (desktop version) at the address www.imagerep.io for quick, simple and informative use of the model.

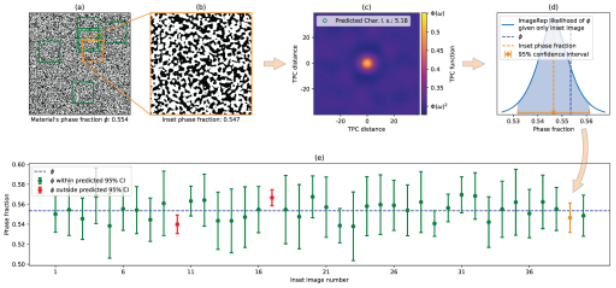
Results

The method was tested for all 77 2-phase materials in microlib, predicting the phase fraction standard deviation for the different materials and image sizes. For each image size, 10 predictions were made for each material (hence the horizontal scatters) vs. the ground truth standard deviation obtained by observing the standard deviation of thousands of images. The prediction percentage errors around 0% (perfect prediction) form a normal distribution and is used in the final prediction as the model error.



Further validation

To further validate the method, we test the method with 50 different materials generated with PoresPy, and further 3 real open-source battery materials. Observing how the method outputs accurate predictions, which are for example having the true phase fraction within the bounds 95% of the time if 95% is the user confidence level.



Bio

Amir is a 2nd-year PhD student, supervised by Dr. Sam Cooper, whose current project is understanding materials image representativity, for adding confidence to image-based results. Prior to that Amir worked on 2D and 3D image data fusion using machine learning. Before joining Imperial College Amir studied Mathematics and Computer Science at the Hebrew University of Jerusalem.

References

- S. Kench, I. Squires, A. Dahari, and S. J. Cooper. Microlib: A library of 3d microstructures generated from 2d micrographs using slicegan. Scientific Data, 9(1):645, 2022.
- A. El Moumen, T. Kanit, and A. Imad. Numerical evaluation of the representative volume element for random composites. European Journal of Mechanics-A/Solids, 86:104181, 2021.
- T. Kanit, S. Forest, I. Galliet, V. Mounoury, and D. Jeulin. Determination of the size of the representative volume element for random composites: statistical and numerical approach. International Journal of solids and structures, 40(13-14):3647–3679, 2003.

IMPERIAL Dyson School of Design Engineering

Haptic Digital Musical Instruments using Self-Sensing Vibrotactile Transducers

Matthew Davison, m.davison23@imperial.ac.uk
Andrew McPherson, andrew.mcpherson@imperial.ac.uk

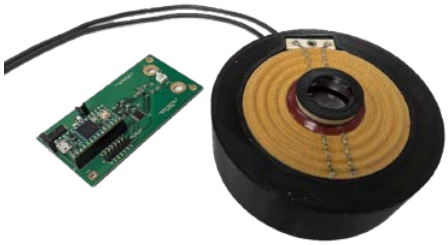
Enabling bidirectional exchange of tactile energy between the physical and digital worlds through a single point of contact

Abstract

An approach to achieving simultaneous, collocated vibrotactile haptic feedback and tactile sensing is presented. A single voice coil transducer is used for sensing transients such as strikes and taps by a fingertip, along with continuous surface pressure. A current drive amplifier provides the actuation signal. This technology can be used in digital musical instrument (DMI) designs to enable bidirectional tactile interaction between the musician and the synthesis model.

System Design

- A voice coil transducer is used for wide-band vibrotactile actuation, using a current drive amplifier, while simultaneously sensing tactile input
- The voltage across the transducer is measured.
- Changes in the transducer's impedance cause a change in the current-voltage transfer function
- Filtering is used to model the impedance response to cancel the actuation signal from the sensed excitation signal
- This provides 3 simultaneous modalities:
- 1. Actuation for vibrotactile haptic feedback
- 2. Sensing as an audio-rate tactile pickup
- 3. Sensing continuous force applied to the transducer

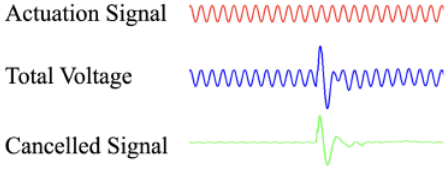


Acting as a Tactile Pickup

- The voltage across the transducer is used as an audio-rate tactile pickup signal, picking up hits upon the transducer's surface
- Like a microphone, movement of the coil creates a voltage
- The total measured voltage is the sum of the actuation signal voltage and the pickup voltage
- The actuation signal is cancelled by applying the modelled impedance filter to the signal and subtracting it from the measured voltage, leaving only the pickup voltage

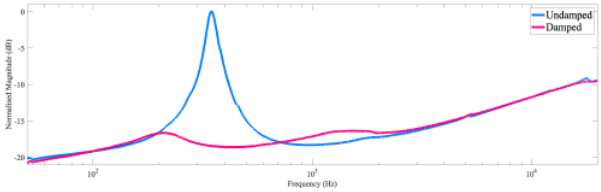
$$V_T = I_a Z + V_p$$

Where V_T is total measured voltage, I_a is actuation current, Z is the transducer's impedance, and V_p is the pickup voltage



Transducer Impedance

- The impedance of a voice coil transducer is dependent upon its mechanical and electrical properties
- A voice coil transducer exhibits a resonant peak due to its moving mass, compliance, and mechanical damping
- There is also a rise in impedance at high frequencies, due to the inductance of the voice coil
- Both elements can be modelled with digital filters, to cancel the actuation signal from the pickup signal, preventing feedback

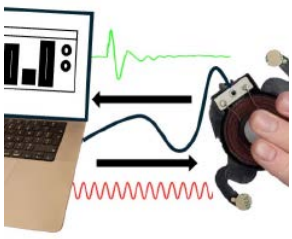


Force Sensing

- Applying force to the transducer varies the mechanical damping; this can be seen in the above graph
- The peak impedance at the resonant frequency is inversely proportional to the damping force applied to the transducer
- By adding a constant tone to the actuation signal at the resonant frequency, changes in the damping can be detected

Instrument Design Implications

- The system is being explored as part of digital musical instrument designs using resonant synthesis algorithms.
- The haptic system enables tactile excitation of the model by feeding the pickup signal into the model's input
- Control parameters, such as virtual damping, can be modulated by mapping the force applied to the transducer to the parameter
- Vibrotactile haptic feedback provides a tactile means of engaging with the output of the instrument



Bio

Matthew Davison is a PhD student within the Augmented Instruments Lab, led by Prof. Andrew McPherson, at the Dyson School of Design Engineering, Imperial College London. His research is centred around exploring techniques for enabling richer tactile experiences within digital musical instrument design.

IMPERIAL Dyson School of Design Engineering

Visual Insight: The impact of data visualisation on decision making – A systematic review

Rui Hu, r.hu23@imperial.ac.uk
Supervisors: Talya Porat, Céline Mougenot

> "This review highlights the factors which contribute to better decision making in a data visualisation."

Abstract

Data visualisation plays a crucial role in enhancing decision-making, but the specific ways it contributes remain unclear. This systematic review analysed 27 studies, identifying visualisation attributes most strongly linked to effective decision-making across various domains. Additionally, standardized metrics for evaluating decision outcomes are provided.

Introduction

Researchers from diverse domains are investigating how visualisation could enhance decision making, which are fundamental, as different visualisation features can significantly influence the decisions people make. However, there are inconsistent findings regarding the effectiveness of different visualisation types and features across different domains, and there is lack of standardisation in how decision making outcomes are measured across studies.

Methods

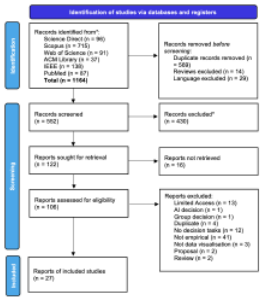


Figure 1 (left). PRISMA flow chart for identification and screening.
Figure 2 (right). Research domains of eligible papers.

Following the PRISMA (Page et al., 2021) show in Figure 1, the criteria we set up to select papers is as follows.
(a.) Must be written in English. **(b.)** Must not be a review paper. **(c.)** Must involve 2D data visualisations in a digital form. **(d.)** Must have an evaluation of decision performances. **(e.)** Must not include group or shared decisions. As a result, 27 qualified articles were included in the review. The domains of the papers are showed in Figure 2.

Results

Domains and Visualisations

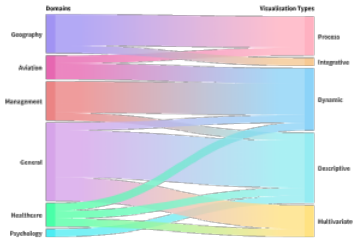


Figure 3. Relationship between research domains and visualisation types.

- Data visualisations are categorised based on the volume of information (Cavaller, 2021).
- Visualisation type preferences change across domains due to data feature and context.

Decision Tasks and Visual Attributes

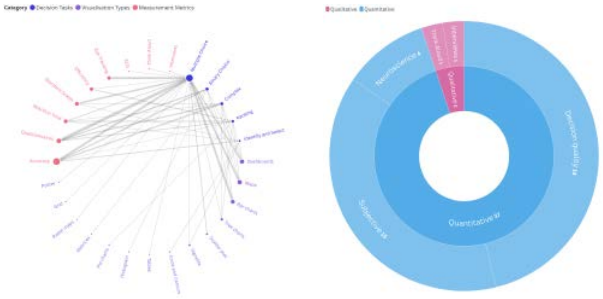


Figure 4 (left). Radial network among decision tasks, visualisation types and measurement metrics.
Figure 5 (right). Quantitative measures and qualitative measures.

Visual attributes: shape, colour, lines and text

- In relatively straightforward tasks, text representations are more effective than graphs. However, when there is time limits, text does not perform better than charts.

Task-related variables: limited time and feedback

- Time pressure and feedback both had no effects on the decision accuracy.

Uncertainty and working memory capacity

- Uncertainty does not increase either the workload of participants or the time required to make decisions. It led to a decrease in confidence, but no significant change in accuracy.
- Users with lower working memory capacity performed worse than those with higher working memory capacity on the same task.

Measurement Metrics

Measurement metrics are classified into two categories, qualitative and quantitative. Qualitative metrics are those associated with the quality of decision-making, subjective assessment, and neuroscience measures (Figure 5).

Conclusion

This review examines empirical articles that investigate the impact of data visualisation on decision making. Our results show that the types of visualisations are influenced by differences in data features across domains.
Decision quality is affected by visual components and working memory capacity, but not by time constraints, feedback, or uncertainty.
Future studies could assess decision quality by tracking reaction time and accuracy, obtaining subjective assessments using interviews and questionnaires, and assessing the cognitive effort using physiological measurements.

Bio

Rui Hu is a PhD student with a research focus on decision-supportive data visualisations. Her interests include human factors, cognitive engineering and human-computer interaction.

IMPERIAL Dyson School of Design Engineering

References

- Page, M. J. et al. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. BMJ, 372, n71. https://doi.org/10.1136/bmj.n71
- Cavaller, V. (2021). Dimensional Taxonomy of Data Visualization: A Proposal From Communication Sciences Tackling Complexity. Frontiers in Research Metrics and Analytics, 6. https://doi.org/10.3389/frma.2021.643533

Considering Uncertainty in Lunar O_2 Plant Deployment: A Multi-Objective Sequential Decision Problem Approach

Kosuke Ikeya*, Michel-Alexandre Cardin*, Jan Cilliers*, Stanley Starr*, Kathryn Hadler**
*Imperial College London, **European Space Resources Innovation Centre

Abstract

With growing interest in human lunar exploration, utilising lunar resources for various applications, such as liquid oxygen for spacecraft propellant, has been extensively researched. Decision-making to realise this concept, lunar In-Situ Resource Utilisation (ISRU), can be challenging due to uncertainty in the lunar environment and lunar ISRU operations. While previous studies have acknowledged these uncertainties, the impact of continuously updating our knowledge has not been thoroughly explored. This research project employs decision tree analysis, Monte Carlo methods, and Bayesian inference to address lunar ISRU as a multi-objective, sequential decision problem, aiming to evaluate the effects of information gathered on the Moon. A case study of deploying lunar ISRU pilot and full-scale plants suggests the significant flexibility added to future decision-making by demonstrating two different oxygen extraction strategies on a pilot scale.

1. Introduction

Artistic image of future human lunar exploration.

In-Situ Resource Utilization (ISRU) : the concept of using resources in space (e.g., lunar regolith)

To deploy efficient and feasible ISRU plants on the Moon, some critical decisions need to be made carefully. However, operational and environmental uncertainty makes this decision-making challenging. Past studies [1,2] concluded that ignoring such uncertainty can lead to inefficient or infeasible ISRU design. However, the effect of constantly updating our knowledge and how to utilise the updated information for decision-making has not been discussed yet.

Aim: assess the effect of information gathering on lunar ISRU deployment decision-making.

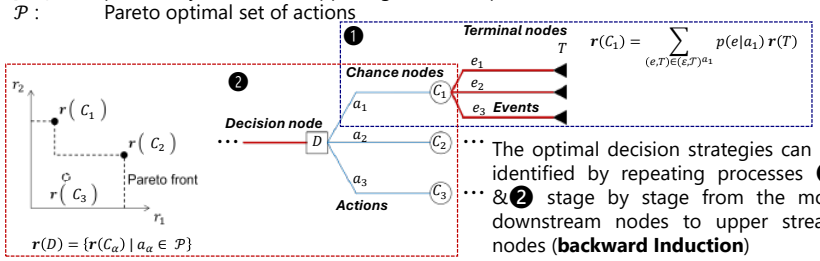
Method: multi-objective decision tree analysis, Monte Carlo simulations, & Bayesian inference.

Case study: deployment of lunar ISRU pilot and full-scale plant in the southern polar region.

2. Methodology

Multi-Objective Decision Tree Analysis [3]

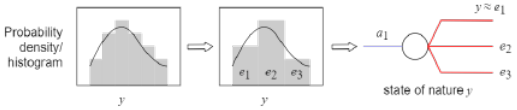
$\boldsymbol{r}(\cdot)$: performance measure to be maximised
$p(e|a)$: probability of event e happening under the previous action a
$\mathcal{P}$: Pareto optimal set of actions



The optimal decision strategies can be identified by repeating processes ❶ &❷ stage by stage from the most downstream nodes to upper stream nodes (**backward Induction**)

Conditional probabilities $p(e|a)$ need to be preassigned to each event branches

Monte Carlo Method



$y = f(\boldsymbol{x}, \boldsymbol{m})$
$f(\cdot)$: system model
$\boldsymbol{x}$: deterministic input to the model (e.g., target production rate)
$\boldsymbol{m}$: uncertain parameters (e.g., resource content) following probability distribution functions

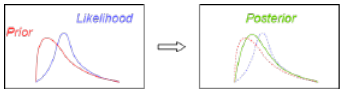
By inputting various sets of $\boldsymbol{m}$ into the model, the performance of the system y under various conditions can be examined as a histogram.

Probability distribution functions need to be updated based on the previous actions & events

Bayesian Inference

$$p(m \mid \mathcal{M}_e) = \frac{p(\mathcal{M}_e \mid m)p(m)}{p(\mathcal{M}_e)}$$

$p(m)$: prior probability
$p(\mathcal{M}_e \mid m)$: likelihood
$p(m \mid \mathcal{M}_e)$: posterior probability



3. Case Study

Deployment of lunar ISRU pilot & full-scale plants in the southern polar region. Decision-makers can pick either the conventional single-technology architectures or novel hybrid architectures [2].

Decisions: ISRU technology

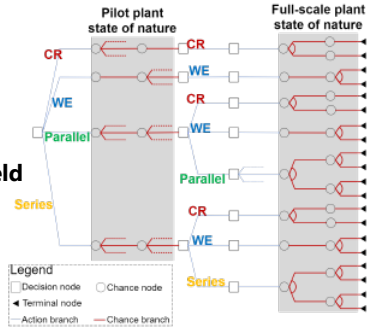
- Carbothermal Reduction (CR)
- Direct water extraction (WE)
- Parallel hybrid of CR and WE
- Series hybrid of CR and WE

Chances: relative oxygen yield

- Large, medium, & small

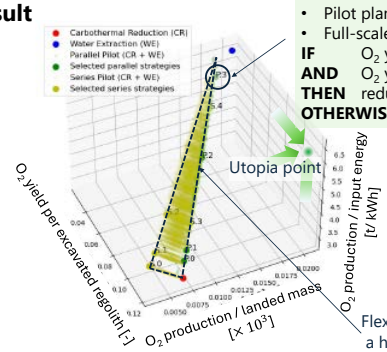
Objectives

- O_2 production / system mass
- O_2 production/ regolith mass
- O_2 production/ input energy



Two-stage decision tree for the case study.

Result



Decision strategy example (P.3):
- Pilot plant: parellel hybrid
- Full-scale plant:

IF O_2 yield from dry regolith is good
AND O_2 yield from icy regolith is bad
THEN reduce to CR;
OTHERWISE, reduce to WE

Flexibility added by deploying a hybrid pilot plant

*3D Pareto front of the case study. Each point represents one **decision strategy**.*

4. Discussion and Conclusion

Summary & Key Findings

- Solving ISRU plant deployment as a multi-objective sequential decision problem.
- A multi-objective decision tree, Monte Carlo simulations, and Bayesian inference are integrated.
- Hybrid pilot plant (**Parallel** or **Series**) shows significant flexibility in operations.

Limitations & Future Work

- Potential high computational cost for a more complex case study.
- Deep uncertainty inherent in lunar ISRU should be addressed.

References

[1] J. J. Cilliers, J. N. Rasera, K. Hadler, Estimating the scale of Space Resource Utilisation (SRU) operations to satisfy lunar oxygen demand, Planetary and Space Science 180 (2020) 104749.
[2] K. Ikeya, F. J. Guerrero-Gonzalez, L. Kiewiet, M.-A. Cardin, J. Cilliers, S. O. Starr, K. Hadler, P. Zabel, Hybrid Lunar ISRU Plant: A Comparative Analysis with Carbothermal Reduction and Water Extraction, Submitted to Acta Astronautica (2024).
[3] Y. Y. Haimes, D. Li, V. Tulsiani, Multiobjective Decision-Tree Analysis, Risk Analysis 10 (1990) 111–127.

Spatial Ecoacoustics Monitoring with a Microphone Array to Assess Biodiversity and Reinforce Conservation Efforts

An approach to listening to **unheard sound**

Author: Rifqi Ikhwanuddin (ri322@ic.ac.uk)
Supervisors: Lorenzo Picinali and Sarab S. Sethi

Introduction

Monitoring biodiversity in protected forests is crucial for safeguarding overall environmental health, yet traditional methods like observer-based monitoring (OBM) are often costly, time-consuming, and limited in scope. Passive Acoustic Monitoring (PAM), leveraging the Internet of Things (IoT) and Artificial Intelligence (AI), offers a promising alternative. PAM involves deploying smart devices that record soundscapes over extended periods, transmitting data to cloud servers for analysis. However, current PAM systems face challenges in filtering background noise and accurately locating species, especially in complex environments like dense forests.

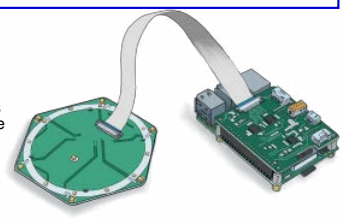


Figure 1. MAARU is a multichannel acoustic recorder that can run online or offline and can be powered by batteries or autonomously through renewable energy sources. MAARU is designed to be built by anyone. All the components are purchasable online and the code is all open source. [1]

Methods

Laboratory Experiments

Soundscape Reproduction: Mimics a forest soundscape in a lab via a multi-speaker system and ambisonic recordings, assessing MAARU capabilities under controlled conditions.

Impulse Response Measurement: Uses Time-Stretched Pulse (TSP) and a turntable to measure system impulse response at various angles, crucial for beamforming calibration.

Performance Comparison: Compares different beamforming techniques (**Figure 2** and **3**) and a monophonic signal using BirdNET for analysis. Finds dynamic beamforming, notably MATLAB IR-beamforming, enhances species identification, especially for faint bird calls.

Field Deployments

Deploys an enhanced MAARU with a 4-microphone array in an Indonesian national park, marking the first ecoacoustic observation using beamforming in Indonesia. This innovative approach allows for biodiversity level measurement, ecosystem safeguarding, and the potential discovery of new species in natural settings.

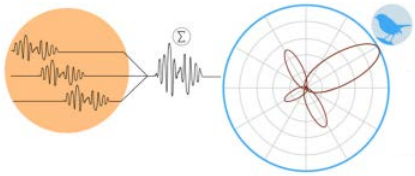


Figure 2. Delay-and-Sum (DAS) beamforming technique to maximise signal-to-noise ratio (SNR) and improve machine learning classification. [1]

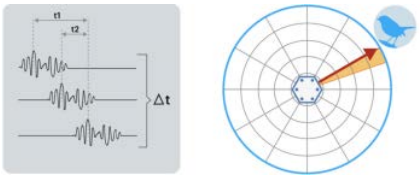


Figure 3. The soundscape recorded in the Multichannel Acoustic Autonomous Recording Unit (MAARU) could locate bird calls by estimating the direction of arrival. [2]

Discussion

The **Figure 5** shows a general trend, where the average confidence score decreases as the sound level of the bird calls decreases. This trend can be attributed to BirdNET's sensitivity to sampling rate and signal-to-noise ratio (SNR). This sensitivity is further evident in **Figure 4**, where the number of detected species also decreases as the sound level of the bird calls decreases.

Results

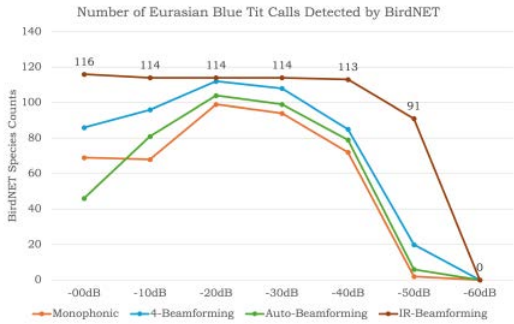


Figure 4. Comparison of species counts between monophonic and beamformed signals at all decreasing bird call levels.

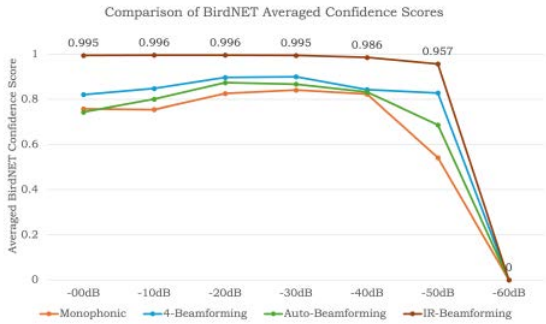


Figure 5. Comparison of BirdNET confidence scores between monophonic and beamformed signals at all decreasing bird call levels.

Conclusion

This research explores the potential of spatial ecoacoustics monitoring using microphone arrays and beamforming techniques to overcome limitations of traditional biodiversity monitoring methods. The project leverages the MAARU system and aims to establish a robust and affordable technology for studying tropical forest soundscapes, ultimately contributing to a deeper understanding of these ecosystems and supporting conservation efforts.

Bio

Rifqi Ikhwanuddin is a PhD student in the Audio Experience Design Lab at the Dyson School of Design Engineering.

He holds a Master's degree in Engineering Physics from Institut Teknologi Bandung and is now working at Engineering Physics, Institut Teknologi Sumatera, Indonesia.

His research interests include spatial audio, soundscape and acoustic ecology.

References

[1] B. E. Heath, R. Suzuki, N. P. Le Penru, J. Skinner, C. D. L. Orme, R. M. Ewers, S. S. Sethi, and L. Picinali, "Spatial ecosystem monitoring with a Multichannel Acoustic Autonomous Recording Unit MAARU," Methods in Ecology and Evolution, vol. 15, pp. 1568–1579, Sept. 2024.

[2] N. Le Penru, A. Borrelli, B. Heath, R. Ewers, S. Sethi, and L. Picinali, "Development and Validation of a Test Platform for Spatial EcoAcoustic Technologies," in Proceedings of the 10th Convention of the European Acoustics Association Forum Acusticum 2023, (Turin, Italy), pp. 4671–4674, European Acoustics Association, Jan. 2023.

IMPERIAL Dyson School of Design Engineering

lpdp lembaga pengelola dana pendidikan

AXD Audio Experience Design

Go Green: Reducing the Environmental Impact of Operating Theatres

A behavioural science approach

Dr Sadhana Jagannath, s.jagannath@imperial.ac.uk
Dr Pelin Demirel, Dr Talya Porat, Mr Aws Almukhtar, Dr Gaby Judah, Dr Anouk Zeeuw van der Laan, Carys Batcup

Background

- NHS accounts for **4%** of England's total carbon footprint
- Operating Theatres are **3-6 times** more energy intensive than the rest of the hospital
- **30%** of waste in hospitals is generated by Operating Theatres
- Carbon footprint of Operating Theatres in 2019 was 5.7 million tonnes CO2e (represents **1.25%** of the UK's total greenhouse-gas emissions)

What we did

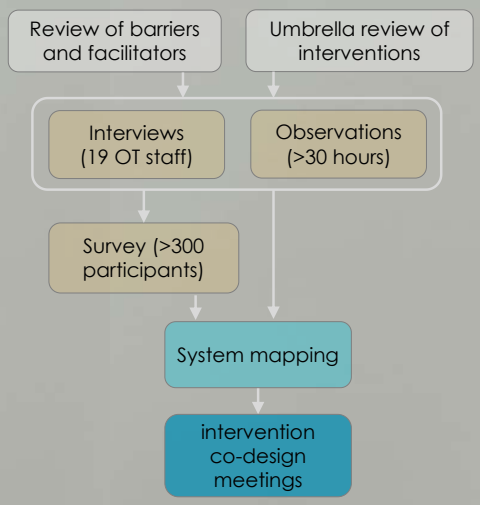


Photo by Clay Banks on Unsplash

WE FOUND

- Gloves are easily available with not enough alternatives
- They promote a sense of safety, readiness, competence, professionalism
- But there are Inconsistencies between and within individuals

9

Pairs (+/- 2) **of**

Non-Sterile Gloves wasted per procedure

Across all NHS theatres in a day, this is equivalent to CO_2 emissions produced from **flying London to Seattle every day**.

Behaviour Change Intervention - Pilot

Aim: To reduce unnecessary Non-Sterile Glove use in theatre staff at Surgical Innovation Centre, St. Mary's Hospital, London

INTERVENTION MATERIALS

Intervention options were guided by Behaviour Centred Design framework (Aunger & Curtis, 2015). Intervention Functions derived from Behaviour Change Wheel (Michie et al, 2011) are:

Education
- Clear list of unnecessary behaviours
- Acronym
- Animation video – Phase 2
- Training – Phase 3

Environmental Restructuring
- Provide Gel dispensers
- Laminated Posters

Modelling
- (and) messaging from a champion

References

- Girou E, Chai SHT, Oppein F, Legrand P, Ducellier D, Cizeau F, et al. Misuse of gloves: the foundation for poor compliance with hand hygiene and potential for microbial transmission? J Hosp Infect. 2004 Jun;57(2):162–9.
- Jeffries SD, Tu Z, Xu H, Harutyunyan R, Hemmerling TM. Use of hand sanitiser as a potential substitution for nonsterile gloves in reducing carbon emissions. Br J Anaesth. 2023 Jul 1;131(1):e22–5
- Imperial College Healthcare NHS Trust (2024) Hand Hygiene Policy V3.1
- CO2 Converter - OpenCO2.net [Internet]. www.openco2.net.
- Michie, S., van Stralen, M.M. & West, R. (2011). The behaviour change wheel: A new method for characterising and designing behaviour change interventions. *Implementation Sci* 6, 42.
- Aunger, R., & Curtis, V. (2015). A guide to behaviour centred design. *London School of Hygiene & Tropical Medicine, London*.

Bio

Dr Sadhana Jagannath is a Postdoctoral Research Associate at the Dyson School of Design Engineering. She has a background in Environmental Psychology and Architecture. She studies the transactional relationships between people and their built environments for societal and environmental benefits.

IMPERIAL

UKRI Medical Research Council

IMPERIAL

Automating the design and production of customised face masks for children with facial differences who need breathing support

Dr Aravind Jayasankar
Dyson School of Design Engineering
Imperial College London

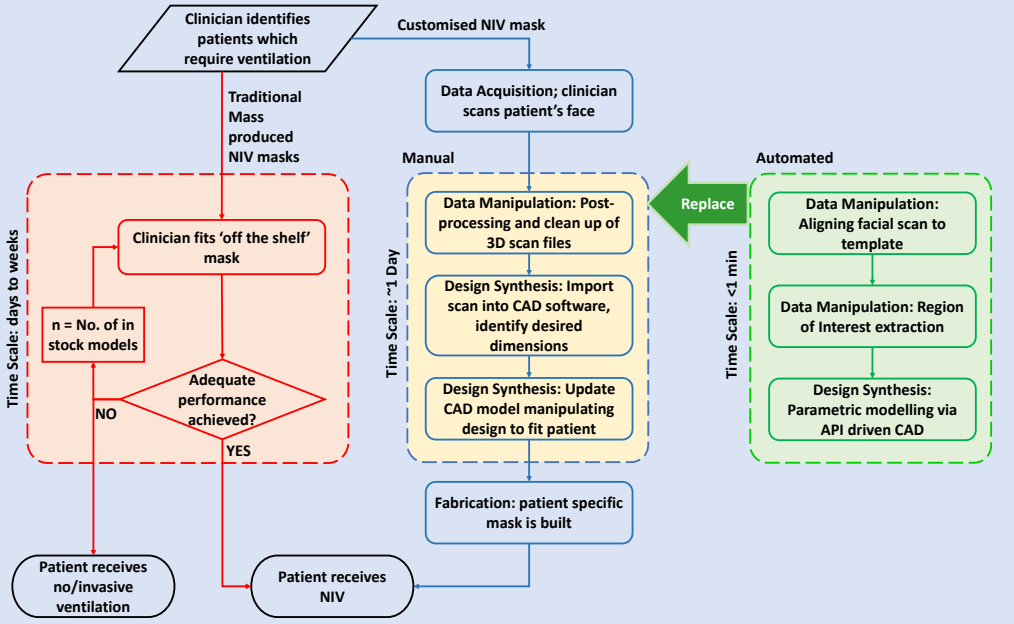
Dr Connor Myant
Dyson School of Design Engineering
Imperial College London

Prof. Heather Elphick
Consultant in Respiratory and Sleep Medicine
Sheffield Children's Hospital

This study is supported by a generous grant from the VTCT Foundation

BACKGROUND: Non-Invasive Ventilation (NIV) is a treatment to aid breathing, which involves a mask connected to a machine which supports a user breathing in and out. NIV significantly improves quality of life and life expectancy of the user, as well as reducing both hospital admissions and days spent in hospital. Over 2,000 children in the UK currently need non-invasive ventilation (NIV) to support their breathing at home – and for most, this will be a lifelong need.

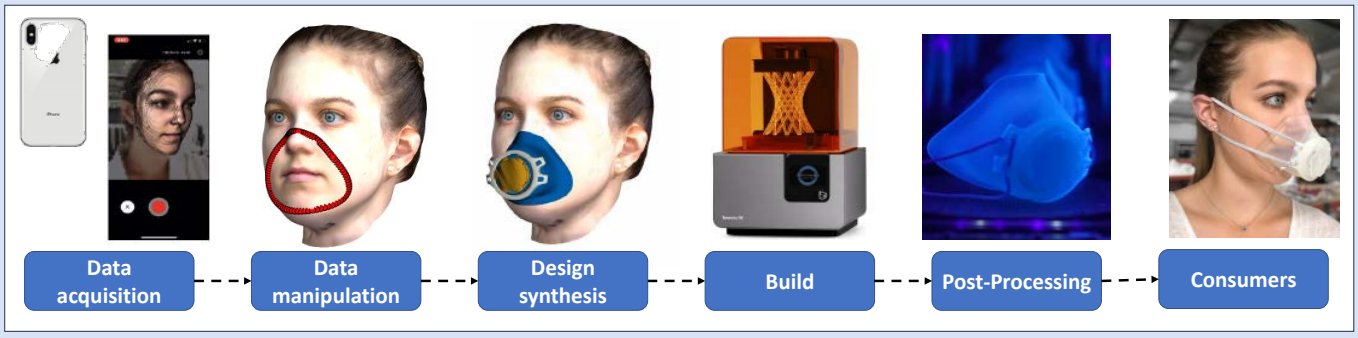
THE PROBLEM: But 'off the shelf' face masks are often a poor fit for children especially those with facial differences. If a suitable mask can't be found, a child may need to have an operation to make an opening in the neck directly into their trachea (breathing tube). Issues with poorly fitting masks are not going away anytime soon.



WHAT THIS STUDY INVOLVES: Establishing a process for the automated design of customised face masks and demonstrate accuracy and ability to accommodate children with facial differences. Utilise 3D scanning technology, computer-aided design, 3D printing to automate mask design and production; to deliver a cost viable platform to healthcare providers. Our proposed intervention will help all those currently at risk of under performing NIV due to poorly fitting masks.

HOW WILL THIS HELP;

- Better therapeutic response.
- Evenly distributed contact pressure.
- More comfortable.
- Caters for population variance.
- Reduction in product cost.
- Outputs are consistent.
- Automation can work 24/7/365.



AI-Enhanced Live-Streamed Environment for Language Learning

Nan Jiang, nj120@ic.ac.uk
Peter Childs

> "This study pioneers AI driven pronunciation feedback and dynamic roles in the design of live streaming experiences to enhance learner engagement and confidence "

Abstract

This study focuses on the application of live-streaming platforms for educational purposes, with a specific emphasis on English learning and adult literacy programs. Through two case studies, the research investigates how AI integration and learning platform design in live streaming can address key challenges in these educational contexts.

Introduction

In China, a novel trend has emerged at the crossroads of education and live-streaming platforms, redefining how knowledge is shared. Platforms such as Douyin (TikTok), originally crafted for amusement, are now being employed by an expanding number of learners for educational purposes.
These platforms enable large-scale, interactive learning environments, but they also present unique challenges, such as ensuring learner engagement and providing personalized feedback. Our research investigates how AI integration can improve learner outcomes by offering real-time support and adaptive learning paths.

Case Study 1: AI-Enhanced English

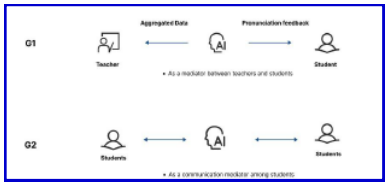
This case study addresses challenges in pronunciation accuracy and practice opportunities through four key phases:
Phase 1: Pre-study Focus Group
Gathered learner feedback on difficulties in live-streamed English lessons, focusing on pronunciation and practice limitations.
Phase 2: Development of Educational Interventions
Designed AI-driven pronunciation feedback modules and conversational practice sessions based on focus group insights.
Phase 3: Initial Testing of Design Interventions
Tested interventions in a controlled setting to evaluate and refine their effectiveness.
Phase 4: Full-scale Experimental Deployment
Conducted large-scale deployment to assess impact on engagement and learning outcomes.

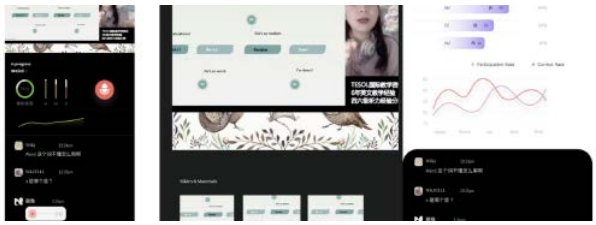
Focus group findings

Challenges Identified:
Uncertainty about Pronunciation Accuracy: Many participants expressed frustration over not knowing whether they were pronouncing words correctly during live-streamed sessions.
Limited PracticeOpportunities: Participants also highlighted a lack of sufficient opportunities to practice spoken English in real-life contexts.

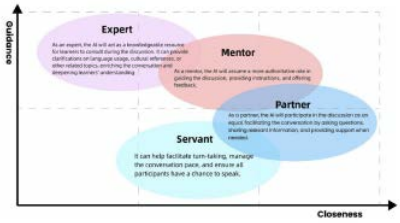
G1 Real-Time Pronunciation feedback;

G2 AI-led conversational practice in BreakOut Rooms





The pronunciation feedback module is an integral part of the platform, aiming to address learners' uncertainty about their pronunciation accuracy. The system should be capable of recognizing and evaluating individual phonemes and prosodic features such as stress, intonation, and rhythm[2].



We identify two primary dimensions to better understand the roles of AI in conversational practice: Closeness and Guidance.These dimensions borrow insights from the social actor theory[3].

In the development of our experimental environment, we chose to create a ChatGPT Telegram bot, specifically designed to facilitate interactions within Telegram groups.

Case Study 2: Adult Literacy in Live-Streaming

In China, 2.7% of the population is illiterate, with women disproportionately affected due to gender inequalities. Traditional literacy programs face high dropout rates and limited retention, with government efforts shifting away from adult education.

Current Progress:

Our interviews reveal that volunteer livestreamers are building a new educational ecosystem by offering flexible literacy lessons on platforms like Douyin. These streams attract learners who prefer informal, interactive formats, but challenges remain in ensuring consistent participation and skill retention. Learners appreciate real-time interaction, though some struggle with digital interfaces. This evolving model shows promise but requires further refinement to maximize impact

Bio

Nan is a third-year PhD student at the Dyson School of Design Engineering, holding a Master's degree in Information & Design from Tsinghua University. Her research interests include interactive media design, artificial intelligence in education, and creativity in design. She also promotes innovative K-12 learning methods and family education strategies through online media and social platforms, helping students and families from lower socio-economic backgrounds in China to access higher quality educational resources.

References

- https://dl.acm.org/doi/10.1145/3274381
- 10.1007/s10639-023-12109-5
- https://doi.org/10.1007/978-3-031-57867-0_14

IMPERIAL Dyson School of Design Engineering

HOW DO GREEN SKILLS AND GREEN CAPABILITIES IMPACT FIRMS' FINANCIAL PERFORMANCE?

Contact: Cece Koczias, ck323@ic.ac.uk
Supervisors: Pelin Demirel, Marco Aurisicchio

- **Green skills and capabilities positively influence financial performance.**
- **GS and GC have a bidirectional relationship with each other.**
- **GS and GC's impact varies based on firm size, ownership, industry, and institutional context.**

ABSTRACT

Does it pay to be green for organisations? This research project examines how green skills (GS) and green capabilities (GC) influence firms' financial performance. A systematic literature review was conducted to assess existing studies, identifying the variables and factors shaping the GS-GC relationship and their impact on firms' financial outcomes.

INTRODUCTION

The Paris Agreement has set a global warming target of no more than 2.0°C above pre-industrial levels, limiting the temperature increase to 1.5°C (UNFCCC, 2015). Business-as-usual is no longer feasible to meet economic, environmental and social needs. Companies need to acquire green skills and build green capabilities.

OBJECTIVES

Undertake a Systematic Literature Review to Identify:

1. What are GS and GC?
2. What is the relationship between GS and GC?
3. How do GS and GC impact firm financial performance? and
4. What are the main variables that shape the relationship and outcome of GS and GC' impact on firms' financial performance?

METHODOLOGY

Systematic Literature Review was chosen to structurally identify gaps in the literature related to GS and GC and provide theoretical and methodological understanding, lending insight into future developments (Boland et al., 2017).

Systematic Literature Reviews Ensure:

1. Research validity
2. Quality assurance of the revision process
3. Scientific adequacy
4. Replicability
5. Transparency (Page et al., 2021).

FINDINGS

GS and GC are the foundational building blocks for the net zero transition.

The concepts of GS and GC are broad, ambiguous and context-dependent.

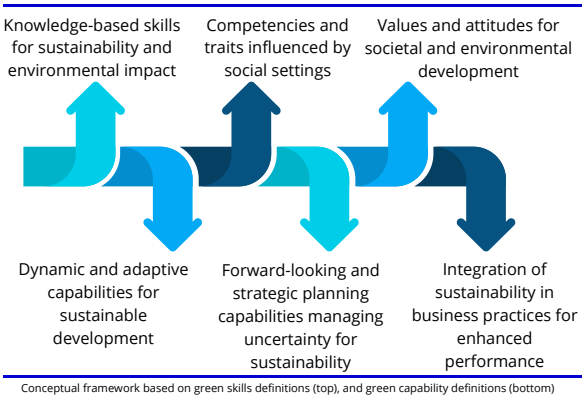
GS and GC maintain a bidirectional relationship.

The impact of GS and GC on firm financial performance is mostly positive, with some caveats.

Firm size and ownership, sectoral and institutional contexts shape the relationship between GS, GC and firms' financial outcomes.

IMPLICATIONS FOR FUTURE RESEARCH

- While GC are well-covered in literature, GS demand more focused exploration.
- The service sector requires further research to understand the impact of GS and GC on financial performance.
- Research should explore how firm size, ownership, sectoral differences, and institutional settings influence the relationship between GS, GC, and financial performance.
- Future research should consider the six prominent financial metrics—growth, profitability, liquidity, market performance, cost, efficiency and productivity.
- This study provides a conceptual framework for future research clarifying and operationalising GS and GC.



Conceptual framework based on green skills definitions (top), and green capability definitions (bottom)

CONCLUSION

GS and GC have a predominantly positive overall financial impact on firms. Further investigation of UK SMEs in the service sector across different regions and green skills is required.

BIO

Cece is a second-year PhD student at the Dyson School of Design Engineering focusing on the financial impact of green skills and capabilities in firms. Her research aims to influence the UK's firms to pursue a green transition, advancing the integration of green skills and capabilities in policy and industrial landscapes.

REFERENCES

- UNFCCC. (2015). Paris Agreement. UNFCCC. https://unfccc.int/sites/default/files/english_paris_agreement.pdf
- Singh, S. K., Del Giudice, M., Chiappetta Jabbour, C. J., Latan, H., & Sohal, A. S. (2022). Stakeholder pressure, green innovation, and performance in small and medium-sized enterprises: The role of green dynamic capabilities. Business Strategy and the Environment, 31(1), 500–514. https://doi.org/https://doi.org/10.1002/bse.2906.
- Boland, A., Dickson, R., & Cherry, G. (2017). Doing a systematic review: A student's guide. https://doi.org/http://digital.casalini.it/9781526416582
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., & Moher, D. (2021b). Updating guidance for reporting systematic reviews: development of the PRISMA 2020 statement. Journal of clinical epidemiology, 134, 103–112. https://doi.org/https://doi.org/10.1016/j.jclinepi.2021.02.003

IMPERIAL Dyson School of Design Engineering

IMPERIAL

Battery passport using distributed ledger technology

Vinayak Kulkarni
(v.kulkarni23@imperial.ac.uk)
Dr. Billy Wu
Dr. Jacqueline Edge
Prof. William Knottenbelt,
Prof. Gregory Offer

What is a Battery Passport?

The battery passport digitally conveys information about battery sustainability, performance, durability, material composition, and manufacturer information by scanning the QR code on the battery

What problems does the battery passport solve?

Improves sustainability by quantifying battery carbon footprint across the value chain

Improves safety by sharing safe battery disassembly practices

Improves circularity & trust by securely sharing battery health information across the value chain

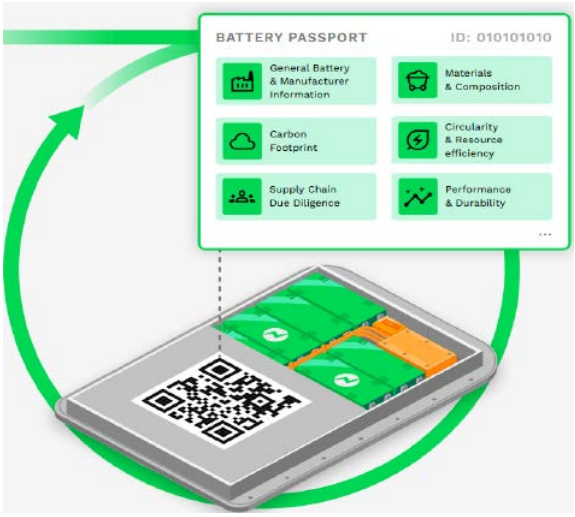


Image source: Image Source: https://thebatterypass.eu/assets/images/content-guidance/pdf/2023_Battery_Passport_Content_Guidance.pdf

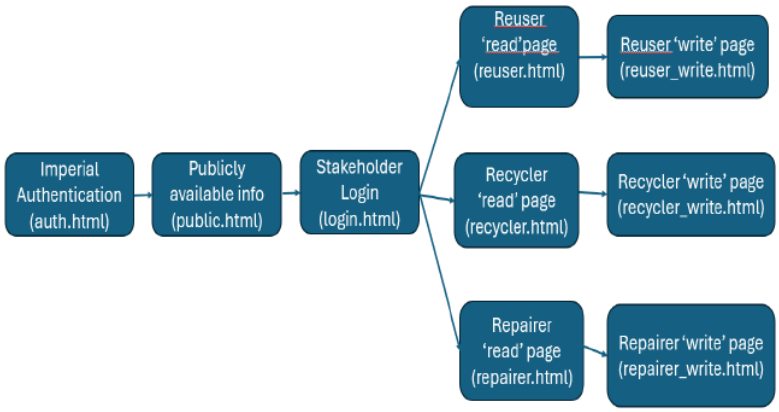
Key Components of Battery Passport

- Identification of battery and stakeholders
- Stakeholder authentication
- Role-based access control
- Data storage
- Data integrity
- Data communication

EU battery regulation:

Battery packs (>2kWh capacity) must have battery passport by:

2027



Recycler workflow for confidential battery data

Route	Python function	HTML call	Input to HTML from python	Purpose
@app.route('/',methods=['GET','POST'])	authentication1	Auth.html	Form (Imperial email and password)	Imperial authentication
@app.route('/public')	home	Public.html	Data_public (dictionary)	Takes user to the home page sharing publicly available battery information
@app.route('/login',methods=['GET','POST'])	Receive_data	Login.html	Form (stakeholder email and password)	Authenticate recycler, reuser and repairer
@app.route('/recycler',methods=['GET'])	recycler2	Recycler.html	Private_recycler (dictionary)	Shares the confidential information which recycler

Conclusion

Proof of concept of battery passport was developed ensuring downstream stakeholders (recyclers, repairers and reusers) authentication and role-based access control mechanisms.

Sponsored by:

IOTA FOUNDATION

Developing and deploying spatial audio recorders for sensing the structure, health and resilience of ecosystems. PhD Overview

Neel Le Penru (NPL16@ic.ac.uk), Becky Heath, James Skinner, Giulia Gieve, Shujie Chang, Sarab Sethi, Robert Ewers, Lorenzo Picinali.

Pioneering **new methods in acoustic ecosystem monitoring** for:
1. **Testing recorders** in the lab under more lifelike conditions;
2. **Spatially segmenting soundscapes** to understand habitat structure;
3. Acoustically sensing approaching ecosystem **tipping points**.

Introduction

Our team develops and applies novel technologies for acoustically monitoring some of the world's most biodiverse – and vulnerable – ecosystems. In recorder deployments across four continents (AS, EU, NA, SA), we are demonstrating new possibilities for sensing the spatial distribution of sounds (and thereby, animals) and, for the first time, exploring whether Early Warning Signals (EWS) of ecosystem collapse appear in the acoustics domain. We have also developed a new way to use the lab as a lifelike test environment, allowing recording hardware to be more rigorously benchmarked before field deployment.

Why?

Ecosystems are under unprecedented, intensifying pressure from human activity and climate change.

Acoustic monitoring of soundscapes – animal, human and environmental noise – is a powerful tool for tracking ecosystem health.

Capturing spatial audio with multi-microphone recorders can unlock insights into animal abundance and behaviour, and habitat structure.

Determining whether EWS of tipping points emerge in acoustic data could provide a vital extra route to detect abrupt, potentially irreversible ecosystem collapse in time to intervene.

Fig. 1. *Left:* MAARU field recorder deployment in UK (Imperial College Silwood Park campus, Ascot, UK); *Middle:* Professional tree climbers install a MAARU to a tree near the Danum Valley Conservation Area, Sabah, Malaysia; *Right:* approximate locations of MAARU deployments for this PhD.

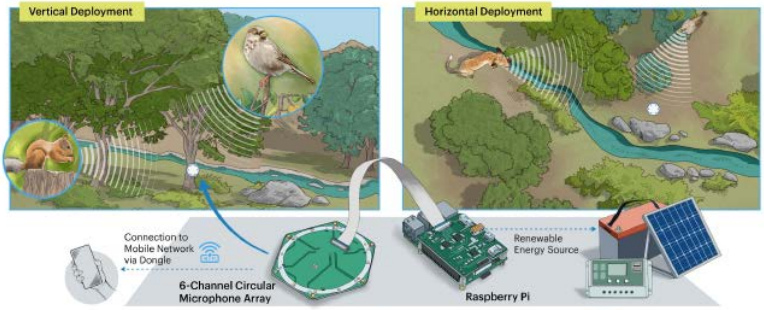


Fig. 2. Breakdown of the MAARU recorder's components and powering system, and example deployment strategies. By leveraging its 6 microphones, MAARU can be used to estimate sounds' direction of arrival or to tune in to specific directions [1].

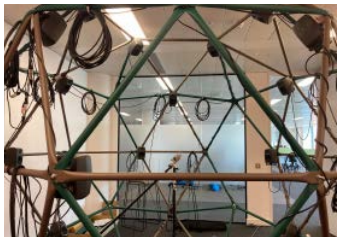
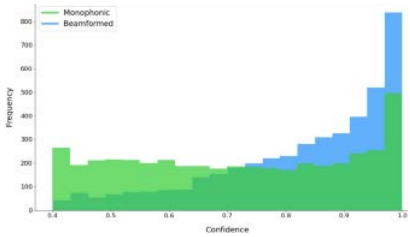
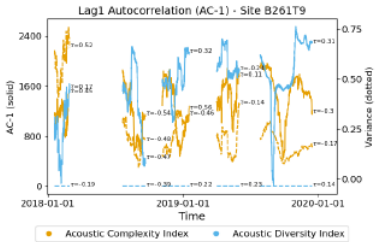
How?

We deploy Multichannel Acoustic Autonomous Recording Units (MAARUs) globally to validate our tools and monitor diverse ecosystems.

MAARU is an open-source, accessible recorder developed in-house [1]. It features a 6-microphone array connected to a Raspberry Pi with a 4G dongle and solar power source, enabling near real-time, autonomous monitoring (Fig. 2)..

Ecological inferences are then generally derived from acoustic data by:
1. **Spectral analysis**: examining activity at different sonic frequencies.
2. Calculating **acoustic indices**: hand-crafted ecological metrics that exploit spectral and other properties of the sound.
3. Running **species call classifiers**, that can identify particular species' calls, e.g., BirdNET (can ID 1000s of birds worldwide).
4. Extracting **feature embeddings** of machine learning (ML) models, i.e., numerical outputs of ML classifiers with the final network layer(s) removed, which often reflect ecological patterns.

Thesis Sub-Projects

Sub-Project	Simulating spatial natural soundscapes to create a lab-based test environment for (multi-microphone) field recorders [2]	Spatially segmenting soundscapes for more efficient and accurate biodiversity monitoring	Do satellite-sensed Early Warning Signals of ecosystem collapse also appear in acoustic data?
	 **Fig. 3.** 25-loudspeaker Virtual Sound Environment with MAARU recorder mounted at its centre.	 **Fig. 4.** Distribution of BirdNET predictions' confidence scores from monophonic (single omnidirectional microphone) signals versus signals beamformed to pre-set directions.	 **Fig. 5.** Autocorrelation and variance of two acoustic indices from recordings in the Amazon rainforest.
Methods	Created a Virtual Sound Environment (VSE; Fig. 3) – spherical array of 25+ loudspeakers – to simulate real, spatial natural soundscapes in a lab setting. Used the VSE to test performance of MAARU and downstream ecological analyses under various conditions.	Deployed multi-microphone recorders in the UK, US, Brazil and Malaysia. Applying signal processing techniques to isolate sounds from specific directions ('beamforming'). Comparing ecological metrics between beamformed and single-microphone signals.	Looking for common statistical EWS (rise in variance + autocorrelation) in ecological metrics derived from: - ~2 years' recordings from 3 sites in Amazon (from: O. Metcalf – MMU / Sustainable Amazon Network); - MAARU recordings from 6 sites along land-use gradient in Malaysian Borneo (deployed Sep. 2024). Comparing to EWS in 20+ years' satellite-derived vegetation biomass [3, 4]. Will also apply ML classifier for detecting tipping points to acoustic data.
(Initial) Results	VSEs can be a powerful tool for evaluating ecoacoustic hardware and software, but can be sensitive to inaccuracies in the sound field reconstruction technique.	Beamforming can improve species call classifier performance (Fig. 4) and shows potential for efficiently differentiating between neighbouring habitats / land use types.	Patterns observed in biomass may not appear in shorter-term acoustic data (Fig. 5), but looking for acoustic-based EWS across a land-use gradient holds promise.

Bio

Neel Le Penru is a final-year PhD student in the Audio Experience Design group, funded via the Science and Solutions for a Changing Planet DTP at the Grantham Institute. He graduated from the Design Engineering MEng at Imperial College in 2020.

References

[1] Heath BE, Suzuki R, **Le Penru NP**, Skinner J, Orme CDL, Ewers RM, et al. Spatial ecosystem monitoring with a Multichannel Acoustic Autonomous Recording Unit (MAARU). *Methods in Ecology and Evolution*. 2024;15(9): 1568–79.
[2] **Le Penru NP**, Heath BE, Dunning K, Picinali L, Ewers RM, Sethi SS. Towards using virtual acoustics for evaluating spatial ecoacoustic monitoring technologies. *Methods in Ecology and Evolution*. [In press] 2024.
[3] Boulton CA, Lenton TM, Boers N. Pronounced loss of Amazon rainforest resilience since the early 2000s. *Nature Climate Change*. 2022; 1–8.
[4] Lenton TM, Buxton JE, Armstrong McKay DI, Abrams JF, Boulton CA, Lees K, et al. A resilience sensing system for the biosphere. *Phil Trans R Soc B*. 2022;377(1857):20210383.

IMPERIAL

AXD

Grantham Institute
Climate Change and the Environment
An institute of Imperial College London

G.O.G: A Versatile Gripper-On-Gripper Design for Bimanual Cloth Manipulation with a Single Robotic Arm

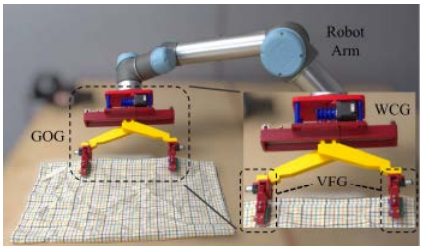
*"**Mechanical design** can improve robotic automation for complex bimanual manipulation, Using only a **single robotic arm.**"*

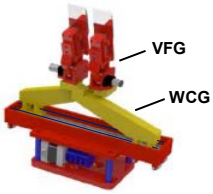
Dongmyoung Lee*, d.lee20@imperial.ac.uk
Wei Chen*, w.chen21@imperial.ac.uk
Supervisor: Dr. Petar Kormushev

Abstract

In this paper, we introduce a novel gripper design, called G.O.G, specifically designed to **facilitate bimanual cloth manipulation using only a single robot arm.**

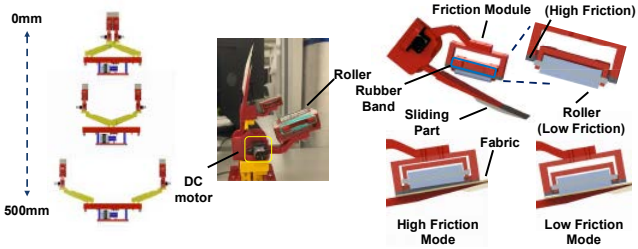
Introduction





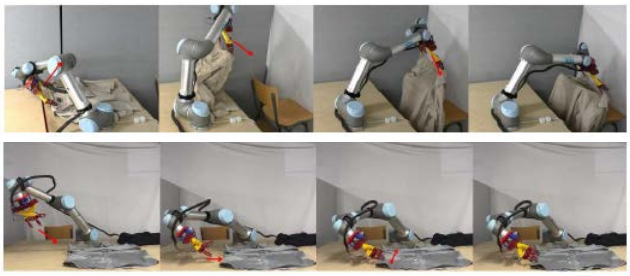
- Deformable object manipulation is challenging due to **extensive variability in shape, size, and material property.**
- Most prior works focused on **robot perception and control** and employed **commercial grippers with dual arms** for bimanual manipulation.
- This generally increases **the overall cost of the robotic system and its control complexity.**
- This work proposes a novel gripper design for **bimanual cloth manipulation tasks using a single robot arm.**

Gripper Design



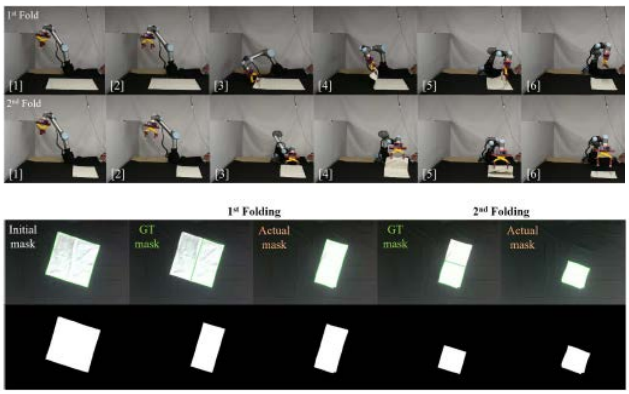
- **Width Control Gripper (WCG):**
  - Adjust the gripper opening width
  - Actuated by **a single stepper motor using tendons**
  - Allow two VFGs not only to **function as a single gripper (0mm)**, but also to **extend outward to approximately 500mm**
- **Variable Friction Gripper (VFG):**
  - Achieve **secure grasping** and **flattening motion passively** by controlling the torque of DC motors

Demonstration



- Explore the potential of our gripper by doing bimanual cloth hanging and flattening tasks

Results



- **Ground truth mask** is generated **by halving the image's contours along the folding direction.**
- The result indicates that the complex bimanual cloth folding tasks can be implemented well.

1-fold (MIoU / WR)	2-Fold (MIoU / WR)
0.917 / 0.0047	0.868 / 0.0059

- However, a slight decrease in performance can also be observed **at the 2-fold stage.**

Conclusion

G.O.G. significantly **reduce experimental costs and control complexity**, while the successful implementation of **complex bimanual cloth manipulation tasks**.

Bio

Dongmyoung Lee is a PhD candidate at the Dyson School of Design Engineering, Imperial College London. His research focuses on innovative gripper design and control systems for the manipulation of deformable objects.

IMPERIAL Dyson School of Design Engineering

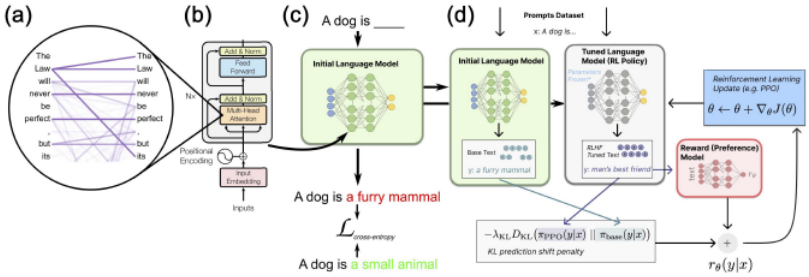
Materials Science in the Era of Large Language Models

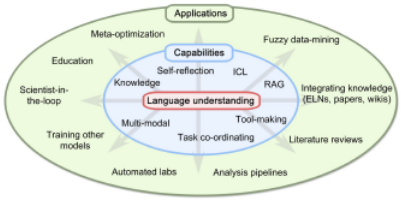
IMPERIAL

Ge Lei g.lei23@imperial.ac.uk, Ronan Docherty, Samuel J. Cooper samuel.cooper@imperial.ac.uk

LLMs PROPERTIES

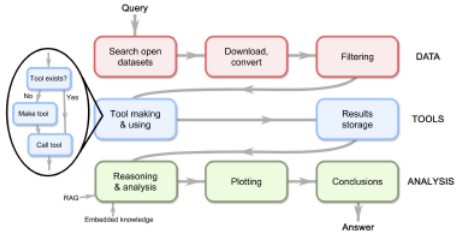
"At their current stage of development, we argue LLMs should be viewed less as oracles of novel insight, and more as tireless workers that can accelerate and unify exploration across domains. It is our hope that this paper can familiarise materials science researchers with the concepts needed to leverage these tools in their own research."





CASE STUDY 1: MICRO GPT

MicroGPT was developed to simplify the analysis of 3D microstructures, demonstrating LLMs' ability to automate tasks such as data search, simulation, visualization, etc. It shows LLM's capability to support battery research by streamlining 3D electrode analysis and providing insights for design and performance improvements.



The code to run Microgpt is available at https://github.com/tldr-group/Microgpt

Microgpt Example Prompts:

- Data Collection

"Can you search for the Microlib online, which is a dataset of 3D microstructures?"

- Custom Tool Creation and Reuse

"Please write and execute a script to unzip the file './microlibDataset.zip"

- Data Filter

"In the 'microlibDataset.zip' file, can you find all the 3D images related to cast iron?"

- Data Simulation

"Could you analyze the 3D images in the './data' folder to determine their tortuosity, diffusion factor, volume fraction, and surface area?"

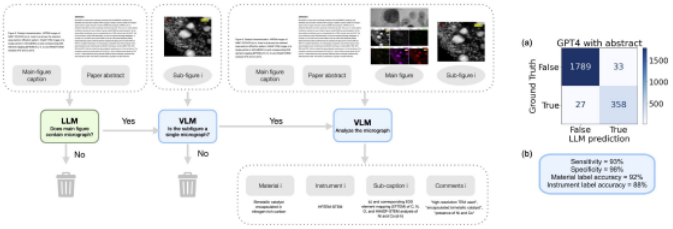
- Data Analysis

"Read the data in ./data_0.csv, compare microstructure 393, 368, and 365" "Which microstructure is more suitable to be used as a filter and catalyst carrier?"

- Data Visualization

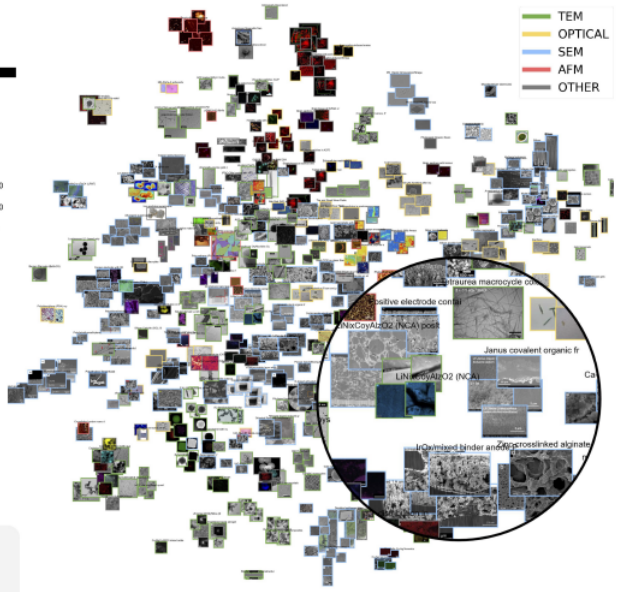
"Can you generate some figures to create visualizations for the data? Histograms for each numerical column to understand the distribution of values. Scatter plots to explore relationships between pairs of numerical variables (e.g., Effective Diffusivity vs. Tortuosity)"

CASE STUDY 2: MICROGRAPH DATASET



We proposed an automated method to generate labelled micrograph datasets from literature. This demonstrates LLMs and VLMs' capacity for context understanding and multi-modal analysis, offering a strategy for building large-scale datasets in the battery field. This is an example of extracting one of the figures from the literature [2].

The code needed to run the micrograph scraping, extraction and LLM labelling (including the resulting dataset) is available at https://github.com/tldr-group/micrograph_extractor.



Bio

Lei Ge is a second-year PhD student at Imperial College London, working within the TLDR group under the supervision of Dr. Sam Cooper. Her research focuses on leveraging large language models to accelerate breakthroughs in materials science, with a particular emphasis on advanced battery materials. Outside of her academic work, she enjoys fashion design, scuba diving, and playing the piano.

Reference:

1. *Lei, G.†, Docherty, R.†, & Cooper, S. J. (2024). Materials science in the era of large language models: a perspective. Digital Discovery.*
2. *Lin, S., Chen, L., Zhang, X., Zhang, Q., & Ma, L. (2022). Ni/Co@ NDC Modulates the Highly Selective Conversion of Vanillin in Flow Reactor under Mild Conditions.*

Simulation Modelling for Lunar In-Situ Resource Utilization Design and Operations under Uncertainty

Luka Malone, Michel-Alexandre Cardin, Jan Cilliers, Kathryn Hadler, Stanley Starr

Author Bio:
Luka Malone is a 3rd year PhD student at the Dyson School of Design Engineering supervised by Michel-Alexandre Cardin and Jan Cilliers. He holds degrees in aerospace engineering from both the University of Manchester and Imperial College London. His PhD project involves utilizing serious games to study decision making under uncertainty in novel engineering systems.

Research Impact Highlight

The intended impact of this research is to develop new ways to design and operate flexible infrastructure systems under uncertainty. For the space community, this paradigm is becoming increasingly important as we move away from one-off missions and more towards continuous space-based infrastructures.

Introduction

Modern engineering systems and the goals they set out to achieve, such as ***sustainability***, are becoming increasingly complex and ill-defined. ***Flexible design***, in particular the use of ***real options***, offers a practical way in which sustainability can be achieved in novel systems. Real options are system elements that provide 'the right, but not the obligation, to reconfigure in the face of uncertainty'. In the case of ***Lunar ISRU***, also known as lunar mining, the design space at the architecture level remains largely unexplored once ***uncertainty***, either endogenous or exogenous, is considered. To study this, a simulation framework was developed to explore the viability of smaller, more modular ISRU elements that would enable a real options based phased deployment strategy.

Simulation Study Design

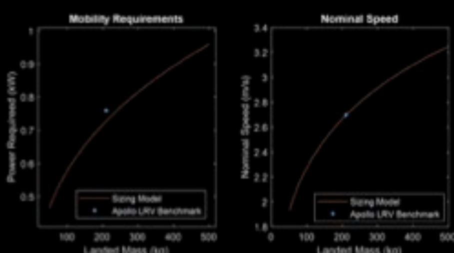
In particular, this study aimed to investigate the effects of unit element ***economies of scale*** on system metrics of interest. Would having larger but fewer infrastructure elements provide advantages over a more modular deployment strategy? ***Monte Carlo analyses*** were conducted within the lunar mining simulator to investigate this research question.

Simulation Methodology for an Infrastructure Mass Sizing Exploration Under Uncertainty

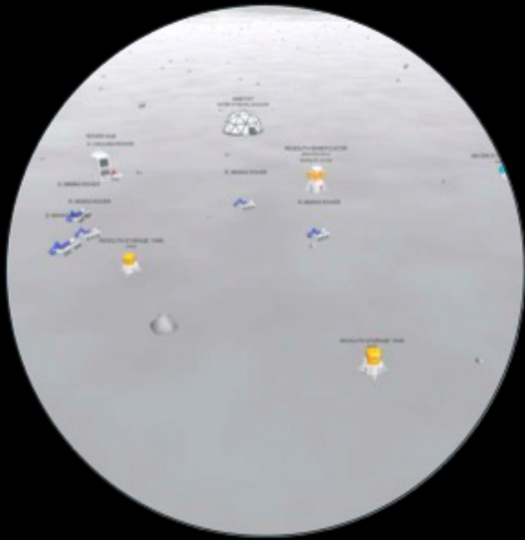
The scenario modelled for this study involved simulating a 5 month lunar mission, where four crew members in a habitat need to be supplied with enough liquid oxygen (LOX) to complete their mission. A 2.5 month LOX reserve was included, but the remaining LOX needed to be sourced in-situ. If this could be accomplished the simulation was deemed to be a pass.

Parametric Sizing Models

Different parametric models were developed to model Lunar ISRU processes, including one for lunar rovers. It can be seen here that the outputs of the parametric model created closely matches the traits of the Apollo roving Vehicle (LRV).



Lunar Rover Parametric Model Validation



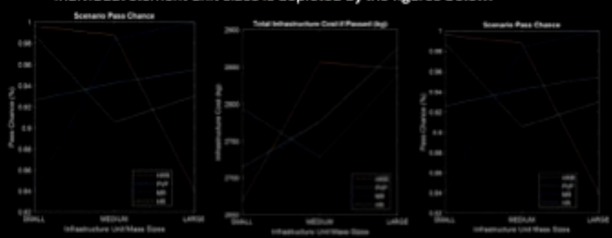
Lunar Mining Simulator

This study was run using a ***Lunar Mining Simulator*** as a research platform to investigate the questions of interest. Developed in the Unity game engine, the Lunar Mining Simulator (LMS) provides a means to simulate the design and management of a pilot lunar ISRU facility that produces liquid oxygen from the hydrogen reduction of lunar regolith.

The LMS allows either a human operator or artificial agent to run preset scenarios with or without the aid of a decision support system. Several options for stochastic effects are included pertaining to the operational availability of different infrastructure elements. The LMS also supports Monte Carlo type simulations, where the same scenario can be rerun under stochastic conditions so the aggregate results can be interpreted.

Results

Three different system metrics were used as the dependent variables in the simulation study, ***Scenario Success Chance***, ***Mean Infrastructure Cost If passed***, and ***Sustainability Score***. The effect of varying the individual element unit sizes is depicted by the figures below.



Simulation Study Mean-Plot Graphs
(Mining Rover [MR], Hauling Rover [HR], Hydrogen Reduction Reactor [HRR], Photovoltaic Power Plant [PVP])

In general, we can see that there is no ***clear advantage offered by the use of economies of scale in any metric of interest***. This warrants a further exploration into the use of a phased ISRU deployment strategy over a more rigid large scale initial deployment.

REFERENCES

IMPERIAL

DECODING SOUND SOURCE LOCATION FROM EEG: COMPARISONS OF SPATIAL RENDERING AND LOCATION

Nils Marggraf-Turley[1], Lorenzo Picinali[1], Niels Pontoppidan[2], Martha Shiell[2], Drew Cappotto[1]

[1]Dyson School of Design Engineering, Imperial College London, UK [2]Eriksholm Research Centre, Oticon A/S, Snekkersten, Denmark

> "Sound source location decoding accuracy from **neural signals** reflects behavioural front-back confusion rate."

Introduction

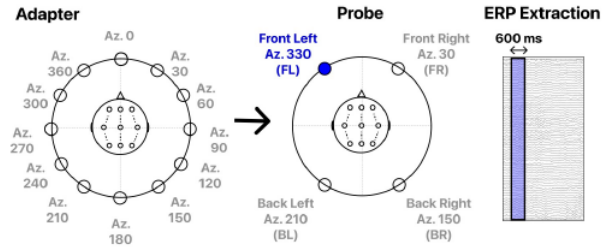
Just by looking at EEG signals recorded when a given sound source was playing from the surrounding environment, can we estimate where the sound source was placed? And if so, what can this tell us?

Spatial cues are often poorly simulated in virtual acoustic environments, particularly leading to **front-back confusions** due to **spectral cue distortion**. Traditional **behavioural assessments** are inconsistent, limited by subject acuity, and may exclude some individuals. **EEG** provides an **objective alternative** by analysing **neural responses** to auditory stimuli.

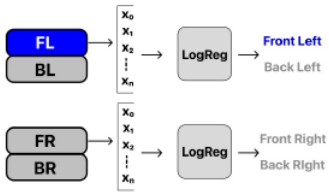
Sound location decoding from neural responses has been successful in **free-field conditions** [1], with indications that **decoding accuracy** correlates with behaviour in free-field median plane localisation [2]. This study **decodes pairwise sound locations** from **Event-Related Potentials (ERPs)** elicited by free-field and non-individual HRTF listening. **Decoding accuracy** is analysed for cortical processing differences and correlated with behaviour. **22** subjects participated in the study.

Method

An adapter-probe paradigm, adapted from [2], was employed to investigate location change responses. Adapters and probes were 1000ms and 100ms white noise bursts respectively played via loudspeakers or KEMAR HRTFs (SONICOM [3]). Subjects reported the quadrant using a number pad while ERPs were recorded.



Decoding

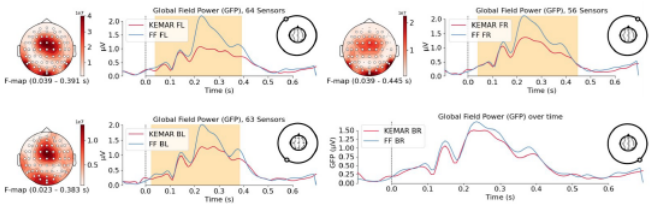


Logistic Regression classifiers were trained on data from all electrodes, using either the **full ERP** or **individual time points**, to distinguish pairwise sound locations.

Results

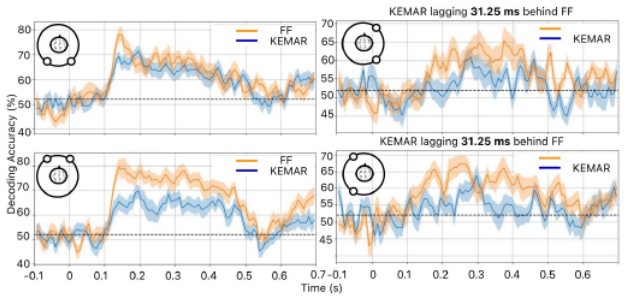
Spatiotemporal Cluster Permutation Test

Shaded areas indicate most significantly different regions. Topographical maps show the spatial distribution of F-values during these periods, with white dots marking sensors contributing to the clusters.



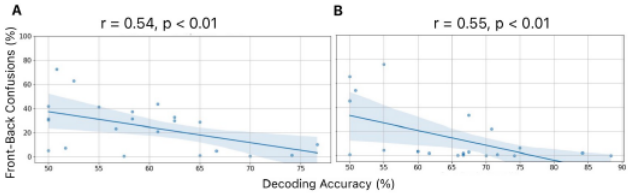
Individual Time Point Decoding

Temporal variation of decoding accuracy across 22 participants shows a **31.25 ms delay** between **free-field** and **KEMAR** for spectral-cue dominated locations.



Behavioural Correlation

Moderate but **significant correlation** between whole-ERP decoding accuracy and front-back confusions for free-field (A) and KEMAR (B) stimuli.



Discussion & Conclusion

Spatiotemporal cluster permutation tests reveal a weaker cortical response to KEMAR HRTF stimuli compared to free-field conditions, with **notable increases in activity** observed in occipital-parietal regions during free-field listening.

Temporal variations in decoding accuracy between free-field and KEMAR listening suggest **cortical processing delays** for degraded spectral cues

Correlation between **decoding accuracy** and **front-back confusion rate** show promise for developing a **neural-inspired metric** of localisation accuracy between spatial rendering methods

Bio

Nils Marggraf-Turley is a PhD student in the **Audio Experience Design (AXD)** group. His research focuses on the augmentation of spatial auditory cues to enhance perceptual experiences, with a particular emphasis on understanding the neurophysiological mechanisms underlying these modifications.

References

[1] A. Bednar, F .M. Boland, & E. C. Lalor, "Different spatiotemporal electroencephalography features drive the successful decoding of binaural and monaural cues for sound localization," European J. of Neurosc., 2017.
[2] O. Bialas, B. Maess, and M. Schönwiesner, "Evoked Responses to Localized Sounds Suggest Linear Representation of Elevation in Human Auditory Cortex," 2023.
[3] I. Engel, R. Daugintis, T. Vicente, A. O. T. Hogg, J. Pauwels, A. J. Tournier, and L. Picinali, "The SONICOM HRTF Dataset," J. Audio Eng. Soc., 2023.

IMPERIAL Dyson School of Design Engineering

Eriksholm Research Centre
PART OF OTICON

Design for Building's Adaptability

Frameworks for the Assessment of Flexibility of Building Structures

Doreen Steven Mlote, Sezgi Yalçınkaya, Peter Ortner, Lynette Cheah & Michel-Alexandre Cardin

SINGAPORE UNIVERSITY OF TECHNOLOGY AND DESIGN

Imperial College London

Keywords: Design-for-Disassembly, Modularity, Open-building, Prefabrication, Reconfigurable, Repurpose

INTRODUCTION

There is growing interest in flexibility, physical redundancy, and reusability of buildings – potentially leading to a more adaptable and sustainable future for facilities, buildings and infrastructure.

Design for Adaptability allow the repurposing of buildings into newer functions hence offering a method to develop closed-loop material flow systems.

AIM

- Extend buildings' lifetime
- Adapt to changing needs
- Reuse of space & materials
- End-of-life emissions

How can we assess Design Strategies for buildings' ADAPTABILITY?

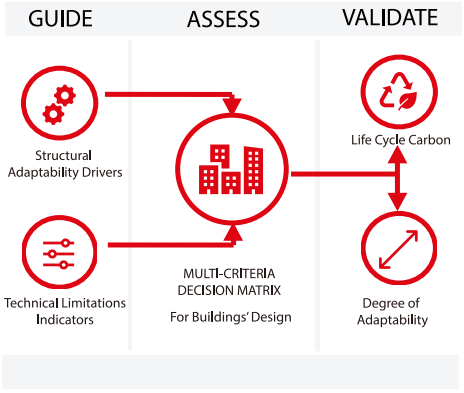
METHODS

Multi-Criteria Decision Matrix

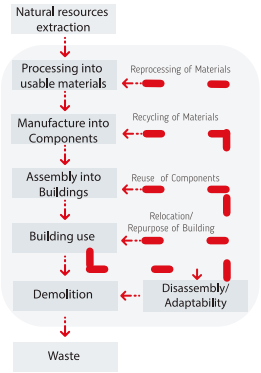
- Spatial Flexibility: Repurpose of Space
- Deconstructability: Resuse of Building Components
- Cost of Construction: Material & Opportunity Costs
- Load Bearing Capacity: Structural Compromise

Engineering Options Analysis is used to understand how we can assess and validate multiple design options for adaptability and select the most desirable option;

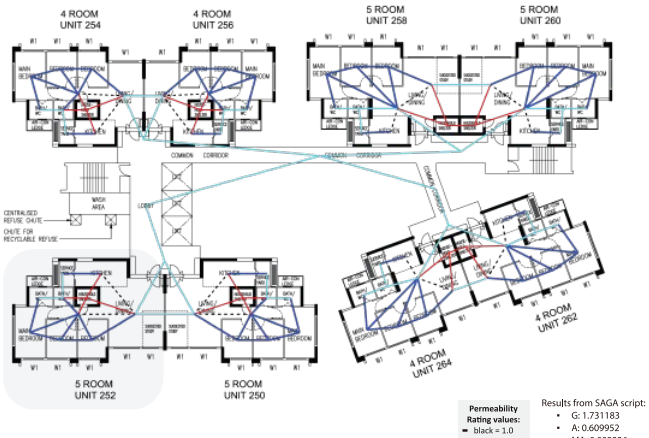
- Demolish & Rebuild?
- Renovate and Adapt?



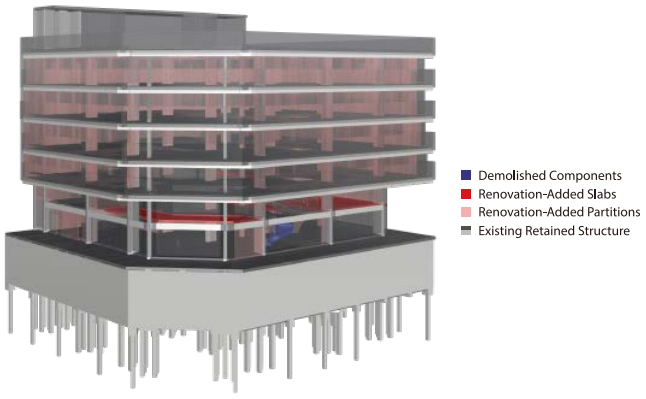
Circular flow of materials through implementation of Disassembly/Adaptability strategies



RESULTS



Spatial Assessment of Generality and Adaptability (SAGA) Results on Bedok South Blossoms HDB building Singapore



GSM building in Singapore Redesigned for change of purpose

Conversion from Commercial (Office) to Residential (Apartments)

CONCLUSION

- Buildings that can adjust their structural configurations, functionalities, and technologies can better accommodate changing occupancy patterns, advances in technology, and evolving environmental or occupancy conditions and requirements - a strategy crucial in our pursuit of a net-zero future.

APPLICATIONS & OPPORTUNITIES

Developing a framework to guide, assess, and validate professionals' designs towards decarbonizing cities.

This framework will act as a structured roadmap that directs architects and engineers towards adaptable designs.

This will improve and emphase influencing factors like material efficiency and longevity of use of structures.

REFERENCES

- Mlote, D. S., Budig, M., & Cheah, L. (2024). Adaptability of buildings: a systematic review
- Herthogs, P., Debacker, W., Tunçer, B., De Weerdt, Y., & De Temmerman, N. (2019). Quantifying the generality and adaptability of building layouts using weighted graphs: The SAGA Method
- Ding, G. K. (2014). Life cycle assessment (LCA) of sustainable building materials
- Akbarnezhad, A., & Xiao, J. (2017). Estimation and minimization of embodied carbon of buildings:

Contact

Doreen Steven Mlote, **d.mlote24@imperial.ac.uk**

BIO

Mlote is a Civil Engineer and Ph.D. Candidate. She is immersed in her Ph.D. research at SUTD where she works in the Adaptive Design Lab (ADL) to explore potential impact of structural designs for adaptive reuse and repurposing of building structures and materials. Currently she is a visiting PhD Researcher at Imperial's Dyson School of Design Engineering.

CALMS - Culturally Appropriate Language Model Systems for Health

Dr Dorian Peters and Marco Da Re
Prof Rafael Calvo

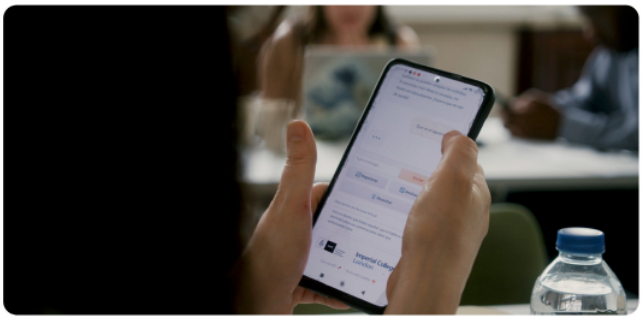
Understanding the cultural limitations and risks of current LLMs and how to overcome these to improve health in low-resourced settings.

Abstract

LLMs are optimised for the Anglophone industrialised West. If AI is to reduce inequality rather than amplify existing bias and disparity, then we need to understand the cultural limitations of current models and how to overcome them. This project, uses **participatory methods to explore how AI could be mobilised to improve healthcare in ways that are appropriate to diverse cultural and social contexts**, especially in low-resourced settings and within the 'majority world'. In partnership with computer scientists at the Universidad Nacional de Córdoba in Argentina, we're developing an LLM-based system focused on identifying and addressing cultural misalignment. Our initial round of fieldwork included 6 workshops conducted in **Argentina, Peru and with Latin American diaspora communities in London and Cardiff**.

Methods

We designed exploratory workshops that leverage structured Storytelling[1,2] as an approach familiar across cultures and literacy levels, and that can make sensitive topics easier to discuss in a group. The goal of the workshops was to improve understanding of: a) how citizens and health professionals from diverse areas of Latin America experience healthcare within their region, b) how and at what points conversational AI might be helpful for improving that experience, and c) how such a system could appropriately respond to cultural, social and practical circumstances that may not be well represented in training data.



Technology

We developed a software environment that allows us to rapidly create and give workshop participants chatbots that represent characters they generated during workshop activities. Participants can then 'talk' to their characters to gain first-hand experience of conversational AI and explore its use within a healthcare context. The tool logs dialog and feedback from users for later analysis and can collect qualitative and quantitative data via pop-up questions.

Team

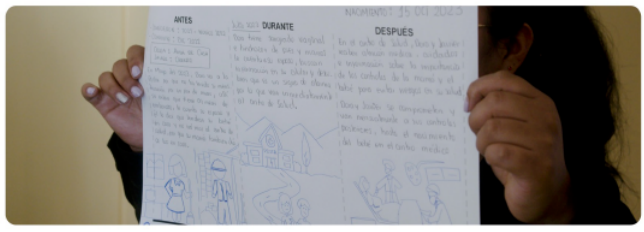
- Prof Rafael A. Calvo (project lead, Imperial College London, UK)
- Prof Luciana Benotti (co-lead, Universidad Nacional de Cordoba, Argentina)
- Marco Da Re (Imperial College London, UK)
- Fernanda Espinoza Lau-Choleon (Imperial College London, UK)
- Guido Ivetta (Universidad Nacional de Cordoba, Argentina)
- Dr Dorian Peters (Imperial College London, UK)

References

1. McCall, B., Shallcross, L., Wilson, M., Fuller, C., & Hayward, A. (2021). Storytelling as a Research Tool Used to Explore Insights and as an Intervention in Public Health: A Systematic Narrative Review. International Journal of Public Health, 66, 1604262.
2. Coleman, T., Till, S., Farao, J., Shandu, L., Khuzwayo, N., Muthelo, L., Mbombi, M., Bopape, M., van Heerden, A., Mothiba, T., Norris, S., Verdezoto, N., & Densmore, M. (2023). Reconsidering Priorities for Digital Maternal and Child Health: Community-centered Perspectives from South Africa. Proc. ACM Hum.-Comput. Interact., 7(CSCW2), 290:1-290:31.

"Maybe there's no way for her to get to the health centre. Often, husbands or in-laws don't let them go, especially if the doctor who will attend to her is male."

Participant, Huancayo, Peru



Bio

Dorian Peters is a Research Fellow in Design Engineering at Imperial College London and Visiting Fellow at the Leverhulme Centre for the Future of Intelligence (LCFI) at the University of Cambridge. She is a Human Computer Interaction and Design researcher who specialises in health and wellbeing.

IMPERIAL Dyson School of Design Engineering

calms.ai

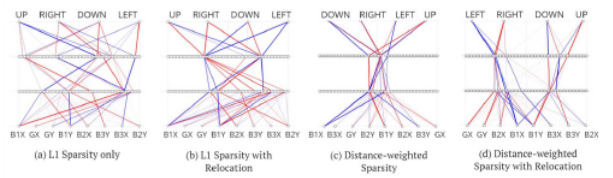
Induced Modularity for Functionally Interpretable Reinforcement Learning

A framework for scalable interpretability in AI systems through alignment with human mental models.

Anna Soligo (ajs1618@ic.ac.uk)
Dr David Boyle, Dr Pietro Ferraro

Summary

Interpretability in reinforcement learning (RL) is crucial for ensuring AI systems align with their desired behaviors and, more broadly, with human values. However, interpreting an RL agent's decision making process in an accurate yet scalable manner remains a significant challenge. We propose a modular approach, inspired by the 'small world' architecture of the human brain. We show how encouraging sparsity and locality in training leads to the emergence of functionally independent modules within an RL policy network. Using community detection algorithms, we show how these modules can be automatically identified and their functional roles verified through intervention on the network parameters. This establishes a scalable framework for RL interpretability through functional modularity, balancing explanation completeness and cognitive tractability.

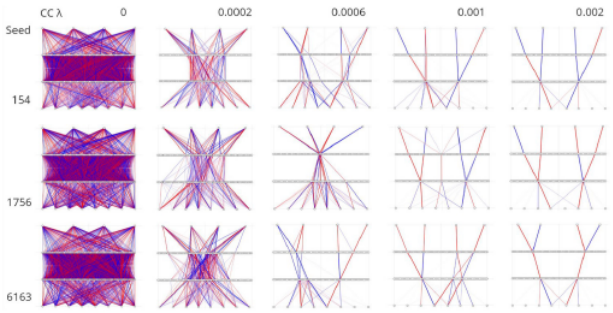


Background

Interpretability refers to the extent to which a neural network's inner workings can be examined and understood. In the RL context, it can enable human oversight, accountability and transparency - key requirements for ethical AI [1]. However, fundamental challenges mean current RL systems rarely afford sufficient interpretability. Primarily, there is an ambiguity regarding what constitutes an 'interpretable' system. A balance must be struck between the scope and detail of an explanation and its utility for a human audience, which raises questions regarding what level of abstraction is suitable. Prior interpretability work largely addresses this by using fundamentally altered architectures, such as decision trees, symbolic equations or sets of logic rules. However, these often scale poorly in interpretability and performance when applied to complex tasks [2].

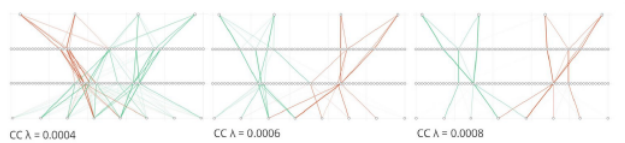
Eliciting Modularity in Neural Networks

This work instead proposes a modular approach to interpretability, inspired by cognitive science's view of cognition as consisting of semi-encapsulated functional modules. We train an agent with the additional objective of minimising the network's 'connection cost' (CC). Each neuron is assigned a 2D position in Euclidean space and the CC loss function penalises weights proportional to both their magnitude and the distance between the neurons they connect. Neurons are additionally iteratively relocated during training to further reduce network CC. As visualised below, this reliably leads to the emergence of modules in the policy network of our toy environment: a 4x4 grid-world with dynamic obstacles (shown right). Input features and output actions reorder to align X and Y feature coordinates with movements along their corresponding axes. The resulting modules share information in the first layer, before diverging into independent processing paths.

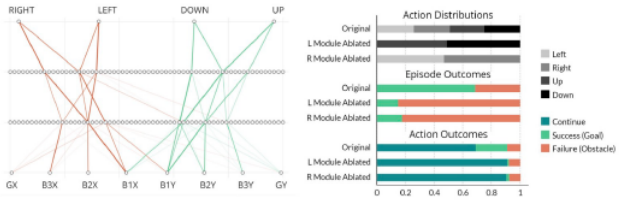


Verifying Modular Functionality

Neurons within a module are characterised as having stronger internal connectivity than external. We thus show that they can be categorised using community detection approaches, and demonstrate this using the iterative Louvain method or, as an alternative approach, using clustering on the second eigenvector. In this application, the latter spectral analysis approach shows better performance, and, as shown below, module separation is further improved as the weighting of our connection cost loss is increased.

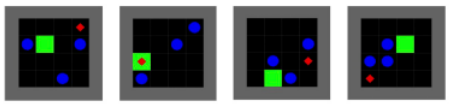


With this environment, we find the module roles can be inferred from inspection of the network. However, to offer a scalable and non-subjective approach to identifying module functionality, we monitor the effects of modifying network parameters. We find that ablating a module prevents the agent from moving along the corresponding X or Y axis and significantly reduces the episode success rate. However, the agent retains the ability to move towards the goal and avoid obstacles in the direction controlled by the non-ablated module. This can be observed in game visualisations and is also reflected in the action outcomes: the proportion of actions resulting in a collision does not increase when a module is ablated.



Conclusions and Future Work

Functional modules may offer a scalable 'unit' for RL interpretability due to their alignment with our mental decision making models. Increasing task complexity can be abstracted at this functional level, while retaining overall interpretability through decomposability (the ability to understand individual network components) and simulatability (the ability for a human to mentally 'simulate' the decision-making process) [3]. Ongoing work is exploring how we can scale our approach to more complex environments, including real-world symbolic applications where parallel, sequential and hierarchical modularity may be observed. Additionally, we are refining the training protocol to address the 14% decrease in performance and 23% increase in train time we currently observe compared to a vanilla PPO implementation.



Bio

Anna is a PhD student in the Systems and Algorithms Lab, focusing on interpretable RL for autonomous systems. She completed her MSc in Design Engineering in 2023.

References

[1] European Comission, & High-Level Expert Group on AI (2019). Ethics guidelines for trustworthy ai.
[2] Glanois, C., et al.. (2024). A survey on interpretable reinforcement learning. Machine Learning, 113 (8), 5847-5890.
[3] Lipton, Z. C. (2016). The mythos of model interpretability. CoRR, abs/1606.03490 .

IMPERIAL Dyson School of Design Engineering

Interactive graphs and animations

Designing Playful Human-AI Music Co-creation for Wellbeing

> “ Elevating Wellbeing Through Delightful AI-Enhanced Music Experiences ”

Jingjing Sun, j.sun23@imperial.ac.uk
Superviseor: Sebastian Deterding, Rebecca Stewart

Abstract

While artificial intelligence (AI) has been widely used in general health informatics and personalised therapy, its applications for creative health [1, 2, 3], specifically using arts engagement to improve wellbeing, have not been extensively explored [4]. Yet the recent rapid development of especially generative machine learning techniques has opened extensive opportunities for creative human-AI collaboration [5], particularly in creating music [6, 7, 8].

Research Question:

How can we design playful human-AI co-creation systems to support both creative outcomes and user well-being?

Musical AIs

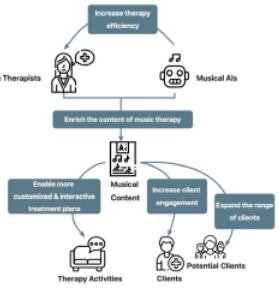
Previous study [9] categorised selected models into five functionalities: (1) General Melody Generation (Ge-Gen), (2) Emotion-based Music Generation (Emo-Gen), (3) Melody Harmonization (Melo-Har), (4) Music Genre Transfer (Genre-Tran), and (5) Tone Transfer (Tone-Tran) (see Fig. 1).

Techniques ID	AI Techniques	Main Functions
Ge-Gen	General Melody Generation	Generate music from scratch: randomly generate melodies from scratch Generate by extending intro music: randomly generate melodies that extend given intro music Create transition: Create a harmonic transition between two separate melodies by performing music interpolation
Emo-Gen	Emotion-based Music Generation	Emotion-based generation: produce music pieces with disparate emotions that may be characterized using Russell's circumplex model.
Melo-Har	Melody Harmonization	Harmonize prime melody: produce a harmonized music piece when given a prime melody
Genre-Tran	Music Genre Transfer	Transfer genres: adapt an existing music piece to a different music genre (e.g., a jazz style to a classical style) Create song mixtures: create mixtures of multiple distinctive songs
Tone-Tran	Tone Transfer	Transfer tone: transform sounds into musical instruments (e.g., transforming the sound of birds chirping into violin performances)

Fig. 1 Five categories of Musical AIs

Potential Benefits of Musical AIs on Music Therapy

These benefits are delineated across three dimensions: from the therapist's perspective, Musical AIs enhance therapy efficiency; Within the context of therapeutic activities, Musical AIs have the potential to diversify therapeutic plans. From the client's standpoint, it may increase their engagement and broaden the range of clients. Overall, Musical AIs enrich the content of music therapy (see Fig. 2) .

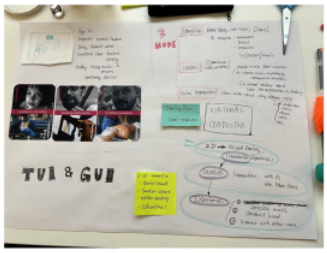


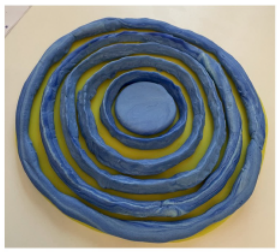
Playful Design for Human-AI Music Co-Creation Interaction

HAICO4M as musical co-creativity refers to the process where humans and computers work together to compose or create music [10]. It is an area of research that explores how AI and machine learning can enhance and extend human creativity in music [11].The computer doesn't replace the human but acts as a collaborator, offering suggestions, generating new ideas, or handling repetitive tasks in the composition process [12]. Tne of the primary issues is the lack of clear and standardised definitions for key concepts, which complicates communication and collaboration among researchers and practitioners. Additionally, there is an insufficient focus on robust system design, leading to the development of AI tools that do not fully leverage the potential of human-AI collaboration in musical creativity. Furthermore, the limited exploration of playful interactions within these systems restricts the ability to engage users effectively, diminishing the overall creative experience. A key design quality that drives this joyful engagement is playfulness[13]. Playful interaction can promote positive emotions, alleviate stress, foster creativity, strengthen social connections, and support self-efficacy [14]. By incorporating playfulness into human-AI music co-creation, this Ph.D. project aims to explore design paradigm in which musical AI systems can enhance both wellbeing and creative outcomes through playful engagement.

Potential Design Outcomes

The research plans to initiate a co-design workshop study utilising playful experience design (PLEX) cards [15] as guidelines to explore playful interactions between designers and music AI technicians. Employing research through design method [16], this study aims to produce design outcomes in the form of prototypes specifically tailored for a target user group aged 18 to 25 with general anxiety. Design outcomes show as follows:





Bio

Jingjing Sun is a first year PhD Student with research interested in HCI research in specific for user research, playful design, human-AI co-creation, human-AI collaboration, design for wellbeing.

References

- 1. Christopher Madden and Taryn Bloom. Creativity, health and arts advocacy. International Journal of Cultural Policy, 10(2):133–156, 2004.
- 2. Kate Phillips. A constructive-critical response to creative health: the arts for health and wellbeing (july 2017) by the all-party parliamentary group on arts, health and wellbeing. International Journal of Art Therapy, 24(1):21–29, 2019.
- 3. Haizi Yu, James A Evans, Donna Gallo, Adam Kruse, William M Patterson, and Lav R Varshney. Ai-aided co-creation for wellbeing. In ICCC, pages 453–456, 2021.
- 4. Fei Wang and Anita Preininger. Ai in health: state of the art, challenges, and future directions. Yearbook of medical informatics, 28(01):016–026, 2019.
- 5. Rowan T Hughes, Liming Zhu, and Tomasz Bednarz. Generative adversarial networks–enabled human–artificial intelligence collaborative applications for creative and design industries: A systematic review of current approaches and trends. Frontiers in artificial intelligence, 4:604234, 2021.
- 6. Cheng-Zhi Anna Huang, Hendrik Vincent Koops, Ed Newton-Rex, Monica Dinculescu, and Carrie J Cai. Ai song contest: Human-ai co-creation in songwriting. arXiv preprint arXiv:2010.05388, 2020.
- 7. Ryan Louie, Andy Coenen, Cheng Zhi Huang, Michael Terry, and Carrie J Cai. Novice-ai music co-creation via ai-steering tools for deep generative models. In Proceedings of the 2020 CHI conference on human factors in computing systems, pages 1–13, 2020
- 8. Augustinos Tsiros and Alessandro Palladini. Towards a human-centric design framework for ai assisted music production. In Proceedings of the International Conference on New Interfaces for Musical Expression, pages 399–404, 202
- 9. Jingjing Sun et al. "Understanding Human-AI Collaboration in Music Therapy Through Co-Design with Therapists". In: Proceedings of the CHI Conference on Human Factors in Computing Systems. 2024, pp. 1–21
- 10. Gianluca Micchi et al. "I keep counting: An experiment in human/AI co-creative songwriting". In: Transactions of the International Society for Music Information Retrieval (TISMIR) 4.1 (2021), pp. 263–275.
- 11. Nantheera Anantrasirichai and David Bull. "Artificial intelligence in the creative industries: a review". In: Artificial intelligence review 55.1 (2022), pp. 589–656.
- 12. John B Smith. Collective intelligence in computer-based collaboration. CRC Press, 1994.
- 13. Tilde Bekker, Janienke Sturm, and Berry Eggen. "Designing playful interactions for social interaction and physical play". In: Personal and Ubiquitous Computing 14.(2010), pp. 385–396.
- 14. Albert Bandura and Sebastian Wessels. Self-efficacy. Cambridge University Press Cambridge, 1997
- 15. Lucero, Andres, and Juha Arrasvuori. "PLEX Cards: a source of inspiration when designing for playfulness." Proceedings of the 3rd International Conference on Fun and Games. 2010.
- 16. Stappers, Pieter Jan, and Elisa Giaccardi. "Research through design." The encyclopedia of human-computer interaction. The Interaction Design Foundation, 2017. 1-94.

IMPERIAL Dyson School of Design Engineering

Designing for Curiosity in Cultural Heritage Experiences: A Scoping Review

Tianxiao Wang, tianxiao.wang19@imperial.ac.uk
Sebastian Deterding, s.deterding@imperial.ac.uk

Keywords: *curiosity, interest, information-seeking, cultural heritage, qualitative content analysis, experience design, scoping review*

Introduction

Museums and heritage sites are tasked with attracting and engaging visitors and creating spaces for free-choice learning and active prolonged engagement. Visitor curiosity is an important user experience in cultural heritage contexts, yet interaction designers working in the field lack systematic guidance on how to evoke curiosity.

In response, we conducted a scoping review to synthesise the current state of knowledge and address three interconnected research gaps: lack of general synthesis (RQ1), lack of actionable design guidance (RQ2), and unclear research translation from psychology and rigour (RQ3).

Methods

Given our exploratory research aims, we conducted a scoping review following Arksey and O'Malley's procedures [1] and the PRISMA extension for Scoping Reviews (PRISMA-ScR) [2] for reporting (Fig.1). After screening 587 records across six databases, we selected 40 eligible studies for qualitative analysis.

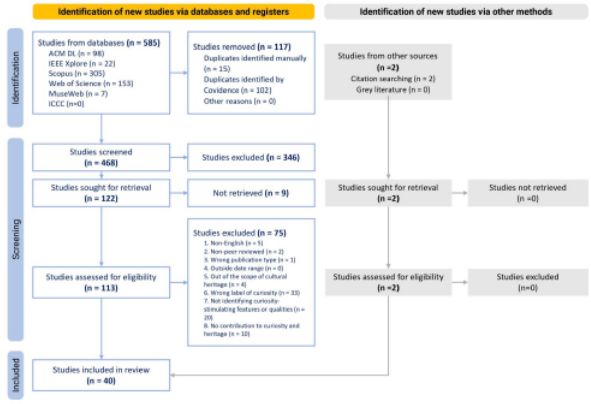


Fig.1. PRISMA-ScR Flow Diagram of the study selection process and information sources

Results

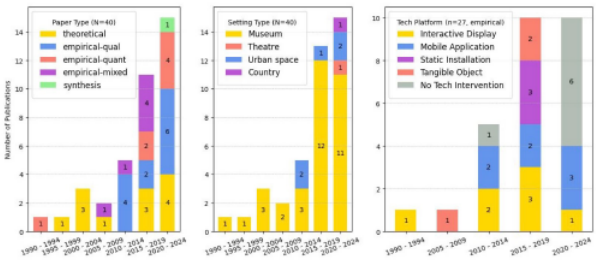


Fig. 2. Publications and trends by paper types, research settings, and technology platform from 1990 to 2024 (group by 5 years)

> "The **first systematic mapping** of visitor experiences and design techniques from prior work, demonstrating the ***potential*** to evoke curiosity in heritage."

RQ1: Characteristics of the Literature are summarised in Fig.2 (left-bottom).

- Research increases since mid-2010s and is mostly theoretical or qualitative.
- Museums dominate as researched heritage settings, including art (18.2%, n=6), science (15.2%, n=5), natural history (12.1%, n=4) and other museums.
- Technology platforms evolve over time, featuring interactive displays and mobile applications whereas non-digital intervention gains momentum recently; Artificial Intelligence (AI) technology has not been applied yet.

RQ2: Experiences and design techniques *could* evoke curiosity in heritage.

- Berlyne's original *collative variables* (e.g. uncertainty or novelty) [3] became a leading category of 15 distinct curiosity-stimulating experiential qualities.
- 21 design techniques in 7 categories were identified, which broadly but not fully aligned with experiential qualities (Fig.3).

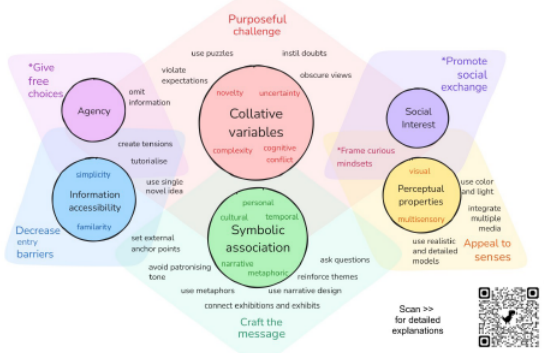


Fig.3. Experiential qualities (in circles) that could potentially evoke curiosity in heritage contexts are associated with design techniques (in diamonds). (*)Technique categories contain a single technique.

RQ3: Curiosity are heterogeneously defined, theorised, and assessed.

- Heterogeneous definitions of curiosity: 60% (n=24) without explicit definitions.
- Rare and heterogeneous use of theories, 55% (n=22) not referencing *any* theory-related prior literature in their study designs and discussions.
- Heterogeneous and careless use of curiosity assessment methods, with little care for finding and using well-validated psychometric instruments.
- We traced connections towards specific "psychological" and "non-psychological" theories based on the authors' disciplinary affiliations (Fig.4).

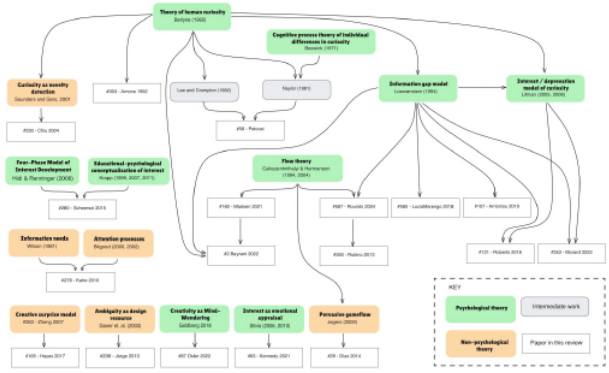


Fig.4. Psychological and non-psychological theories traced from the selected studies

Discussions & Conclusion

Although the research marks a first step in a *rigour cycle* [4] towards building a knowledge base through and for design around curiosity in heritage experiences, we readily acknowledge this systematic inquiry is itself not in a ready translational format for HCI [5]. The literature landscape does not warrant meaningful results from quality appraisal. Our thematic categories are not yet validated by practitioners.

Future research should address research gaps in 1.natural and built heritage interactions, 2. non-digital asset-based design, 3. Artificial Intelligence technologies, 4. psychological theories, evidence, and methods, and 5. empirical validation and practical translation of these techniques and experiential factors.

IMPERIAL Dyson School of Design Engineering

References

1. Hilary Arksey and Lisa O'Malley. 2005. Scoping studies: towards a methodological framework. https://doi.org/10.1080/1364557032000119616
2. Andrea C. Tricco et al., 2018. PRISMA extension for scoping reviews (PRISMA-ScR): Checklist and explanation. https://doi.org/10.7326/M18-0850
3. D. E. Berlyne. 1960. Conflict, arousal, and curiosity. https://doi.org/10.1037/11164-000
4. Alan Hevner. 2007. A three cycle view of design science research. https://aisel.aisnet.org/sjis/vol19/iss2/4
5. Lucas Colusso et al., Translational Resources: Reducing the Gap Between Academic Research and HCI Practice. https://doi.org/10.1145/3064663.3064667

Design: Mingke Wang
Editor: Mazdak Ghajari
2024 July

IMPERIAL Dyson School of Design Engineering