

The Co-Design and Development of Reusable Theatre Caps with NHS Scotland

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ABSTRACT

This paper describes the co-design and development of a plant-based, biodegradable, and reusable theatre cap project, developed in collaboration with NHS Scotland. This project forms part of an ongoing UKRI / AHRC-funded Green Transition Ecosystem Hub entitled Design HOPES (Healthy Organisations in a Place-based Ecosystem, Scotland). Design HOPES is a transdisciplinary initiative that applies design-led innovation to address health service challenges while supporting net-zero sustainability goals. Recognising that healthcare is a major global emitter of greenhouse gases, this project seeks to reduce waste from single-use, disposable operating theatre consumables whilst improving communication amongst NHS Scotland theatre staff wearing Personal Protective Equipment (PPE). By co-designing reusable, plant-based theatre caps with NHS Scotland theatre staff, the project aims to enhance comfort, functionality, and environmental sustainability. In 2023, an estimated 110 million disposable caps were sent to landfill worldwide, with around 2.5 million used annually in NHS Scotland hospitals alone. The reusable alternative theatre caps presented in this paper offer a scalable solution to reduce waste and carbon emissions, contributing to a more sustainable healthcare system and improved working conditions for theatre staff.

Keywords: Biodegradable, Co-design, Design, Net-Zero, NHS Scotland, Regenerative Design.

INTRODUCTION

The increasingly recognized enmeshment between healthcare, the environment, and design demands that the design discipline offer new, scalable methodologies for addressing complex, systemic crises (Ceschin and Gaziulusoy, 2016). This plant-based reusable theatre cap project, in collaboration with NHS Scotland, is part of a larger AHRC-funded Green Transition Ecosystem Hub entitled Design HOPES (Healthy Organisations in a Place-based Ecosystem, Scotland) - a transdisciplinary research project that aims to exploit the potential of design-led thinking, making, and acting to innovate and tackle multifaceted health delivery challenges to meet urgent net zero goals for a sustainable health and social care system. The effects of climate change on health will affect most populations and put the health and wellbeing of billions of people at increased risk (Costello et al., 2009). The global imperative for this work is stark: the effects of climate change on health place the wellbeing of billions at immediate risk (Costello et al., 2009), a crisis compounded by the fact that if global healthcare sector were a country, it would be the fifth-largest emitter of greenhouse gases on the planet (Health Care Without Harm, 2019).

Working closely with NHS Scotland theatre staff, this paper will describe how we have co-designed a range of reusable plant-based theatre cap options that reduce theatre waste whilst improving staff communication and comfort. While this paper describes the co-design of a range of reusable, plant-based theatre cap options that reduce waste and improve staff communication, its contribution to the wider design field extends beyond a descriptive project case study. Rather, this work serves as an empirical model for operationalizing systemic design frameworks within highly regulated, risk-averse public sector environments.

It is estimated that in 2023 a minimum of 110,557,119 (over one-hundred-and-ten million) disposable theatre caps ended up in landfill (Costello et al., 2009). In Scotland alone, around 2.5 million single-use disposable theatre caps were used across Scottish hospitals in one year between September 2022 and September 2023 (Centre for Sustainable Delivery / NHS Scotland National Green Theatres Programme, 2024). The reusable theatre caps described in this paper will help to reduce significantly the environmental impact of medical waste.

It is common practice across NHS Scotland for disposable single-use theatre caps to be used within operating theatres. Extrapolated figures have identified that over 2.4 million single-use caps were ordered across NHS Scotland between September 2022 and September 2023. This equals over 12.8 tonnes of waste entering Scottish waste streams annually. The majority of theatre caps are composed of a combination of cotton or polyester. Polyester can take up to 300 years to decompose in landfill and often ends up being disposed of through clinical waste streams. Moreover, during manufacturing of the materials there is an embodied carbon footprint of approximately 62 tonnes of Co2e annually. This calculation is based on 1 manufacturer’s product which has a material composition of 55% cotton and 45% polyester. By making the change to plant-based reusable theatre caps, the associated carbon footprint would reduce to just under 11 tonnes of Co2e over a 3-year period (Table 1) equating to over 90% reduction in associated emissions.

Table 1: Projected Carbon Savings

	Reusable Carbon Impact (tCo2e)	Single Use Carbon Impact (tCo2e)
Year 1	8.34	62.3665
Year 2	1.04	62.3665
Year 3	1.04	62.3665
Total	10.42	187.0095

Reusable theatre caps have at least a 3-year average lifespan, depending on the material used and the washing and maintenance guidelines being adhered to. By changing to reusable theatre caps from their single-use disposable counterparts, a carbon saving of 51 tonnes would be achieved in the first year across NHS Scotland, the equivalent of planting nearly 2,000 trees.

From an economic perspective, reusable theatre caps can offer cost savings to NHS Scotland. Whilst varying in cost, reusable theatre caps average around £6.00 per cap. Table 2 estimates the costs savings if reusable theatre caps were introduced across NHS Scotland hospitals. This estimate assumes that all NHS Scotland theatre staff adopt reusable caps and accounts for a 13% annual staff turnover, which is almost 400 staff changes each year. Each new employee would be provided with 5 reusable theatre caps. In this scenario, switching to reusable theatre

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caps could reduce costs from just under £150,000 to £94,402 in the first year and reducing to £11,800 in the second and third years.

Table 2: Projected Cost Savings

	Reusable Cap Cost (annual)	Single-use Cap Cost (annual)	Projected Financial Saving
Year 1	£94,402.40	£147,705.12	£53,302.72
Year 2	£11,800.30	£147,705.12	£135,904.80
Year 3	11,800.30	£147,705.12	£135,904.80
Total	£118,003	£443,115.36	£325,112.32

The UK's National Health Service (NHS) is responsible for approximately 4% of the country's carbon emissions, and over 7% of the economy. As such, it has a vital role to play in meeting the net zero targets set under the Climate Change Act "Delivering a 'Net Zero' National Health Service" (NHS England and NHS Improvement, 2021). Design HOPES' focus, NHS Scotland, has set its own ambitious targets for net zero to 2040. As a significant contributor to meeting this 2040 target, NHS Scotland offers considerable design-led opportunities for a green transition. Design HOPES working closely with NHS Scotland and other relevant stakeholders has the potential to scale and amplify successful design-led innovations to wider NHS UK contexts and beyond through an international coalition of over 50 countries who have committed to developing low-carbon health Systems (NHS Scotland, Climate Emergency & Sustainability Strategy, 2022 to 2026, 2022).

Design-led research in health and social care contexts has changed in recent years, shifting from a focus based largely on economic growth towards one of wider social and environmental issues that highlight more design-led systemic approaches. Many design researchers including several members of Design HOPES are involved in the sustainable design of interventions such as innovative products, services and systems that positively impact on the environment, health and healthcare, promote dignity, and enhance quality of life, and action change in a range of settings (Robertson *et al.*, 2022; Bruce and Baxter, 2008; Rodgers, 2021).

Recent research into health service design, delivery and improvement has presented compelling evidence that a design-led systems approach to addressing health delivery challenges may lead to significant improvements in both patient and service outcomes (Komashie *et al.*, 2021). At the same time, the UK Design Council Systemic Design Framework (Design Council, 2021) offers guidance to designers, collaborating disciplines and sectors to create meaningful change. Design HOPES, part of Future Observatory, the Design Museum's national research programme for the green transition funded by the Arts and Humanities Research Council, which is part of UK Research and Innovation, is a collaborative, design-led green transition ecosystem hub that comprises five Scottish Universities (Strathclyde, Dundee, Heriot-Watt, Abertay, and Edinburgh), health boards across Scotland's National Health Service (NHS), the third sector (charities, social enterprises, co-operatives etc.) and organisations from the design economy. The climate emergency is a health emergency and in response Design HOPES aims to exploit the potential of design-led thinking, making and acting to innovate and tackle multifaceted health and social care delivery challenges by creating,

prototyping, and testing new products, services, tools, and systems needed for NHS Scotland to meet, and move beyond, urgent net zero goals.

Comfort and ergonomics have long been recognised as decisive factors in the adoption of healthcare workwear yet remain under-tested relative to their clinical significance. Ergonomic clothing research emphasises that fit, mobility, and thermal regulation are primary determinants of garment acceptability in demanding occupational settings (Mukhopadhyay and Singh, 2022), while durability and wear performance under repeated laundering cycles are increasingly recognised as inseparable from comfort outcomes in healthcare textiles (Wang, Lu and Song, 2020; Russell, Keshavarz and Arnold, 2021). Within NHS contexts specifically, functional detailing (i.e., fastenings, pockets, and closures) has been shown to directly shape user satisfaction and willingness to adopt new uniform designs (Petersen and Riisberg, 2016). Ultimately, this paper contributes to the contemporary discourse on the pluralistic and democratic nature of design research (Rodgers et al., 2025; Rodgers and Yee, 2023). By chronicling the negotiations between design researchers, clinical staff, procurement officers, and laundry service stakeholders, this paper offers a transferable methodological framework for navigating the pragmatic and philosophical tensions of transdisciplinary healthcare design.

In doing so, this work honours Ranulph Glanville's assertion that protecting and documenting a variety of design research journeys is vital (Glanville, 2015). We move beyond a simple project description to offer a concrete critique of how design-led thinking, making, and acting can practically dismantle systemic dependency on single-use materials in public healthcare systems.

1. DESIGN HOPES' PROJECTS

The plant-based reusable theatre caps are just one of several ongoing Design HOPES projects each highlighting powerful design-led thinking, making, and acting methods and tools used (Figure 1). These projects illustrate how, using a design-led and rich collaborative approach, one can re-imagine the design and delivery of future health and social care provision in ways that will deliver environmental sustainability. Design HOPES projects sit at the intersections of design, health and wellbeing addressing complex net zero challenges with an emphasis on inclusive, equitable, and sustainable design-led interventions. These projects encompass diverse interventions across and beyond conventional design boundaries such as architecture, product design, and textile design providing outcomes that demonstrate the impact of design-led research on real-world net zero issues.

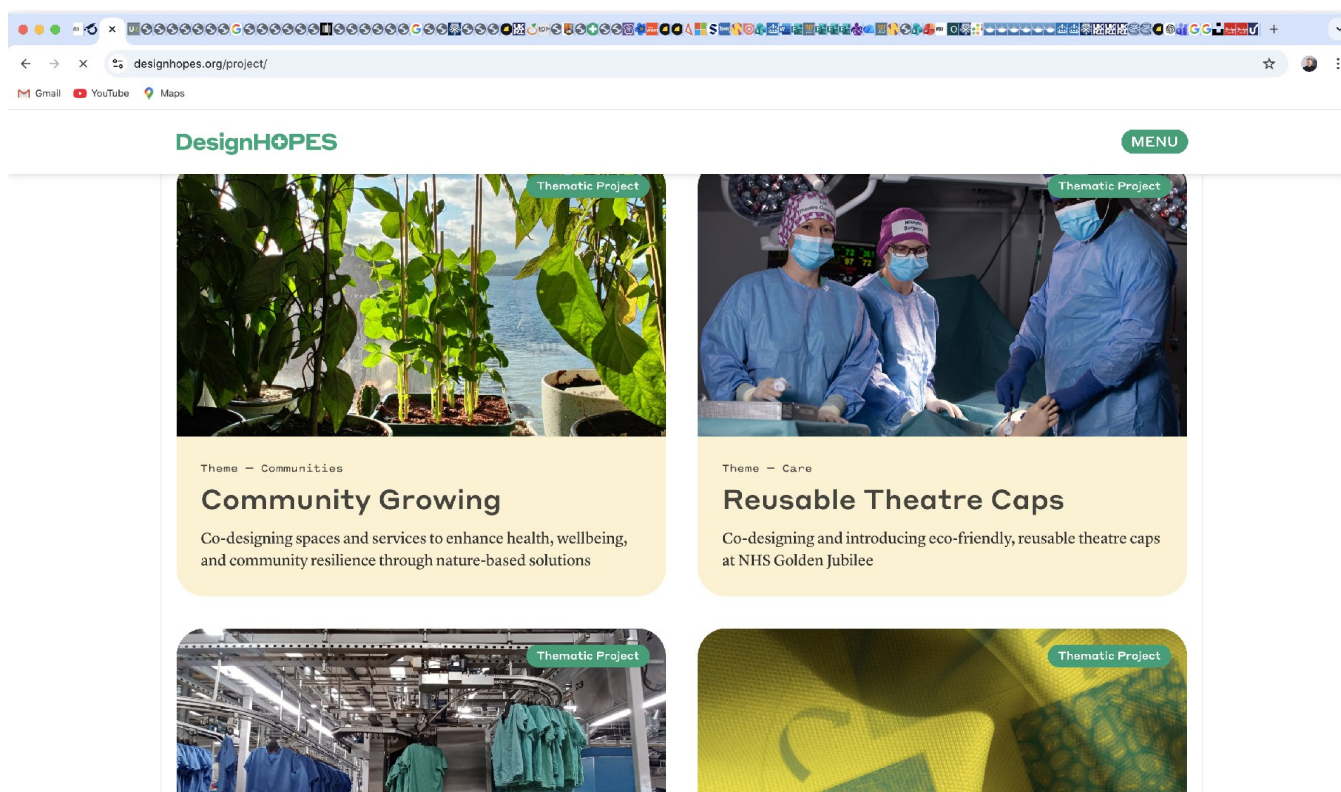


Figure 1. Selection of Design HOPES' Projects.

The ongoing Design HOPES projects were identified through a rigorous process of stakeholder engagement involving NHS Scotland, the Scottish Government, and the wider Design HOPES team. Through a series of co-design workshops and collaborative activities, participants explored challenges, considered diverse perspectives (including those often overlooked or marginalised) and reframed issues to support the transition towards regenerative futures.

Guided by the UK Design Council's Systemic Design Framework (Design Council, 2021), this process focused on four interconnected stages: **exploring** current conditions, **reframing** challenges, **creating** new possibilities, and **catalysing** action through testing and implementation. Bringing together expertise from different sectors and disciplines enabled the sharing of knowledge, methods, and approaches, helping to generate innovative responses to complex challenges facing NHS Scotland.

2. METHODS

Central to Design HOPES is its co-design approach, with the voice of NHS Scotland staff core to the definition of problems and the generation of appropriate design-led interventions. By including NHS Scotland staff and other relevant stakeholders at the Design Sprints, and central in the design research activities of projects, some clear characteristics emerged. Firstly, time and resource pressures were a primary concern and a barrier to change. Health and social care services are increasingly required to do more with less (The Health Foundation, 2022), meaning that although staff would like to transition towards more effective working methods, they lack the capacity to develop and implement new models. Another major challenge we have encountered is the interaction of a wide range of stakeholders with complex dynamics. The NHS is the largest employer in Scotland with nearly 200,000 people and is a deeply hierarchical organisation with distinctly defined job roles. This, combined with the fact that it serves the breadth of the national population (not only patients but supporting families and

visitors) means that there are a huge number of competing incentives and agendas in delivery of its overall goals that are not easily tracked by performance management systems (Ojiako *et al.*, 2023). Nevertheless, there remains strong incentives towards health and wellbeing amongst staff. Individuals who work in healthcare have a tendency towards high levels of empathy and are motivated to help individuals (Moudatsou, 2020). While this is a powerful force to be harnessed, it can lead to high levels of stress and disillusionment when it is not possible to deliver the services expected (May 2024; Wilkinson, 2017). There is also a historical and ongoing conflict between regulations and desire for change. The rigid regulatory environment to protect hygiene and safety, and the bureaucratic culture that has emerged in the wake of this, means that change can be difficult to implement even where opportunities and benefits are clear (Arora, 2021).

The conversations that have emerged in Design HOPES projects have helped to embed the overall project ethos and have facilitated the development of strong bonds between NHS Scotland staff and project partners.

This innovative work started by undertaking a series of activities that (1) aimed to understand the current use of disposable single-use theatre caps and (2) to co-design and develop a sustainable reusable theatre cap. Initially we conducted a series of exploratory co-design workshops with NHS Scotland theatre staff to ascertain what happens in NHS Scotland operating theatres, determine the key issues, and co-develop with NHS Scotland theatre staff a bold and innovative reusable and sustainable alternative to the current single-use disposable cap.

Each co-design workshop involved approximately 25 NHS Scotland theatre staff, including surgeons, anaesthetists, and nursing staff, that lasted between two and three hours. Sessions were held at a number of NHS Scotland hospitals including the Golden Jubilee National Hospital, Glasgow and the Royal Alexandra Hospital, Paisley, Scotland between January 2023 and May 2024, which were facilitated by members of the research team using a series of design-led methods including design probes (Figure 2) and hands-on prototyping activities. Workshop outputs were recorded through these probes and additional field notes and observations that the research team compiled during the sessions.

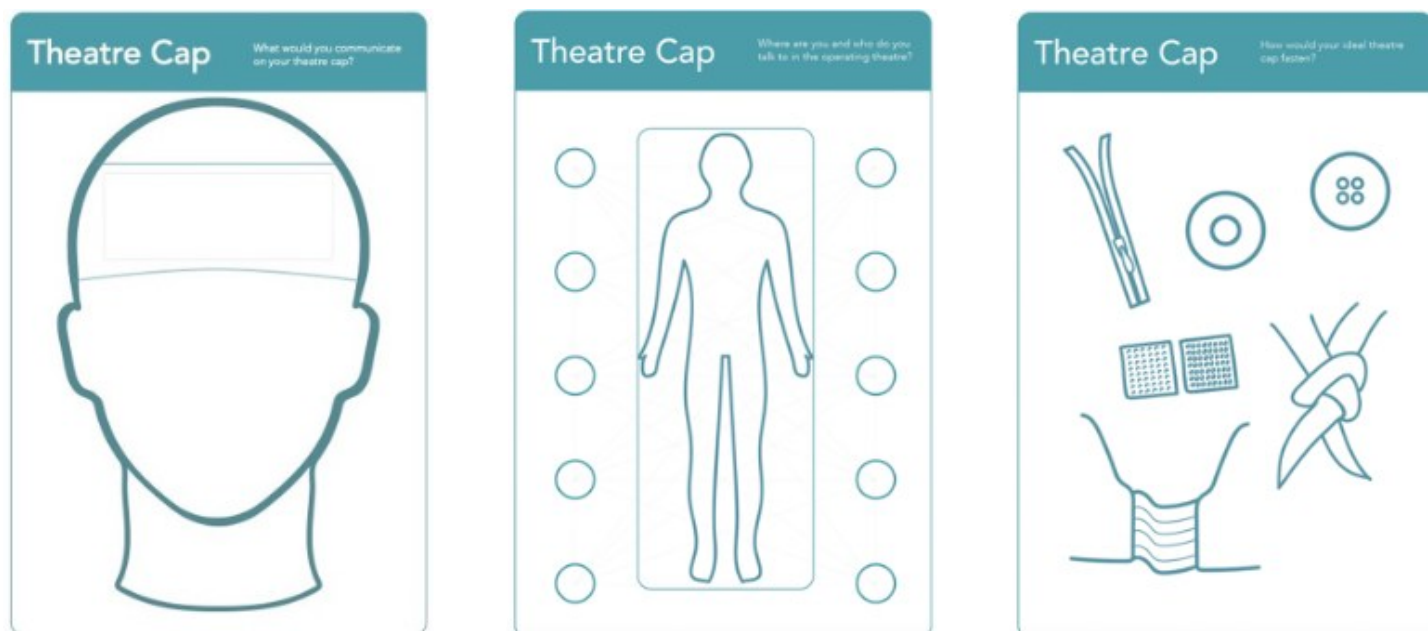


Figure 2. Reusable Theatre Caps Design Probe.

At this stage, we asked via a design probe (Figure 2), semi-structured interviews, and a series of co-design paper prototyping workshops (Figure 3) the following questions:

- What barriers are there for you in using reusable theatre caps?
- What would you like to communicate on your theatre cap?
- What material would you like your theatre cap made from?
- How many theatre caps (on average) do you use each day?
- What else you would like to say about theatre caps?



Figure 3. Paper Prototyping Reusable Theatre Caps (photo credit: authors).

At the end of the first round of co-design workshops with NHS Scotland staff, our explorations revealed a number of key insights related to what happens in theatre settings as well as some of the significant issues involved. In these co-design sessions, we actively drew on perspectives from key stakeholders including surgeons, anaesthetists, and nurses and others that might have been marginalised historically. The responses highlighted clearly a number of features that the theatre staff wished to see in any new reusable theatre cap:

- Breathable; hair-friendly; easily washed; soft; comfortable
- Should evoke friendliness; should clearly show first name and job role

- Should be friendly and welcoming in appearance; available in different colours

After gathering different types of knowledge and feedback from a range of NHS Scotland theatre staff with different perspectives, we started making a series of first series prototypes (Figure 4) that would meet the staff's initial requirements. Specific feedback on our first series of reusable theatre cap prototypes included - *"the "square caps are uncomfortable... more rounding on caps needed", "Oscar the jersey hat is the best material!", "The new theatre cap is comfortable, breathable and fits perfect over hair clips... it fits securely and there is no worry of it falling off my head", "the drawstring to ensure good fit is good", "I like the feel and fit of the Skye (woven) hat with ties, and also the Oscar hat with ties", "having a choice of sizes is good", "I prefer the tie at the back due to different hairstyles", "not keen on the square shape - perhaps sew corners more rounded", "nice feel of fabric, light and airy"*.



Figure 4. Reusable Theatre Caps - First Series of Prototypes (photo credit: authors).

After several months of further iterative design development, most notably involving zero waste pattern layout and cutting, digital printing tests, textile and laundry tests, and wearability and fit testing, we returned to NHS Scotland staff with a range of second series reusable theatre cap prototypes (Figure 5). The insights from this round of user-testing with NHS Scotland staff included the following:

- NHS Scotland staff preferred the softer fabric made from cellulosic fibre material
- Staff liked the tie fastening at the back
- Staff liked the idea of S, M and L sizes
- Staff preferred the "rounded" shaped pattern
- Staff name and role needs further work
- Name clearly at front is good



Figure 5. Reusable Theatre Caps - Second Series of Prototypes (photo credit: authors).

Following extensive feedback on the first and second series of prototypes received during the co-design workshops, further prototypes were developed focusing on design, style and fit to address the following comments:

- “Unique personalisation is important”
- “Solid colours as well as patterns is good”
- “Good for identifying each individual”
- “Colourful, easy to identify staff”
- “I would like the roles to be added... this is beneficial for both patients and staff. Especially in emergencies!”
- “Names and roles can help as it gets confusing. Will be more helpful for patients also.”

To date, the Design HOPES reusable theatre cap team have facilitated five co-design workshops that have progressed through the Design Council’s Systemic Design Framework four iterative stages - explore, reframe, create, and catalyse (Design Council, 2021). The team have presented this work to the Scottish Government Cabinet Secretary for Health during his visit to NHS Golden Jubilee hospital on 25 September 2024. Furthermore, the reusable theatre caps have been exhibited as part of a Design HOPES Work-in-Progress exhibition at the V&A Dundee (6 December 2024 to 23 February 2025) and more recently at the Future Observatory: Tools for Transition exhibition at the Design Museum, London¹ (12 September to 2025 August 2026) (Figure 6).

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¹ <https://designmuseum.org/exhibitions/future-observatory-tools-for-transition>



Figure 6. Tools for Transition Exhibition - Design HOPES section (photo credit: Luke Hayes).

Ethical approval for this study was granted by the University of Strathclyde's Ethics Committee (reference number: UEC24/26 Rodgers: Design HOPES), secured through the University of Strathclyde's strategic research partnership with NHS Scotland. All participants provided informed consent prior to taking part in workshop and interview activities.

3. RESULTS

The Design HOPES plant-based reusable theatre caps deliver significant benefits to NHS Scotland in three important ways, namely (i) environmental, (ii) economic, and (iii) patient safety:

1. **Eliminates single-use disposable theatre caps.** In 2023, it was estimated that a minimum of 110,557,119 (one-hundred-and-ten million) disposable theatre hats ended up in landfill. The Design HOPES plant-based reusable theatre hats make a significant impact on reducing total landfill waste. On average a UK hospital disposes of around 100,000 single-use disposable hats every year. Changing away from single-use disposable theatre hats to our plant-based reusable theatre hats eliminates disposable items from going to landfill across NHS Scotland.
2. **Reusable theatre caps save money.** Studies show that reusable theatre caps are more cost effective as they last longer (approximately 3 years with regular washing) than their single-use disposable competitors (Billingsley, 2022). Moreover, it is reported that whilst 1,443,264 single-use disposable caps have to be manufactured every year, only around 10,459 reusable theatre caps have to be produced every three years (Billingsley, 2022).
3. **Reusable theatre caps increase patient safety and overall efficacy.** Studies show that reusable theatre caps allow less contaminants into the operating room atmosphere than

disposable ones, potentially reducing surgical site infections (SSIs) (Markel et al., 2017). It has also been shown that reusable theatre caps have no association to risk of SSI in general surgery (Haskins et al., 2017). A significant feature of the Design HOPES' reusable theatre caps is their personalization (name and role of the NHS Scotland staff member prominently displayed at front). Studies report that between 30 to 50% of people forget their colleagues' names after surgical briefings (Birnbach, 2017; Burton 2018), and that teams work better when they know the names and roles of other members (Bobb, 2018; Leonard, 2004).

News / Glasgow & West

Hospital trials biodegradable theatre caps in bid to reduce waste

They are made from plant-based fibre.



Figure 7. STV News Feature on the Reusable Theatre Caps (photo credit: Marsaili McGrath).

In addition to the clear environmental, economic, and patient safety benefits of these new plant-based reusable theatre caps, this research project has secured significant traction across UK media channels with over 200 coverage hits to date. Highlights include print coverage in a number of UK national newspapers including *The Glasgow Herald* (Martin, 2025), *The Scotsman* (McDougall, 2025), and *The Daily Telegraph* (Daily Telegraph Reporter, 2025),

broadcast television coverage e.g., STV News² (Figure 7), regional UK coverage (*i.e.*, London Evening Standard, Glasgow Evening Times), key online sites like MSN, Yahoo, and current affairs titles such as *Perspective* magazine and *Health Industry Leaders* magazine. Future work planned includes further testing of the plant-based reusable theatre caps including laundry and biodegradation tests, extensive user-testing across NHS Scotland health boards, and the launch of a start-up company that will design and manufacture the Design HOPES plant-based reusable theatre caps in Scotland.

Recently, we have undertaken user testing with over 250 theatre staff including surgeons, anaesthetists, and nurses across 15 NHS Scotland health boards (Figure 8). The response rate has been excellent with close to 40% of the 254 NHS Scotland theatre staff responding to the survey, which is a significantly higher response than is typical for studies that collect data from organisations (Baruch and Holtom, 2008).

NHS Scotland Theatre Roles

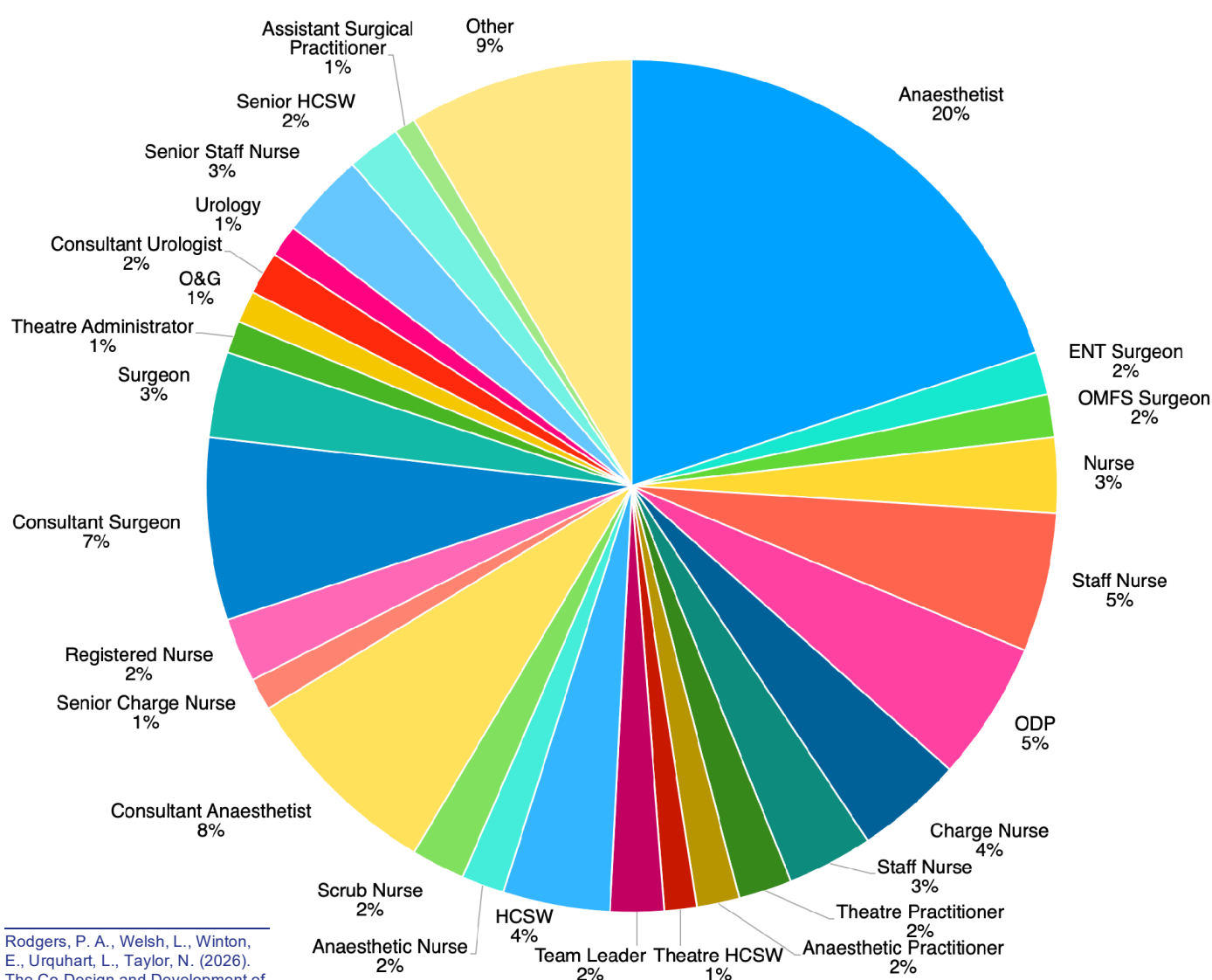


Figure 8. Breakdown of NHS Scotland Theatre Staff Roles Involved in User Testing

In our user testing, we asked the theatre staff a series of questions via an online survey that explored their views on their new reusable theatre cap (Table 3).

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² <https://news.stv.tv/west-central/hospital-trials-biodegradable-theatre-caps-in-bid-to-reduce-waste>

Table 3: Selection of Reusable Theatre Cap User Testing Questions and Results

Theatre Cap Element	Question	Results
Aesthetics	Do you think the style of the reusable theatre cap is aesthetically pleasing?	Nearly two-thirds of respondents (61%) think the style of the Design HOPES Reusable Theatre Caps are aesthetically pleasing.
Quality	Do you think the material feels high quality?	More than two-thirds (69%) think the material of the Design HOPES reusable theatre cap feels high-quality.
Comfort	Do you think the reusable theatre cap is comfortable to wear?	87% of respondents think the Design HOPES reusable theatre cap feels comfortable against the skin.
Fit	Do you think the reusable theatre cap fits well?	Over half of the respondents think their reusable theatre cap fits well.
Washing	Are you willing to follow the washing instructions provided?	92% of respondents are prepared to follow the washing instructions provided.
Design	Are you satisfied with the design of the reusable theatre cap?	Half of respondents are satisfied with the design of their reusable theatre cap.
Ease of Use	Do you think the reusable theatre cap is easy to put on and take off?	Nearly two-thirds think the Design HOPES reusable theatre cap is easy to put on and 85% think it is easy to take off.
Reduce Waste	Would you be willing to replace disposable theatre caps for a reusable theatre cap to help reduce waste?	Three-quarters (75%) would like to replace disposable theatre caps for a Design HOPES reusable theatre cap to reduce waste.
Improve Communication	Would you like to replace disposable theatre caps for a reusable theatre cap to improve communication?	69% of respondents would like to replace disposable theatre caps for a Design HOPES reusable theatre cap to improve communication.

These results indicate that the NHS Scotland staff involved in the national user testing study overwhelmingly support the concept of reusable theatre caps and the personalisation features that show the name and role of the individual member of staff. NHS Scotland staff highlight that this particular feature clearly has the potential to improve team communication. There is also a clear sustainability motivation amongst those involved in the study to make a change from single-use disposable theatre caps to a reusable alternative.

The findings reveal that the success of the reusable theatre cap project extends beyond environmental performance and enters broader questions of design adoption and organisational stewardship. User testing suggests that sustainability alone is not sufficient to secure widespread acceptance of new healthcare products. Although 75% of respondents indicated a willingness to replace disposable caps with reusable alternatives to reduce waste, acceptance was strongly mediated by user experience factors such as comfort, fit, ease of use, and perceived quality. This finding aligns with human-centred design research, which argues that adoption is influenced not only by functional performance but also by how products support users' physical, emotional, and professional needs (Krippendorff, 2004; Hernandez et al., 2018). The high ratings for comfort (87%) and willingness to comply with washing procedures (92%) indicate that key behavioural barriers to adoption may already be relatively low.

A notable finding from the study is the significance of personalisation features. While the environmental benefits of reusable caps provided an initial rationale for change, participants frequently highlighted the visibility of names and professional roles as a major advantage. This suggests that the reusable theatre cap functions not simply as a sustainable product but as a **communication aid** within complex healthcare systems. Previous research has shown that identification of team members in surgical environments can improve communication, situational awareness, and teamwork performance, particularly in fast-paced or emergency situations (Birnbach et al., 2017; Bobb et al., 2018). The support expressed by 69% of respondents for replacing disposable caps to improve communication indicates that adoption may be accelerated when sustainability interventions also address existing operational challenges.

At the same time, the results demonstrate that implementation challenges remain significant within NHS settings. The recurring concerns regarding sizing, hair containment, tie mechanisms, and perceptions of inclusivity highlight the importance of ergonomics and user diversity in healthcare design. These issues illustrate how even relatively simple product innovations must accommodate a wide range of bodies, identities, and working practices if they are to achieve widespread acceptance. Similar challenges have been identified in studies of healthcare apparel and personal protective equipment, where fit, comfort, and inclusivity are critical determinants of user satisfaction and continued use (Moudatsou et al., 2020; Steen, 2013).

User testing identified several issues requiring further refinement. The most common concerns related to fit, sizing, and hair containment. Participants described the caps as either “too big” or “too small” depending on hair type and head size, while some felt they were not suitable for female users. The drawstring fastening was also a frequent pain point, with comments that it was too long, caught in hair, irritated the neck, came undone, and was difficult to use quickly. Hair containment emerged as both a comfort and safety issue, particularly for staff with long hair, leading participants to suggest elasticated backs, alternative shapes, and a wider range of sizes.

Feedback on material quality was mixed. While some users described the fabric as “thin”, “itchy”, or prone to creasing, others praised it as “soft”, “breathable”, “comfortable”, and durable after washing. Responses to the personalised name-and-role feature were similarly divided. Some participants felt the large name block detracted from the appearance of the cap, whereas others viewed it as a significant benefit that could improve communication, reduce ambiguity, and enhance team coordination, particularly in emergency situations.

Inclusivity also emerged as an important consideration. Although the caps were designed for a broad range of users, some participants perceived them as being better suited to male head shapes than female ones. Such perceptions may influence willingness to wear the caps and could affect wider adoption across NHS Scotland unless addressed through future design iterations.

Importantly, the findings show that resistance to adoption is not necessarily rooted in opposition to sustainability goals. Rather, user feedback suggests that implementation risks emerge when sustainable innovations introduce additional burdens or fail to align with existing workflows and established clinical routines. This reflects broader systemic design literature, which emphasises that innovations in complex organisations such as healthcare

systems must be sensitive to existing institutional structures, professional cultures, and everyday practices (Design Council, 2021; Komashie et al., 2021).

Consequently, the results suggest that future iterations of the Design HOPES reusable theatre cap should be understood not as final product refinements but as part of an ongoing process of co-design and institutional learning. The issues identified through user testing provide valuable insights into how sustainable healthcare innovations can move beyond prototype development towards long-term adoption and scale. From a design research perspective, the project demonstrates that successful sustainability transitions require the integration of environmental objectives with user experience, workplace communication, and implementation feasibility. The findings therefore contribute to growing discussions within systemic and transition design regarding how design-led interventions can support behavioural and organisational change in complex public-sector settings (Design Council, 2021; Rodgers et al., 2025)

4. DISCUSSION

The Design HOPES' reusable theatre caps project harnesses the power of design-led research for net zero challenges in an innovative and collaborative way. Rather than viewing design as a retrospective mechanism for styling or optimising a standalone medical product, this research aligns with contemporary frameworks that position design as an infrastructural and translational layer within highly complex, multi-stakeholder public systems. Design HOPES' collaborative work with NHS Scotland, industry partners, and other relevant stakeholders uses a diverse set of innovative co-design and co-production methods and tools to develop novel and useful prototypes including the work described in this paper.

Design HOPES' researchers continue to collaborate closely with key clinical and operational figures across NHS Scotland health boards, building trust through co-design workshops, design sprints, and sustained specific projects. During the last three years, this collaboration has been fundamental in creating an environment where ideas can be shared, discussed, and critiqued freely and openly. With this foundational trust established, various design-led tools and methods have provided a variety of means to observe, interrogate and understand user (NHS Scotland staff) behaviour in order to respond better to specific needs. This is particularly important where values and beliefs are not easily articulated or motivations for behaviours not readily apparent (Krippendorff, 2004). Across this Design HOPES' project, we have seen design-led tools such as pop-up exhibitions, cultural probes and paper prototyping being deployed to help bring clarity to the specific requirements of NHS Scotland stakeholder groups and individuals. As a precursor to these collaborations, we have secured appropriate ethics approval for NHS Scotland engagement in all design collaborations. In addition to the legal and ethical necessity of this, it has been an important activity in highlighting procedural and cultural issues associated with the organisations involved. The need to focus on NHS Scotland theatre staff as opposed to patient engagement has dictated the format and configuration of the design methods and tools employed.

The co-design workshops did not simply gather user requirements; they served as an institutional diagnostic tool. By engaging frontline medical staff, procurement officers, and laundry service managers, the design process brought to light the operational friction between top-down regulatory stringency and frontline aspirations for clinical and ecological change.

Furthermore, this project expands our understanding of co-design dynamics within rigid institutional hierarchies. Healthcare settings are notoriously high-stress, deeply segmented environments where workforce capacity is constrained by the imperative to do more with less (The Health Foundation, 2022). While the empathetic drive of healthcare professionals is a powerful asset to harness (Moudatsou et al., 2020), introducing new practices can inadvertently amplify systemic stress if the design fails to respect workflow constraints (May et al., 2024; Wilkinson et al., 2017).

Design is a creative, playful and engaging process, and when delivered effectively can allow designers and non-designers to collaborate fruitfully in the generation of new solutions that are innovative but grounded by expertise in relevant contexts (Steen, 2013). Most of us find creative involvement to be rewarding (Bujacz *et al.*, 2016), and the co-design activities undertaken in this work, with designers acting as facilitators, have mobilised and motivated clinicians including surgeons, anaesthetists, and nurses, care-givers, technicians, administrators and other relevant stakeholders to generate new perspectives on existing problems. Across Design HOPES' projects, we will continue to create design-led methods and tools to meet the demands of the NHS Scotland workforce including online formats for remote contribution, timings to accommodate shift working, acknowledgement of regulatory and procedural constraints etc. Where scepticism has arisen, and individuals have been reluctant or unwilling to engage, we have found the provision of visual material and tangible prototypical artefacts critical in stimulating engagement. We have made extensive use of quick-and-dirty and low fidelity models and prototypes, such as those described in this paper, to make design possibilities tangible and aid effective communication for those both directly involved in, and those observing, the design process. This has allowed the authors to iteratively design, make, evaluate, and test solutions in conjunction with NHS Scotland staff and to highlight the possibilities to NHS Scotland and Scottish Government policy makers. Together, these functions embody how design has been utilised to help all types of healthcare professionals, from frontline medical staff to supporting managers, recognise where issues lie, imagine new ways of working, and participate in their design and implementation.

5. CONCLUSIONS

This paper has detailed the co-design, prototyping, and extensive user evaluation of plant-based, reusable theatre caps developed in collaboration with NHS Scotland as part of the Design HOPES Green Transition Ecosystem Hub. In doing so, it addresses a persistent critique within design literature by demonstrating how a localised material intervention can serve as an empirical vehicle to advance systemic design theory and practice within the public sector. Pragmatically, the project demonstrates a viable path toward circularity in carbon-intensive institutional environments such as NHS Scotland. The introduction of the Design HOPES reusable theatre cap addresses three simultaneous vectors of impact:

- **Environmental:** Transitioning from single-use synthetic caps to plant-based cellulosic fibre alternatives yields a potential 90% reduction in associated manufacturing and disposal emissions, diverting millions of non-biodegradable items from clinical waste streams.
- **Economic:** Lifecycle modelling disrupts the pervasive bureaucratic assumption that single-use procurement is inherently cost-effective, projecting significant long-term financial savings even when accounting for high institutional staff turnover.

- **Patient Safety and Communication:** Incorporating prominent, personalised typographic markers directly addresses documented communication barriers in high-stress, full-PPE environments, leveraging product design to enhance team performance and mitigate risk.

Beyond these important metric-driven successes, the primary contribution of this research to the wider design field lies in its methodological framework for transdisciplinary systemic innovation. This study moves beyond a descriptive project narrative to illustrate how the design process can successfully operate at the intersection of conflicting institutional values: the rigid, risk-averse mandates of healthcare regulation on one side, and the urgent, adaptive demands of the climate emergency on the other.

By documenting the friction points identified during user testing, including pattern modifications for inclusivity, hair-containment ergonomics, and the cultural perception of personalization, this work offers a transferable roadmap for future design researchers navigating complex, multi-stakeholder public systems.

Future work will expand upon this empirical foundation through accelerated laundry and biodegradation testing, broader implementation across a wider selection of UK health boards, and the establishment of a dedicated spin-out enterprise to manufacture these innovations locally – as has been considered directly by Urquhart et al. (2026). Guided by Glanville’s (2015) call to value and preserve diverse design research journeys, this project confirms that design-led thinking, making, and acting can practically dismantle entrenched institutional reliance on single-use waste, providing a replicable blueprint for systemic transformation in global healthcare.

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