connected everything.

Developing the future of adaptive materials based on HD-reprogammable matter

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What is the project?

Significant waste, pollution and resource depletion can be associated with linear design and fabrication processes. This is because an object's or structure's material make-up (atoms, molecules, particles etc) cannot interact with/be radically updated post-fabrication. Nor can they be self-healed when damaged. Essentially, this project is about developing new design and fabrication processes that enable matter to be iteratively updated/re-programmed and self-healed when damaged, all at high resolutions. In doing so, truly adaptive objects and structures may become possible, which could significantly reduce waste and increase bespoke design properties over time for various application areas.

The project created materials samples (18x18cm) that can have multiple material properties (global patterns, compositions, opacities, rigidities, textures) and iteratively re-programmed/updated at high resolutions. Throughout the project, the application area of medical prosthetics became a targeted area to inform our investigations. This was due to the nature of the set-up, slow material responses and in-situ responses not possible at this stage. The project consisted of two main activities: *prototyping*, to create a design and fabrication system, tangible user interface and material sample development that enable iterative interactions i.e. reprogrammable matter. *Workshops,* two online workshops were carried out with industry partners regarding medical prosthetics. The industry collaborators were Preston hospital's SMRC and GB para-triathlon. The workshops were extremely valuable at defining fundamental challenges within current prosthetics, interrelationships, future desires and what constitutes desirable material responses for patients, athletes, prosthetists and consultants.

What did the project achieve?

The project achieved several main aspects across these various activities. In regards to the physical prototyping research, the major achievement was demonstrating that multiple material properties can be iteratively updated at high material resolutions by maintaining discourse with digital design tools as well as sensor data when using a multi-stimuli system (heat and magnetism) combined with state-changing materials. However, various design principles were also highlighted when continued multi-material interactions are possible. These are;

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- **Trade-offs**: over time certain material properties diminish as others become increasingly significant. This highlights the need to define time-based hierarchies for various properties when they are desirable and for given applications. Additionally, due to a stimulus (magnetism) informing the majority of material properties there need to be system hierarchies defined in regards to threshold sensor readings and how they elicit desirable material properties for a given application.
- **Legacy**: iterative material interactions resulted in previous properties persisting to an extent. These could be useful in fine-tuning updates but they could also potentially hinder future and radical updates. There is a need to reset materials to a 'blank canvas' when employing this approach.
- **Remote updates**: creating a tangible user interface enable a user to interact with sensor data to inform guide/inform material properties. This was achieved over wifi, which opens up the possibility of remotely updating material properties.

In regards to the key and similar findings from the online workshops, we felt that our sample was most relevant to issues with prosthetic liners and sockets. These were;

- Develop composite materials capable of having variable properties/stiffnesses so they can flex and autonomously shape-change to stop irritation at joint areas. Additionally, anti-bacterial materials to aid prevent infections.
- The need to update the global shape of liners and sockets due to continuous physiological changes of a patient's limb, which can also aid athletic performance.
- Create material that allows for open prosthetics structures but still enables a 'vacuum' fit to deal with overheating and sweating. Additionally, climate-controlled prosthetic devices to alleviate issues with seasonal changes and phantom limb.

How we did it

The research activities involved prototyping, workshop and material development. In regards to material development the chemistry department produced multiple biodegradable and non-toxic material samples of Poly ε-caprolactone (PCL). Six different molecular weights were used (530, 900, 2000, 14000, 45000 and 80000 Da), which informs the mechanical properties of the sample as well as their viscosity of them when heated. Iron (II, III) oxide (Fe3O4), with two different particle sizes (powder (P) < 5 µm and nanopowder (N) 50-100 nm), were combined with PCL so they become ferromagnetic and can be affected by modulating magnetic and heat stimuli. From a design perspective, the main criteria to select samples for further development and scaling up were: 1) mechanically robust when solid. 2) Enabling properties to be updated when in a liquid state, with a focus on; global 2D shape changes, material gradients, surface texture, volumes, and rigidities. Through multiple small sample tests (see video) it was determined the PCL; P14 50:50 and P2 80 50:50 were suitable to investigate further and determine the implications of scaling up to 18x18cm samples. This was done on a weekly basis with all members, which significantly helped interdisciplinary collaboration to get suitable samples and tune the set-up to enable material interactions. The P14 50:50 sample is comparatively weaker than the P2 80 50:50 sample, however, it responded comparatively faster (still slow) and generated an increased palette of material responses. To achieve material interactions between data and digital design tools we created a system capable of modulating localised stimuli, which is governed by a string of CSV, which is sent from the software Processing to the hardware platform Arduino via serial communication and UDP for sensor data. Various videos of material testing are availed at these links (P14 50:50 and TUI) The workshop was carried out online using miro and involved semi-structured workshops with defined topics to be discussed/expanded upon with industry collaborators. Figures 1 – 6 highlight the set-up and material results.

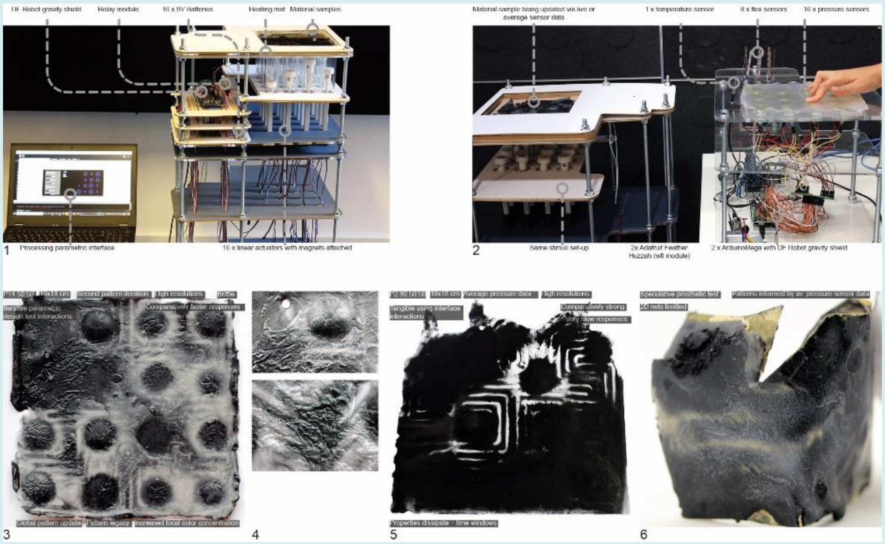

Figure 1) prototype system enabling digital design updates have a continued discourse with materials. 2) Tangible user interface developed enabling live and average data to be captured that can be remotely pushed into materials, which could enhance bespoke design solutions.
3-5) Final images of material samples, which highlight multiple properties that can be updated at high resolutions. A limitation is they are 2D.
6) An initial attempt to develop 3D forms by using 2D nets for speculative medical prosthetics that can have multiple properties tuned to enhance patient conform.

Future plans

There are multiple main limitations to this research; *firstly*, the two dimensionalities of the samples due to the prototype set-up limits applications. *Secondly,* feedback is required between design tools, stimuli and material properties generated is required to ensure intended, desirable and robust material properties are generated but without compromising material resolution. This may require stochastic/ probabilistic based digital models to be incorporated. *Thirdly,* the need to refine and tailor material properties to enable viable applications with industry. We intend to secure further EPSRC funding to further investigate adaptive prosthetic applications. Additionally, we are also interested in securing funding to investigate and physically develop adaptive architecture that behaves as a living eco-system capable of sharing and replenishing resources to meet fluctuating design demands. To do so we intend to target suitable EPSRC funding, such as a new investigator grant. We have had two publications created from this research so far (see below). We are also intending to produce further publications to discuss our workshop findings and the results from out tangible user interface development.

References and publications

Blaney, A., Richards, D., Gradinar, A. & Stead, M. 2021. Prototyping Circular Materials Based on Reprogrammable Matter. *IASDR 2021: WITH DESIGN: REINVENTING DESIGN MODES.* Poly U Design, School of Design, Hong Kong Polytechnic University. https://www.iasdr2021.org/session/pic1033

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