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Engaging publics in imagining the future of engineered living materials

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Engineered living materials (ELMs) are technologies that respond to environmental cues and are able to remodel, self-organize, and self-heal. We conducted two workshops with a wide range of stakeholders and identified key themes in open discussion. Our approach enabled participants to engage with dimensions of technologies normally reserved for engineers, scientists, or policy makers and should be used in further public engagement in ELMs as well as other emerging technologies.

Defined as any "composite material that has a biologically derived component and a synthetic component,"[1] engineered living materials (ELMs) are technologies that respond to environmental cues and are able to remodel, self-organize, and self-heal. An alternative definition of "animate materials" identifies the key defining characteristics of this type of materials as being active, adaptive, and autonomous.[2] A standard approach entails genetically engineering cells to optimize the biosynthesis and assembly of cellular materials, such as cellulose, enzymes, and structural proteins, or to express materials derived from other organisms. Emergent ELM applications include the design of macroscopic functional materials deploying fungi, mammalian cells, or consortia of unicellular organisms. ELMs are seen to have "the potential to transform virtually every modern endeavor from healthcare to infrastructures to transportation."[3]

These potential wide-ranging implications for domains across society suggest ELMs, as a research field, could benefit from drawing on responsible research and innovation (RRI) framework. RRI is a set of approaches that aims to support the collective, reflexive exploration of possible technological futures through inclusive and responsive processes.[4] Given the exploratory nature of ELM research, it has been suggested that public engagement in ELMs should foster collective imagination, "harnessing ideas [and] creating a repository of ideas for future applications of animate materials."[2] To address this challenge, we drew on the methodology of speculative design[5] and invited members of the public to participate in a set of activities aimed at exploring and discussing the social implications of these new materials for everyday life in the future.

Methods

Our main aim was to assess the feasibility and fruitfulness of using speculative design methodologies in engaging stakeholders in discussing the social and ethical implications of future ELMs. Speculative design enables anticipatory engagement that is essential to responsible innovation while facilitating contributory membership, which is usually restricted by expertise boundaries. In order to ensure that participants were able to envision future ELM uses, we designed a set of activities building from existing experiential knowledge to scaffold engagement with a set of scenarios as probes through which speculative ideas could be generated and made manifest. We structured the workshops into two phases: (1) participants were asked to place familiar organisms along dichotomous scales of roles, relationships, and perceptions, followed by a group discussion. (2) We developed collaborative story-telling templates—3 fictional scenarios of technological use (Figure 1)—intended as prompts to elicit collective sense-making.

Given the structure of the activities we designed, we envisaged a sample size of 12–15 participants distributed across two workshops. We obtained a diverse sample (n = 10) with a good spread and fair proportionality in relation to the stakeholder map we drafted, including individuals working in medicine, nature conservation, science, engineering, market research, amateur gardening, farming, games design, and art.

Workshops (2 × 3 h) were conducted online, recorded, and transcribed verbatim. We used standard qualitative data analysis techniques[6] to identify themes and forms of reasoning used by participants to make sense of our possible futures with ELMs. The value of qualitative data is less on its generalizability and more on the ability to identify unknown dimensions of stakeholder and public views on emerging technologies. Our analysis should be further validated by extending data collection points. Ethical approval was obtained from the Durham University

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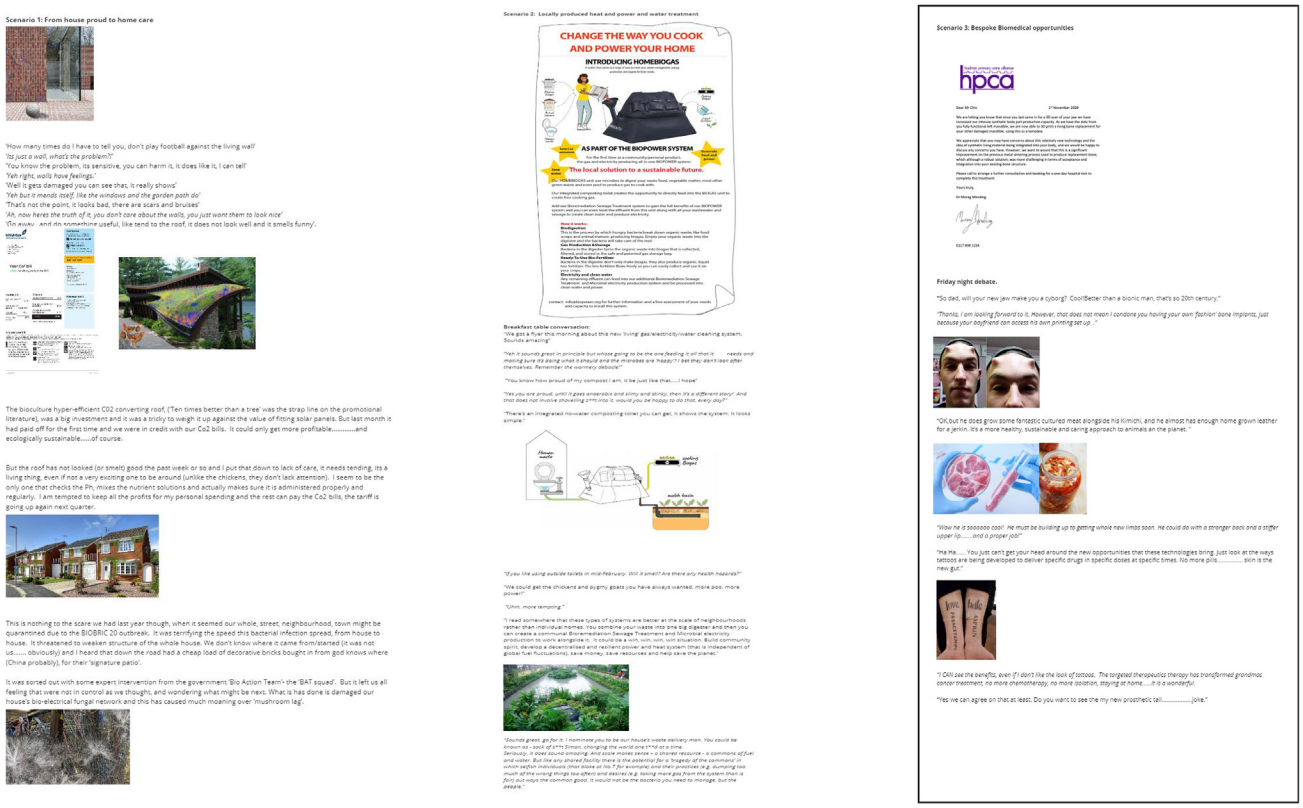

Figure 1. Speculative ELMs scenarios

Department of Sociology Ethics Committee.

Results

Our analysis identified three main themes in the data (see Table). Participants made sense of the type of relationship ELMs would entail in everyday life by reflecting on issues of control and predictability. They saw ELMs as requiring a more user-centered, collaborative form of engagement than standard engineered materials. While it was acknowledged that ELMs might decrease the amount of control users have of the technologies they use, a key uncertainty was whether this required foregoing the core functionality that ELMs were designed for. How to balance core, engineered function against other values was our second main theme. Participants attempted to set parameters of acceptability of the autonomous and adaptive behavior that ELMs might display by imagining specific breaches of expectations we ordinarily hold about the performance of technologies (safety, predictability, reliability, etc.). Our last theme was the collective recognition that maintaining the balance of values—between safety, reliability, adaptability, etc.—required increased responsibility on the part of the user. Participants reflected on the importance and the social tensions inherent to the practice of maintenance and care of living materials.

The focus of the workshop was to prompt reflexive reasoning on our interactions with ELM technology as this enables understanding of the collective imaginary that structures engagement with new biotechnologies. Here, the question of control and predictability became paramount: participants made sense of their relationship with technology by redescribing their present and past experiences (see Table 1). Some technologies make the users feel caught in the grip of forces they can do little about, while others empower their users (Table 1). This contrast between what can be labeled technological determinism on the one hand and social control on the other enabled participants to engage with the ELMs' specificity. For them, the question was whether ELMs enabled more or less control of technological innovation processes. In other words, participants were concerned with the path dependence of ELM development and implementation.

Scenarios (Figure 1) were useful in that they prompted deliberations about the technological user and ELM challenges to assumptions of function. In this, one of the main issues discussed in our workshops was the extent to which active, adaptive, and autonomous materials would retain the core functionality for which they were designed or engineered. Participants reflected on the value of handling and relying

Table 1. Key themes in participants' anticipatory engagement with ELMs

1. Control	2. Adaptability/predictability	3. Care and maintenance
1.1. GP: "So I'll put fungus. There's a few dichotomies over [there] in the bottom right, which are kind of slightly odd dichotomies, but fungus is midway between collaborative and service relationship, uh, because we do use them in service like my hot compost bin outside, but **I'm not really in control of them** and they cause lots of problems in patients as well. So that's, that's not collaborative." [Worskhop1: 45]	2.1. Nature conservationist: "But yeah, in general, I would love to have something that self-mended as long as I kind of had a reasonable idea of how long it was going to take. And if I knew that I wasn't having to replace roofs or bricks, and that, you know, I'd be quite intrigued by it. It's like, 'Oh look, that crack that was there yesterday is now closed up,' so for me that's what I would find and I would be, that would be both practical, uh, and a little bit emotional." (Pause) "You know, do you want a predictable roof or do you not want to predictable roof, you know, it's some things you want predictability or you expect it should continue to [behave how we] expect it to." Physicist (MS): "Well, we want predictable pancakes. It's Saturday morning." [laughs] GP: "I think we probably want a predictable roof when it's raining." Physicist (MS): "Yeah." [Workshop 1: 106]	3.1. Gardener: "Yeah, I think the thing that caught my interest was the fact that if we go down this road with these living materials, we're going to have to be so much more involved than we are at the moment. And it's here, but we'd have to be so much more involved and we'd have to care for our homes and our generators and our waste. We'd have to be much more responsible, and I guess. And more about it, and I don't know if it would be a thing that these things would have novelty value and that people would do it for a few months and then think it's too involved and go back to the old ways."
1.2. Games designer: "We're humans, that this is what we do, we create new stuff. It's going to be out there and we're just going to have to deal with it in one way or another, so I don't know, I think I needed a different, a different axis to put my kind of [idea] through the helplessness [scale]. [We] should have had a helpless and power scale, which I didn't think of, but that's a good comment because I think that gets to kind of some of the nub of this conversation: [it] is like, do we feel empowered or do we feel like these living materials are like another technology? **Do things lead us or do we lead them** is always [a] tricky thing in development, stuff of technology, and if living materials are kind of, they're not technology or so, well, it could be considered technology, that, that equally [leads the process, then] the debate is to be had, isn't it?" [Workshop 2: 96]	2.2. Nature conservationist: "Why? If it got to like [doing] self-healing things, what if they got too clever for us and they started: say you had a self-healing road and it's sort of got to the point where it got, I don't know, got sick of healing. It was like, every time a car goes over my [surface] it gets damaged. What if it just evolved to have, like, spikes, so every time a car went over, it just shredded the tires, so then this road starts like protecting itself. Sociologist (TM): "Yeah, yeah." Designer: "You mean a road going rogue?" Nature conservationist: "How do we stop it? It's like, oh, look, we've got a self-healing road that goes rogue and before you know it, you've got a mountain [going rogue] or you know, who knows?" [Workshop 1: 110]	3.2. Artist: "Well, like, well, a couple of things we're thinking about is when somebody was, I don't know, someone of the visiting explorers or visiting researchers or whatever on this [scenario] we're talking about the service relationship we have with animals. And then that got me thinking, you know, are we going to have like an RSPCA for living materials that you're, you know, you're mistreating your roof? Is somebody going to come and say, 'Actually you can't look after your roof anymore? We're gonna take it off you and you just have to have, you know, you just have to go back to having slates and tiles.'" [Workshop 2: 67]

on materials that were predictable—that's to say, knowable from a user's point of view (Table 1). They agreed that ELMs could challenge some of the assumptions about what one could know and expect from materials and collectively explored the acceptable boundaries of surprise within "rationally designed" materials. In this, they balanced the value of efficiency with other forms of worth that materials might provide.

The group's consensus was that as long as materials adapted and self-repaired to continue to fulfil their intended purpose(s), ELMs might offer added dimensions through which users can engage with them. These were not functional uses but rather emphasized playfulness, aesthetics, and "liveliness"—the creativity of life itself, one might say (Table 1). Although secondary, these uses were drawn upon time and again in the workshops to demonstrate the distinctiveness of ELMs. Part of the collaborative relationship with materials, as the group defined it (see above), was that both parties—human and non-human—were seen as capable of generating change within the relationship as part of the "give and take."

Participants reflected on the consequences of implementing ELMs in various areas of people's lives and suggested that it entails a higher level of participation in the day-to-day management of this "technology" (Table 1). Participants were keenly aware that the consequence and trade-off of a more collaborative relationship with ELMs was that it requires more commitment from users. Participants seemed to agree that one of the consequences of ELM implementation was that it would demand specific kinds of people—committed, imaginative, skillful, etc.—as its users. There were thus concerns expressed that ELMs would be designed with this "average white male" in mind and ignore the diversity of possible users.

Participants were also interested in exploring the alternatives of relying on individual users to guarantee the ELMs' sustainability (Table 1). They agreed that there should be systems in place to support individuals in sustained ELMs maintenance.

Discussion

Speculative design methodology is effective in engaging and eliciting public views on ELMs. Participants were able to meaningfully engage with the proposed tasks and generate reflective, rich discussions on the topic. This, we propose, was significantly facilitated by the structure of the workshops, which supported focus on issues while not making access to membership and participation reliant on previous knowledge and expert status. In this regard, the design fiction approach enabled participants to engage with dimensions of technologies normally reserved for designers, engineers, scientists, or policy makers. It enabled participants to articulate their own vision of how these technologies could be put into use in everyday life and the normative implications that ELMs bring to bear.[7]

In these imaginaries, key themes in our data were control, functionality, unpredictability, and maintenance. The issue of control links with debates on how to govern uncertain or potentially undesirable innovations. It is the aim of RRI interventions to emphasize the search for alternative scenarios and technological options and embed accountability upstream in innovation pathways. We aimed to explore visions and understandings on the part of non-specialists where this was posited as a complex balance between functional predictability and other technological values. Participants emphasized that, in ELMs, organic form generation should never trump pre-planned function. They recognized, however, that this maintaining of balance depended on users, and that, in this respect, ELMs required a redistribution of tasks and skills of users and devices.

The workshops brought to bear the normative assumptions embedded in ELMs. In particular, discussions highlighted the hidden work of putative users that ELMs might rely on. A societal move toward a circular economy entails value production in recycling, re-use, and repurpose, which depends heavily on users' behavior. In contrast to the policy-making emphasis on "the technological challenges" involved in this transition, our workshops highlighted the importance of involving users in imagining this shared future. It is well known that users play a fundamental part in contesting, modifying, or influencing innovation. Involving users as stakeholders in specific ELM development is a requisite for their success in delivering environmental sustainability.

The workshops generated rich data on the practices and reasoning entailed in the maintenance of living things, which participants saw as relevant to ELM use. Our analysis suggests that the practice of care and attention to what is involved in the care of things is fundamental to the shaping of future ELMs. As the stories and scenarios that participants developed make clear, caring weaves lives, human and non-human, together. In these, humans are not only considered as skillful users but also as living components whose needs evolve and adapt in concert with the other living and non-living components of the material.[8] This means that we need to explore in more deeply existing knowledge of living with living materials to define, anticipate, and explore future uses of ELMs. We therefore recognize that the themes we identified in our data should be explored in further qualitative and quantitative research on responsible innovation on ELMs.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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