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Revealing the hidden: Using a co-design approach to explore on campus energy use through the representation of consumption data

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Abstract: Cites around the world are looking for ways to reduce the energy consumption associated with the built environment, but there are a number of significant challenges in this. These include, difficulties in making energy consumption data meaningful, particularly when people are not financially liable for consumption, and communicating the complexity associated with energy mix. In this research, data physicalisation principles are applied through a co-design approach to investigate how the users of a university campus understand the concept of energy. Key findings include a tension between a scientific understanding of energy and the experience of various forms of human energy including both physical and metaphysical understandings of energy, and the importance of translating energy data from the quantitative into an emotional context in which people can be encouraged to stop and take note. This is reflected upon in the context of sustainability transitions and behaviour change approaches more generally. The paper also reflects on the process of using a series of creativity tools to facilitate the co-design process, asking the same group of participants to reflect on similar questions using multiple co-design and creativity techniques. The results of this approach show promise as a way of facilitating complex co-design processes with diverse groups of stakeholders.

Keywords: *Data Physicalisation, Co-design, Design Thinking, Sustainability, Visualisation*

1. Introduction

This paper outlines a research project which uses a collaborative, creative design methodology to investigate how people might become more cognisant of their energy consumption behaviours at university. The site of this investigation is a typical university campus, and focusses on the attendant community which inhabit this environment from students and university employees to ancillary service providers, first nation people and visitors. Multilevel stakeholder representatives where invited to take part in a number of participatory, co-creation activities to share their own perspectives, interests and experiences with energy consumption on the campus. In addition, a set of Research Through Design (RtD) methods were used to capture and respond to these values and drivers, and to inform a series of prototype design responses, designed in conjunction with the participants and project researchers. The project began by gathering information on what energy data was currently collected, the forms that this was made available and how this data is shared with different sectors in the campus community. A key objective of the project was to explore what forms energy consumption data is currently communicated, to who and where, and to use this information to propose, through the co-design process a series of novel visualisation methods which would lead to greater transparency and awareness of this data.

2. Context

Various studies demonstrate that energy consumption is increasing dramatically within many households and businesses, posing issues for sustainable practice both nationally and internationally (Allouhi et al 2015). In Australia, recent data shows that energy consumption is increasing significantly year on year, setting new records and driving expansion in the energy supply system (Department of the Environment and Energy 2017, p.12). Globally, buildings are responsible 6.3% of direct greenhouse gas emissions and can also be attributed with 12% of emissions related to electricity and heat production (IPCC 2014). There have been significant efforts to decarbonise the energy supply (Alcott et al. 2012), and to improve the energy efficiency of buildings (IEA 2016). However, energy efficiency approaches in particular have been criticised for omitting end-user behaviours as a component of energy consumption (Shove, 2010; Sustainability Transitions Research Network 2018; URBACT 2018). Efficiency-based approaches often deliver smaller than expected overall reductions because improvements in efficiency are realised through increases in consumption rather than a reduction in overall demand (York 2010; Jevons 1865). It has been well recognised in the field of Sustainability Transitions that there is a need to drive sustainable behaviour change alongside the implementation of energy efficiency measures (Darby 2006; Jalas et al. 2017; Geels 2002). User-driven reductions in energy consumption have been discussed in the literature since the 1970s, and there are many approaches that have been tested, from information-based campaigns to the provision of real-time feedback (Darby 2006). It has been shown that attitudes towards energy usage depend upon an individual's understanding, value and expectations of the benefits of saving energy (Butler et al 2016) and on the way in which information is presented (Pierce et al. 2012; Jain, Taylor & Culligan 2013). For large institutions such as universities, this translates into a significant challenge in motivating end-users to reduce energy consumption (Darby 2006).

Despite this, technological advances in our media systems and communication capabilities mean that capturing or connecting to large data sets of information has never been easier than in our current 'Information Age' (Yang et al 2017; Mayer-Schönberger & Cukier 2013). With cultural shifts towards greater transparency and accessibility of data, we have all become participants in the consuming of information through our digital devices and greater global connectivity. Researchers face the challenge of how to use appropriate tools and systems to find and extract meaningful content from the masses of digital information while presenting it in fresh and effective ways, that work with particular end-user communities (Prendiville, Gwilt & Mitchell 2016).

The hypothesis of this research was that visualising energy consumption of a university community in-situ and in real-time, would inform people about energy consumption around the campus, thus generating an insight around energy usage patterns and people's role in this process. The intention of the project (entitled 'Insight'), was to use co-design as a methodology for bringing together a diverse group of stakeholders to stimulate discourse around people's carbon footprint, leading to more informed choice around energy usage and savings within society.

Co-design (sometimes labelled as participatory design, co-creation, or co-production) is increasingly being seen in the literature as a useful way of approaching challenges such as this; however, it can be difficult to access guidance about how these processes are applied as a facilitated process, and to link the specific tools and approaches used with the kinds of outcomes that are being desired (Davis 2019, Forester 2013, Brause2017). To this end, this paper presents the processes and methods used by the research team, in engaging with a diverse and multi-disciplinary team to address the challenge of reducing energy consumption on university campuses. It also reflects on the results generated from these collaborative processes in respect to peoples understanding of their own energy consumption behaviours.

2.1 The site of research

The research was conducted at the University of South Australia Mawson Lakes Campus which is home to the Division of Information Technology, Engineering and the Environment. Many of the buildings on this campus were constructed in the 1960s as a part of establishing the South Australian College of Advanced Education, and became a part of the University when it was established in 1991. The Mawson Lakes campus is undergoing a significant transformation in the large-scale adoption of renewable energy

and energy storage technologies that is intended to result in a substantial reduction in the campus' carbon impact. This physical transformation is seen by the University as providing a unique opportunity to catalyse new conversations with students, staff, visitors to the campus, as well as with the local community about energy use. This therefore provided a unique opportunity to facilitate a co-design process with some of these stakeholders including community representatives, and staff and students from a range of disciplines including art, design, computer science, engineering and architecture.
The central aim of the project was to explore novel ways of visualising and/or physicalising real-time energy use data to enable individuals to better understand their energy consumption patterns and activities, and to begin to make informed choices that might begin to reduce this impact. The project also focused on:

- exploring the potential of the 'augmented campus' through the creative design of information physicalisation technologies
- collecting and analysing narratives of the campus
- exploring and prototyping new strategies for how we might communicate energy-generation mix information and the associated impacts to the Mawson Lake campus community as a whole.

3. Methodology and Methods

The research used a co-design methodology to engage with a broad range of stakeholders through a series of semi-structured interviews and workshops. Co-design was used to structure the approach as, similar to Grounded Theory (Glaser & Strauss 2017), it allows the researchers to enter the field of investigation during their study, and provides a framework for engaging with end-users that treats them as partners in research rather than as subjects of research (Franz 2014). The co-design methodology can be linked with various collaborative and participatory approaches, including but not limited to the systems-based approaches described by Ackoff (1974), processes of reflective practice (Schön 1983), and quadruple-helix models of research collaboration described in the living laboratory literature (Arnkil et al. 2010). Co-design research uses practice to build knowledge rather than defining and testing hypotheses as might be expected in a physical-sciences model of research.
Co-design has been used in a number of Research studies as a way of exploring sustainability transitions (Mitchell et al. 2016; Krzywoszynska et al. 2016; Manzini & Coad 2015; Alexander 2014), and energy transitions (Jalas et al. 2017; Stevenson, Barborska-Narozny & Chatterton 2016; Heiskanen et al. 2010). However, many of these studies have focused on macro-scale change rather than on individual behaviours. This research builds on the approaches used in these studies and uses the authors' experience in facilitating product and service-oriented co-design approaches to evaluate the success of the approaches used in this project.

3.2 Methods

The research was conducted across four stages that have been mapped against the British Design Council's double diamond design approach in Figure 1 below.

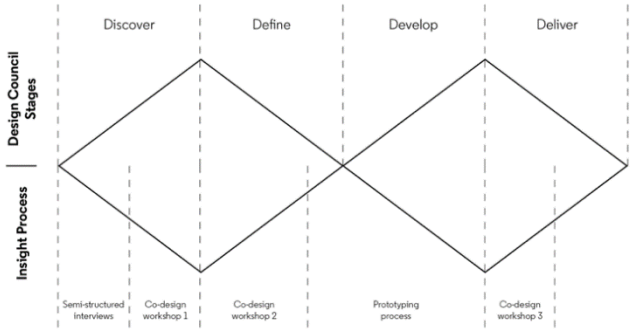

Figure 1: Insight Process mapped against British Design Council double diamond design process

The four stages are as follows:

1. A series of semi-structured interviews using a convenience sampling methodology. These interviews were used to inform the researchers' baseline understanding of attitudes toward energy-consumption among staff, students and visitors to the University's campuses, and provided a secondary avenue for participant recruitment for the workshop series.
2. Two co-design workshops with a diverse range of staff, students and community members. These workshops were used to discuss the findings from the initial interviews, and to translate these into draft concepts.
3. A development phase where the researchers worked with a small group of students to translate the workshop outputs into design provocations that could be tested with participants.
4. A final co-design workshop where the design provocations (developed from the initial concepts) were reviewed and iterated.

The tools that were used during each workshop are summarised in Table 1 below. The coloured regions indicate the design approaches being applied through each of the tools. Some tools were used for both idea generation (ideation) and idea development (iteration).

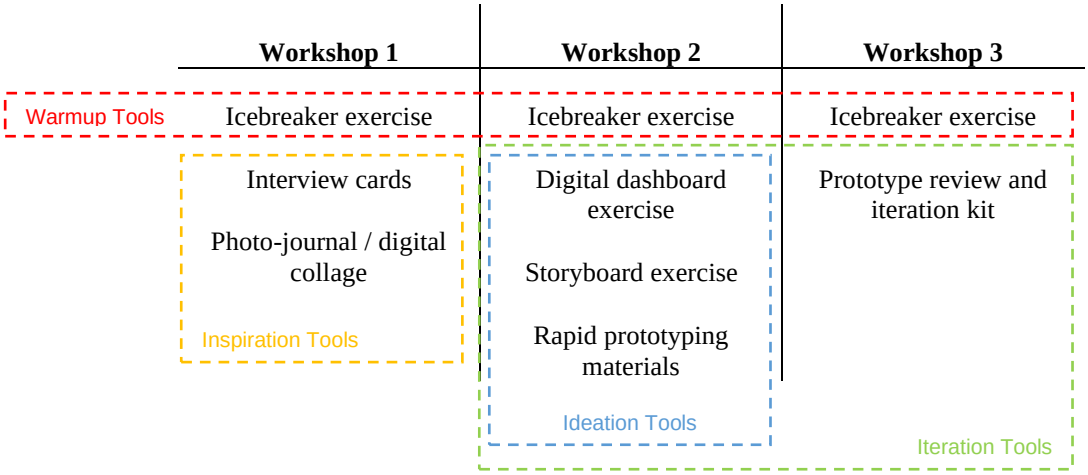

Table 1: Co-design tools used in the Insight project workshops

4. Tool Descriptions, Outcomes and Discussion

The following sub-sections describe the processes associated with the tools described in Table 1 above, and discuss the results that were achieved through their use.

4.1 Icebreaker exercises

The icebreaker exercises across each of the three workshops were used as a way of helping to encourage collaboration between the various people involved in the workshops, and as a way of beginning to overcome the established power hierarchies between different participant types and the roles that they would typically assume in a workshop process. The icebreaker activity across each of the workshops remained consistent, asking participants to fill in a nametag template that had a space for their name, and a response to a simple question. These questions were based on what can be described as low-floor high-ceiling questions with an easy entry threshold but a large number of possible responses. Examples include: "As a child, when I grew up I wanted to be a _____", "My special (non-professional) skill is _____", and "If I could be an animal, I would be _____". In this research the icebreaker question used was "My special (non-professional) skill is _____".

These icebreaker discussions began to facilitate connections between participants, and to ease those who were approaching the workshop with a more technical focus to begin to understand the creative process. Critically, these exchanges also established an asymmetric value exchange between participants, something Mauss (2002) describes as being of tremendous importance in establishing social bonds.

4.2 Interview cards

Interview cards were used as a form of questionnaire to facilitate the early discussion between participants. Participants were given a deck of cards (Figure 2) and asked to fill as many as they could in the allotted time. This approach gave each participant the opportunity to express themselves without having to compete for dominance in the group, and allowed each person to choose the order in which they focused on the questions. Once each person had filled in some or all of the cards, a discussion was facilitated so that each person could make their contribution. This is in line with the creativity approaches described by Paulus and Nijstad (2003) and allowed the discussion to take many directions. The discussion focused on five main questions: 'What does 'energy' mean to you?', 'what forms does 'energy' come in?, 'can 'energy' mean something else?', 'how many different forms of 'energy' are there?', and 'what does CO_2 impact mean?'. Of particular note was an interesting split in the discussion between energy as electricity and a technological resource, and energy as a human or natural concept. The perspective of energy being something that is held and exchanged by individuals was an unexpected contribution for many in the group, and stimulated some interesting reflections and discussions on how this energy can be related to the technological concept of energy that is typically dealt with in the energy efficiency and sustainability transitions literature. This interplay between different notions of energy was similarly reveal in the 'Drawing Energy' project undertaken by the Royal College of the Arts, Helen Hamlyn Foundation (Royal College of Art 2015).

Figure 2: Example of aggregated participant responses on interview cards

4.3 Photo-journal / digital collage

This activity was facilitated using a Yogile online gallery (www.yogile.com) to aggregate participant contributions of energy visualisation or physicalisation strategies that they were aware of or could find in a short allotted time. As with the interview cards approach described above, the activity was structured to give each participant the opportunity to contribute independently and generated some interesting, although largely expected results.

There was a general consensus in the group that although they were aware of energy dashboards in a number of buildings, both on the University campus and in the city more widely, these were not particularly engaging for most in the community. Examples that were presented included electricity bills that compare a household's consumption to average consumption data in their local area, various dashboards that present live, daily and weekly energy consumption data, smart meters that provide in-home live feedback, and the National Energy Market dashboard that presents live data about the energy generation mix in the Australian grid. The one example that went beyond the representation of data in a largely technical way was the presentation of Olafur Eliasson's *Weather Project* at the Tate Modern in London, UK. This was seen as a very interesting project because although it was not linked with energy consumption data, the approach of providing a spectacle and a point of interest that people could gather around resonated with all in the room.

4.4 Digital dashboard exercise

At the start of the second workshop, following the icebreaker exercise, participants were provided with a digital dashboard template as a first ideation and iteration tool. The template provided participants with a blank canvas in the form of a digital display and asked to consider how they would display information about energy consumption on a screen. In preparation for this exercise examples of existing energy consumption screen-based visualisation were shown and discussed. Participants were asked to consider whether they would divide the template or not, and to draw an example of the kind of data that might be presented.

The main ideas that emerged through this exercise were; the use of gamification to encourage people to want to lower their energy consumption, and the use of emotive imagery to reinforce when people were causing environmental degradation through their energy use behaviours. More conventional information visualisation techniques such as diagrams, usage sliders, dials and graphs were used alongside more expressive or contextual imagery or wording. Examples of these outputs are provided in Figure 3 below.

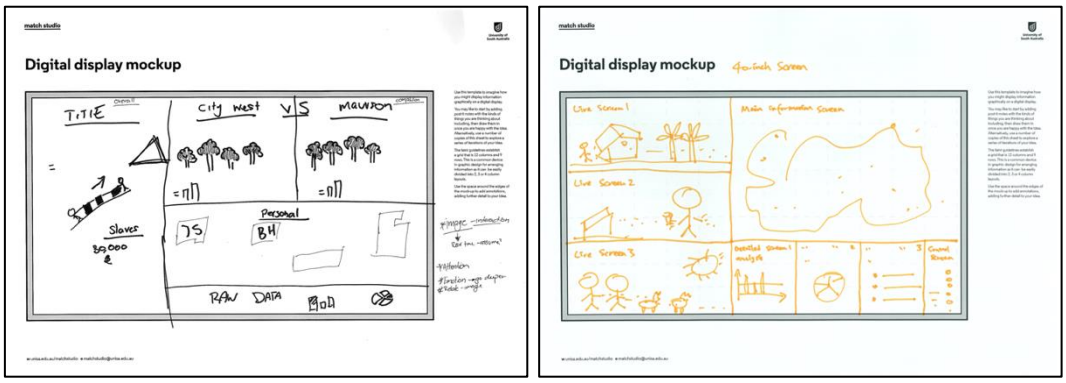

Figure 3: Digital dashboard examples

Much attention was paid to the fact that dashboards should not be highly detailed so that they can be read at a glance, but also, that they should have something that attracts people to look at them. Ideas included:

- a live stream of a coal power station or wind energy plant depending on energy-mix
- a graphic showing how many 'human slaves' would be required to meet the energy consumption of the building
- a competition indicator to make campuses compete with each other
- a boomerang spinning at different intensities to show energy consumption
- an image of paper dropping and filling up the screen across the day, linked with paper consumption
- map-based graphics showing 'good' and 'bad' performance
- live streams of people impacted by energy consumption
- clear and intuitive binary data representations ('good' v.s. 'bad')
- 'fun facts' about energy
- a leaderboard associated with energy efficiency
- shocking images to attract attention
- 'daily suggestions' to save energy

One of the interesting concepts to emerge from this discussion was about how display mechanisms such as this can be used to shift the understanding of energy consumption from 'all energy consumption is bad' to 'energy consumption that drives demand for non-renewable energy is bad'. It was discussed that with the energy transformation that was occurring at this campus, there were times of the day when energy was being supplied by 100% renewable sources, while there were others where the energy was being taken from the grid. Further development of this discussion revealed greater nuance in this position, with the mix of energy coming from the grid being of significant importance.

This discussion began to shift the narrative of the challenge, and of the Insight project, from being about reducing energy consumption, to being about enabling more intelligent and considered use of energy at times when it could be produced with no (less) environmental impact.

4.5 Storyboard exercise

After sharing and discussing the digital dashboard mockups that participants had created, the workshop moved on to ask participants to consider a similar question about how representations of energy could be made as something which might be physically experienced (an intervention) and to describe how somebody might experience this intervention through a storyboard. A template was provided that prompted participants to imaging how they might interact with the intervention and to consider what they think people would be doing before encountering a proposed intervention, and what they would do after they encountered it. The template also asked them to identify with whom, and where this experience might occur. Example storyboards are presented in Figure 4 below.

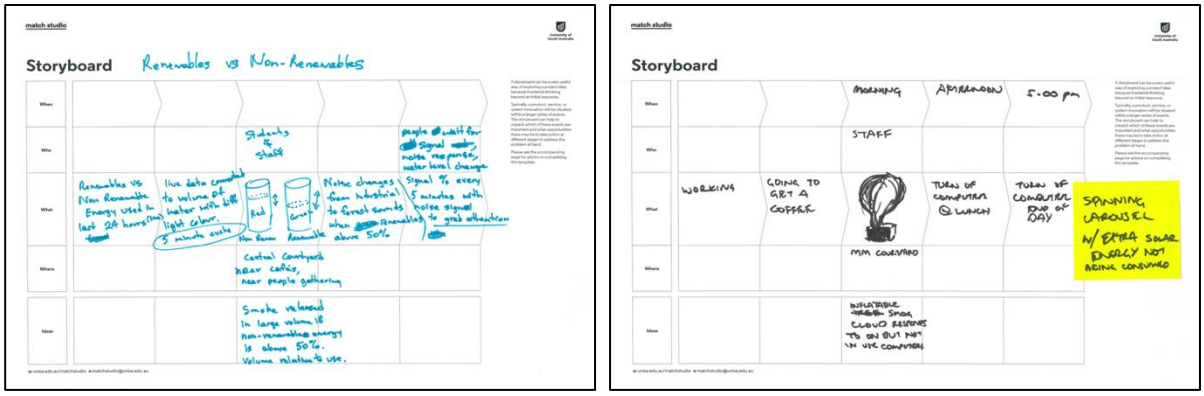

Figure 4: Example participant storyboards from Insight project workshop two

The key theme that emerged from the discussions about this activity was that interventions are of little use unless they can get people to stop and take notice. There were a number of different approaches to how and where the intervention might be placed into the campus environment, but there was a general agreement that in order to translate into any action, the intervention needed to create a sense of an event and become some kind of spectacle.

From a facilitation perspective, this was an interesting moment, because the hierarchy of importance of skills noticeably shifted from seeing the engineering and data analysis skills in the room as of primary importance, to seeing the artists and architects in the room emerge as being leaders in the discussions at this point. Of course, both skill sets are critical for the Insight project, but it was interesting to see that the storytelling processes associated with this activity generated this kind of response.

The relationship between intervention and action links this research with some of the complexity associated with behaviour change. The researchers note the criticism in the literature of behavioural approaches that focus on the role of a singular intervention (Shove 2010; Crocker 2012; Manzini & Tassari 2013). However, when contextualising this concept through the lens of Social Practice Theory (Shove, Pantzar & Watson 2012; Reckwitz 2002; Bordieu, 1977), the facilitation of a public conversation about energy can be seen as strongly supporting the meanings or communal attitudes dimension of Social Practices.

4.6 Rapid prototyping

At the end of the second workshop, participants were presented with a rapid prototyping kit and asked to build a physical model of how they could physicalise energy consumption data. Because this was the third iterative exercise within the workshop, participants were influenced by the discussions and responses to the first two exercises, but translated these into some very novel and unique prototypes.

These prototypes included:

- A piece of art that had a glowing element that could change colour in response to different levels of energy consumption

- A kinetic sculpture that changed speed according to energy consumption
- Lines running through the ground or between buildings that physicalised energy flows
- A ball machine that delivered an hourly or half-hourly verdict on energy consumption, building a picture each day of which colour balls had dropped
- A ball on a wire that floated between 'good' and 'bad' energy behaviours, and a see-saw mechanism that performed a similar visualisation
- An oversized light bulb that contained smoke machines and strobes to create weather patterns according to energy consumption

One of the limitations that emerged in this process, was that the materials the participants had been presented perhaps weren't as abstract as they might have been. For example, the inclusion of ping-pong balls in the kit led to a number of the responses using these balls to represent an 'orb of energy' and other somewhat literal translations. Despite this, the prototyping process again led to a very strong and interesting discussion, and further refined the group's position on how concepts of energy could be both physicalised and made meaningful. In further iterations, the researchers are planning to investigate how Lego® Serious Play® can be used in place of rapid prototyping to facilitate a similar abstracted conversation without the same opportunities for direct physicalisation links.

4.7 Prototype review and iteration kit

The final tool used in the workshop series was a one-page prototype review canvas. After the second workshop, the researchers worked with a small team of undergraduate students to develop some of the concepts that had emerged from the first two workshops into design propositions that could be taken back to the workshop group for review. Two of the concepts that were developed are presented in Figure 5 below, and included:

- A sculptural tree connected to a powerline that displayed energy flows through LED branches
- A competition dashboard for comparing two of the university's campuses' energy consumption
- Data visualisation animations that represented energy consumption through an increase or decrease in the number and speed of boomerangs or dots overlaid on an image of the campus
- A performative sculpture that pumped coloured water into transparent tanks shaped as a coal power station chimney and a tree depending on the amount of each in the campus' energy mix
- A transparent cylinder with a mannequin inside that adjusted its level according to the amount of energy being consumed by the campus
- An installation of recycled plastic cups that glows to match energy consumption intensity
- A floor/wall that peeled back to reveal an LED screen showing a visualisation of energy flows beneath the ground or inside a wall
- Sequenced lights along main walkways that 'moved' to show energy flows around the campus
- A 'sci-fi' generator that glowed according to energy consumption
- 'Dancing noodle' / wavers installed to inflate and 'dance' when excess renewable energy was being produced by the campus
- A large light bulb with atmospheric generator visualising 'good' and 'bad' energy consumption
- A kinetic sculpture that moved between 'good winning', 'neutral' and 'bad winning'.

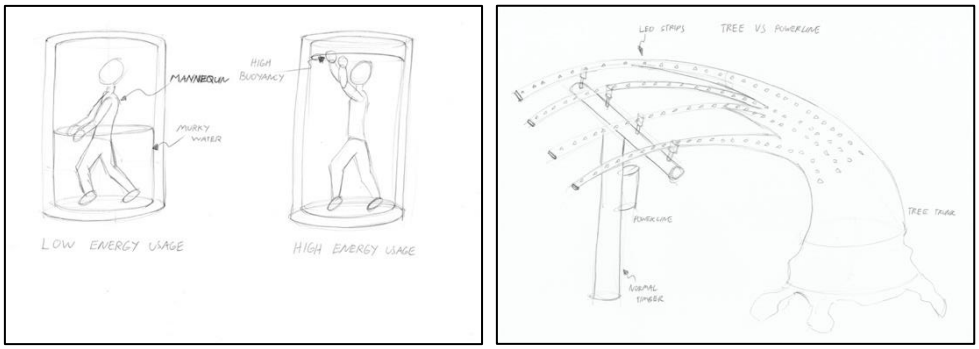

Figure 5: Prototype concepts developed with students for the Insight project

The prototype development review canvas was designed as a way of capturing participant feedback on these concepts. It included space for participants to individually and anonymously give feedback on the elements they liked or disliked form the ideas, to make suggestions for where it might be installed or created, to describe how they thought the concept would make people behave, think, or feel, and space to provide suggestions for improvements to the idea. Participants were asked to review as many or as few of the concepts as they wanted to and then had a discussion about which of the ideas might be taken forward as proposals for full-scale mock-ups and design testing.
The review exercise identified two main concepts to focus on:

- the difference between renewable energy and non-renewable energy which was captured in a number of the sculptural propositions, and
- the visualisation and uncovering of the flow of energy into and out of buildings and around the campus.

There was a particular interest in the drowning mannequin concept because of the ability to catalyse conversations and debate about many issues to do with sustainability. Further investigation and design testing is required to assess the psychological impact of such an installation, and to determine the kinds of audiences and messages that would need to be targeted in order to generate a positive impact.

5. Conclusion

The approach of blending individual and group creativity approaches described by Paulus and Nijstad (2003) appears to have been very successful in this project. The volume and variety of the ideas that were generated through his process was higher than the research team had expected. In particular, the co-design process appears to have successfully catalysed discussions about energy consumption and the representation of this consumption that go beyond typical visualisation of data usage. The project demonstrates the success of using the co-design process to develop novel ways of visualising and physicalising real-time energy consumption information. It has uncovered a number of new opportunities to physicalise energy consumption and energy-source data that engage with emergent narratives of the experience of the campus environment.
Another key contribution of this research is the observation that the medium through which participants are asked to contribute ideas can have a significant impact on the nature of the contribution. In this project the researchers demonstrated how the triangulation of three different methods (dashboard template, storyboard, 3D model construction) can help to mitigate against this bias. The concepts that have been presented in this paper demonstrate a number of new opportunities for researchers to expand the network of disciplines collaborating on energy visualisation/ physicalisation projects and underline the importance of considering social as well as technical forms and elements in communication.

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