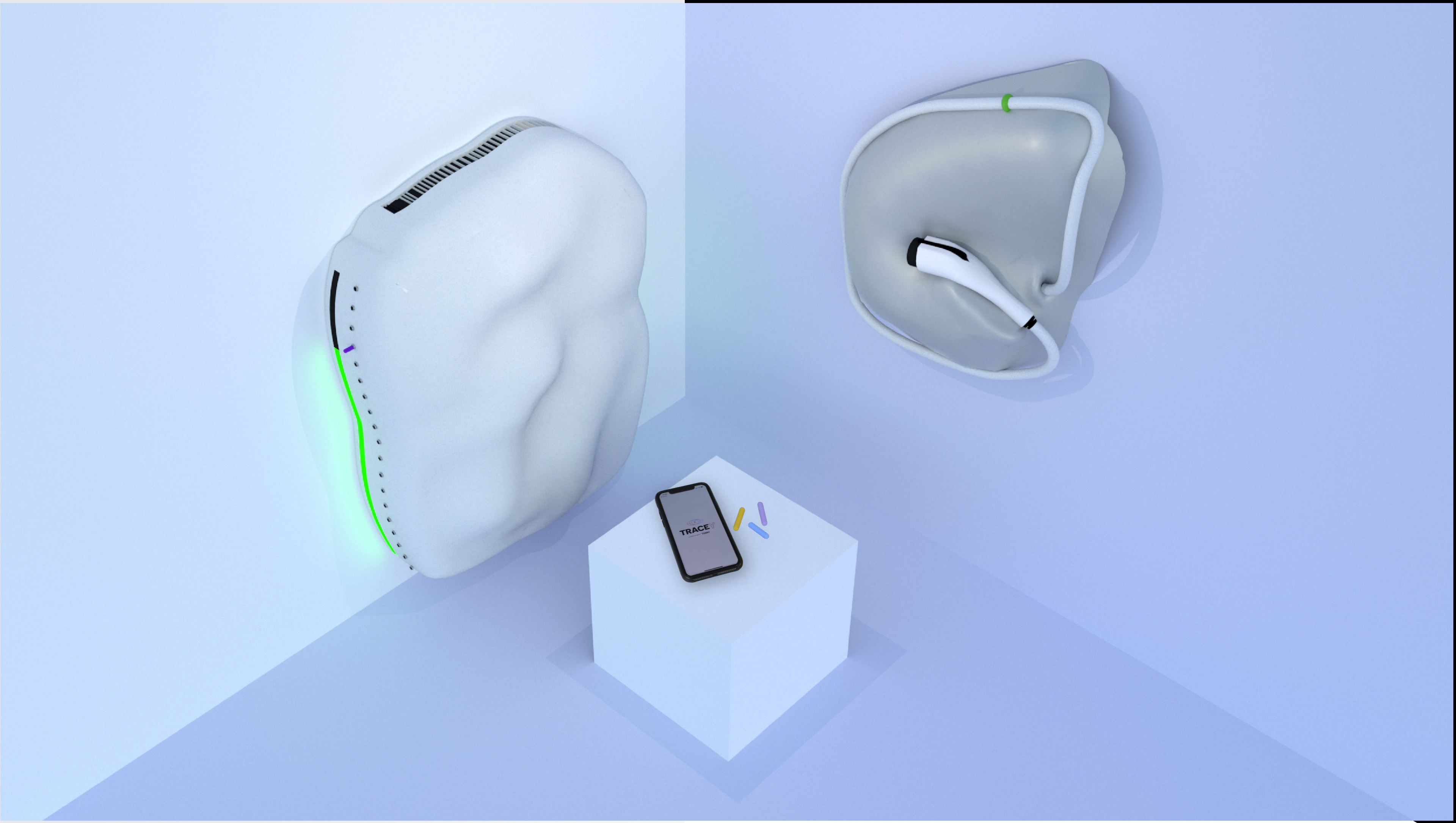


# ‘Terry: Home Battery and Product Family

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DIGSIM
Designing for Growing Systems in the Home

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# Executive summary

This report describes the project entitled " 'Terry product family" which includes a home battery named 'Terry, a management tool, named Tracey, and a car charger, named Troy. 'Terry is placed in the living room, to disrupt the current norm of hidden energy systems. In this project, the role of the battery in the smart home of the future is explored through a speculative design approach. This approach aims to explore and define an alternative perspective for humans to re-evaluate the abstracted relationship with energy in their homes. The 'Terry Product Family offers an attractive solution by creating a series of prototypes that highlight and communicate the most relevant aspects of its use.

In this report, the project is framed by introducing the goals and requirements in designing for the "Use and Produce" group within the DIGSIM squad, and the main themes underlying the project. This includes the black box paradigm and emergent phenomenon within smart homes in the year 2030. These themes tied together, define the design space in which the project was executed and which it aims to explore and expand.

The next section of the report describes the reflective transformative design process used. This starts with an envisioning phase consisting of research and defining the context of the energy-human relationship. This was then abstracted and analyzed within the themes. Validating activities were then done in parallel, including user research. This, along with researching data and emergent phenomena further explored how to embody design choices. After describing this research, multiple sensing, perceiving, and doing phases were conducted. The resulting prototypes and explorations helped envision the designs in context.

This report then concludes with a summary of the prototypes designed. This includes both physical and digital prototypes and data sharingbetween this project and other DIGSIM projects. Additionally, an experiential interaction survey and self-study implementations were conducted.

Overall, the 'Terry product family helps illuminate the relationship users have with energy by integrating 'Terry within the home. Tracey and Troy extend this relationship by allowing the user to explore deeper into their energy storage habits and the impact of their energy usage in their electric cars. These are synthesized in our vision on the future of energy in the smart home, as well as recommendations for a future continuation of this project.

# Content

# Framing the project

Self-sustainability is the future. By 2030 most residential houses will be equipped with solar panels and home batteries. As homes start to generate, store, and consume our energy, our everyday life becomes dependent on invisible systems.

As COVID has accelerated people to work from home, people are more than ever reliant on their own home as the environment that shapes and enables their behavior. At home, the advantages of sustainable living are closer than ever, yet without sustainability week at work, users have to take responsibility. This also requires a more critical attitude in everyday living.

Design enables or disables human actions and behavior by shaping the material environment in our everyday. This also means that design should present alternatives, expose choices, and consequences of behavior.

While every new device in the smart home is another consumer, the IoT system also provides new ways to design the relationships between humans, energy, and technology. As an artifact is incorporated into a system of smart people and smart artifacts the persuasive arguments (or choices) made by the designer will be reshaped by the choices of the user and other artifacts in the IoT. 'Terry aims to give space where perspectives meet; how a user's relationship with energy evolves as emergent behavior arises over time.

This project looks into how the design of home batteries can change the perception and use of energy through embodied interaction (Dourish, 1999, 2001), for which we draw on the rich interaction framework (Frens, 2006) to close the gap between engineering and form-giving.

Drawing on ideas from diverse areas such as sustainable design, interactive materiality, and speculative design, this paper describes how the 'Terry project was conceived as a way to explore the possibilities of home batteries by re-evaluating the human-technology relationship in the smart home of 2030.

## Context

**(Squad) Vision**

This project was executed in the Designing for Growing Systems in the Home (DIGSIM) squad, a research and vision driven squad that explores new ground in systems of interactive products or 'the Internet of Things' (IoT) in the context of the smart home of the near future (Frens et al., 2020a). We understand this system both as a technological as well as a social construct to identify and design for the relationships and interactions between humans, artifacts, and the environment. Within the squad's vision this project aims to design for the distribution of energy within the smart home of the future; the physical, yet intangible system that fuels and connects the technologies in the smart home.

The DIGSIM squad approaches IoT systems as being inherently open, while energy systems are inherently closed. This project is interested in how constant change of the IoT system extends to the constantly changing balance between the production and use of energy within the smart home. Houses are becoming self-sustainable through solar generation, while IoT devices are autonomously deciding when they use energy. This is where the passivity and invisibility of energy storage become less evident and we find the need to design for the connection between the energy system and the IoT as being interconnected.

**Home batteries**

The home battery is an energy storage technology that will play a key role in the production, use, and distribution of energy for the smart home of the future (Mallapragada et al., 2020). While the technology is already available for consumer homes, (Luu, 2020) additional advancements are needed to realize the storage's full potential. Tech giants, such as Tesla, LG, Mercedes, and Nissan, are already long competing in a battery race for storage capacity, efficiency rates, etc. (Hesse et al.). Most improvements are in the realm of engineering, where form and integration follow technology, and the storage unit is installed by specialist engineers.

There is little attention to what implementation means for the architecture of everyday life; user behavior, the human-energy relationship, and the IoT. Design can play a role to introduce home batteries into the human experience, but also shape the human side of this technology and use this to steer their development. Unexplored aspects like the physical form, placement of the storage unit, and connectedness in the system give rise to design opportunities. By looking through a speculative lens at home batteries in the context of the smart home of 2030, this project explores the future of this technology from an interaction, system, and societal perspective.

An important thing to notice is that the settings of the battery impact its degradation rate which in turn affects its maximum capacity and usable lifespan. Users might be faced with dilemmas when, for example, the battery is charged to its ideal level, but solar panels are still generating energy. They can choose to keep storing, sell it to the grid, consume it, or store it in an electric car.

**IoT sandbox**

To create a design within the complexity of an IoT system the DIGSIM squad offers the IoT Sandbox and connected data-canvas (Frens et al., 2020a) as design tools and research demonstrator. Inside the IoT Sandbox lives a family of mundane characters; the Gorre's (Djajadiningrat et al., 2000). Together with other projects within the DIGSIM squad, the layout of the home, the characters, and their practices were established. In this process, special attention was paid to create tensions between sustainability, wish for comfort, and economic motivations, as well as the occupation of the virtual living room in which this project is situated and the home's energy production and consumption behavior. The data canvas is an online platform in which the IoT sandbox artifacts are virtually connected through OOCSI (Funk, 2019). For this project, distributing energy to the other IoT artifacts forms an interesting opportunity to explore the relations between energy and IoT systems.

Furthermore, IoT is a leaky system where functionalities can emerge in unpredictable ways. It's also where the choices of this project meet the choices of other designers and homeowners, who appropriate the system's artifacts to fit and evolve their choices of their own. We're interested in the emergent behavior at the intersection of energy and IoT systems, and how this can further enable sustainable social living.

# Themes

**Human-energy relationship**

The interfaces in our everyday life distance us from the production and consumption of energy as a resource in many ways. Energy infrastructures are hidden by design, but energy is also impossible to see or hold by nature, only experienced through energy-consuming devices or augmented data. This makes it hard to grasp what you saved or used (Lutzenhiser, 2014). For a design to persuade a change in energy consumer behavior, users foremost need to be aware of energy and energy systems to reflect on choices and actions (Broms et al., 2017). Even though energy production is moving inside the home, human interactions with electricity are still primarily limited to plugging a device in an outlet or reading a battery percentage. 'Terry uses embodied interaction (Dourish, 2001) to couple the aesthetics and engineering (Backlund et al., 2006) of a home battery that gives users a more general understanding of energy. Because energy is intangible, this requires a dematerialization (Campenhout, 2016) of the energy system and re-materialization (Pierce & Paulos, 2010) into a form that relates the user to their energy choices each time the product is used and how this extends to a societal choice over time (Broek, 2019).

In a literature review of energy-related work within HCI by Pierce and Paulos (2012), three themes that characterize the work in this area of design are described; consumption feedback (data); energy awareness and conservation behavior (sensorial); lack of engagement with emerging energy systems. This project attempts to unite these themes and aims to make users engage with, experience, and understand energy based on a direct, visible, and physical connection to the production and consumption of energy that is now possible by connecting the localized energy system to the IoT.

**Black box paradigm**

Borgmann who specializes in philosophy of technology argues that the devices that hide technologies have led us to a device paradigm (Borgmann, 1984) in which the interfaces in our homes increasingly alienate us from the technologies and commodities that we need in everyday life, which he deems "focal things". For example, in the past a fireplace required effort and care (focal practices), but returned a user with warmth and light (focal things), forming a central point in the living space that enabled social and symbolic rituals.

In smart homes, a great deal of the modern infrastructures that provide us with the focal things we are dependent on is hidden in the basement, beneath floors, or behind walls. To not be aware of this is arguably a luxury of modern life, but also makes us blind to the material and social relations of which we are a part as well as our dependence on the systems of production that support this living (Hornborg, 2010).

This abstraction of everyday life is accelerated by IoT interfaces that become increasingly augmented and distanced from their source. For example, a modern heating system is integrated into the floor and controlled through an application.

In our vision, self-sustainable technologies like home batteries bring an interesting notion on the device paradigm; while the device paradigm is distancing us from what is significant for everyday life, the material production and storage of energy is moving from the grid to the home. Current home battery implementations are creating a literal closed 'black' box inside the home, that only communicates through an application and is maintained by outsiders. We become dependent on a big battery that is at the heart of the focal things in the home, yet more abstract of a device than any device before. The black box paradigm.

Following the paradigm, we foresee 'capacity anxiety' as a possible phenomenon that can emerge. Similar to that of phone battery anxiety and range anxiety in electric car batteries, the fear of your home battery running low could move users or the devices in the IoT to behave on the battery's terms, altering their choices to or distancing themselves from the battery. This project approaches the DIGSIM sustainability and system challenge by aiming to create more meaningful relations between humans and the systems in their home, rather than an approach of technological progress or individual products (Corbett, 2005).

As these boxes require a place inside the home, why not give home batteries the prominent place they deserve? By taking inspiration from a technology that used to be a focal thing as well as the focal point in the living room, the fireplace, this project enables inhabitants to build up a relationship of care with their energy system by making the home battery the focal point in the living room. As users care for the battery, the battery cares for them.

**Speculative approach**

A speculative design approach has been chosen to take the upcoming technology of home batteries out of isolation and explore its possibilities in the context of everyday life and IoT systems. The abstract opportunities, challenges, and questions that this project is interested in are made tangible and experientable through the IoT Sandbox, data-canvas, and physical deployment of a speculative artifact (Broms et al., 2017). In this project, we also attempt to contribute to the state of the art in the field of speculative energy futures (Just Powers, 2021; Rieur & Alahmad, 2014; Pierce & Paulos, 2012) by exploring the human-technology relationship from an interaction and system perspective.

While speculative design is interesting for examining the effects of implementations of home batteries on a societal level, it might be equally as valuable to explore its influence on experiences in the everyday. To do so, we dubbed several themes in the next section that express our understanding of the everyday experience of technology and the everyday itself that this technology will be formed through. Rather than examining just the technology, the project has led to the development of speculative products that could come forth from the developments of home batteries and imagines a possible future in how we can live with these. The deployment of the speculative prototype is itself a way to discuss the kind of future people want and do not want, as well as a way to examine the current relationship users have with energy, exposing the limited choices that are hardwired in the current situation (Dunne & Raby, 2001).

# Design process

The reflective transformative design process was used throughout this project (Hummels & Frens, 2009). At the beginning of the project, exploration was done by **envisioning** how users currently interact with their energy systems and how they could interact with them in 2030. Once an interesting area, energy storage, and home batteries, was chosen, further research into themes like the black box paradigm was done to **abstract and analyze** the topic. In parallel, **validating** activities were done, such as user research in the format of surveys. After collecting all of this data, the research went into a **sensing, perceiving, and doing** phase where physical prototypes were built and CAD renderings were designed to **envision** these designs in context. These activities were iterated on repeatedly to include multiple modalities and revise based on reflection and feedback. In parallel, activities such as data sharing with other groups were done to find new emergent phenomena. At the end of this project **validating** activities were done such as conducting self-study implementations and an experiential interaction survey was designed.

## Early process

At the start of the design process, various ideas of energy (Broek, 2019) were explored that connect the home of the Sandbox family to the neighborhood; greywater, garbage recycling, and excess solar energy production. We set out to investigate the question: “What happens with our energy when a home goes beyond Net Zero?” See Figure 1 for an overview of the early process.

Inspired by IKEA’s project SolarVille (SPACE 10, 2021), a research project that explores democratizing access to clean energy through neighborhood microgrids, the first iteration of our ‘Beyond Net Zero’ concept focused on using IKEA’s microgrid as a system to trade excess energy with neighbors (distribution).This required the design of an in-home trading interface and considered physical interactions with the invisible energy system by means of de and re-materialization (Campenhout, 2016; Pierce & Paulos, 2010).

The dystopian and utopian sides of this concept were tested through future scenarios with discussion with peers in the ‘Futuring’ workshop (Robbins et al., 2020) and the placement of the Beyond Net Zero scenarios on the Taxonomy of Futures scale (Dunne et al., 2013) indicated that this possible future relied on the developments of too many components. To create a closer and preferable future, the individual technologies required for this trading system to work were examined (see Figure 2). Energy storage technologies are both preferable and a crucial part of the distribution of energy in the future. Relating this to the state of the art, the majority of related work about speculative energy futures looks to support sustainability through either the production, distribution, or usage of energy (Broms et al., 2017; Wilson et al., 2019), whereas storage does not receive a lot of attention from designers, yet is a hot topic for engineers and tech companies (Luu, 2020).

The state of current home battery designs was explored through market research and literature reviews on the state of the art (Djajadiningrat et al., 2000; Hesse et al., 2017). General observations were that the form designs are very uninspiring and that home batteries have no clear role in the home, where they are placed, and what feedback they give. The plausibility of a future with home batteries as well as the current device paradigm (Borgmann, 1984) inspired us to define the ‘black box’ paradigm and explore a future where home batteries strengthen the human relationship with energy. To create meaningful interaction with energy, next iterations focused on coupling form and function (Frens, 2006) to merge aesthetics and engineering (Backlund et al., 2006) and took inspiration from the rich interaction workshop in which a physical-digital hybrid interface was created (Frens et al., 2020b).

In the process of exploring embodied interactions with energy (Dourish, 1999), the idea of creating a living interface popped up, based on the idea of a Material User Interface (Ishii et al., 2012). The next iterations of this concept considered a dynamic shift across the interaction attention continuum (Bakker & Niemantsverdriet, 2016) to blend the interface with the living room and only direct attention when the energy balance requires user intervention (Weiser & Brown, 1996). The interface became a physical metaphor for energy systems, like wall art, whereas the physical energy storage was located elsewhere and remained a black box. Analyzing the energy system and realizing that the battery was to become the heart of the home, the decision was made to redesign the battery itself. This step opened up new design space and invited a more speculative approach to how the human-energy relationship can support sustainable living.

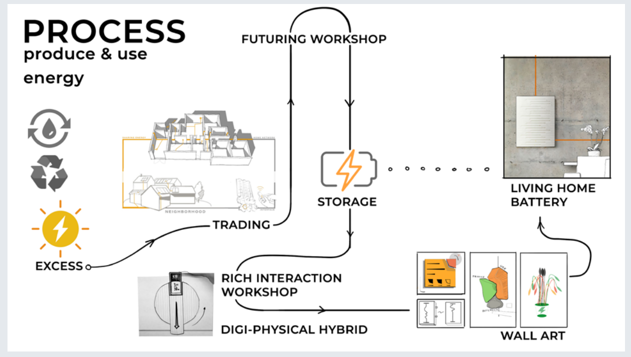



**Figure 1** Overview of the early process.

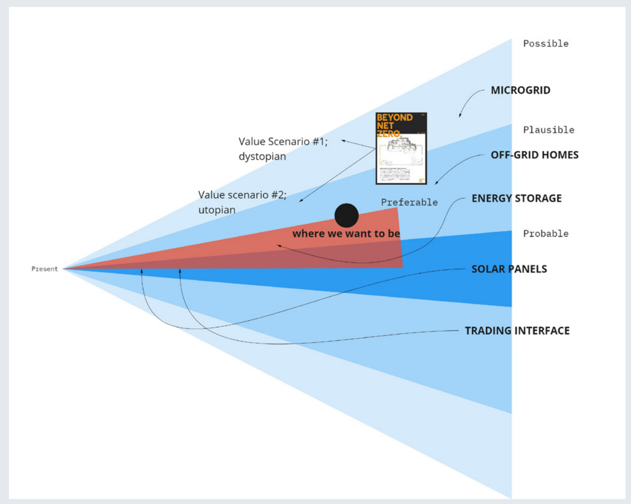



**Figure 2** Taxonomy of Beyond Net Zero with isolated technologies.

## Defining the design space

The design space imagines a future where humans have a more meaningful relationship with the systems in their home and the things they are dependent on. In this future, the battery is the heart of the home and the starting point to reevaluate how humans interact with these systems. The home battery designed in this project is called ‘Terry, a living battery that is placed in the living room of the home of the Gorre’s.

Three themes were defined, as already described, that form the foundation of the design space, based on the state of the art of speculative energy futures and the human-technology relationship. To redesign interactions with energy as a focal thing, we looked to the focal practices around the center of the home in the past; the fireplace. For centuries the fireplace has been the heart of the home that provided us with warmth and light as we took care to keep the fire burning. To give a home battery this meaning and role as the heart of the home, four points were considered in designing ‘Terry:

• ‘Terry becomes the sensorial focal point in the living room. The form represents aesthetics of energy that fuses form and function, through embodied and rich interaction. Caring rewards the user with commodities of comfort. Like a fire or lava lamp, the battery’s movement allows for endless staring.

• ’Terry seamlessly blends in with the living room furniture and gives users an ambient awareness of the energy system, but takes the user’s attention when action is required.

• ‘Terry reclaims the function of a fireplace mantel as a symbolic focal point, as, with memorabilia to be placed around it and takes in a central place in the family’s evening rituals.

• ‘Terry is a living interface that embodies the state of the material storage and the trends in energy use over the time of day and seasons.

**Battery specifications**

The type of battery which would be both practical and fit within the design mission needed to be defined. Many different types of batteries exist, such as led acid, nickel-cadmium, nickel-metal-hydride, and lithium-ion (Qian & Barsukov, 2013). Lithium-ion is currently the industry standard however due to capacity and low-maintenance benefits. All popular home batteries on the market are currently using lithium-based batteries (Jossi, 2020).

A capacity of 30kWh was also defined. This was discussed with other projects within the DIGSIM squad. It was also calculated based on online calculators which estimate how much energy the Gorre family might consume within their residential home, how much their car might consume, and how much energy their solar panels might produce (Great Home, 2020; March, 2021; NREL, 2021).

## Exploring the design space

Once the scope of the project around home batteries was found further exploration was taken into the subject. Two separate surveys went out. These were tools within this validation and exploration phase of the design process. With both of these surveys, a pilot was conducted with one participant to help edit the questionnaire questions for clarity.

**Energy usage at home questionnaire**

The first survey, the “Energy usage at Home Questionnaire”, aimed to gain an understanding of how people currently live in their living room space. See Appendix B for the entire questionnaire questions. This was a very elaborate and qualitative survey so only eight participants completed the survey. All participants answered questions about their demographics, their own living room preferences, and their energy usage habits. After that, they were either asked hypothetical or more detailed questions about solar panels and home batteries depending on if they own the devices.

*Demographics and energy usage*

The households with both larger age ranges and older participants, there were more clear divisions of roles within the household of who was responsible. For example, Participant 6 explained that “my parents pay the energy bills but I’m somewhat aware how much” energy the home uses. Participant 3 also said that they “don’t really keep tabs on energy usage much, but my husband does”. This was important to understand, as the project wanted to address this division in management, but also create a more transparent product for the entire household.

Energy usage and awareness attitudes ranged greatly, the participants who responded that they were unaware of energy usage also did not care about their energy usage. While those that were slightly aware listed reasons such as “environmental impact”, “energy is expensive”, and “wastefulness” as to why they cared.

No matter how much they cared or were aware of usage, every single respondent mentioned that either they had no way of monitoring their energy or that they only were able to monitor it through their bill or an app. Furthermore, when asked if they do anything to reduce this, every single participant responded that they do not try to reduce their energy or that they participated in vague personal habits such as turning off lights, heating, or unplugging devices. These responses indicated that regardless of their demographics, or how these habits and activities were delegated within a household, there is a strong need for a physical tool that could help users engage in understanding their energy usage.

*Living room context and arrangement*

Only two out of the eight participants uploaded a photo of their living room, see Figures 3 and 4. While these households were dramatically different, as Participant 4 lived in a student house with roommates and Participant 3 only lived with their husband, they had striking similarities in how the photos were framed. Both of the photos were taken from outside the living room as if you were walking in, and were angled at the wall which contained the couch. Participant 4 acknowledged in a later question that the centerpiece of the living room was indeed the couch. Participant 3 however said that the "bookshelves with tv on top" was actually the centerpiece of the room. This object can be assumed to be on the left-hand side of the photo, not entirely visible. Seeing these photos created fascinating insights, as it brought up the question of if the centerpiece to the room was what was most apparent when entering the room or what was most apparent or used while

**Figure 3** Participant 3 living room.

**Figure 4** Participant 4 living room.

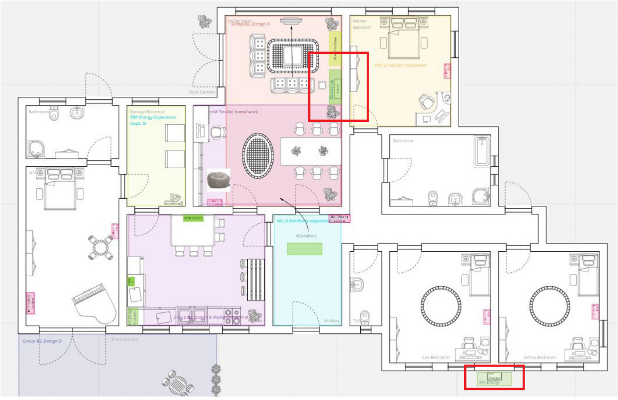


**Figure 5** IoT sandbox.

in the living room. For this project, it was resolved to place the battery in a space that would be immediately apparent when walking into the room. The battery was placed next to the couch in the Gorre family home, see Figure 5 for an overview of the IoT sandbox.

*Solar and battery hypotheticals*

The last questions were split between hypotheticals about solar panels and batteries and questions about the devices if they had owned them. The hypotheticals were key in understanding what thresholds users perceive when it comes to this technology. One of the main takeaways from this was that users were often skeptical about battery safety, cost, and environmental impact of a home battery. Additionally, many people indicated that they do not own their own home or would not be allowed to install anything.

*Battery questions*

This survey found responses that later showed that it is not uncommon for some American properties to have an emergency battery. Participant 3 stated they had a small emergency battery. This device is not however a modern home battery, as it was just a small backup system with no user interaction. Participant 3 acknowledged this saying the only interaction with the device was to "occasionally restart'' it. They go on to say that they do not monitor it and want "more interactive features on usage". While the participants who responded to hypothetical battery questions had concerns, it was encouraging to see that there is already existing infrastructure in some places and a desire for a more transparent, interactive system.

*Overall insights and limitations*

Overall, it was found that within households there is often distinct segregation of roles when it comes to energy management. These roles and attitudes are often also linked to the energy bill. To incorporate this new understanding within the project there was a focus on making sure that the energy usage and the system were more integrated and visible within the household. This resulted in placing 'Terry next to the couch, as this can be seen as a focal point of the living room. The separation of roles also led to understanding that different users will have different needs and interactions. Ultimately, this led to designing a family of products that could address these different needs.

While this questionnaire guided the research greatly it had limitations that should be considered. The sample size is one of the largest limitations, with only eight participants. One of the factors which reduced the number of responses was the format. This survey required participants to sign in to google to upload photos. This dramatically impacted the willingness of people to take the survey. Additionally, while homeownership is not a concern for the Gorre family, we still acknowledge this threshold for the future work of this project.

**Electric car questionnaire**

The second survey was a case study on electric car owners. This was an especially interesting demographic to study as electric car owners maintain their car batteries which are similar types of batteries that you would find in the home. Later, when expanding the product family to include Troy, the electric car charger, these responses were also invaluable.

This survey was targeted towards only electric and hybrid car drivers because of their experience and insights into using and caring for these vehicles. 89 responses were collected. Demographics and electric car background were first gathered to understand the context of the participants. Participants were asked questions about each electric vehicle they own. After filling in details about their cars, habits such as shared usage, charging habits, maintenance, and community were explored to better understand the most important elements. See Appendix C for the entire questionnaire questions.

*Demographics and context*

Almost the entire population, over 80.9%, of this survey was composed of Americans. This is important to understand as there might be a large cultural difference between the participants and the Gorre family. All but three out of all 89 participants (3.3%) had either a Nissan Leaf or Tesla as their electric car. Also, only 8 out of the 89 (9.0%) of the participants indicated that they had ever leased any of the cars they have owned. The information about if they lease or own the cars was collected as it could have impacted the relationship users have with the maintenance and battery degradation of the cars. However, given the responses heavily showed this demographic owned the cars no significant difference was found.

When asked how they would describe themselves on a scale of one being "New to eclectic/hybrid cars" and five being an "Expert in electric/hybrid cars" 79 out of 89 (88.8%) of participants ranked themselves a three or higher. Additionally, when asked how aware they are about their energy usage 72 out of 89 (80.9%) of participants ranked themselves a three or above on a scale of one to five. The demographics and the responses to these questions then help frame the majority of respondents as extreme users. Graphs outlining this data can be seen in Appendix D.

*Shared usage and responsibility*

One of the goals of this survey was to better understand the shared nature of electric cars. This later helped the project understand which features different users would be interested in for managing charging and maintenance. Similar to the Gorre family, the survey found that 68.9% of participants indicated that cars are shared, often between significant others like spouses or between family members, see Appendix D for a graph showing this data. While this indicates a shared nature, 95.2% of participants indicated that they were solely responsible for the maintenance of the vehicle. The shared and individual nature of this then led to developing the interactions in both a shared and individual way. Ultimately, moving detailed maintenance interactions to Tracey, a more individual format.

*Charging habits*

The next section was designed to gain a better understanding of the type of settings, concerns, and habits users have around their energy consumption. When asked how "full" the user charges the battery and how frequently they charge it was found that many users had their own specific preferences. When asking how full it was seen that while 25.0% of users always charge to 100% many users charge to different percentages.

Similarly, 26.3% of participants indicate that they charge every day a week, but others have less regular charging habits. Graphs outlining this data can be seen in Appendix D.

When participants were questioned about these habits, it was found that some attributed their habits to need, saying that they charge based on their "commute to work" or "how often it needs it". This includes users who looked at their long term needs and varied their charging "depending on season and amount of driving". A subset of these participants cited "range anxiety", a term that was coined to describe the concern about running out of energy in the middle of a trip. Learning about the phenomenon of "range anxiety" later led to 'Terry addressing what was deemed "capacity anxiety" by exhibiting calming movements when full.

Other participants changed their habits based on their battery health. One participant said "we were told that we shouldn't charge every day" while another said, "I've been told that keeping the Tesla plugged in whenever possible is best for the battery". Other users have kept a closer eye on their battery health saying that they conducted their own "investigation about battery health" or that they have seen that "battery longevity is best with frequent shallow charging sessions". These responses validated the need for a secondary tool, for those interested in battery degradation statistics and further setting control.

*Social media*

This survey also validated the need for a community or social media component within the Tracey app. Most of the 89 follow or belong to at least one social media platform, see Appendix D for a graph of social media platforms users participate on. When asked why they participated in social media, responses revolved around learning new information, sharing experiences, and collecting tips within the community. A word cloud based on participants' responses can be seen in Appendix D. These aspects then were included within the Tracey app.

*Limitations and conclusion*

Overall, this survey resulted in a few major findings which helped guide the project. Charging habits were based on usage or battery health management. These same features were expected to also apply to home battery management and were therefore included within the final controls for 'Terry and Tracey. This survey also found that cars were often shared between household members which led to some shared responsibilities and some individual responsibilities. Understanding what interactions were shared and which ones were individual helped validate having both physical aspects of Tracey in addition to an application platform.

The main limitation of this survey was that eclectic cars are not home batteries, meaning that the results collected here need to be interpreted for what this means for home energy storage and usage. Additionally, one of the conclusions of this survey was that the participants involved were extreme users of electric cars. These users greatly valued data, system control, and they want to have a community to talk about usage and habits. However, because these were extreme participants, more casual users might not have similar interests. Understanding that this demographic exists in addition to more casual users helped define the separation of functions between 'Terry and Tracey.

**Data exploration**

The workshop provided about data-sharing on November 11th, 2020 helped explore and develop the project further. When researching lithium-ion batteries it was found that all modern batteries include a battery management system (BMS) (Friel, 1998). These systems are also used for electric cars. With additional software such as "Leaf Spy" this data can be visible (Pollock). This data includes:

- Percentage state of charge
- Depth of discharge
- Voltages for each cell
- Battery health information (such as shunts)
- Temperature information
- kWh remaining
- Watt-hours used since the last reset

Additional data points were then defined to be able to calculate the current battery level and if 'Terry should be charging from the grid or from solar at that time: Grid prices, Times, Solar production estimations, Seasons, Energy needed for devices and background house activities, All BMS data from electric car, Range of car, Charging of car.

Once the data used was defined, emergent phenomenon between the 'Terry product family and other projects were explored, these are a few:

- If people are in the room then 'Terry should wake up / shut down.
- 'Terry could communicate the capacity to tell devices that it is okay to spend energy or to delay energy actions.
- Troy could communicate the range of the car to other devices.

# Material & shape exploration

As material and shape are such a large part of designing a physical product there were a lot of iterations. Figure 6 depicts an illustration of the process. It shows the first four iterations had patterns and mathematical themes. Next, the best way to express the functions of the prototype was explored. This is seen by the three iterations in the middle. The next iterations occurred when introspecting about the values the physical form should embody. These resulted in a few different iterations which were then revised into the final, an organic and softly shaped design with straightforward functions.

**Early experiments in paper and origami shapes**

The first iterations focused on how to express the complicated numbers of the energy system in a pleasing way. For this reason, mathematical patterns were explored. Origami became one of the focuses of the project and can embody different forms when manipulated. Kirigami was also explored at this time to explore ways of incorporating lighting, see Figure 7.

**Feedback from midterm**

The origami exploration was then influenced by the research into focal points in the home (Borgmann, 1984; Ishii, 2012). The home battery at this point was named ‘Terry. ‘Terry was also designed in a more organic fashion to embody the home energy system as a living being. The physical prototype seen in Figures 8 and 9 was presented at the midterm. This prototype was part organic and part inorganic. The organic part was designed to embody the state of the battery and communicate with the users through lights and movement. The inorganic part was able to connect to the users' phone to enable setting changes to the device.

The midterm feedback and the surveys help guide the next activities in finding a form for the product. It became clear that the communication of the device was unclear so functions and interactions should be more clearly defined. The abrupt distinction of the product into organic and inorganic shapes was also a little bit unsettling. The sharp lines of precise patterns in origami were also seen to conflict, so softer more organic feeling materials were explored. The interactions from the phone later evolved into Tracey.

**Physical lo-fi prototyping with straws + CAD**

After the midterm, lo-fi physical prototyping was done in a group where we could talk about how to visualize the functions clearly, see Figures 10. This was later expanded into more refined ideas through computer modeling, see Figure 11. The model displayed in Figure 11 shows the defined functions, a line represents the current charge of the battery level on ‘Terry. Overflow light on top and more detailed side lighting was also included.

By this point, functions for the entire family of products were more clearly defined, so the same design choices for ‘Terry were applied to the car charger Troy (see Figures 12, 13 and 14) and Tracey (see Figure 15). In this iteration, Troy the car charger showed a current charge and charge goal as lines, on the face of the charger, just like how ‘Terry displays the battery level. The Tracey functions were also just starting to be clearly defined. Figure 15 shows Tracey as a control panel on the side of

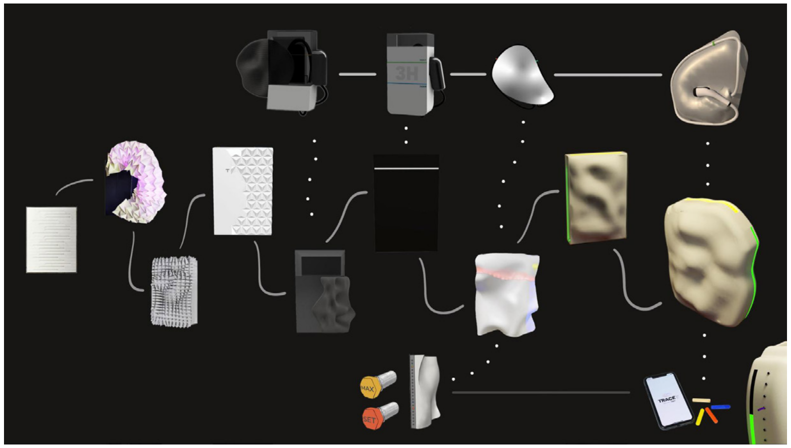


**Figure 6** Overall process through different prototypes.

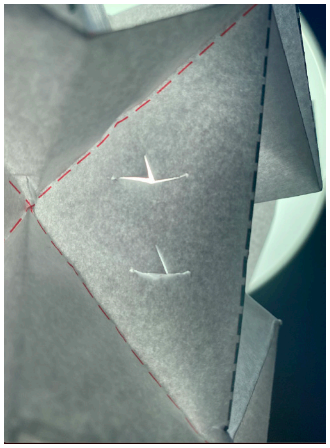


**Figure 7** Kirigami and origami prototyping.

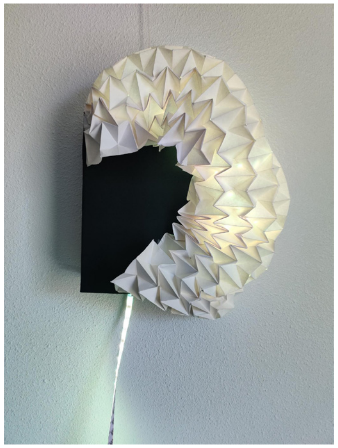


**Figure 8** Midterm prototype.

**Figure 9** Midterm prototype holding a phone.

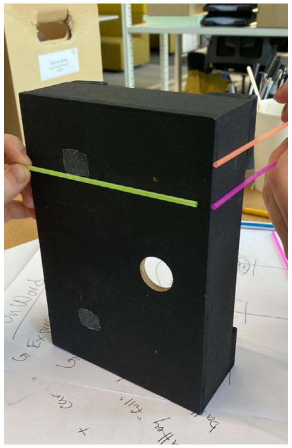


**Figure 10** Lo-fi function prototyping.

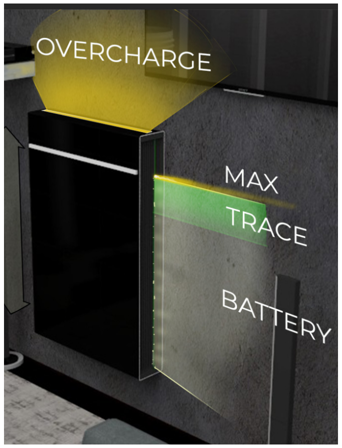
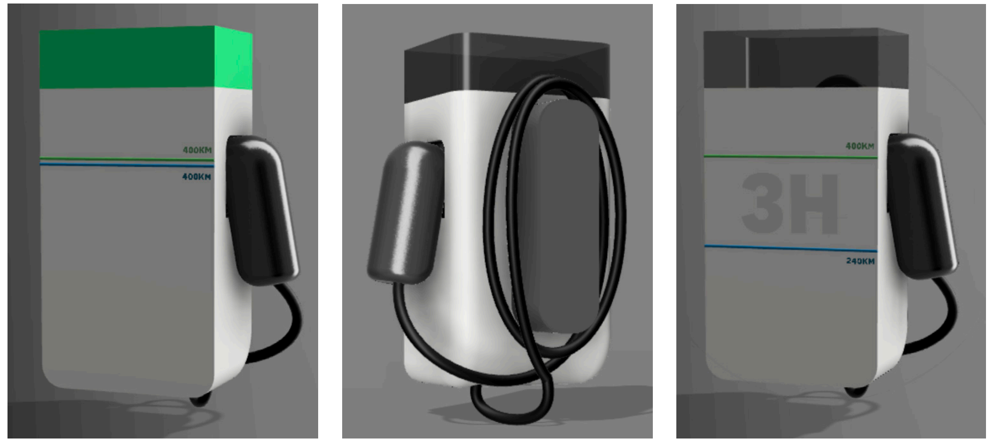



**Figure 11** Computer model of function based prototype




**Figures 12, 13 and 14** Computer modelof car charger Troy, with goal and charge lines.

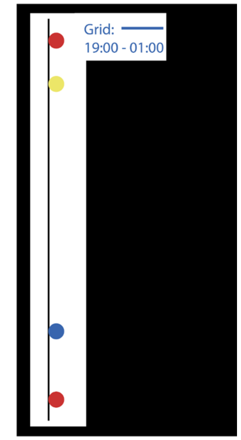



**Figure 15** Digital sketch of Tracey

'Terry. The dots represent stickers that could be placed on a scale and a way to control the grid connection.

**Value of materials**

Once the functions and interactions between all the products in the family were more clearly defined, integrating organic principles within the entire form was explored. Many different fabrics and materials were discussed but the one that felt the most dynamic and organic while still having a clean feel to it was the foam seen in Figure 16. It shows the foam being manipulated in an exploration. At this point, movement and shape inspiration from lava lamps, shadows, and houseplants were explored. The foam also was able to incorporate lights in a very interesting manner, as it refracted and diffused the lights in a more organic and pleasing way. Different colors were explored, as well as different ways the lights could be affixed and moved behind the foam to create organic, expressive lines. See Figure 17 for a photo of this light exploration.

**Organic soft shape**

The more subtle organic shapes throughout the entire product family were then applied. Figure 24 displays a digital sketch of how the new materials could be integrated into the design. The lighting which could embody organic and expressive shapes was used to communicate the battery level across the entire product. The edge of 'Terry was also then used for Tracey, a product that could do detailed system settings for the energy storage system of the house, see Figure 18. Instead of dots or stickers, pins were used to physically put new settings into 'Terry. This was incorporated along the entire side of 'Terry so where Tracey pins were placed could communicate different things, such as "don't charge above this point".

The same subtle organic shapes were then applied to Troy, the car charger, see Figure 19. Its shape represented an organ and was subtly referencing the comma in the name 'Terry. The most notable difference however was switching the interface from the charger itself to the cord, as a way of reinforcing the idea that the energy flows from the house and is transformed into fuel for the car. Moveable rings were then used to enable further detailed interaction with the cord.

**Final shape and materials**

Upon further reflection, a new physical prototype was developed. The entire shape became more organic, to enable the movement and soft nature a wireframe was built which was then wrapped in the soft foam. The final form seen in Figure 20 was a soft semi-organic shape with side lighting. See Figure 21 for the making of the form for the physical prototype.

**Figure 16** Foam exploration of organic and dynamic shapes.

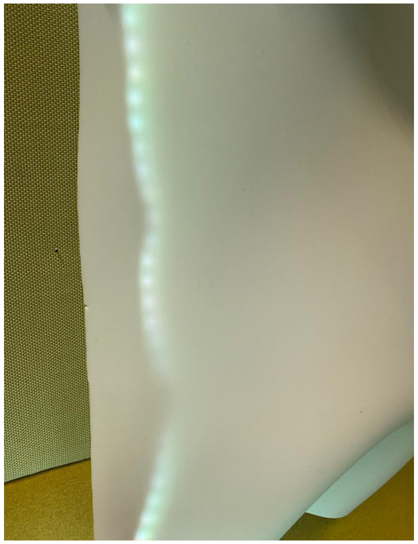


**Figure 17** Foam exploration with internal lighting.

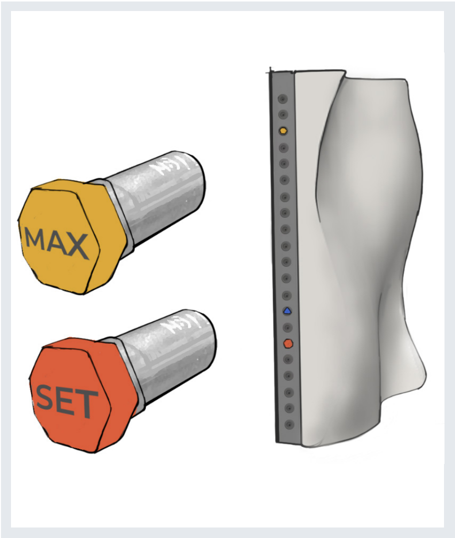



**Figure 18** Digital sketch of the new prototype with Tracey pins.

**Figure 19** Computer model of Troy with more organic shape.

**Figure 20** Final physical form of 'Terry with an organic shape.

**Figure 21** The wireframe under the foam exterior of 'Terry that allows for the organic movement.

# Behavior exploration

### Light

The use of light is key in our designs and prototypes. It creates a spectrum of understanding at a glance and while its subtlety allows the users to put the system in their peripheral attention field (Bakker & Niemantsverdriet, 2016). In order not to overcomplicate and prevent misunderstanding, information is displayed in both direction and color. Every new inclusion of light has been weighed against its added value, in cohesion with the function it performs.

'Terry has two types of light emission. Along its sides, and at its top (see Figure 22). These locations were directly coupled to their functions. The side lighting is used to show the current charge of the battery. This was previously displayed on the surface of 'Terry, but after considering the subtlety and entity creation was moved to the side (see Figure 23). As the location allowed the user to easily access the sides of the design, it opened up interaction possibilities. The user could set (detailed) range and charging settings on the linear scale alongside the device. This changing of the settings was not only displayed by the colored pins sticking out, but the location of these pins was transferred in light on both sides of the battery. This enhances the entire visual experience. The top lighting is reserved to function as a complimentary light output when the solar energy production excesses the charging goal. These overflow lights turn on and beam up to shift the user's attention to focus on deciding whether or not to take action (Bakker & Niemantsverdriet, 2016).

Some light implementations were left out because it strained the eyes and distracted from the other information. The underside of 'Terry initially had bottom lights. We iterated these lights to function similar to the top, overflow, lights. It was able to display when it was charging from the grid with blue lights. This made sense, as the grid connection was through the floor. We ultimately decided to leave this out, because it was not needed to always see the charging source for the specific functions we set 'Terry out to have.

Troy uses light to show its charging sequences. The combination of different colored lights on the cable interface illustrates the conversion of energy from the house (green lights) to drivable kilometers (orange lights). The user is able to set the car charging goal with a green colored tangible ring on the cable. When the light passes this ring, the light color changes from green to orange and adds up to the current charge of the car (see Figure 24). In an earlier iteration, we included an additional orange ring to show the current charge of the car. This was done to show the relation of the charge and the goal even when the car was away because the lights would turn off when the cable was not plugged into the car. However, we decided to exclude this second ring from the final concept as it was unrealistic to have the ring move automatically along with the charging of the car.

**Movement**

The material on the front surface area of 'Terry allows for motion to convey particular 'emotions' to the user. Using an entire interface opens up a much larger variety of interaction possibilities. Shape-changing advancements in the industry introduce not only flexibility but can also reconfigure into different shapes when demanded (Qamar et al., 2018). This is ideal when trying to develop products that are meant to be future-proof. As the material was carefully selected to afford these shape changes, the subtlety of movement could be used to achieve a shape-changing surface to talk to the user.

These movements can be divided into two states. The first one comforts the user, expressing that energy levels are within the user's preferred settings. It shows that it needs very limited attention to continue what it's doing. When these conditions do require attention, 'Terry expresses his anxiety through fast, uneasy movements. The action of switching states can go from subtle changes to sudden ones, depending on the urgency of the message it wants to convey.

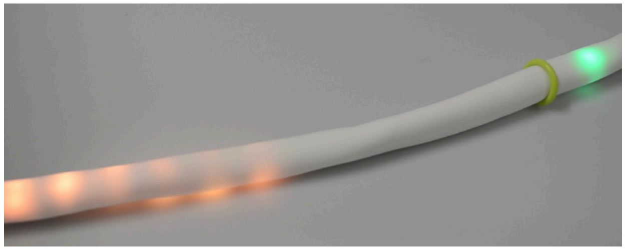


**Figure 24** Light sequence on Troy's cable interface.

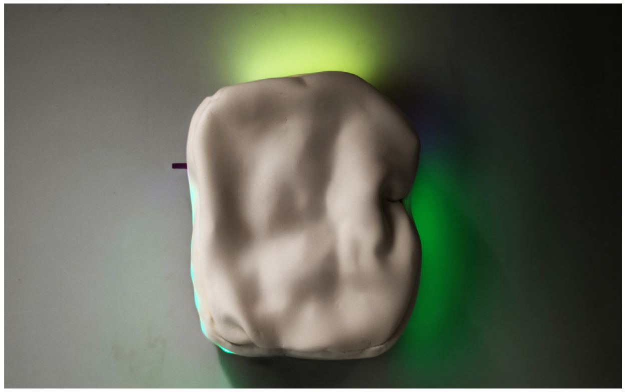


**Figure 22** 'Terry side and top lighting.

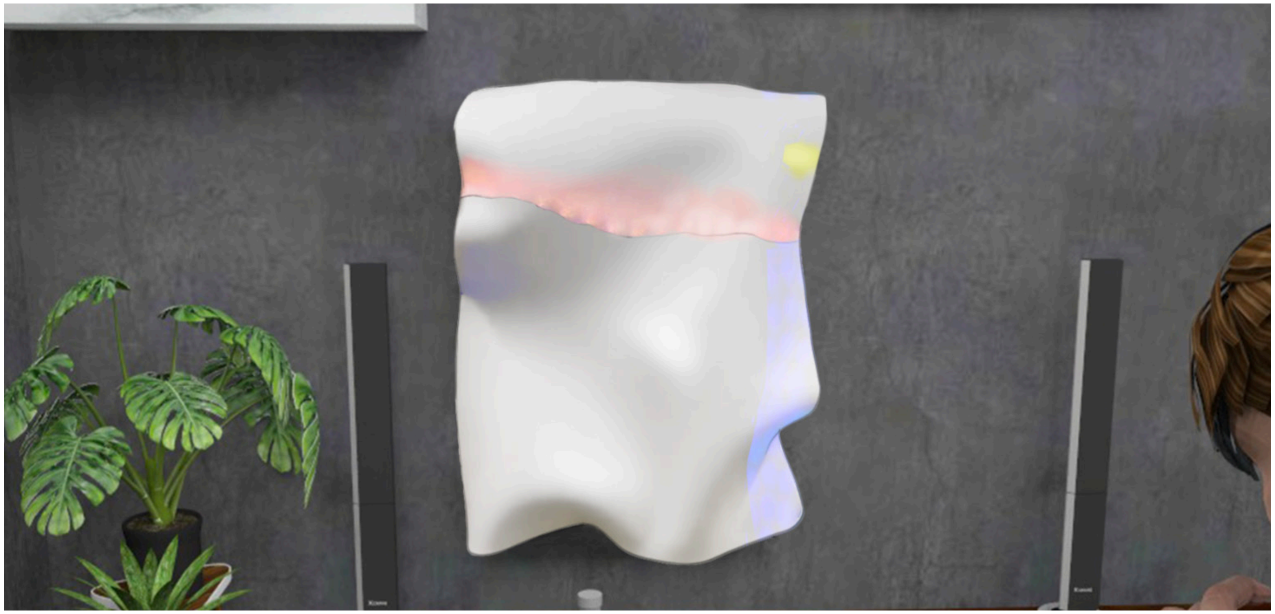


**Figure 23** 'Terry surface light iteration.

**Sound**
Sound design supports the mostly visual language of our products in the periphery of attention (Eggen et al., 2008). Some of these auditory components are triggered by the actions of the user, some are made autonomous by the system's functioning. Sounds are integrated to function as character traits of the products to develop a better understanding of what the system feels and wants, contributing to the ability to have a human-computer conversation. All of the sounds can be found and listened to in our final product family video (Appendix A).

The lights on top of 'Terry visually address the overproduction of solar energy and indicate the possible need for a user intervention in the energy system. We make the user aware of this state through a sound that can be described as brief and vibrant, emerging from the top. This couples the sound to the lights, which become apparent at the exact same time and place (Wensveen et al., 2004). In a complimentary way, a reversed form of the original sound plays when the overflow lights turn off by a contradictory action. The collective sound-set is designed for the user to recognize a change of state in a specific part of the energy system while still being able to distinguish how it changes from the periphery of their attention (Bakker & Niemantsverdriet, 2016).

Next to this, the system sounds give an understanding of what 'Terry wants to convey to the user by supporting its surface movement. This sound-set informs the user about the energy balance in a more subtle and continuous manner. At low volume the state can be better heard when coming closer to the product, to not overload the auditory space of the users. The sound design consists of an adaptation of two sorts of cat sounds: comforting purring and more alerting growling. When the energy balance is safe and changes are calm, 'Terry makes slow surface movement and produces a kind of purring, like the comforting sound that a cat makes when it is content. On the other side, when the surface movement is rapid and uneasy, the system wants to convey that it needs more attention. The purring changes to a deeper, more anxious sound which informs warning.

## Product family

**Connections**
In the process of creating our product family, one of the focus points was to form an understanding of how everything is connected and why every individual product exists. Next to the idea that they should function without the help of others and thus could be bought on their own, there should be an added benefit for each of them to work in relation to each other. Thinking this way created a lot of opportunities, but also helped to limit functionality on single products.

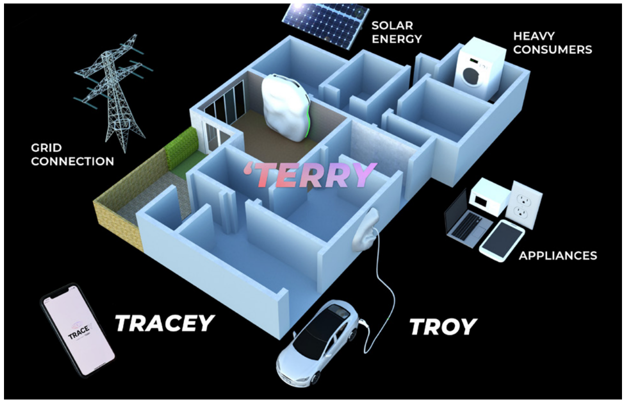



**Figure 25** Final energy system overview.

Figure 25 shows a sketch of our final energy system. As we have given the source of energy both a symbolic and functional place inside the center of the home with 'Terry, it needed to blend in the living room and shift the attention of the user when it is needed (Bakker & Niemantsverdriet, 2016). Tracey was developed as a tool/instrument, to have the ability to put in more detailed range settings. This allowed us to keep 'Terry himself basic in its functionality and speak to a variety of users, from normal users to more tech-savvy ones like Neils, in the Gorre family.

Troy expands the energy system by connecting the car (which is a moving battery system) to the home energy system. Here it was key to evolve the system to a point where it was able to convert the energy from the house to other units. The stored energy was thereby translated to drivable kilometers. In this way, we have grown from just a battery system to an entire family, consisting of three products that are all interconnected.

**Form family**
To ensure that our products were recognizable as an actual coherent product family, we designed them alongside each other. It was important that 'Terry, Tracey, and Troy could not only function together but also shared the same DNA in their look and feel.

The shared DNA consists of multiple elements. For one, they have similar organic forms. These are specific to our family, as they use their shape to support the idea that they are actual 'living things'. This is also done to create a direct relationship between the home energy system and the place where it can connect to other energy systems


**Figure 26** Final product family logos and icons.

outside the house, with Troy functioning as a passageway. Another shared element is that all products use light as a motive. It is used in similar ways to create unity in interaction cycles and keep a fluent transition to other products of the family. For example, the green lights on 'Terry that inform about the energy level, come back as the same green when plugging in the electric car. In this way, it becomes clear that the energy that was stored in your house is used to charge the car.

**Branding**

Branding was integrated at an early stage to capture the design language and adapt it to a graphic interpretation. Figure 26 is our product family emblem, containing all logos and family icons.

The name 'Terry originates from the project working name: 'Living Home Battery' and is an abbreviation of the word battery. As we wanted to create an entity with our designs, it was obvious that we took a humanized approach in the naming as well to personify our products. The 'Terry logo consists of its name that is split into two segments; a solid and a transparent one. It is a metaphor for the transparent view it gives in the home energy system. Also, the contrast of the two segments gives away the balance it tries to create between its expressivity and blending in. Additionally, the apostrophe at the start of the logo was made into the family icon (as 'Terry is the central product) with a connectivity field around it to complete the connected family aspect, this icon can be seen above the product logos in Figure 26.

The Tracey name and logo flow from the 'Terry one, as she is able to 'trace' all that is happening in the battery system. It uses the same font, but switches to an outline instead of a solid letter in the Y to inform that it can be used as an addition to 'Terry, while immediately giving away its purpose of tracing detailed information. Lastly, for Troy, we used the same font to complete the set but distorted the letters to show the additional connection to other battery systems. The flow of movement in the logo stands symbol for the flowing of energy from the house to outside, simultaneously creating a sense that a rapid car just drove by and made the letters wiggle.

## Final prototypes

**Physical model**

A physical prototype was built for a few different reasons. For demo day it provided a physical prototype that could interact with other projects. This interaction was displayed at Demo Day and is elaborated on in the section "Data Sharing". The second reason to build a physical prototype was to assess physical interaction and behavior, such as the actions of physically putting Tracey pins into 'Terry and seeing the lights change depending on the energy data.

These physical attributes were also assessed over a longer duration, see the subsection "Living with 'Terry" under the section "Deployment / Evaluation" for more details. Figure 27 is a photo of the final physical prototype displayed on Demo Day.

A physical Troy cord was also built to materialize and interact with the moveable rings in combination with the lighting (see Figure 28).

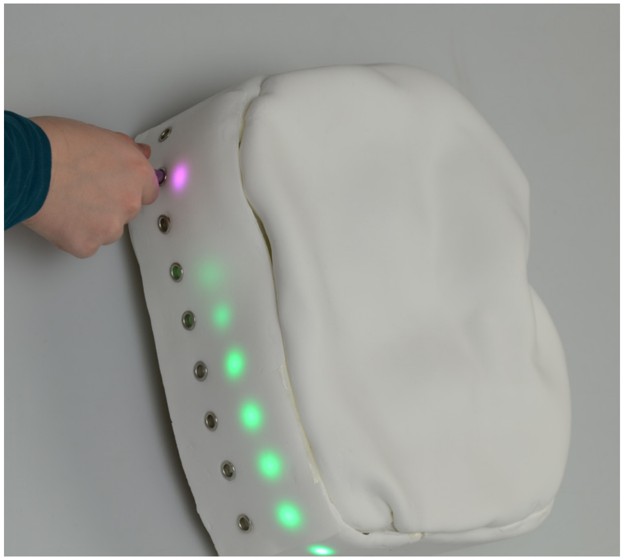


**Figure 27** Final physical prototype of 'Terry.

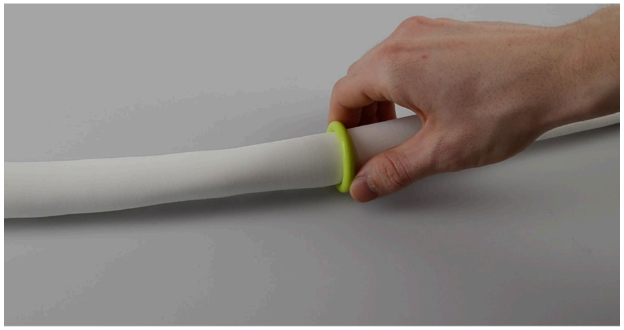


**Figure 28** Final physical prototype of Troy.

**Figure 29** Final 3D model of Troy in context.

**3D rendered models**

The decision was made to also include 3D models of the product family in the final deliverables (see Figures 29 and 30). As the earlier models in the process were made to explore the shape, these final renders were used to give our system context. This helped to put the designed products into perspective and give a feeling of how we envision the living space with the integration of the 'Terry family.

In these final renders it was key to adhere to the physical prototype as close as possible. This was done to create a coherent visualization of the outcome of our process. It was clear that the possibilities of 3D modeling reached beyond the limitations of physical prototyping, but the organic flowing surfaces were easier to create physically. Still, the combination of these two types of prototyping aided the process of distilling the concepts to their essence.

By paying attention to the details that make up our designs and keeping them similar in both the physical and digital space, we were able to show the system in all its complexity.

**Tracey screens**

Along with the physical pins that are put into the side of 'Terry, a mobile application was created to complete Tracey (see Figure 31). It accommodates the digital atmosphere to which our system reaches and transforms Tracey into a multi-purpose tool. The most prominent function is the detailed range setting. Individual pins can be scanned, from which the user goes through a brief sequence of choices to program how the pin should behave. The user can set the charging source and whether it should charge beyond or below the inputted range. This concludes in a changed pin overview, which is a graphical representation of these detailed settings (see Figures 32 to 35). The pin can then be physically inputted into 'Terry to set the range.

**Figure 30** Final 3D model of 'Terry in a living room context.


**Figure 31** Tracey physical pins and mobile application.

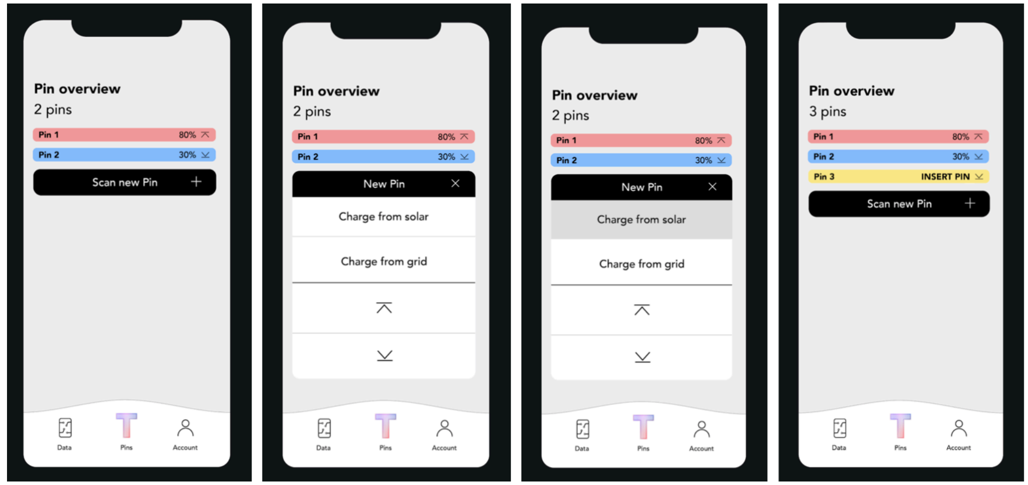



**Figure 32, 33, 34 and 35** Tracey application screens with the pin overview and scanning.

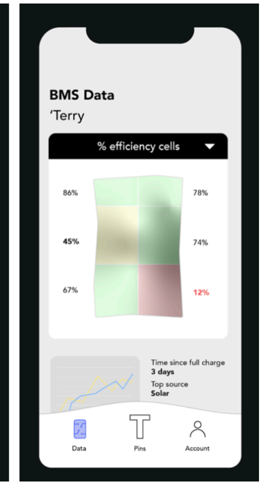



**Figure 36** BMS data.

Additionally, at a different tab, the battery management system (BMS) data is shown (see Figure 36). This function is mainly integrated for the more extreme users of our product family but can be viewed by all users when demanded. It displays the efficiency and performance of the individual cells and the charging habits over time. This function is integrated to inform about the degradation rates of the battery. The last key aspect is the social media platform, which can be found under the "Account" tab. This was included based on the car survey and provides the extreme user with a medium to talk about 'Terry related topics.

## Deployment & Evaluation

### Interaction survey

An interaction survey was designed to evaluate the design and to provide a virtual experience of 'Terry and Tracey. This survey was deployed on Demo Day to provide this experience.

The survey was designed to first introduce 'Terry and Tracey. After establishing initial feedback, the survey then proposed a scenario asking participants to imagine that they live in a residential house in 2030 with solar and grid power connections. Participants were then asked initial installation questions and asked if they would like to buy Tracey in addition to 'Terry. Depending on their response they then are sent to a different section of the survey, similar to a choose your own adventure story. If the participant chose to not buy Tracey then they are sent to a random section of either a summer or winter scenario asking what interactions they would have with 'Terry and why. If the participant does not know if they want Tracey they are sent to the same scenario and then asked if they would like to buy Tracey at the end. If they decide to buy Tracey at this point they are then asked a series of questions about how they would like to set up Tracey. This set-up section is very similar to the section that would immediately follow if the participant decided to buy Tracey at the start. At the end of this section, the participant is then asked if they would like to program a Tracey pin. If they say yes then they are sent to a section that allows them to do so. If the participant decided to buy Tracey at the start, then after they set up Tracey or program a pin they are then given either the winter or summer scenario and asked what actions they would take. All of the questions can be seen in Appendix E.

*Results*

This survey had one pilot test to edit the questions and seven participants. As this was an experience and qualitative survey a lower participation rate was expected.

All of the participants decided to place 'Terry in the hallway. Participants 4 and 5 mentioned moving they preferred just being "kept up to date with the app". This attitude towards hiding this technology is not surprising as all considering current home batteries are designed this way (Jossi, 2020) and it also confirms the current norm of hiding technology (Borm, 2017).

Another similarity was that all except one of the participants indicated that they would not buy Tracey right away. The participant who wanted Tracey right away indicated that they made the decision because they thought "you need the app to control the device". Not buying Tracey right away or at all was something expected, as it was a tool designed for a market segment of people who were extreme users. 'Terry was designed so that most users would not need to fine-tune control, as Participant 2 recognized "I would never store less than the maximum storage capacity".

However, it was encouraging to see that three out of four of the people who indicated that they might buy Tracey became interested in it after going through an interaction scenario that was designed to pique their interest in their control over the energy system. All of these same participants also indicated that they wanted to program a pin, which further illustrates their desire for control. These same participants all programmed their first pin the same way, saying to charge from solar if the 'Terry battery level is below 60% or 30%. Participant 3 also indicated that they would also like to program a pin to "charge from grid if percentage below 10%". Further research will need to be done into these particular settings to see if it is a common and functional need for 'Terry.

While all participants who bought Tracey later seemed interested in programming pins, there were mixed opinions about the social media and battery health scanning features of Tracey. On a scale of one, being never using social media, to seven, being using social media frequently, Participant 1 said one while Participant 5 said six. When asked how frequently participants would imagine scanning 'Terry with Tracey to see battery management statistics however Participant 1 and 5 said five and Participant 3 said two on a scale of one to seven; one being 'never' and seven being 'frequently'. Participant 5 justified this as that they would use both the scanning and the social media applications "mainly the first weeks to get the most out of it. After that probably almost never". These responses showed that while some participants are interested in Tracey not all participants would use Tracey the same way.

Ultimately within this interaction survey, some people want more control but as expected we see some people do not desire more fine-tune control. Additionally, all of the participants don't want to integrate 'Terry into their life, it currently breaks the norms of this type of technology which is often hidden in the background or garages.

**Living with 'Terry**

To better understand the long-term interactions and how 'Terry would integrate into a household, two of the designers did week-long self-study implementations where 'Terry was installed into their homes. To emulate the changing energy conditions within the homes, a program was written to randomly change the lights every few minutes, see Appendix H for the code used. The participants took informal notes in the format of a diary study. This study was interested in:

"How does Terry blend in and/or stand out from the space?"

"Does integration create emergent behavior?"

"How do users appropriate Terry as an artifact?"

The first home 'Terry was installed in was Rachel Feldman's studio apartment, see Figure 37. For it is a single room studio, 'Terry was visible from every single place within the home. The second deployment was in Piet de Koning's apartment, where he lives with his girlfriend, referred to as 'A'. Terry was installed in the living room, an open area that connects the kitchen and workspaces, see Figure 38.

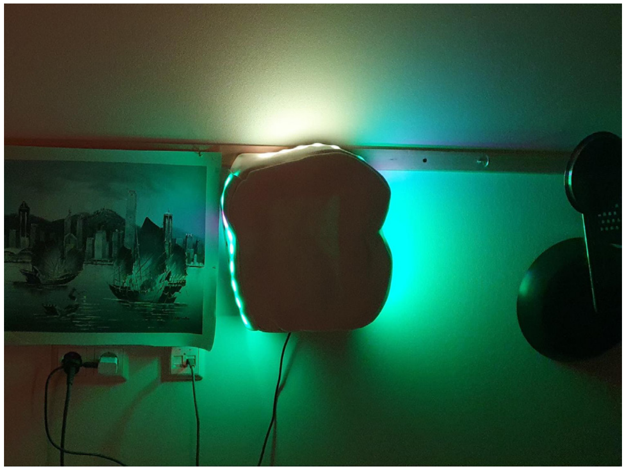


**Figure 37** Implementation in Rachel's home with overflow lights on in the dark.

**Figure 38** Implementation in Piet's home with overflow lights on during the day.

*Results*

*Integration of form / aesthetics*

In the living room of Piet & A, Terry "blends in nicely with the white wall", "catches the light in a soft and interesting way that changes through the day". A noted during the installment that she found 'Terry "cute-looking" and after the first day that his presence was "cozy and nice to stare at".

*Focal point*

This invitation for staring was appreciated by all participants. As Rachel noted, "sometimes when I was cooking or absent-minded I would just stare at 'Terry to watch the lights change, and see if I could predict if they would go up or down". Piet mentioned "when my eyes start to wander (often during work), they often go to the battery and I notice that it changed". This is fascinating since even though the lights did not mean anything they still became the focal point of the space.

At times 'Terry was also more consciously noticed as a focal point by all participants. For example, every time Rachel returned home it was one of the first things she saw and she would watch it to make sure it would change. Piet noted that he would forget about 'Terry during work, but "immediately look at it when I come back from the toilet".

'Terry also served as a symbolic focal point in different ways, as Rachel reflected "it ... actually made me look at the artwork there in a more conscious manner than normally". Where Piet & A chose to use Terry as evening light over the lighting next to it several times because A noted "it is calmer on the eyes, and the colors give a nice atmosphere", as designated evening light it also started to function as reading light.

*Energy awareness / state change*

'Terry's being the focal point in the living room functioned in communicating the state of the energy. Piet found that every morning before opening the curtains of the living room, Terry was the only lighting in the room and instantly drew attention to the status on the side of the lamp. During the day, he noticed that "the natural light makes the energy lights difficult to see, but the shadows and form of 'Terry become way more noticeable". At bedtime, Terry gives an update on the day "the last thing I do is to check the lights on Terry when I turn all the other lighting off".

In the household of two, Piet and A often told each other when they saw the lights change, or ask the other if it changed. These short exchanges on the battery's status, although superficial, would make them talk about something as abstract as energy, which they previously rarely talked about. One of the conversations in turn actually led to checking the Eneco app to compare the days of the week. Another time, a change in Terry's light reminded Piet to check and unplug some of the idle devices consuming energy to reduce the bill.

*Emergent behavior*

Integrating 'Terry into the home also created new interactions for Rachel, she noted that she "made the conscious decision a few times to not turn on my projector because the overflow lights would be disruptive". During deployment in the home of Piet and A, they chose to use Terry as evening light over the lighting next to it several times, Piet recalling "if it was warmer I could use it as reading light".

# Data-sharing

Data sharing between this project and others was envisioned earlier, see section "Data Exploration". Once a final physical prototype was built these ideas and connections were discussed with other groups. Interesting connections between 'Terry and the central heating systems, the laundry, and the solar panel control panel were then found.

To connect with these projects OOCSI (Funk, 2018) was used through a Processing script that could then output a digital graphic (see Figure 39). Figure 39 was presented at Demo Day and represented the side of the physical prototype. The Processing script then also sent data through serial communication to the Arduino Uno controlling 'Terry. The Processing code and the Arduino code used for this communication can be found in Appendix F and G respectively.

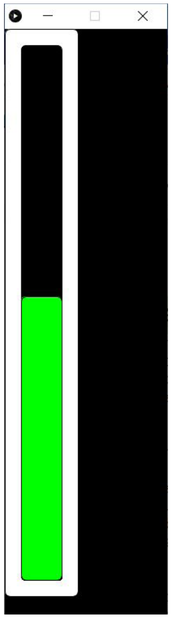


**Figure 39** Processing graphic, representing the battery level that changes based on the received data.

The laundry project, named Lavo designed by Kristen Tensen, was a perfect example of an energy-consuming project that could communicate with 'Terry (Tensen, 2020). Lavo could ask 'Terry if there was enough energy stored to run the laundry at that time and then tell 'Terry how much energy the laundry plans to use. 'Terry also needs to communicate with energy-producing products in the house, such as the solar panels. 'Terry received solar panel data from a project named Tala designed by Elisa van de Schoot (van de Schoot, 2020). Tala was able to tell 'Terry how much solar energy should be stored. Both the storage of generated energy and energy spent by connected products was reflected in the prototype by turning on or off lights on the physical prototype or filling or draining the battery bar of the Processing script.

The central heating system project, named Kota designed by Jelle Wijers, utilized the grid data that 'Terry collects (Wijers, 2020). Kota used the grid pricing information to frame the heating of the home in an economic way. Kota also tracked if rooms in the house were occupied or not. This data was used to awaken 'Terry or put 'Terry to sleep depending on the occupancy of the living room, this not only is an energy-saving behavior but it deepens the idea that 'Terry is an entity that can greet and say goodbye to the household members.

# Conclusion

In the interaction scenario, we found that current homeowners are used to living in Borgmann's device paradigm (1984) and when initially confronted with home batteries just choose to do what fits the current norm. Participants would like more insight into their production and consumption of energy, often economically motivated. However, the only option they acknowledge is the already existing phone applications which quite paradoxically, creates more distance to their own production.

The deployment of the speculative prototypes elicited reflection and even action on sustainable energy use through form and lighting that did not have a real connection to the energy status of the home. This shows that while energy is an intangible focal thing with no inherent focal practices, a more direct experience and relationship with energy can support a more sustainable living through everyday reflection. Our project found that creating a focal point in the living room is a fruitful opportunity to engage users with energy through aesthetics (Backlund et al., 2006).

Even though batteries have no interactions by definition, and the placement in the living room was more of a means than an end, the deployment exposed that this passivity is not something that designers, architects, and battery engineers have to take for granted. Especially as the energy system finds new meaning in connection to the IoT; batteries contain valuable data about the system that can be shared with or materialized in other devices to create emergent functionalities and behavior in a home's local 'smart' grid. Putting the battery as the center rather than an end node in the system allows for a completely new holistic design approach for other devices in the IoT; how does the function of electric cars change when they are seen as a mobile energy storage that can disconnect from an otherwise inherently closed system. For example, it could lend some of its stored energy to the laundry machine or transport energy from a free charging station to the home system.

# Discussion

In our presented concept, we focus on electricity consumption in industrialized or "developed" home contexts, of the typically upper-middle-class population. This is of influence in the outcomes of the designed products. We have taken care to design for our imagined Gorre family, which contains a set of very specific characters. As the functions, placement, and integration of our designs are tailored to the needs of these personas, we can not say with certainty that the outcome of our project brings the same significant benefit to other types of families. Surely, the element of taking care of your home energy system can be integrated into a variety of households, but further investigation is needed to validate where our specific concept can be applied there as well.

When conducting user research it was found that there were three major thresholds that prevent the average users from installing home batteries, homeownership, safety, and cost.
As the trend of people renting their homes is increasing, future research should explore marketing as the target audience of home batteries might not be the homeowner but the building manager. Currently, there are also large concerns among users about the safety of batteries. While modern lithium-ion batteries are considered safe enough to install into cars, these perceived risks will need to either be normalized or new alternatives will need to be found. This also helps address the last concern, cost. As the cost of lithium-ion batteries is quite high, it will either need to be addressed with creative marketing or implementation of alternative technology to have it be widely adopted.

Also, the fact that 'Terry has been defined as a lithium-ion battery conflicts with the sustainable mission. Lithium-ion batteries are not sustainable to produce. Because sustainable development is a cornerstone to this project, future research for the 'Terry product family is committed to finding sustainable alternatives, such as refurbishing old electric car batteries.

While our speculative approach helped in the explorative phases of the project to define what the future of smart homes could look like, it was difficult to find a form of validation that suited our intentions for the user study. Still, we were able to use a combination of digital and physical experiences to accomplish this. The interaction scenario and the in-house living with 'Terry allowed us to evaluate important aspects of the concept. In spite of this, the optimal situation when working with a speculative approach would be to integrate the physical experience on a higher level. Unfortunately, this was made impossible by the COVID-19 situation.

Future steps towards the digital component of Tracey could be the addition of emergent uses. We have found for example that a social media platform could be set up to grow the community around our type of system. We have chosen not to exploit this at the moment, because it goes beyond the scope of the project. Another aspect to acknowledge in the physical pins of Tracey, is the possible child hazard. There should be an improved level of safety to prevent children from choking in the small pins that are now in their reach. Additionally, the physical form and use of materials in the car charger Troy is open for further development, as we mainly focused on implementing the cable interface in our system.

This project steers the societal discussion about home batteries by referring to the battery as the heart of the home energy system. 'Terry demonstrates its uses in connection with the products Tracey and Troy, to illustrate the possibilities of the integration of such a system and ultimately inspire future design and research in the field.

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# References


Backlund, Sara & Gyllenswärd, Magnus & Gustafsson, Anton & Ilstedt, Sara & Mazé, Ramia & Redström, Johan. (2006). Static! The aesthetics of energy in everyday things.

Bakker, S., & Niemantsverdriet, K. (2016). The interaction-attention continuum: Considering various levels of human attention in interaction design. International Journal of Design, 10(2), 1-14.

Borgmann, A. (1984). Technology and the character of contemporary life: a philosophical inquiry. Chicago, University Of Chicago Press.

Broek, K.V. (2019). Household energy literacy : A critical review and a conceptual typology. Energy research and social science, 57, 101256.

Broms, L., Wangel, J., Andersson, C. (2017). Sensing Energy: Forming Stories through Speculative Design Artefacts. Energy Research & Social Science 31C, pp. 194-204. DOI: 10.1016/j.erss.2017.06.025

Campenhout, L.D.E. Van (2016). Physical Interaction in a Dematerialized World. Unpublished Doctoral Dissertation, Eindhoven University of Technology, Eindhoven, the Netherlands. (retrievable from https://pure.tue.nl/ws/files/39076821/20161011_Campenhout.pdf)

Corbett, J. (2005). Altruism, Self-Interest, and the Reasonable Person Model of Environmentally Responsible Behavior. Science Communication, 26(4), pp. 368–389.

Djajadiningrat, J. P., Gaver, W. W., & Frens, J. W. (2000). Interaction relabelling and extreme characters: methods for exploring aesthetic interactions. In Proceedings of DIS'00,(pp. 66-71). ACM.

Dourish, P. (1999). Embodied interaction: Exploring the foundations of a new approach to HCI.

Dourish, P. (2001). Seeking a foundation for context-aware computing. Human–Computer Interaction, 16(2-4), 229-241

Dunne, A., & Raby, F. (2001). Design noir: the secret life of electronic objects. Springer Science & Business Media.

Dunne, A., & Raby, F. (2013). Speculative everything: design, fiction, and social dreaming. MIT Press.

Eggen, B., Mensvoort, K.V., Menting, D., Vegt, E., Widdershoven, W., & Zimmermann, R. (2008). Soundscapes at Workspace Zero – Design Explorations into the Use of Sound in a Shared Environment.

Frens, J.W. (2006).Designing for Rich Interaction: Integrating Form, Interaction, and Function. Unpublished Doctoral Dissertation, Eindhoven University of Technology, Eindhoven, the Netherlands. (retrievable from https://pure.tue.nl/ws/files/1743335/200610381.pdf)

Frens, J., Funk, M., Hengeveld, B., Y.Huang, Robbins, H., Elderman, J., Noortman, R.,& Viaene, E. (2020). Designing for Growing Systems in the Home; Project description 2020/2021, semester A. Retrieved from: https://canvas.tue.nl/courses/16423

Frens, J., Elderman, J., (2020). Rich Interaction Workshop. Designing for Growing Systems in the Home. Semester A.

Friel, D. (1998, December 11). Smart Battery System Specifications (Tech.). Retrieved December 31, 2020, from Smart Battery System Implementers Forum website: http://www.sbs-forum.org

Funk, M. (2019, May). OOCSI. Zenodo. http://doi.org/10.5281/zenodo.1321220.

Great Home. (2020, October 01). Average Energy Consumption Calculator. Retrieved January 05, 2021, from https://great-home.co.uk/average-energy-consumption-calculator/

Hesse, H.C.; Schimpe, M.; Kucevic, D.; Jossen, A. (2017). Lithium-Ion Battery Storage for the Grid—A Review of Stationary Battery Storage System Design Tailored for Applications in Modern Power Grids. Energies 2017, 10, 2107.

Robbins. H, Noortman, R., (2020). Futuring Workshop. Designing for Growing Systems in the Home. Semester A.

Hummels, C.,  & Frens, J. (2009). The reflective transformative design process. 2655-2658. 10.1145/1520340.1520376.

Ishii, H., Lakatos., D., Bonanni, L. and Labrune, J. (2012) Radical Atoms: Beyond Tangible Bits, Toward Transformable materials. MIT.

Jossi, F. (2020, November 3). Best Home Battery Storage Options: 2020 Guide. Retrieved December 31, 2020, from https://www.buildwithrise.com/stories/2019-guide-to-the-best-home-battery-storage-options

Just Powers & University of Alberta. (2021, January 5). Speculative energy futures. Retrieved from: https://www.justpowers.ca/projects/speculative-energy-futures/

Kathryn Luu, (2020, August 12). Assessing the value of battery energy storage in future power grids. MIT Energy Initiative, August 12, 2020, Retrieved from: https://news.mit.edu/2020/assessing-value-battery-energy-storage-future-power-grids-increasing-integration-wind-and-solar-0812

Lutzenhiser, L., (2014). Through the energy efficiency looking glass. Energy Research & Social Science, 1, pp. 141-151.

Mallapragada, D., Sepulveda, N., Jenkins, J. (2020). Long-run system value of battery energy storage in future grids with increasing wind and solar generation, Applied Energy, Volume 275, 2020, 115390, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2020.115390.

March, A. (2021, January 5). Tesla Model 3 Performance charging cost and time calculator. Retrieved January 05, 2021, from https://evcompare.io/cars/tesla/tesla_model_3_long_range_awd_performance/charging/

NREL. (2021, January 5). PVWatts. Retrieved from https://pvwatts.nrel.gov/

Pierce, J., & Paulos, E. (2010). Materializing energy. Conference on Designing Interactive Systems.

Pierce, J. & Paulos, E.. (2012). Beyond energy monitors: interaction, energy, and emerging energy systems. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12). Association for Computing Machinery, New York, NY, USA, 665–674. DOI:https://doi.org/10.1145/2207676.2207771

Pollock, J. (2014, December 12). Leaf Spy [Computer software]. Retrieved December 31, 2020, from https://play.google.com/store/search?q=leaf%20spy&c=apps

Qamar, I. P., Groh, R., Holman, D., & Roudaut, A. (2018). HCI meets material science: A literature review of morphing materials for the design of shape-changing interfaces. In Proceedings of the 2018 CHI Conference of Human Factors in Computing Systems (pp. 1-23).

Qian, J., & Barsukov, Y. (2013). Battery Power Management for Portable Devices. Artech House.

Rieur, E., & Alahmad, M. (2014). On the Discourse of Energy as Material: Future Feedback Technologies and Directions for Experiencing Energy. IEEE Transactions on Industrial Informatics, 10, 742-751.

Schoot, E., van de (2020, December 18). Tala. Retrieved January 05, 2021, from https://demoday.id.tue.nl/projects/bB1yekoXp9

Sheena Wilson and Natalie Loveless (2019). Speculative Energy Futures: Prototypes for Possible Worlds Exhibition. University of Alberta. December 10, 2019 – January 11, 2020.

SPACE 10. (2021). SolarVille. SPACE 10. Retrieved from: https://space10.com/project/solarville/

Tensen, K. (2020, December 18). Lavo. Retrieved January 05, 2021, from https://demoday.id.tue.nl/projects/bdlX4aWjN6

Weiser, M. & Brown J.S. (1996). Designing calm technology. PowerGrid Journal, v.1.01, July 1996.

Wensveen, S. A.G., Djajadiningrat, J. P., and Overbeeke, C. J. (2004). Interaction frogger: a design framework to couple action and function through feedback and feedforward. In Proceedings of the 5th conference on Designing Interactive Systems: processes, practices, methods, and techniques, 177-184. ACM.

Wijers, J. (2020, December 18). Lavo. Retrieved January 05, 2021, from https://demoday.id.tue.nl/projects/0bpXvq8LWq

# Appendix

**Appendix A: Videos**
Link to midterm video: https://youtu.be/ItC1nuDA5UU
Link to final product family video: https://youtu.be/FA-7tzTI--Y

**Appendix B: Energy usage at home Questionnaire**
https://drive.google.com/file/d/1L2hXej9CPMim-lioIP7NIIVVRIadqcGj/view?usp=sharing

**Appendix C: Electric car Questionnaire**
https://drive.google.com/file/d/1eVgqyCLxF9iQavcxrU74xXvXflzyTXGT/view?usp=sharing

**Appendix D: Electric car Questionnaire graphs**
https://drive.google.com/drive/folders/11f2lgmlXAsAvEtM_u_UgcuXMEkXD3ybZ?usp=sharing

**Appendix E: 'Terry family interaction scenario**
https://drive.google.com/file/d/11ug7pijAdag7LpGSXUWyB_R2ucpmG6Uf/view?usp=sharing

**Appendix F: Processing code for data sharing**
https://drive.google.com/file/d/18pPjGq-kJX3271NeVTP47QZzI6xhJexG/view?usp=sharing

**Appendix G: Arduino code for data sharing**
https://drive.google.com/file/d/1DG4xhODnU3RNQpYJ0bzQ01XmK2dBir1O/view?usp=sharing

**Appendix H: Arduino code for long term implementation**
https://drive.google.com/file/d/1J3KoM7MnIMrLe5QKQexRiiPTJXRelWn2/view?usp=sharing