# The Tilting Bowl: Electronic Design for a Research Product


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## ABSTRACT

The Tilting Bowl is a ceramic bowl that unpredictably but gently tilts multiple times daily. This pictorial reports on the crafting of the electronics of the Tilting Bowl within the concept of a research product [10]. From this perspective, the seemingly simple task of making a bowl tilt holds unique challenges and demands – especially as a research product that is deployed in everyday settings for lengthy periods of time. We highlight electronic design challenges that came up in three processes of making the Tilting Bowl: the tilting mechanism, hardware integration of electronics and power management. Lastly, we offer three suggestions for designing electronics for research products.



**keywords:** research product, research through design; design process; circuit prototyping; material speculation; making




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**Two different tilts of the Tilting Bowl.**

The Tilting Bowl is a counterfactual artifact [13] that is part of a methodological approach to design research known as material speculation [13]. A counterfactual artifact contradicts what would normally be considered logical to create given the norms of design and design products. This countering of norms opens the possibilities to empirically investigate multiple alternative existences (or what-ifs) as lived-with realities of the counterfactual artifacts [13]. More broadly, and for the purpose of this pictorial, a counterfactual artifact can also be seen as a research product [10]. A research product is a high-quality finished design product that drives a research inquiry. The characteristics of a research product emphasize the making of an actual artifact that can be deployed in a real-world setting for a lengthy period of time, unlike a research prototype that is highly constrained in terms of use.

Recently in HCI, researchers have adopted research products as a way to examine diverse and emergent topics related to human technology relationships in everyday contexts [2, 3, 9, 10, 12]. However, examples that detail how to create or make a counterfactual artifact or research product are sparse. This is especially critical as the research and speculative nature of research products creates unique demands for the design of the electronics and form factors. Both counterfactual artifacts and research products set the terms for our design goals and process for the Tilting Bowl.

The Tilting Bowl is similar to any other ceramic bowl, however it periodically throughout the day, at random intervals, tilts to one side. While it creates a slight sound during each tilt, its movement may go unnoticed. The research goal of the study with the Tilting Bowl was to investigate the relations of humans to technologies, specifically as a matter of technological mediation as described in postphenomenology [6]. For more details see [14].

In this pictorial, We highlight electronic design challenges that came up in four processes of making the Tilting Bowl that emphasize and characterize the particularities of crafting electronics for research products, especially for small design research studios in academic settings. We describe the challenges, our process to address these challenges, and the final designs. We conclude with three suggestions for designers to help them craft the electronics of research products.

**Project Description** The Tilting Bowl project spanned multiple years, with a small academic design research team having conceptualized, prototyped, and implemented its design. The approach of the project required the Tilting Bowl to satisfy the four qualities of a research product: inquiry driven, independence, fit, and finish [10]. These qualities drive requirements for the computational system within the bowl to be robust, durable and stable. Concurrently, the artifact needed to be highly resolved in order to fit in the homes of participants as part of the deployment study with the Tilting Bowl.

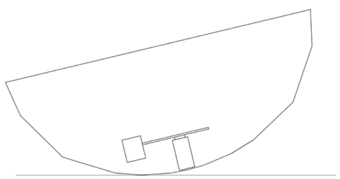
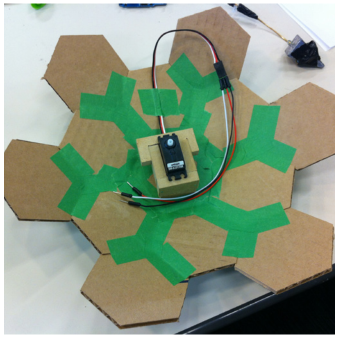
A total of six identical versions of Tilting Bowl were fabricated and deployed. Each Tilting Bowl's electronic hardware was comprised of an Attiny 84 microcontroller, a DRV 8835 motor driver, two 3600 mAh LiPo batteries, a 2-coin cell battery, and a 10 RPM DC motor. These components were mounted on a wooden base plate, then inserted into the false bottom of the bowl. Determined by the long-term study, the components needed to operate in low power mode, and draw minuscule amounts of power from the battery in order to last long periods without needing to be charged. Multiple times a day, at random intervals, the electronic components would activate for two to six seconds in order to tilt the bowl. Through careful power management, we expected the 3600 mAH battery to operate the Tilting Bowl for over a year on a single charge.

**Computational Behaviour of Tilting Bowl** The periodic tilting of the bowl was aimed at eliciting reflections on the relations between people and computational artifacts over time, while living with it. The tilt created a defamiliarizing of the expectations and norms of an object such as a bowl, that in turn also created a unique computational presence or alternative technological experience.

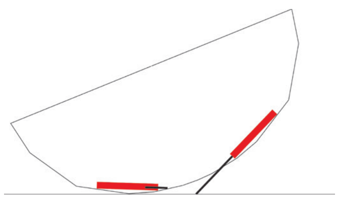
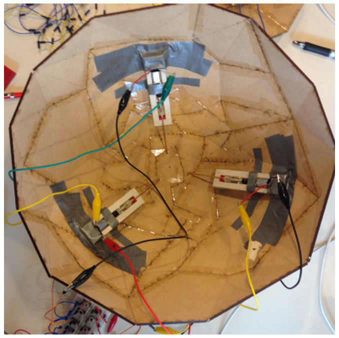
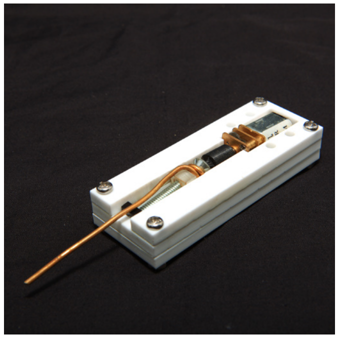
**Ceramics as the material form** The bowl was fabricated in ceramics using slip casting and was double fired and glazed. Its form was replicated from our prototype, that was created by assembling laser cut pieces of MDF. For details on the ceramic fabrication see [12]. The bowl measured 35 cm in diameter by 15 cm in height, and it weighed approximately 4 kilograms including the electronics and battery.

## 1. EXPLORATIONS OF THE TILTING MECHANISM

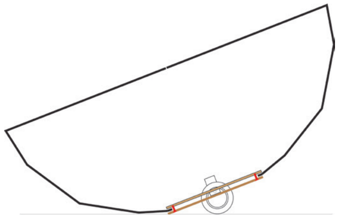
While tilting a bowl may appear to be a simple design problem, for our requirements it was quite challenging and required several explorations. The design of the mechanism needs to be compact enough to fit inside the faux cavity of the ceramic bowl, and also needs to have the strength to actuate weight subjected to the bowl under normal usage conditions.


The first exploration used a spinning weight attached to a motor, with the goal of shifting the center of gravity of the bowl with a weight, in order to tip it. A motor was attached to the base of the bowl, along with a lever and a weighted mass. When the motor activated and rotated the weight, the bowl changed its orientation as a result. This concept seemed to work conceptually, but practically, when the prototype was built, we realized that the design had two issues. One, there was no control over precisely how the bowl would tilt or shift its position: the weight and the position of our mechanism was fixed, resulting in a stagnant tilt position. Two, our tilting mechanism could easily be overpowered by adding items into the bowl.

The second exploration was a linear motion drive mechanism designed to address the issues we encountered with our first prototype. Rotational movement of the motor was translated into linear movement of the metal rod via a coupler and threaded rod. The physical design of this mechanism was made to be more compact, and able to give the bowl multiple degrees of movement. The principle behind this mechanism gave the bowl the dynamic movement needed to be able to tilt in various directions. However, this design was not adopted, as the copper rod used as the linear piston often bent under the weight of the bowl. While a change of the material for the rod was possible to make it stronger, the design was not feasible since it was too difficult to securely mount the actuating mechanism onto the curved surface of the bowl.



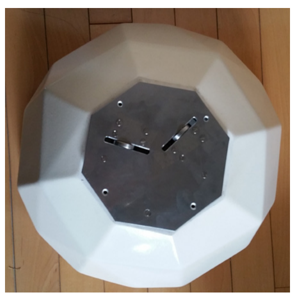
The third and final exploration of our tilting mechanism was a rotating disc off-set to the center of a motor shaft. Using an off-set connection shaft from the center of the disc, we achieved tilting by creating an upwards and downwards elliptical movement.

These explorations reveal how we tackled the tilting actuation and the need to refine our approaches with each exploration.

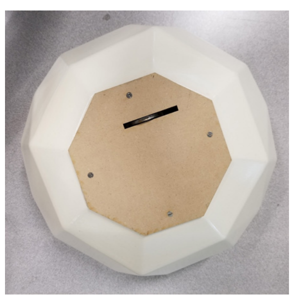
## Selecting the Right Motor for the Tilting Mechanism

Determining the most appropriate motor to actuate the bowl was an essential part of the process of designing the tilting mechanism. There are a wide variety of motors with different characteristics to consider, such as stepper motors, servo motors and DC motors. Our challenge was to determine the type of motor that would have enough torque to lift the weight of the bowl, yet also be small enough to fit inside it. Specifications on the motor such as maximum torque, stall torque, power consumption, and dimensions were the primary considerations in this process. We will now discuss the three different motor implementations in our prototypes that were tested with different versions of our tilting mechanism.

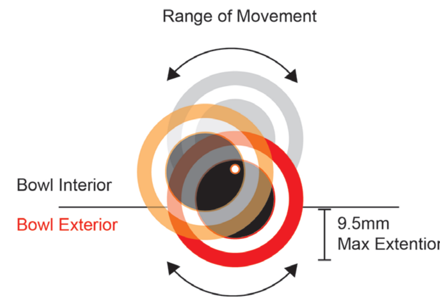
Our initial MDF prototype used three small and low-powered 30 RPM DC motors with a capacity 1 kg load. These motors were cheap and readily available, and they allowed the design team to quickly implement and explore configurations in the prototype. However, the low torque and light load capacity meant that it could not be used in the final implementation in ceramic that is much heavier than MDF used in our prototype.

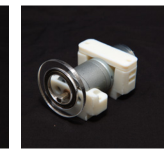


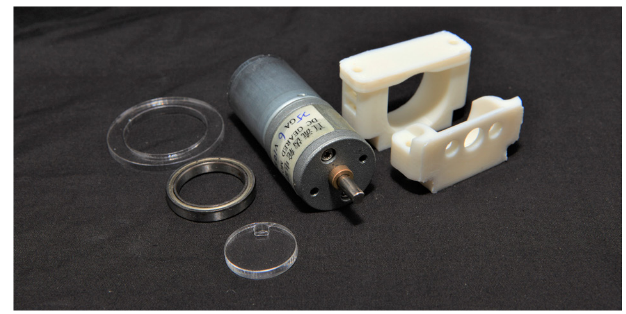
The MDF bowl was replicated in ceramic. The ceramic bowl component alone weighed approximately 6 pounds (3.4 Kg) or more, and as a result we switched to a stronger 33 RPM DC motor with a maximum torque rating of 11 kg. However, upon further experimentation and testing, we realized the sound of the motor was quite loud that would make it difficult to live with for longer periods of time. Also, the use of aluminum as a material for the base plate was a design choice incongruent with the ceramic material of the bowl.



And so, in the final implementation, we used a 10 RPM DC motor with a maximum torque rating of 30 kg, which had a lower pitch due to its lower gear ratio. Additionally, in our different iterations we experimented with multiple motors per assembly that allowed us to change the direction of the tilts. However, with limited internal space and larger motors we eventually reduced our design to a single motor and rotating disc mechanism, and we also realized we did not need the Tilting Bowl to tilt in different directions since directionality was rarely perceived in our own testing and living with the prototype.

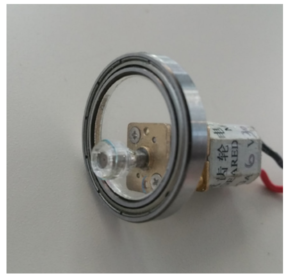




## Mechanic of the Tilting Mechanism

The concept of a rotating disc mechanism was the final design component for tilting the bowl. The design of this mechanism was comprised of an inner disc and an outer disc, with a lubricated bearing sandwich in the middle. The shaft of the motor was connected to the edge of the disc creating an elliptical movement when spinning, thus creating a vertical displacement effect. This mechanism had a maximum movement potential of 9.5 mm, actuating the bowl up and down. A further benefit of this mechanism, in contrast to the second tilting mechanism design, was the robustness of the design, having the ability to hold the tilting position at any given point and being able to withstand ample weight without changing its position.


## Fine Tuning the Tilting Behaviour

The original design of the rotating mechanism was a simple acrylic disc cut out and attached off-center to the motor. After the rotating disc mechanism was implemented, we noticed that the bowl started to "crawl" instead of having a linear upward and downward motion as we intended. This was a result of the laser cut wheel being placed off-center, creating an elliptical movement. Although in concept and in simulation the design appeared to produce an upwards and downwards motion, in practice over time, any load applied to the rotating disc had created a forward and backward rolling motion instead, similar to the functionality of wheels on a motor vehicle.

To prevent the crawling motion, we attached a bearing over the acrylic insert, allowing it to rotate freely inside the bearing, allowing the outer part of the bearing to rotate in the opposite direction to mitigate the crawling effect we observed in the earlier design. Addressing this challenge meets the criterion of fit in a research product, where the design of the tilting behavior shapes the lived-with experience.

## Acoustics of the Motor

Throughout the design process, members of the design team periodically lived with the Tilting Bowl in their home to fine tune the experience of the design. This led to our decision to forego multiple motors to create different directions of the tilt. Equally important, members of the design team reported that the acoustics of the motor would fluctuate between a lower pitched and a higher pitched tone. The culprit of this phenomenon turned out to be the weight of the bowl and additional items inside it would change the sound coming from the motor's internal gearing, as the motor would try to drive the mechanism under load.

The design team's experiences with these acoustics also created new tensions: even though the performance of these motors was not an issue, the fluctuation of the acoustic tone from the motor certainly could be an annoyance if the pitch became too high.

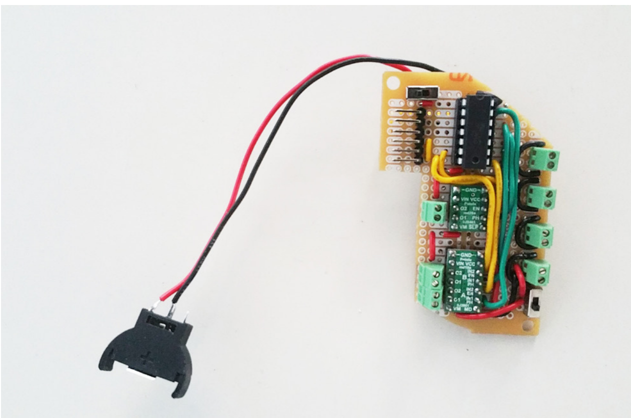
Over the course of the design process, the acoustics of the Titling Bowl led to the decision of using a different motor. The design team had to find the balance of having a motor that would support the weight of the bowl and a relatively quiet motor under different conditions so as not to attract too much attention to the bowl. Addressing this challenge meets the criteria of fit in a research product, as the Tilting Bowl needed to (acoustially) fit into a home environment.

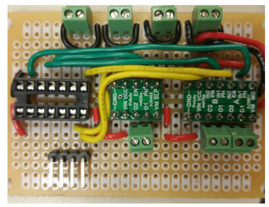

## A Self-destructive Motor

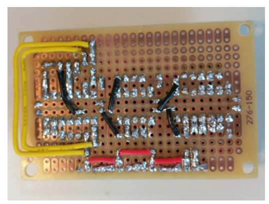
Mistakes in hardware implementation were often difficult to notice while designing Tilting Bowl. For example, during our implementation of the motors, it never occurred to us when we initially implemented the tilting mechanism that any force subjected onto the mechanism would cause the motor to rotate. Over time, these slight rotation movements on the motor body caused the connection wire on the motor to twist back and forth. Due to metal fatigue, the solder point between the wire and motor would break. This motor issue did not become apparent until it was deployed in an initial study. This finding led to the redesign of a mounting bracket that securely fastens the motor on to the base plate preventing any movement of the motor body that caused the twisting of the connection wires. Addressing this challenge meets the criterion of independence in a research product, where the design of the electronics need to be robust enough for an extended period for deployment.

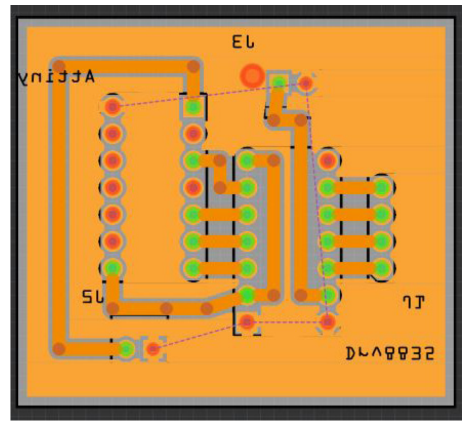
## 2. DESIGN AND INTEGRATION OF HARDWARE

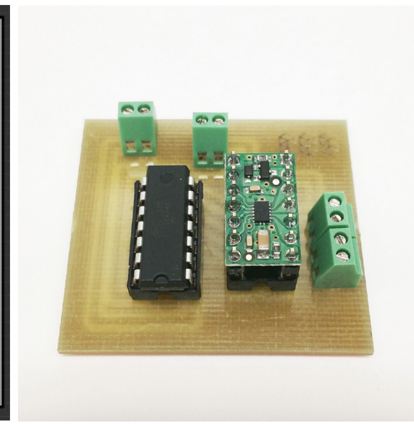
The construction of the ceramic bowl was comprised of a shallow top and a deeper bottom creating a false bottom cavity to house the electronics. The integration of electronic hardware was limited given the available space inside the false bottom. The fit and robustness of the circuit was important for the purpose of the long-term deployments of the Tilting Bowl. Therefore, the second unique requirement of the Tilting Bowl, as a counterfactual artifact, was for the entirety of the electronics to be neatly fitted within the small interior cavity of the bowl. In the following sections, we will describe the exploration of circuit design, integration strategy and challenges we encountered.











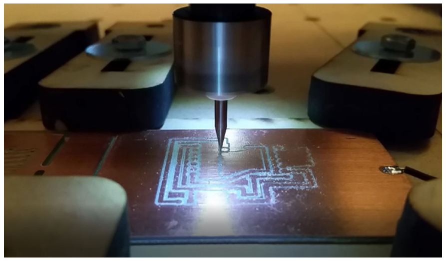
### Perforated Circuit Board

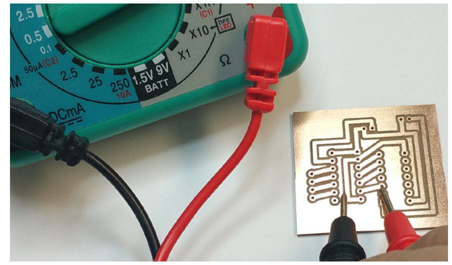
At the beginning of this project, it was not evident that designing and fabricating our own custom circuit board would be necessary. Our original goal was to design a robust perforated circuit board (perfboard) soldered by hand; however, as the project progressed, we became aware of the difficulties in building perfboards in larger quantities. These included issues of quality control, time, and physical constraints imposed by the internal cavity of the bowl.

Only a single copy of this circuit was built. At the time, it did not seem to be a feasible production method to scale up our production even if that was only for six Tilting Bowls. There were three reasons contributing to the lengthy production time: one, while soldering components on the board requires very little time, wire management took significantly longer. Specific wire lengths had to be measured and bent in an organized manner. Two, our prototype design required running a connection on the top and bottom sides of the board, due to a flip orientation. This increased the chance of human error when making each connection. Three, the perfboard had to be trimmed to avoid contact with other hardware on the mounting plate.

### Custom Printed Circuit Board

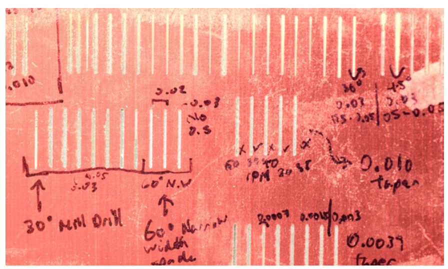
The final implementation was a custom designed printed circuit board (PCB), designed and fabricated within our studio. A PCB has advantages over the perfboard: one, a PCB has printed traces as opposed to a perfboard's physical wires running over the board, which are more compact, and resilient to breakage. Two, PCBs can be scaled up and replicated easily as wire management has been eliminated from the process. Three, PCBs simplify the assembly process for a simple circuit. Four, PCBs allow customization of a circuit board to make its overall dimensions more compact. In order to design a smaller circuit board that will take up the least amount of space on the base plate that houses all the electronic hardware, we transferred our circuit schematic from a perfboard design to a PCB design. To optimize the layout, we manually designed the wire traces to be as compact as possible. The final PCB circuit measured 40mm by 40 mm by 5mm, compact enough to fit inside the ceramic bowl.

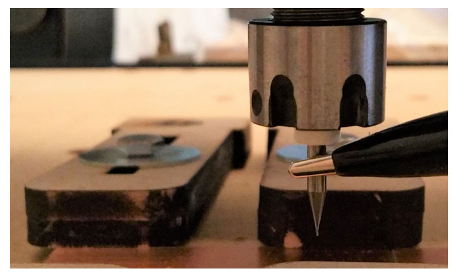
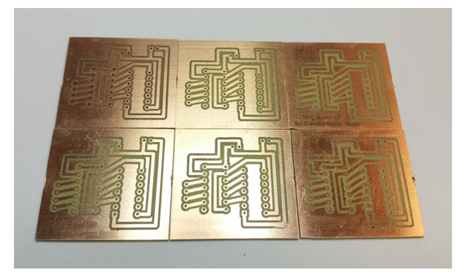




## Fabricating Custom PCB

In order to fabricate our design quickly, we built our PCB design through a subtractive fabrication method called "Trace Isolation" CNC milling, a fabrication method that uses a milling machine with a very sharp cutter to recreate the design of a layout file on a blank copper board [8]. The most significant reason for choosing a subtractive fabrication method for producing the Tilting Bowl PCB was that this process was non-chemical, and as such, it could be completed in a studio environment without exposure to hazardous chemicals. In addition, to have the ability to fabricate our own PCB in house had streamlined our design process when it comes to designing hardware, the design team does not have to wait for days or weeks to wait for a PCB to be shipped by a fabrication company. A total of 6 boards were fabricated using this process and a layer of silicon coating was applied to prevent oxidation of the copper board.

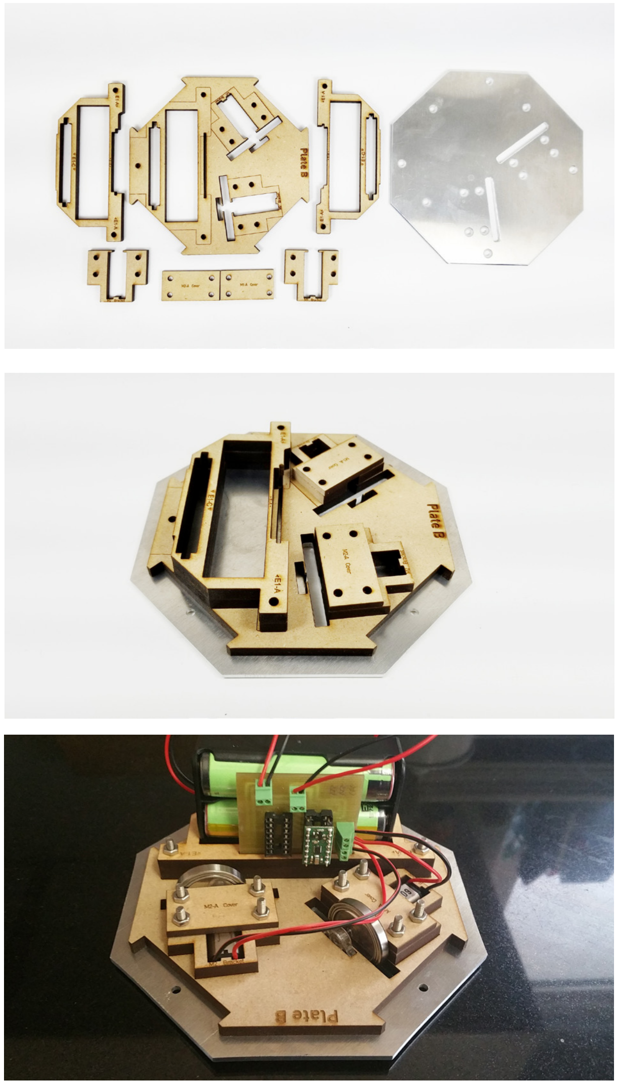



## Challenges and Tension of Milling a PCB

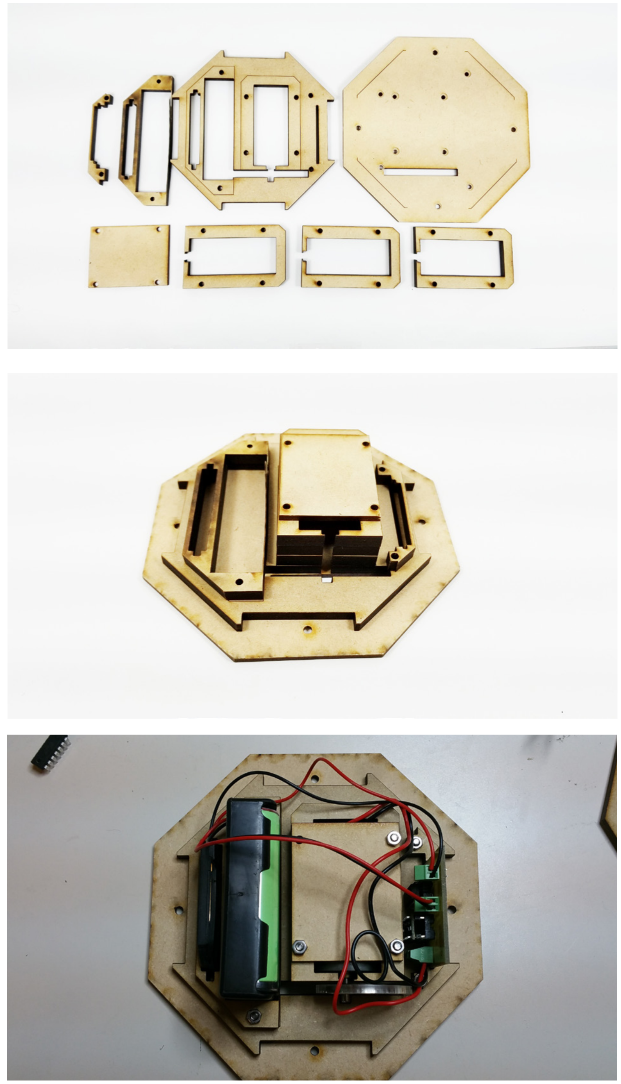
A notable challenge of scaling up to produce multiple PCB's in a small studio environment was quality control. We found that some of the end products were not cut appropriately due to the blank copper board used for PCB production not being sufficiently flat or even. This resulted in the V bit endmill either cutting too deep or not cutting through the copper board. Consequently, we opted to mill each PCB on a CNC machine individually while probing the surface of the copper board to ensure that the CNC machine could adjust to the co-planarity of the copper board that would ensure that traces are cut properly. Despite this challenge, there are potential benefits of in-house production of small batch PCBs, such as the forementioned rapid iterations of PCB designs as well as the knowledge and control the design team gained over the fabricated PCB's by learning through our mistakes. Addressing this challenge meets the criteria of independence in a research product, as we were able to fabricate a robust PCB specific to our needs.

## Base Plate

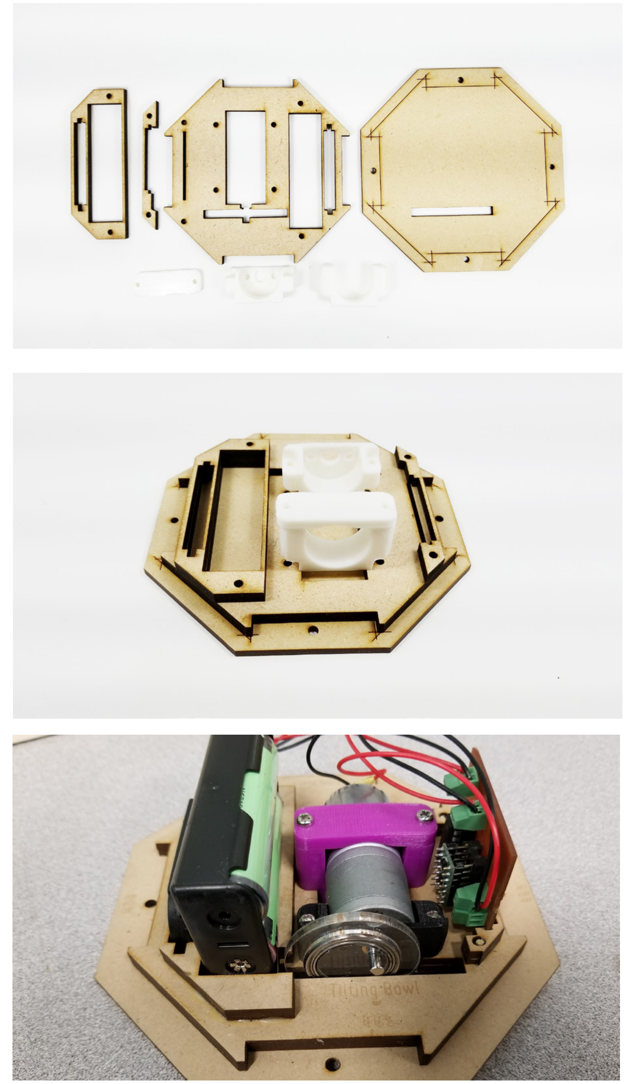
In order to ensure all the circuit, motors, and batteries would fit securely inside the bowl, the design of the base plate was iterated to accommodate the changes that made in the hardware.



**Version 1:**
2 motors designed with PCB circuit



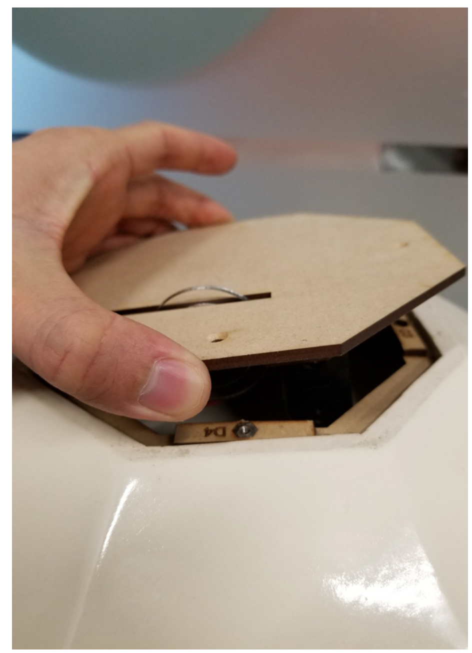
**Version 2:**
1 motors designed with PCB circuit



**Version 3:**
1 motor designed with PCB circuit and enhanced bracket to secure motor.

## Integration Base Plate with the Ceramic Bowl

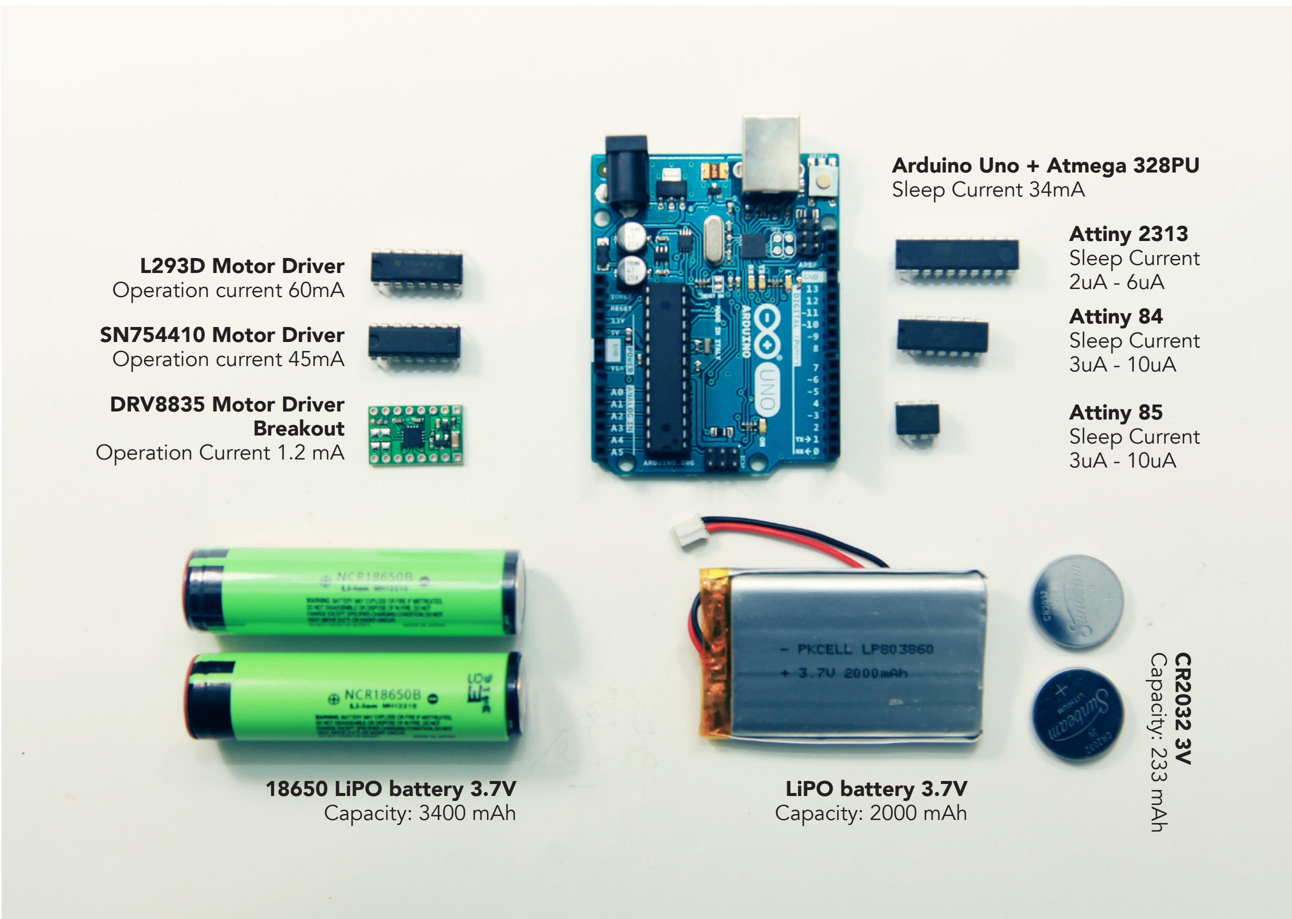
The ceramic bowl possessed new design challenges for how the base plate would be secured into the bottom of the bowl. We were not able to use metal brackets and screws (used previously in our MDF prototype) to secure the base plate onto the ceramic bowl as that could damage the bowl.  A retention ring was created out of MDF to allow the attachment of the base plate. This retention ring was sealed to the ceramics using silicone and situated inside of the ceramic bowl. Four integrated hex nuts in the retention ring allowed the four screws attached to the base plate with the ring to secure it to the ceramic opening.



# 3. POWER MANAGEMENT

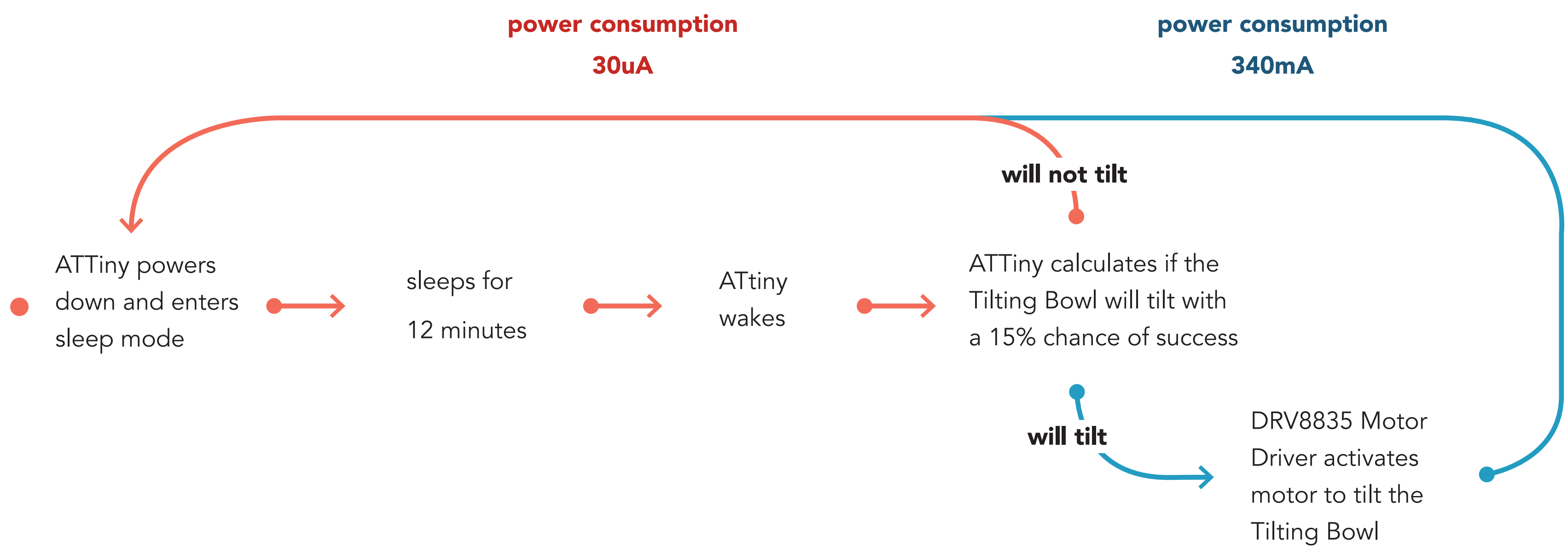
The field deployment was a vital part of the Tilting Bowl research study and each deployment period could last from several months to over a year. Due to the nature of this long deployment period, the design of the electronics was required to operate independently for the entire duration without intervention from the research team. We also felt that opting for recharging the Tilting Bowl (by the participants) would shift the perception and attention needing to be paid to it too strongly toward being a device, rather than a bowl. We wanted our participants to live with the bowl and to perceive and to use the Tilting Bowl like other kitchenware in the house. This design decision implicated the longevity of the battery was a central design concern. To achieve the length of the system's operation period, various hardware power saving techniques and software optimization techniques were implemented to prolong the battery life.

There are a number of works that discuss this in the process of designing computational devices [3, 11] and offer power saving strategies s [4, 5, 7]. While designing for power management is not novel, in this section we illustrate the combination of power saving strategies were adopted for designing the circuit and optimizing the software of the Tilting Bowl [5].




## Choosing Components for Low Power Circuit Design

To design a low power circuit, we started to optimize our design for low power hardware very early in the design process. We started by measuring power consumption of the microcontrollers and motors in various state of operation. Next, we built the prototype circuit out of a combination of these microcontrollers, motor drivers and DC motors to determine the combination that yielded the lowest power draw in sleep mode.




## System Optimization

By keeping the microprocessor in sleep mode, it was possible to drastically lower its power consumption to a fraction of its original power expenditure. Most modern AVR chips have different types of low power modes built-in. These modes include idle mode, standby mode, power save mode, and power down mode. Each of these modes put the microprocessor in a deeper sleep state by turning off unwanted feature inside the chip, resulting in a lower power consumption. The implementation of the different modes in the microprocessor was coded in the software.

Lastly, the software program of the Tilting Bowl was set to have a burst operation. This means, every time the bowl wakes up the circuit only operates for 6 seconds before going back to sleep. The principle behind this technique was to minimize the time that the circuit would spend in its active mode of operation to be only long enough to complete its task before the system fully powered down again. By shortening the duration of its active operation, the system consumed less power.

## Long Term Deployment Requires Careful Consideration of Power Management

In summation, our insight with regards to power management is that when designing a research product for long-term deployment and needing it to be battery operated, researchers will need to consider both hardware and software optimization for low power management. The qualities of independence require that the electronics operate independently with minimal intervention from researchers for the duration of the deployment. If the electronics will be battery power without the ability to recharge, then the system cannot remain constantly on and power saving strategy needs to be implemented in the software to keep power consumption of the circuit low to extend the battery life.

## SUGGESTIONS FOR DESIGNING ELECTRONICS FOR RESEARCH PRODUCTS

### A High Degree of Creativity Within a High Degree of Constraint

In typical design and prototyping process, the design constraints are kept to a minimum at the beginning of the process. Research products conversely dictate a high degree of constraints that are largely non-negotiable such as independence. When designing for research products, designers need to be creative within these non-negotiable constraints early in the design process. For example, the simple act of designing the tilting behavior was our end goal and was chosen given the constraints of a research product, but as we have shown, there are many different design and implementation strategies to explore to achieve the simple act of tilting.

### Be Mindful of Power Consumption

If the research product is battery operated, then a power saving technique is required. Be mindful of which components you choose, and how you program the behaviour that will affect the battery life of the artifact. Whether the electronics are custom designed or an off-the-shelf platform, power saving techniques (e.g., Sleep Mode) need to be implemented on a software level.

There are two important decisions one has to make when designing power management for a research product:

1) Is it 'always on' (when powered) or does it have a sleep cycle?

2) Is it exclusively battery powered? Or does it require a continuous AC/DC power source?

The research question framing the design project will guide the design team in making this decision; and this pictorial provides case insights into what to do and how to do this once the design team has made this decision and must begin to put it into practice.

### Living with the Prototype as a Method of Fine Tuning

Prior to actual deployment, we recommended fine-tuning and testing the research prototype in the intended context. That is, the research prototype needs to be lived with by the designer/researcher as a means of ensuring that the artifact's specifications and that the four research product qualities are achievable. It is important for the designer and researcher to live with the research prototype in its imperfect state as a method to fine-tune the design artifact. The advantage of living with the prototype is the ability to expose hidden technical issues previously not known during the prototype process. The disadvantage of not fine-tuning and testing the prototype will be that technical issues previously not known to the researcher will become an issue during deployment that affect how the artifact performs and affect the experience of living-with the artifact.

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