Designing Drone Chi

Unpacking the Thinking and Making of Somaesthetic Human-Drone Interaction

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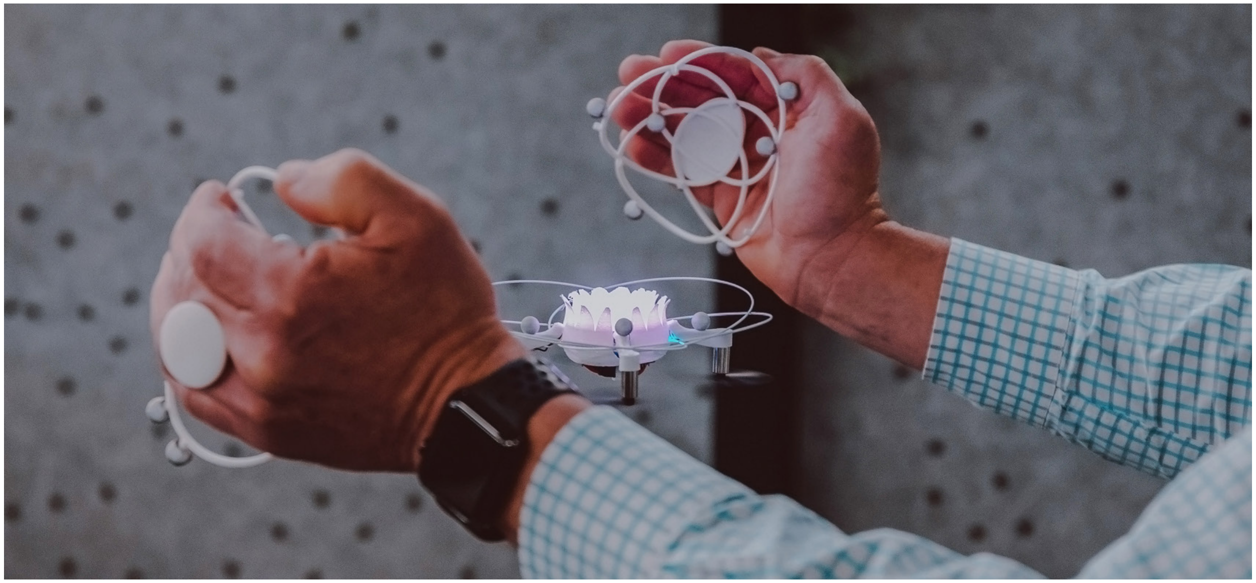
ABSTRACT

Drone Chi is a Tai Chi-inspired human-drone interaction experience. As a design research project, Drone Chi is situated within somaesthetic interaction design, where a central topic is cultivating bodily and sensory appreciation to improve one's quality of life. Drone Chi investigates the potential of autonomous micro-quadcopters as a design material for somaesthetic HCI. In this pictorial, through a quasi-chronological account of the design process, we articulate how the sensory experiences of Tai Chi were integrated into Drone Chi. Taking a slow and open-ended design research approach, we iteratively developed the project through somaesthetic, product design and engineering perspectives, drawing heavily on analogies and imagery for inspiration. This elevated the influence of the soma against narrow engineering parameters and usability requirements. This pictorial means to serve as a reflective resource for designers who are looking for synergies between their native discipline and someasthetic interaction design.



Keywords

Drones; Gestural Interaction; Human-Drone Interaction; Movement; Soma Design; Somaesthetics; Somaesthetic Appreciation; Tai Chi.

CSS Concepts

• Computer systems organization~ Embedded and cyber-physical systems ~ Robotics
• Human-centered computing ~ Human computer interaction (HCI) ~ Interaction techniques ~ Gestural input
• Human-centered computing ~ Interaction design

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INITIAL ENGAGEMENT WITH THE MATERIALS

Drone Chi is the result of a research project which began with investigating interactive systems to support bodily awareness and meditative movement [10, 11, 12, 15]. Initial investigations within this project brought us into contact with the intellectual “somatic turn” in HCI, where “bodily sensing, feeling and moving” are foregrounded [8, 17]. Drone Chi emerged at the intersection of the technological tools, materials, theories, and practices familiar to the first author and principal designer.

Technological Materials

Autonomous drones are becoming popular as a material for interaction design [1, 2, 4, 6, 18]. Drone Chi investigates the potential of autonomous drones as a material for somaesthetic HCI. The somaesthetic ideals of leveraging space and forming an “w correspondence” between the human body and the artifact translate to technical requirements:

1. The drone must be comfortable to use in close proximity, preferably within the “intimate space” of around half a meter from the body [7]; thus it must be small and quiet. It must also afford rapid experimentation with aesthetic and functional augmentations, e.g. lights, sensors, and claddings.
2. Drone motions must be smooth, stable, and coupled to the body. Hence, the drone must be kept under closed-loop control, receiving low-latency feedback from a sensing system that monitors points of interest on the human participant.

Informed by previous work that describes apparatus for HDI research [3], the design team oopted for a micro-quadcopter platform and a motion capture (mocap) system as the primary design materials.

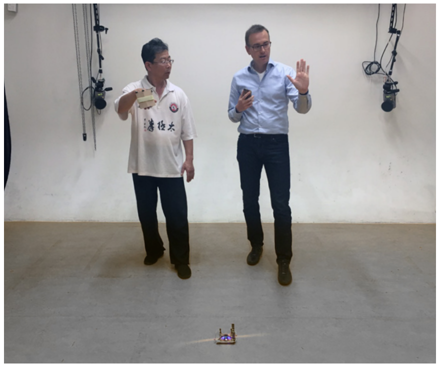
Optical Motion Capture (Mocap)

We used a Qualisys mocap system, which can track spherical infrared-reflective markers with sub-millimeter precision at a sample rate exceeding 100 Hz, within a space measuring 5 m on each side. By attaching unique asymmetrical formations of markers to the drone and the hands (via hand pads), we were able to track these objects of interest in 6 degrees of freedom.

Micro-Quadcopter Platform

Drone Chi is built on the Bitcraze Crazyflie micro-quadcopter platform, based on a single printed circuit board that integrates the control electronics and the load-bearing frame. Measuring approximately 10 cm between motors, the drone is remote controlled via a host PC running Bitcraze’s open source software. Components like LED lights and proximity sensors can be added via expansions boards.

Theories and Practices

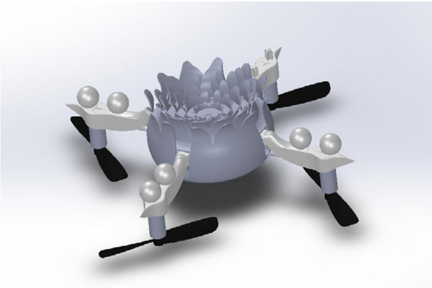


Tai Chi Practice

To inform the project, the principal designer established a personal Tai Chi practice. First, he attended public classes led by an instructor. Here, the instructor would perform movements, which a large group of students would copy. Subsequently, to deepen his practice, the designer turned to more intensive lessons with one-on-one instruction on correct technique. During the course of the project, we also consulted to the “somatic connoisseurship” [8] of the Tai Chi master, via a 2-hour co-design session in conversation with the technological materials.

Somaesthetics in HCI

With the motivation of creating computing artifacts to support bodily awareness, somaesthetics within HCI was explored as a theoretical scaffolding that addresses both somatic awareness and interactive digital materials. Within this literature, the soma design approach provided a grounding from which the design team could utilize technological materials as “socio-digital materials” [8]. Somaesthetic Appreciation was the concept to characterize the desired experience [9].



Product Design Engineering (PDE)

Product design engineers typically design mass-produced consumer products, their practice is “the convergence point for engineering and design thinking” [19] They combine a reflextive, open-ended design approach with pragmatic problem solving methods. A product design engineer commonly works to a set goal, balancing creativity with specificity, within contraints that can be evaluated by criteria declared in a Product Design Specification (PDS) [5, 16].

INITIAL ENGAGEMENT WITH THE MATERIALS

We began with familiarizing with the design materials. Here, “materials” include the drones, the body, and the ways in which these elements move together. The results of this permeated through the development of the PDS, which guided how the process and the final design were executed.

During the design process, the principal designer was learning the Beijing 12—an easy set of Tai Chi movements that can be performed in small spaces. A single move from this set, “cloud hands,” stood out for the designer as emblematic of the 6-month learning experience. This move involved distinct imagery, coordination, and slow movement. Below is an excerpt from the first author’s notes; sensory reflections on performing “cloud hands:”

“The point at which the top hand turns to point to the earth and the bottom hand turns to point to the sky, evoked a simultaneous feeling of symmetry and synchronicity in movement. A feeling of slowness and lightness was generated through the articulation of the wrists, accentuated by letting the fingers spread out and “drag behind” as if they were gently brushing the clouds.”

“The mental effort required to coordinate these movements aided the suppression of a ruminating mind giving me the mental space to concentrate moment to moment. The imagery evoked during these sessions not only informed my movement but presented me with a narrative, however small, to follow whilst performing the movement. Filling the newly vacated mental space with a scene of bright sunshine, crisp air and feather soft clouds.”

The initial low-fidelity prototypes for Drone Chi comprised of performing the “cloud hands” move in coordination with a drone. At this stage, we experimented with drone designs that resemble a cloud, and moved in a semi-circular pattern around the body at waist level. This prototype was devoid of sophisticated capabilities for sensing the human body. It was realized by adding optical sensors underneath the drone, which enabled flight control and stabilization.

Moving with the cloud drone revealed that the metronome-like rhythmic movement of the drone led to a focus on pace and slowness, but fell short of delivering imagery and a more sophisticated sense of coordination.

We presented this prototype informally to around 20 participants at two gatherings [12, 14]. We noted that a curious “illusion of control” was apparent, where some participants were unable to tell if they were controlling the drone themselves, despite being informed of the prototype’s nature. This compelled us to investigate the roles of “leading” and “following” the drone.

These engagements with the materials informed a detailed PDS. In tandem, we investigated technical parameters for the drone and the mocap system through separate performance tests.

For the PDS, we used more open ended language than typically seen in PDE practice. This was to ensure that the sensory experiences of Tai Chi were given proper weight in the project, before being subject to technical and usability requirements.

Product Design Specification (excerpt)

Moving with the drone must emulate the coordination, pace and imagery of Tai Chi.

A visual aesthetic treatment that egenders a sense of lightness and grace during flight.

Hide electrical hardware and move visual aesthetic toward the organic and the natural.

Use radially symetrical examples from nature to inspire the visual treatment and allow movement around the drone.

Investigate the roles of leading and following the drone.

Technical and Usability Requirements

Controllers must be ‘one size fits all,’ quick to put on and withstand repeated use during demonstrations.

Battery life > 5min

Net weight < 34g

Maintain factory centre of gravity position

Marker size > 8mm

No. of visible markers ≥ 4 (asymetrical formation)

EXPERIMENTS IN FORM AND TEXTURE

Through sketching and making, guided by the PDS, critical conversations with the materials propelled the design towards the final concept.

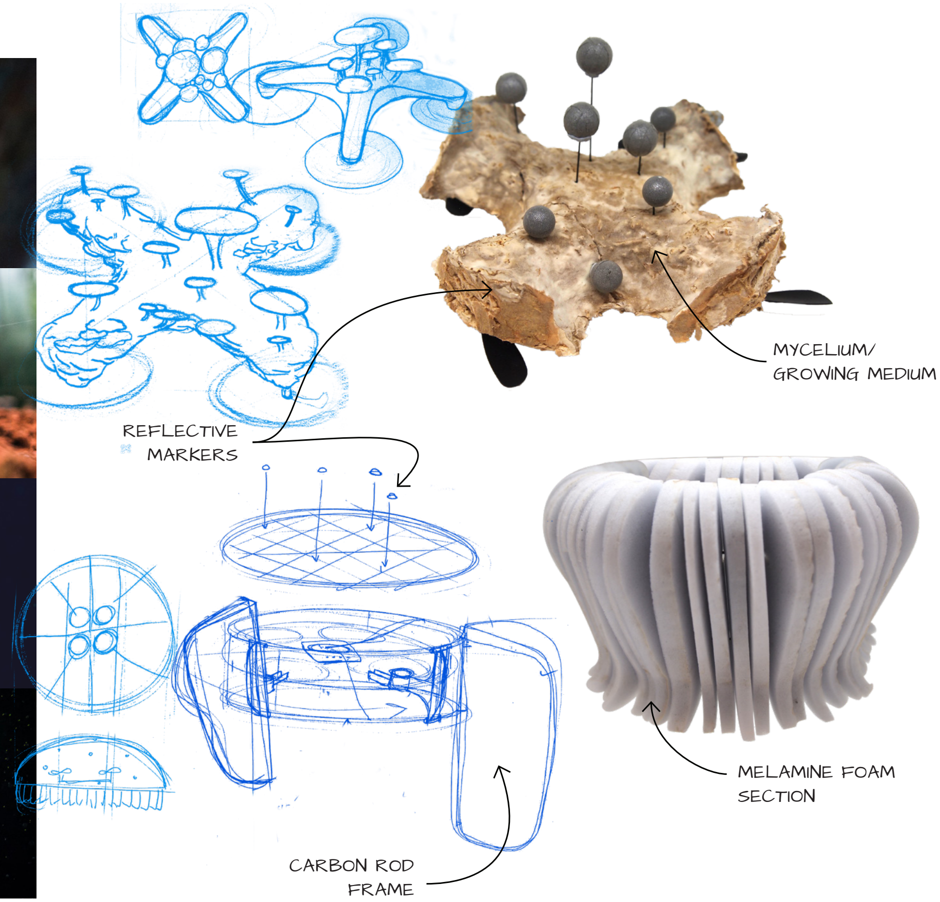
In developing the drone's aesthetics, the initial inspiration came from radially symmetrical forms in nature such as mushrooms and jellyfish. By attempting to radically move away from the typically rigid materials that are synonymous with drones and experimenting with softer materials and textures, we explored re-framing the sensory perception of drones as hard mechanical objects.

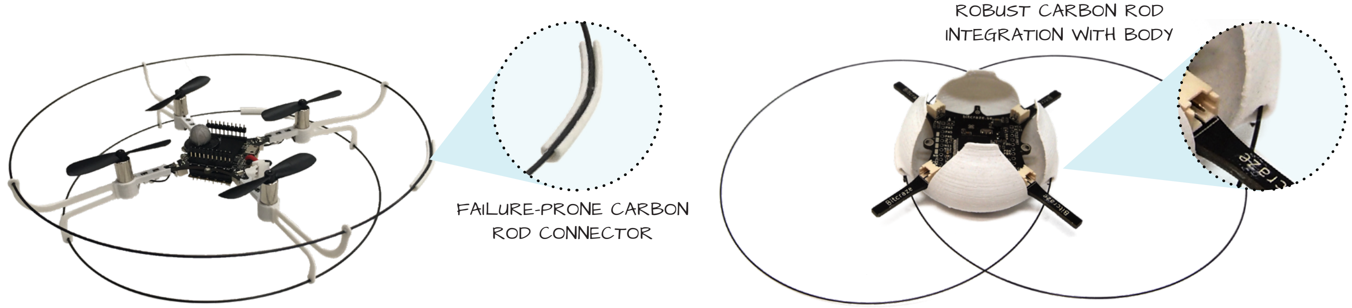
In an early design, the fungal root system grows over a mouldable growing medium which encased a drone. Although the texture delivered a convincing earthy feel, attempts at getting the mycelium to produce mushrooms did not prove successful.

Material explorations were then moved to foam. Melamine foam was found to be impressively light and easily available. Melamine foam was procured in small pre-cast blocks and cut into thin sections to create a silhouette mounted over a concentric carbon rod frame. The sections were able to articulate in and out to mimic the pulsing body of a jellyfish. Here we co-experimented with movement, repeatedly raising and lowering the drone to get a sense of "pulsating" movement.

While the foam and mycelium drones were promising in some areas, they were technically challenging in others. These materials were subsequently abandoned in favor of a 3D printed plastic hull. Foam and mycelium structures also suffered from poor weight distribution, and thus the drone did not fly well.

We also experimented with a delicate frame around the drone. We looped concentric carbon rods around the drone to mount exterior structures, though initially were prone to breaking open, due to a flawed design. To attach the rods more securely, they were integrated into a central body. These overlapping loops serendipitously resembled flower petals and spawned the idea to use the lotus flower as a core aesthetic theme.





REFINEMENT OF FLOWER CONCEPT

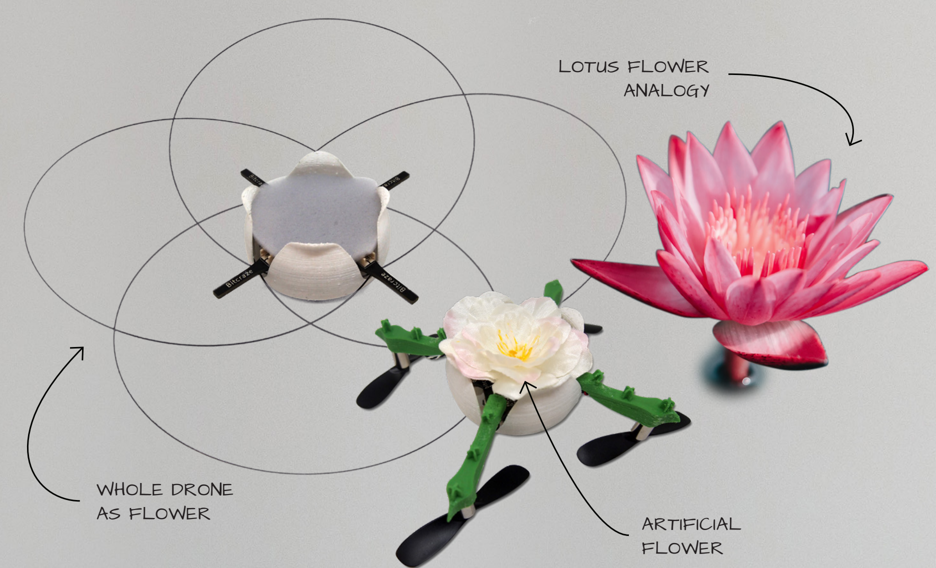
In developing the drone's floral aesthetic, the nature of the imagery invoked by design informed the visual aesthetic treatment. These functional prototypes were light and balanced enough to fly unassisted, allowing the designer to experience them in a cohesive union with the body language of the the drone.

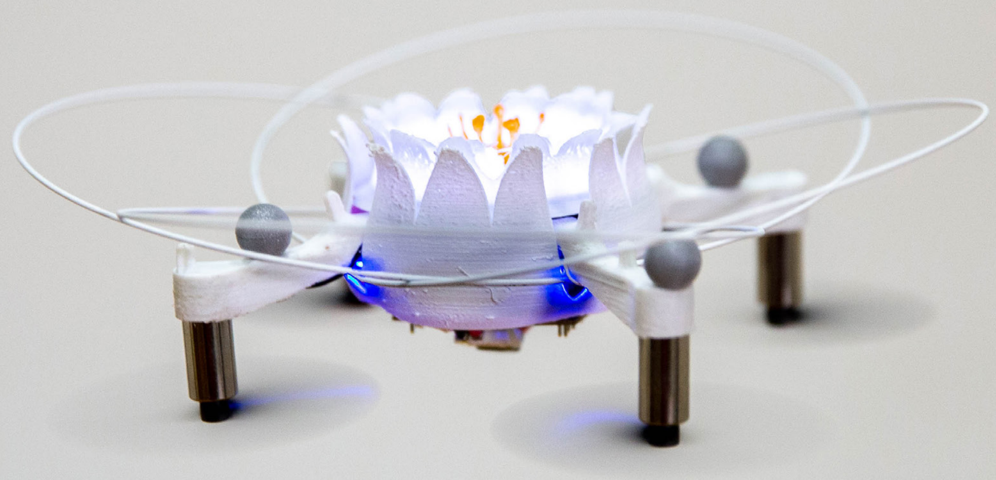
Initially the whole drone was treated as the flower. The melamine foam formed the centre of the flower and the carbon rods formed the petals. In stable flight, there was something delicate about the carbon rods that made it feel more like it was floating than flying. Overall this idea was not convincing in it's interpretation of a flower - the required "suspension of disbelief" was too great.

Consequently, the foam and carbon was replaced with an artificial flower, with green drone arms masqerading as leaves. The stamen added a focal point to the drone, making it easier to focus on than the foam version. Whilst the artifical flower removed any doubt that the drone was meant to be perceived on some level as a flower, the "floating flower" sensation created by the concentric circular forms was noticeably absent.

As the flower imagery was a central catalyst for evoking experiential qualities of Tai Chi, we decided to combine these forms. By merging these design iterations, the final drone design became analogous to an object drifting on the surface of a still body of water when in flight. The lotus a flower that seemingly floats on the surface of a still pond as a significant symbol in Tai Chi emerged as a key aesthetic construct in the project.

As the final design direction became clear, we sought balance between a natural floral styling and an artificial designed object. We 3D-modelled a lotus flower, as opposed to finding a life-like counterpart. We also lessened the aesthetic treatment of the drone's arms.The stamen carried through from the artificial flower.



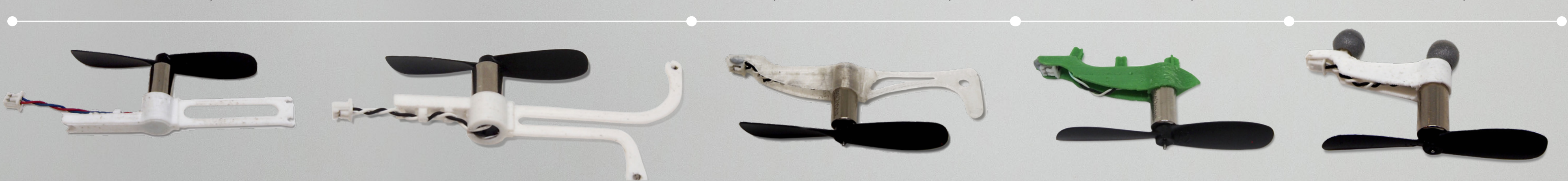


DESIGN FOR CONCENTRIC CARBON ROD FRAME

ORGANIC 'JELLYFISH' DESIGN

'LEAF' DESIGN

PLAIN DESIGN



HAND PAD DEVELOPMENT

The hand pads played the important role of the conduit between the body and the drone. The third author was the principal designer for the hand pads. By embedding deep spiritual concepts into the design, she endeavoured to create a more intimate relationship between the digital, material, and human.

The development of the hand pads moved through four major iterations, each with a few months in between as the team got a feel for how they facilitated the interactions between the drone and the body. The first iteration used a set of fingerless gloves with a set of markers glued to the back. This offered a high degree of freedom of movement within the fingers, a feeling reminiscent of Tai Chi practice. However this presented a raft of technical and usability issues, and was abandoned.

The second iteration was a low fidelity cardboard prototype with reflective mocap markers. The cardboard squares were a barrier between the hands and the drone, this also flattened the hands out and restricted the movement of the fingers. Interaction felt desensitised compared to the fingerless gloves, making the drones feel more distant in a figurative sense.

The third author wanted the hand pad to be imbued with meaning and resonate sentimentally with an individual. Therefore the main body of the hand pads referenced the “flower of life” concept from the New Age movement. Turning the hand pads into symbols of the life force, or Qi that according to the teachings of Tai Chi runs through the body and exits through the hands [20]. By sitting between the fingers, the hand pad fits any sized hand and was quick to take on and off. However the flat profile of the Flower of Life detail also tended to flatten the hands out and restricted movement of the fingers.

The final iteration of the hand pad utilized a curved flower of life profile'which allowed the hand to curve gently around the hand pad reminiscent of moving a ball of Qi energy.This design noticeably changed the way in which the drone was approached, a more intimate ‘holding’ of the drone was experienced as the hands cupped around the drone. Consequently, the physical design of the pads made actions relevant to ‘holding a ball’ now at hand to explore such as lifting, pushing, pulling, carrying and dropping.

The rich imagery provided by the final iteration of the hand pad introduced to the first author the utility of imagery and analogy when designing the mapping between the drone and the body.

MAPPING THE DRONE TO THE BODY

When considering how to map the drone to the body, it became apparent that the question was not "how can a drone make people do Tai Chi" but, "how can we move with a drone in the same manner as Tai Chi".

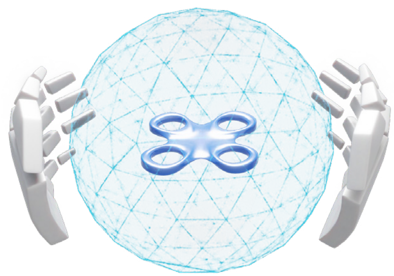
Rather than use an actual Tai Chi movement to lead the drone, Tai Chi imagery was used as a starting point to create mechanical analogies to map the drone to the body. We employed variations on "embodied sketching" [8] to act out these analogies with the drone. In some instances, the drone was flown autonomously, and sometimes it was controlled by a another person. These analogies also serve as a tool for the reader to imagine the dynamic relation between the drone and the body, and how it changed over the course of the design process. The depicted analogies were the mappings that were realised with a fully autonomous drone and are accompanied by reflections from the first authour.

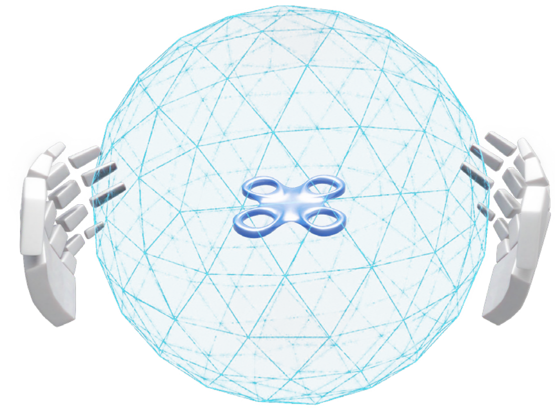
Starting with the idea of "holding a ball," the drone was programmed to remain in between the hands. This mapping was extremely responsive, whilst delivering a very light feeling as the drone faithfully darted around the room. However, it did not inspire slow movement qualities, which are a cornerstone in Tai Chi practice.

Placing a speed limit on the drone of .2 m/s helped to slow down movements and cleared some mental space to focus on the body. However, this mapping did not respond to any movements of the wrists, which are a defining feature of the "cloud hands" movement. In response. the drone was programmed to position itself at the intersection of two vectors protruding out of the palms of the hand.

These experiments culminated in the design of an 'offset-midpoint' mapping between the hands and the drone. This is computed by first taking two points 20 cm away from the palms — the "offset." Then, the midpoint between these two offset points is found. When leading or following the drone, the intensity L of the light indicates the quality of the correspondence between the hands and the drone. The light intensity L is driven by the distance Δ between the midpoint and the drone, using the equation below:

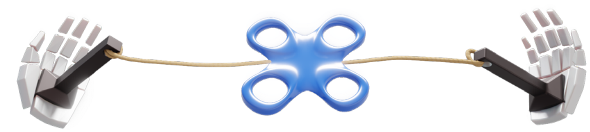
$$L(\Delta) = \begin{cases} 1 - \Delta/20\text{cm} & \text{if } \Delta < 20\text{cm} \\ 0 & \text{if } \Delta >= 20\text{cm} \end{cases}$$



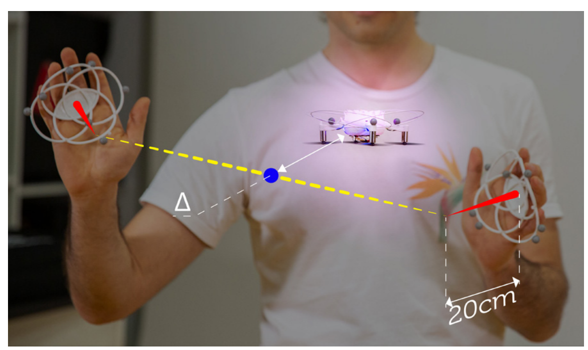


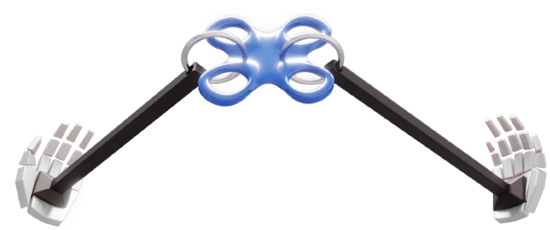
"Feels like moving a floating, impenetrable force field around with your hands, with the force field growing larger as you opened up your hands. "

"The drone feels more weighty, taking time to catch up to the hands and gently swinging around once it gets there."



"The drone responds to the movements of my arms and my wrists, I enjoy turning my palms up to gently 'sling' the drone upwards."



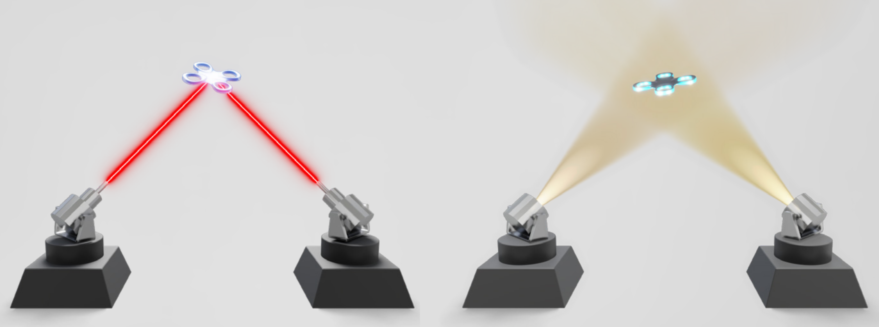


"The drone flew as if it was linked to the end of two rods protruding from the hands and was extremely responsive to the movement of the wrists."

THE ROLE OF FOLLOWING THE DRONE

The “illusion of control” that was experienced with the early “cloud” prototype, compelled the team to investigate how to leverage this natural curiosity. Following the drone was designed to facilitate exploratory movements so as to discover how to co-move with the drone. Once this has been achieved, the system can seamlessly transition an individual from following the drone to leading, where they can create their own movements in the same slow and coordinated fashion.

Development of the Feedback from the Onboard LED



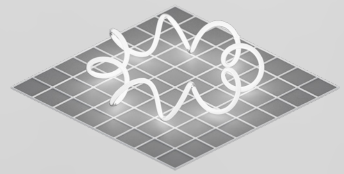
When deciding how to best use the onboard LEDs, various experiments with inverse relationships of brightness to velocity and acceleration were explored; e.g. having the light glow bright when the drone’s velocity or acceleration is low. We also experimented with brightness relative to hand proximity. However, none of these relationships guided the experience towards Tai Chi movements quite like the relationship between brightness and palm orientation; i.e. when the palms face the drone, the drone glows bright. This relationship brought attention to fine motor movement of the wrists in much the same way that ‘cloud hands’ did.

In an attempt to give the reader an idea of what the feedback felt like a pair of analogues have been depicted for the reader to imagine. On the left, a pair of lasers follow a drone, on the right a pair of spotlights. The reader is asked to imagine the sensitivity of tracking a drone with a pair of lasers compared to a pair of spotlights. The lasers require a high degree of concentration and coordination to track the drone, the spotlights are more forgiving and don’t require as much attention. These analogies also helped the principal designer to fine tune the sensitivity of the LED, which eventually felt somewhere in-between the above examples.

While we wished to also make use of the LEDs’ ability to change colour, we were mindful of falling into the trap of creating a dazzling display of colour and information that would draw attention away from the body. We used this capability for a gradual change in colour whilst following the drone, to signify progress in the progression from following to leading.

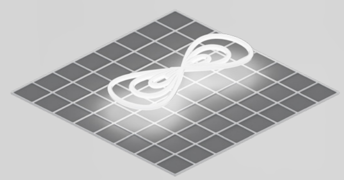
Development of the Followed Flight Path

We moved through a number of iterations in choosing the right flight path for the “follow” mode. We experimented with a number of flight paths, all of which related to Tai Chi some way. Informal user testing was also done to ensure the flight paths were user-friendly enough not to cause frustration, but still evoked attention and reflection on movement.



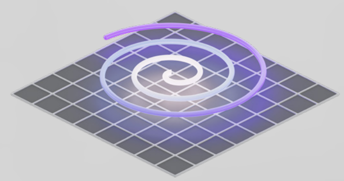
“Calm me!”

In the first design experiment, the drone would fly quickly, drawing jittery circles. When the hands are brought in close proximity, the jitters would ‘calm down,’ and the drone would fly smoothly and slowly. This relates to a similar feeling in the very beginning of a Tai Chi lesson, where the pace of life quickly and significantly drops. However some preliminary user testing revealed the initial speed made it challenging to catch the drone and resulted in a frustrating chase.



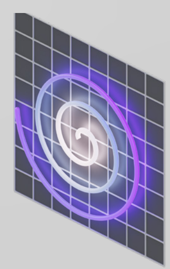
Expanding Figure of Eight

This flight path would expand slowly as the proximity between the drone and the hands was maintained. The expansion was effective in adding a dynamic challenge by varying reach and therefore balance. This relates to practicing with both sides of the body in Tai Chi, where movements are repeated in mirror form. In preliminary testing, many participants found it hard to predict this flight path; they ended up standing in its way and having to awkwardly navigate around it.



Expanding Horizontal Spiral

The flight path was further simplified into an expanding spiral in the horizontal plane to reduce confusion. Again, the expansion of the spiral depended on the constant close proximity of the hands. Preliminary testing revealed that as the drone moved away from the body, many would instinctively take a step forward, resulting in casual circular shuffling in circles. This movement style did not inspire a sense of mindful coordination.



Expanding Vertical Spiral

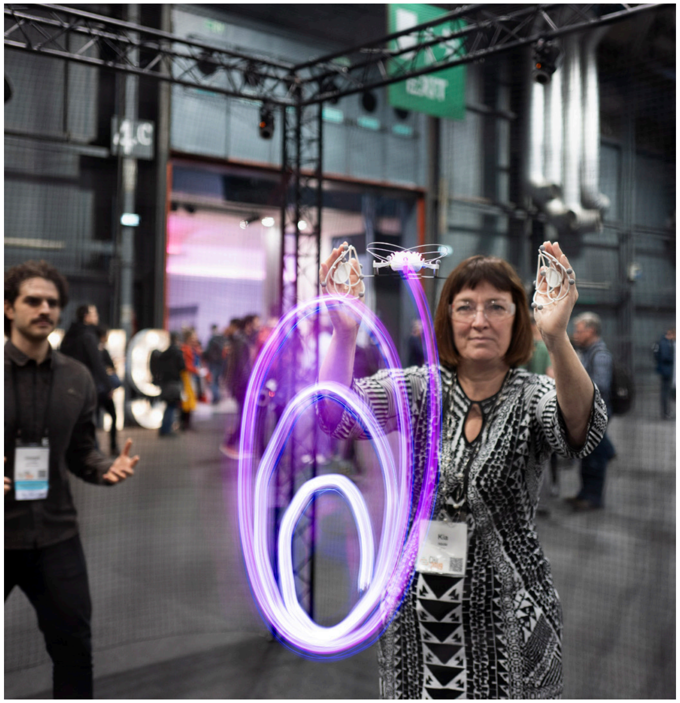
In the final flight path, the drone flies in an expanding spiral oriented on the vertical plane. Thus, the knees must be engaged as the drone drops below the waistline and the arms must be engaged as the drone rises above the shoulders. Informal testing saw that most people kept their feet planted and shifted their weight around to follow the spiral. This required a fair amount of coordination, especially at such a slow pace.

THE DRONE CHI EXPERIENCE

The final prototype for the Drone Chi experience involves a facilitator who guides the participant. However, the particulars of the facilitator's involvement vary based on the context and the participant's experience level. For example, during lab studies aiming to characterize the Drone Chi user experience, the facilitator would minimize instructions that could direct the participant's attention, so that the influence of various design elements would dominate. In other contexts, such as investigating rehabilitative applications, the facilitator's instructions would be more comprehensive. In certain cases, where some users had the chance to become more experienced with the system, Drone Chi can also be practiced without a facilitator, purely for reflective or playful purposes.

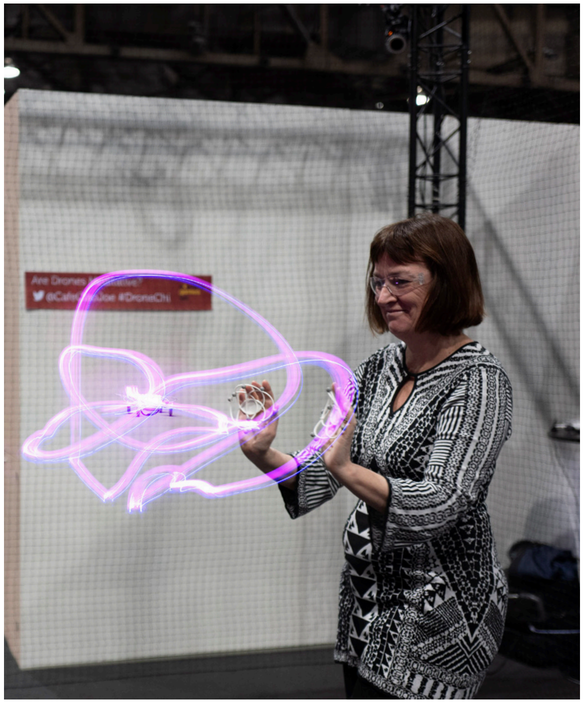
Picking a Drone from the Vine

The experience begins with the participant picking a drone, from a charging station designed to resemble a vine. When the drone is removed from the vine and turned on, it emits a beeping sound and spins each of its motors once; LEDs at the center of the drone's 'petals' begin to glow in white. The participant then places the drone on the floor and picks up the hand pads.



Following the Drone

The drone shortly takes off and begins hovering in a still position at around waist height. When wearing the hand pads with both hands orientated towards the drone, the LED's glow more intensely, and the glow diminishes if the palms point away from the drone. The participant is allowed to experiment with this interaction as the drone hovers in stillness, and the only instruction they are given is to maximize the glow. Then, the `follow' exercise begins, where the drone begins to slowly fly in a circle. The participant follows the drone with their hands as the circles grow larger, aiming to keep the light as bright as possible. Meanwhile the drone's glow gradually changes to a brilliant purple.



Leading The Drone

The drone seamlessly transitions into being lead by the participant. The participant now controls the drone, but they must do so with slow and focused movements; moving too quickly causes the light to dim and the drone to fall out of control. If this happens, the drone must be `recaptured' by cupping the palms around it. Throughout the experience, movements require coordination and focus, and the light's intensity is used to gauge the quality of the connection between the hands and the drone.

FINAL ASSEMBLY AND TECHNICAL CHALLENGES

Through a systematic approach, we experimented with the physical limits of our technological materials.

Several options for motors, payloads, batteries, and propellers were tested, and the impact of these decisions on maximum flight time assessed.

The mocap system came with its own set of unique limitations imposed on the design of the drone and the hand controllers. The first issue is line of sight: at any given moment, at least three markers must be visible to at least three mocap cameras. Further, the markers attached to any unique object must be arranged in an asymmetrical and unique configuration. An inverted motor configuration was introduced as a solution that allowed the markers to be mounted in three different positions, ensuring asymmetry. A fourth marker was added for redundancy and even weight distribution. To save weight, the unused mounting bases were clipped.

Using the smallest possible marker detectable to the system was also desirable to minimize weight. 8 mm markers were found to be the right balance of weight and visibility. The flower body has been designed to secure the diffuser via an interference fit and also accomodates both slightly different production versions of the drone.

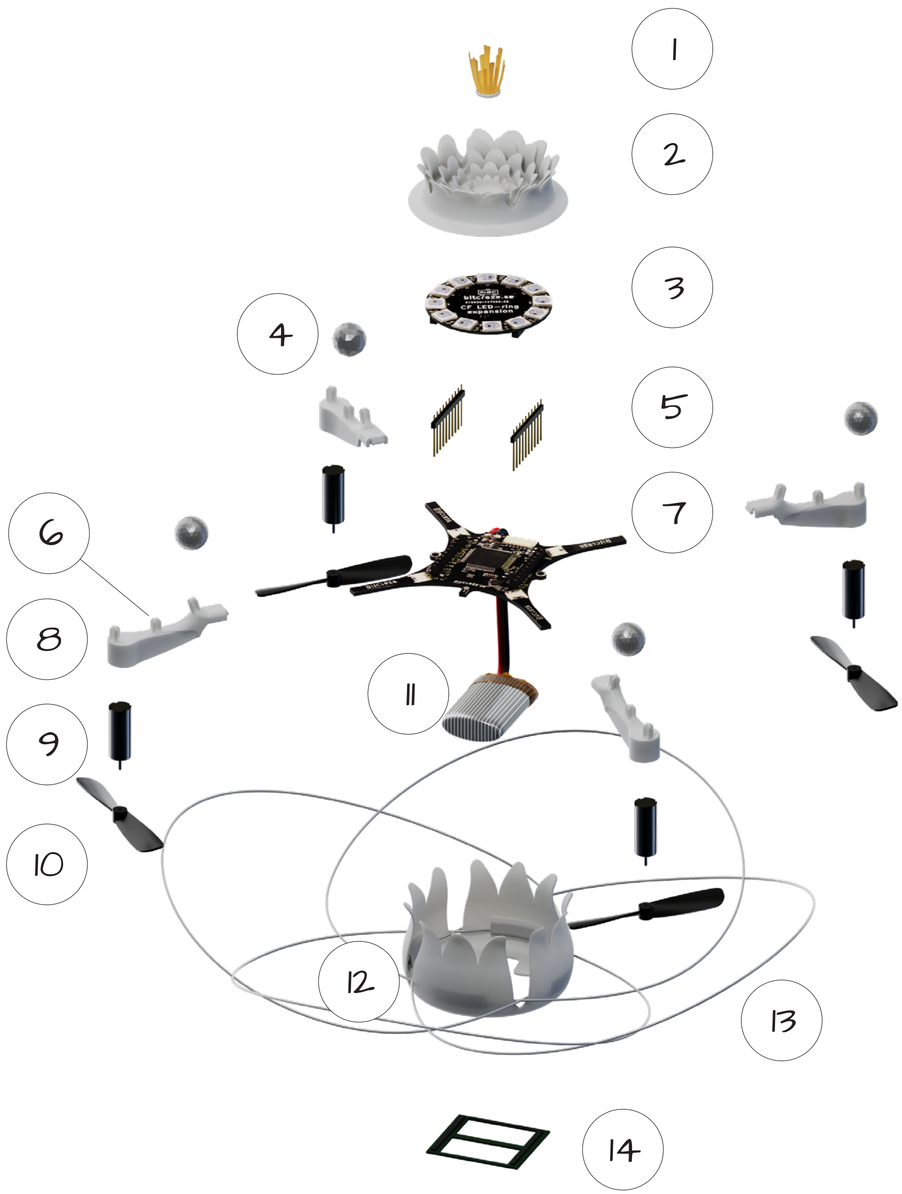
The final weight of the drone came in at 32g; which is merely 5g more than a stock drone with no expansion decks. At this weight, our drone was able to achieve a flight time of 6 minutes 20 seconds.

Optimizing Wall Thickness

By bolstering areas of the arms that often failed and thinning areas that did not, we reduced the use of plastic by 12%, saving a total of 2 grams over four arms. The flower body and diffuser were also optimised for minimum wall thickness, designed to be printed at .4mm to save weight.

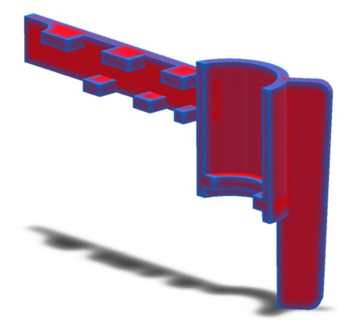
WALL THICKNESS GAUGE

.4 mm  1 mm

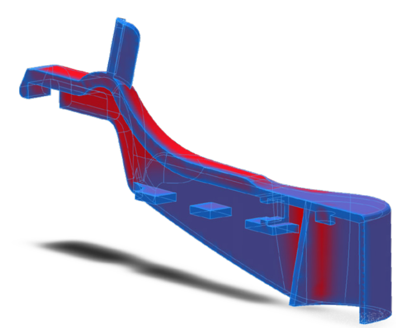


1. STAMEN
2. PLA PRINTED DIFFUSER
3. LED EXPANSION DECK
4. 8MM PASSIVE REFLECTOR
5. HEADER PINS
6. M3 REMOVABLE MOUNTING BOSSES
7. DRONE CHASSIS AND MOTHERBOARD
8. INVERTED DRONE ARMS
9. STANDARD 7MM BRUSHED MOTOR
10. STANDARD 45MM PROP
11. 350mAh LIGHTWEIGHT BATTERY
12. PLA PRINTED FLOWER BODY
13. .7MM CARBON ROD BUMPER
14. RETAINING PLATE

STOCK DRONE ARM



MODIFIED DRONE ARM



DESIGN TIMELINE AND REFLECTION

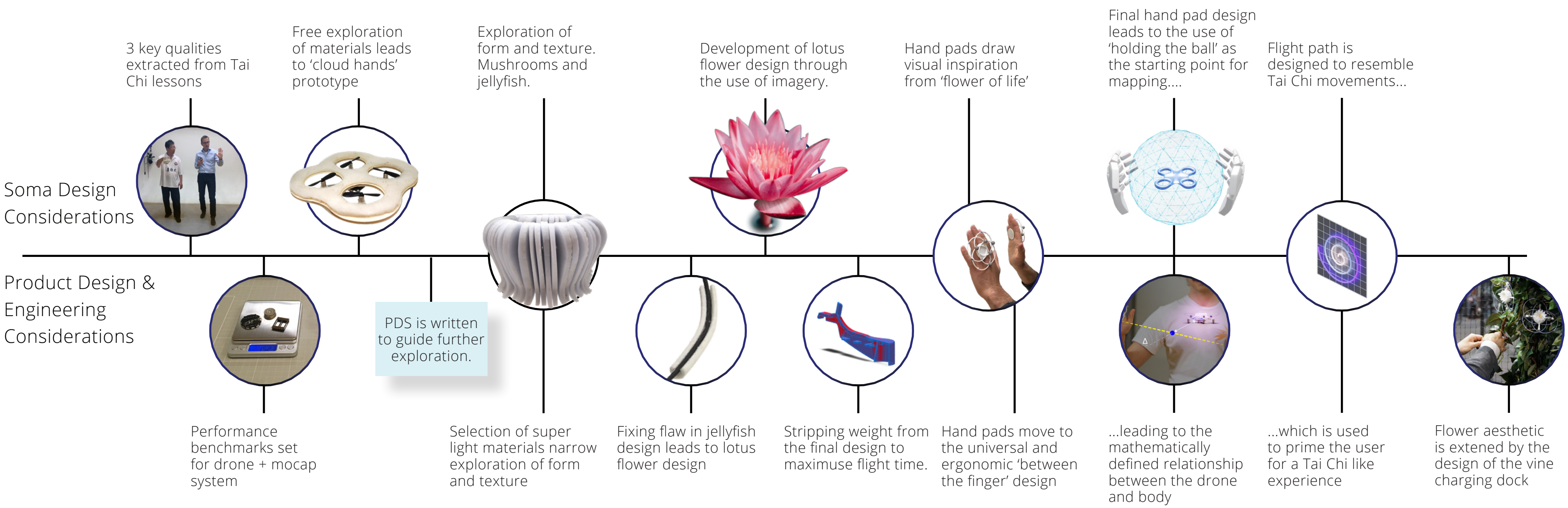
Our process represents a synthesis of skills and methods from somaesthetic interaction design [8, 9] and more conventional product design engineering (PDE). The timeline below articulates when the design team was influenced by the principles of somaesthetic interaction design and when by PDE. This highlights elements in the design which are born from each, as well as how they influenced each other. We aimed to leverage the strengths of both approaches to deliver a meaningful and reflective experience while also mitigating engineering and usability issues.

Soma design calls for slow and reflective in-person engagement with design materials, which include one's own body. The first person, felt perspective is the principle source of design inspiration [8]; delivering an outcome that is reflective and meaningful to individuals – both designers and users. In contrast, PDE intends to be quicker and more objective in its engagement with design materials, and this engagement may not explicitly involve the felt experience. The aim in PDE is to deliver technically feasible outcomes that are user-centered, intuative to use, and serve a population or persona [16, 19].

The timeline represents stages in the process when the designer's first -person experience is foregrounded, when the performance of the system or the user is foregrounded, and when both are being considered simultaneously. The principal designer reflects on this process, writing:

"How can I share this experience with someone else through the drone? What are the essential sensory elements to the experience? How can I introduce these to a user? How can I reliably engineer a system to deliver these interactions?"

This pictorial documents a research-through design project that employed a fusion of soma-focused design approach with PDE. Thus we contribute to somaesthetic interaction design by exemplifying how its values, strategies, and tactics can be instantiated in synergy with an approach that foregrounds engineering and usability constraints.



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