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WHITE SPACE DESIGN CHALLENGE 2019

Homeowners need to sanitize surfaces without posing health risks to themselves, their families, or the environment.

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Luma combines controlled UV-C light and mechanical scouring to kill bacteria and break down grease on a molecular level without the need for harsh antibacterial liquids or aerosols.

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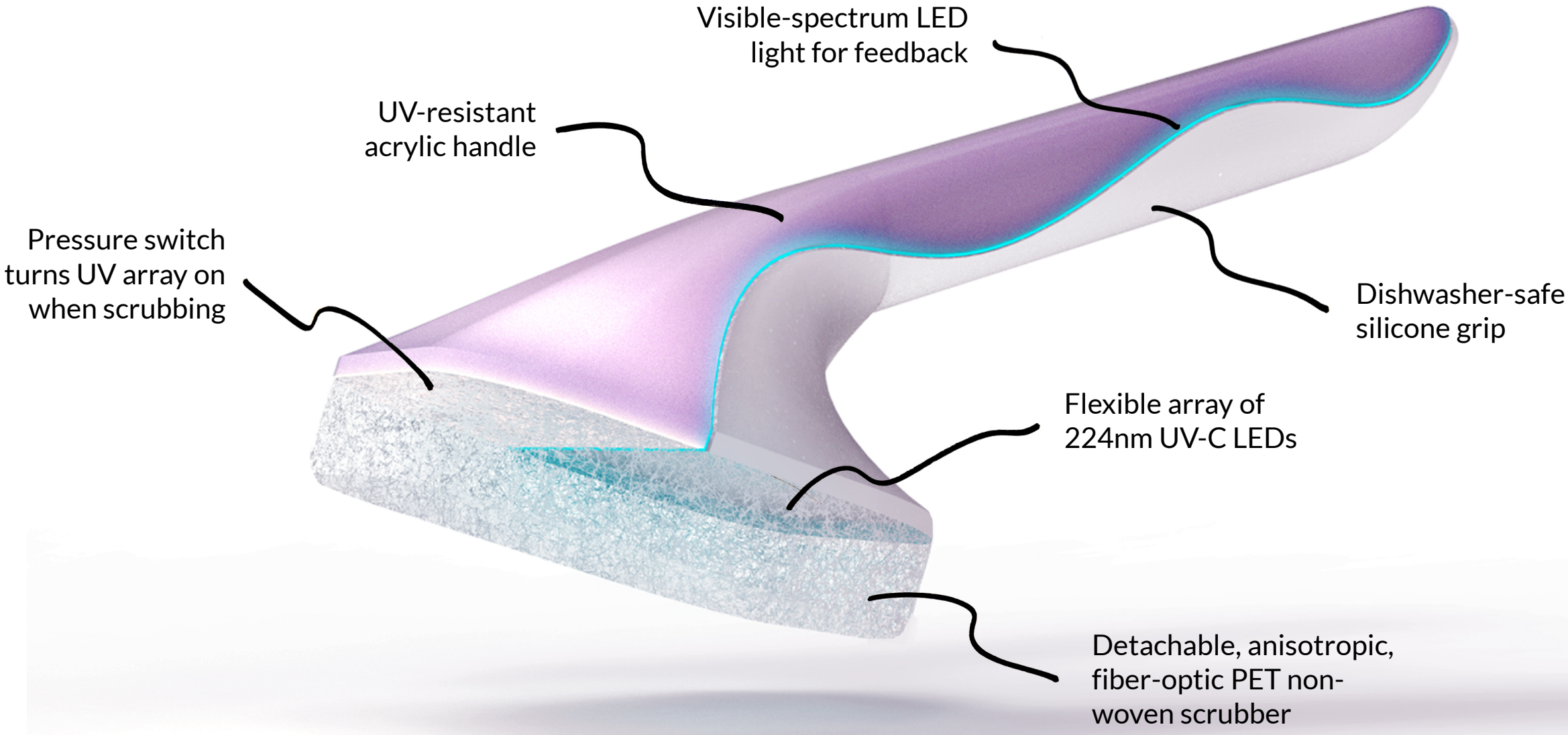
Visible-spectrum LED light for feedback
UV-resistant acrylic handle
Pressure switch turns UV array on when scrubbing
Dishwasher-safe silicone grip
Flexible array of 224nm UV-C LEDs
Detachable, anisotropic, fiber-optic PET non-woven scrubber

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Current Conventional Cleaning Methods are Hazardous[1]

Chemical cleaners (e.g. bleach)[2, 3]

- Dangerous around food, eyes and skin.
- Contaminates waste water.

- Requires users to wear gloves and ventilate work area.
- "the most common agents of occupational asthma and occupational rhinitis in cleaning workers."[4]

Antibacterial solutions (e.g. dish soaps)

- Exerts selective pressure leading to the spread of antibiotic-resistant genes (super-bacteria)[5]

- Needs to sit for 5 to 10 minutes to kill bacteria.[6]
- "Triclocarban [the active ingredient in antibacterial soap] does not lead to a meaningful reduction in bacterial levels during use as compared to plain soap."[7]

Aerosol cleaners (e.g. disinfectant spray)

- Exacerbates extant asthma and increases risk of new onset.[4]

- Use of cleaning sprays at least weekly (42% of participants) was associated with the incidence of asthma symptoms. [8]

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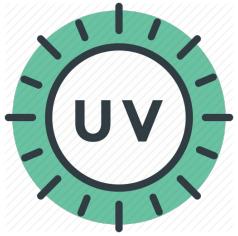
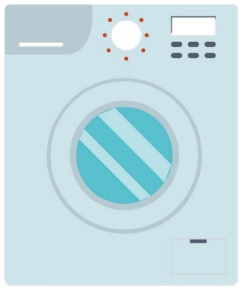
Non-Chemical Cleaning Methods Have Other Problems



Ultraviolet light cleaners (e.g. UV wand)[9]

- Does not remove dust/dirt.

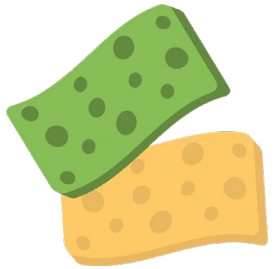
- Conventional germicidal UV light (>255nm) is a known carcinogen and can cause burns.
- Contactless, i.e. no visual/tactile feedback of cleaning and making them hard for users to trust.



Autoclaves (e.g. medical equipment sterilizer)

Presents risk of scalding.

- Uses high temperature steam that would damage most household items.
- Sterilizes hospital equipment between uses but not suited for home environments.



Physical Abrasives (e.g. scour pad)

- Does not kill microbial contaminants alone.

- Can scratch many wood, metal, and coated surfaces, e.g. Teflon.
- Must be used with a chemical solution and/or water to remove dust/dirt/bacteria/grease.
- Sponges and scour pads harbor bacteria if not routinely disinfected.[10]

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Ethnography

- Cleaning is a ubiquitous part of the experience of homeownership and tenantship in western cultures.
- We conducted ethnographic research comprising of **28 qualitative studies** on cleaning techniques, preferences, and mental models on a set of **young adults** in an established apartment setting.
- We presented users with a collection of conventional and unconventional cleaning products, and asked them to clean a kitchen and toilet as they would in their own home.
- The outcomes of this research showed us the **ways that people clean, for how long, and with which products**. These data included **cleaning motions and ergonomics, conceptual models of cleanliness** and interior hygiene, as well as consumer preferences in cleaning product utilities.
- Heat maps and conceptual models that we created based on our qualitative data helped to drive design decisions throughout the process.

Case Study 1: Scotch-Brite Scour Pad

- $8.56 for 8-pack
- Users only used the scour pad to scrub the sink
- Requires the use of antibacterial soap
  - Most users did not use soap, i.e. surfaces were not sterilized
- **Users did not clean the scour pad after use**
- Dishwasher-safe

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Case Study 2: Scotch-Brite 2-in-1 Sponge

- $10.45 for 12-pack
- Users only used the sponge to scrub the sink
- **Users did not clean the sponge after use**
- Most users used the sponge with antibacterial soap
- The combination of sponge and soap both cleaned AND sterilized the sink

Case Study 3: Bioexcel UV Sanitizing Wand

- $29.99
- **Not a single user in our study chose to clean using the UV wand**
- Can be unsafe if used incorrectly: uses 255nm UV-C light which can burn skin and eyes
- Does not clean dust/dirt
  - Users will not know when a surface is sterilized
- UV-light does break down hydrocarbon-based greases, but the remains must be wiped away afterwards

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Case Study 4: Clorox Antibacterial Spray/ Paper Towels

- Spray: $5.93
- Paper towel: $2.41 per roll
- Users only sprayed the countertop (not the sink)
- Before wiping, **no users left the solution on the surface for the required 5-10 minutes** for bacteria to be killed
- The combination of spray and paper towel cleaned AND sterilized the countertop surface

Case Study 5: Mr. Clean Magic Eraser

- $6.99 for 8-pack
- Users used the Magic Eraser mainly on the sink, but some also used it on the countertop
- **Users did not clean the sponge after use**
- Users commented that the Magic Eraser picked up dirt particularly well
- Users used water, but did not use antibacterial soap, i.e. surfaces were not sterilized
- Warped and disintegrated faster than other cleaning tools

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Case Study 6: Clorox Disinfecting Wipes

- $3.53 per pack
- Disinfecting chemicals got on user's hands
- Non-abrasive
- Requires the disinfecting solution to be left on the surface to dry for 4 minutes

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Case Study 7: Clorox Toilet Cleaner and Toilet Brush

- Cleaner: $6.32 per bottle
- Brush: $8.95
- All users scrubbed and flushed almost immediately
  - They did not leave the solution on the surface for the 5-10 minutes required for the bacteria to be killed

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Case Study 8: Seventh Generation Disinfectant Spray

- $5.47 per can
- Users liked that rinsing was not required
- **Spray had a strong, toxic odor**
- Users left the bathroom and shut the door immediately after use

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Conclusions from Ethnography

- Participants shared a common conceptual model of what effective cleaning entails.
- The most common model observed in the ethnography was of visual cleanliness– the feeling that a surface or object appeared to be sufficiently cleaner than it had been prior to cleaning based upon qualia including "shine" and "lack of visible dust or grime."
    - A secondary model observed was of tactile cleanliness – the feeling that a surface was "smooth" after cleaning.
- Participants also used a common mental model for scrubbing and wiping motions that was based on tactile feedback of the effort needed to remove visible pieces of refuse from a surface while cleaning.
- **None of these models of cleaning and cleanliness referenced an understanding of the time or activities needed to kill germs, but rather the activities needed to remove visible debris to a sufficient level.**
    - This highlights the difference between being "clean" and being "sterile."

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User Motivation

The lack of effective AND safe solutions appropriate for home environments opens up a white space for a new household cleaner. Our solution must:

1. Kill viruses and bacteria
2. Remove dust, dirt, grease, and stains
3. Provide users a tactile sensation of cleaning
4. Be safe without the need for gloves or air circulation
5. Be affordable in the home cleaning supplies market
6. Be all-purpose, able to clean multiple different surfaces

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User Motivation

	Chemical Cleaner	Antibacterial Soap	Disinfectant Aerosol Spray	Medical Autoclave	Scour Pad	UV Sterilization Wand	Luma
Sterilization efficacy	✓	✓	✓	✓	☒	✓	✓
Cleanliness efficacy	✓	✓	☒	✓	☒	☒	✓
Feedback	✓	✓	✓	✓	✓	☒	✓
Safety	☒	☒	☒	✓	✓	☒	✓
Price	✓	✓	✓	☒	✓	✓	✓
Applicability to multiple surfaces	☒	☒	☒	☒	✓	✓	✓

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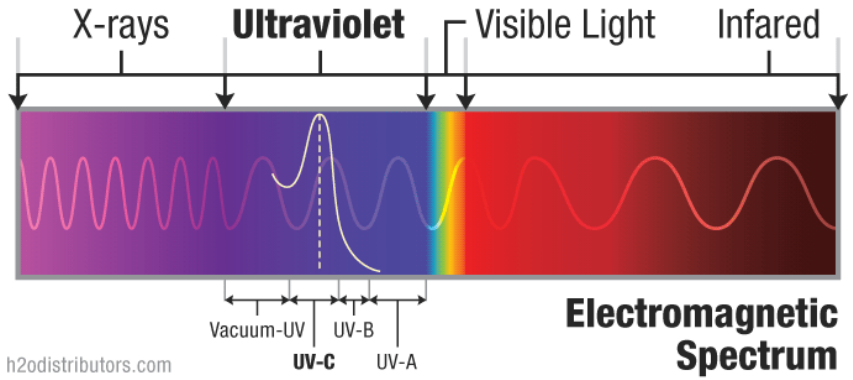
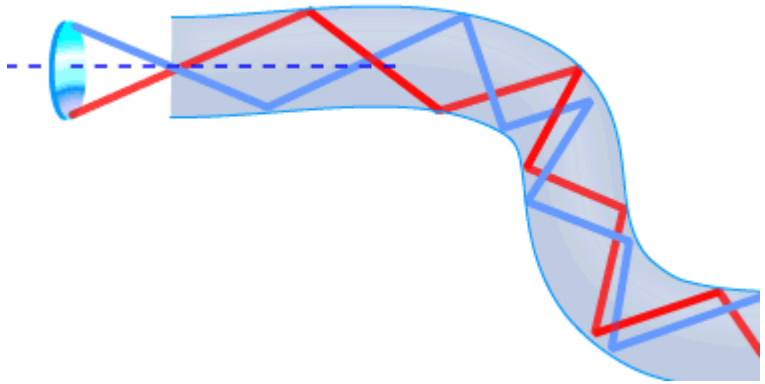
Technology to be Applied





- UV-C light catalyzes covalent bonds between thymine nucleic acids in the DNA of bacteria.[11] This prevents bacteria reproduction, thus killing the population.
- UV-C light dramatically accelerates oxidation of fatty acids found in hydrocarbons, helping to break up oil and grease stains.[12]

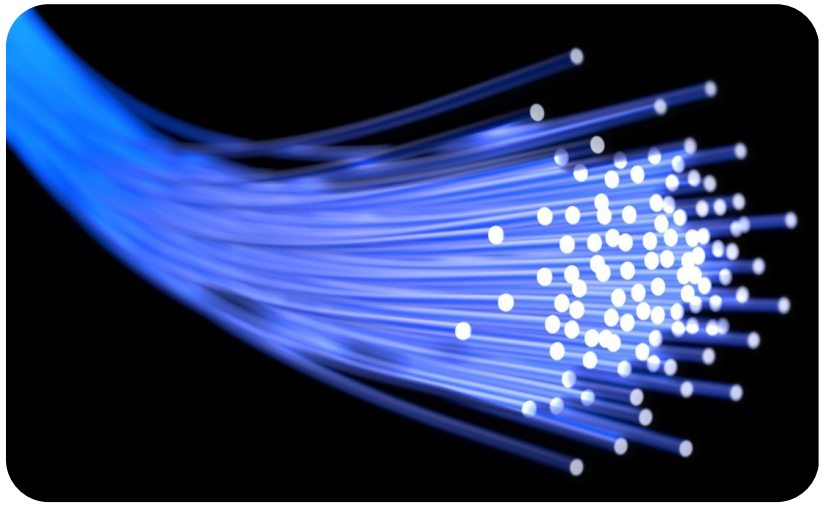
- Optical fibers make use of a material's high index of refraction to transmit light in a controlled manner.
- The light is introduced at one end of the fiber, and total internal reflection allows light to bounce along the fiber's inner walls along the length of the fiber.

Technology in Context

- Unlike broad-spectrum UV-C traditionally used in sanitation (255-308nm), recent research has shown that far UV-C (207-224 nm) light efficiently kills drug-resistant bacteria, without apparent harm to exposed mammalian skin.[13]

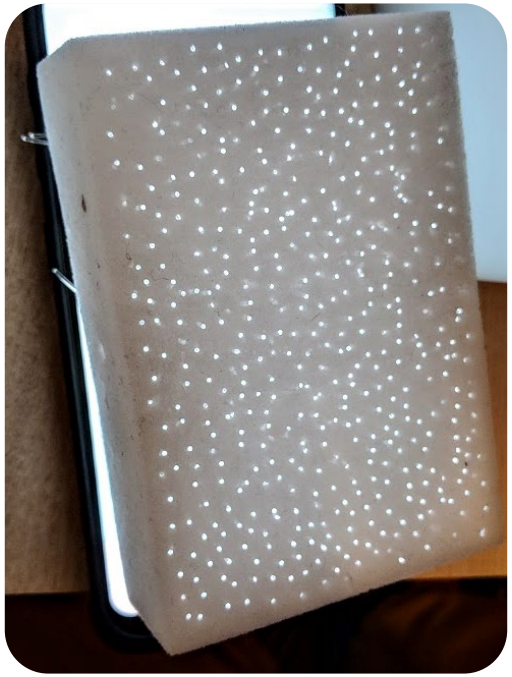
- Applied in a flexible array of LEDs, this light can be applied to soft electronics in home goods.

Technology in Context



- UV-C light can be used with optical fibers to introduce the radiation to infected surfaces.[13]
- Applied as anisotropic fiber pads, plastic fibers can act as an abrasive while exposing contaminants to the light.

Design Process: Technology Prototyping



- Prototypes were created to test the transmission of light through fiber-optic sponges.
- The tests were intended to combine fiber-optic light transfer and scrubbing functionality.
- Prototype testing revealed that fiber bristles would be too rigid and abrasive.

- **While these prototypes tested light transfer through a nearly opaque sponge using optical fibers, Luma would use nonwoven PET fibers extruded into an anisotropic 0.75” thick sheet and die cut into a scouring pad.**

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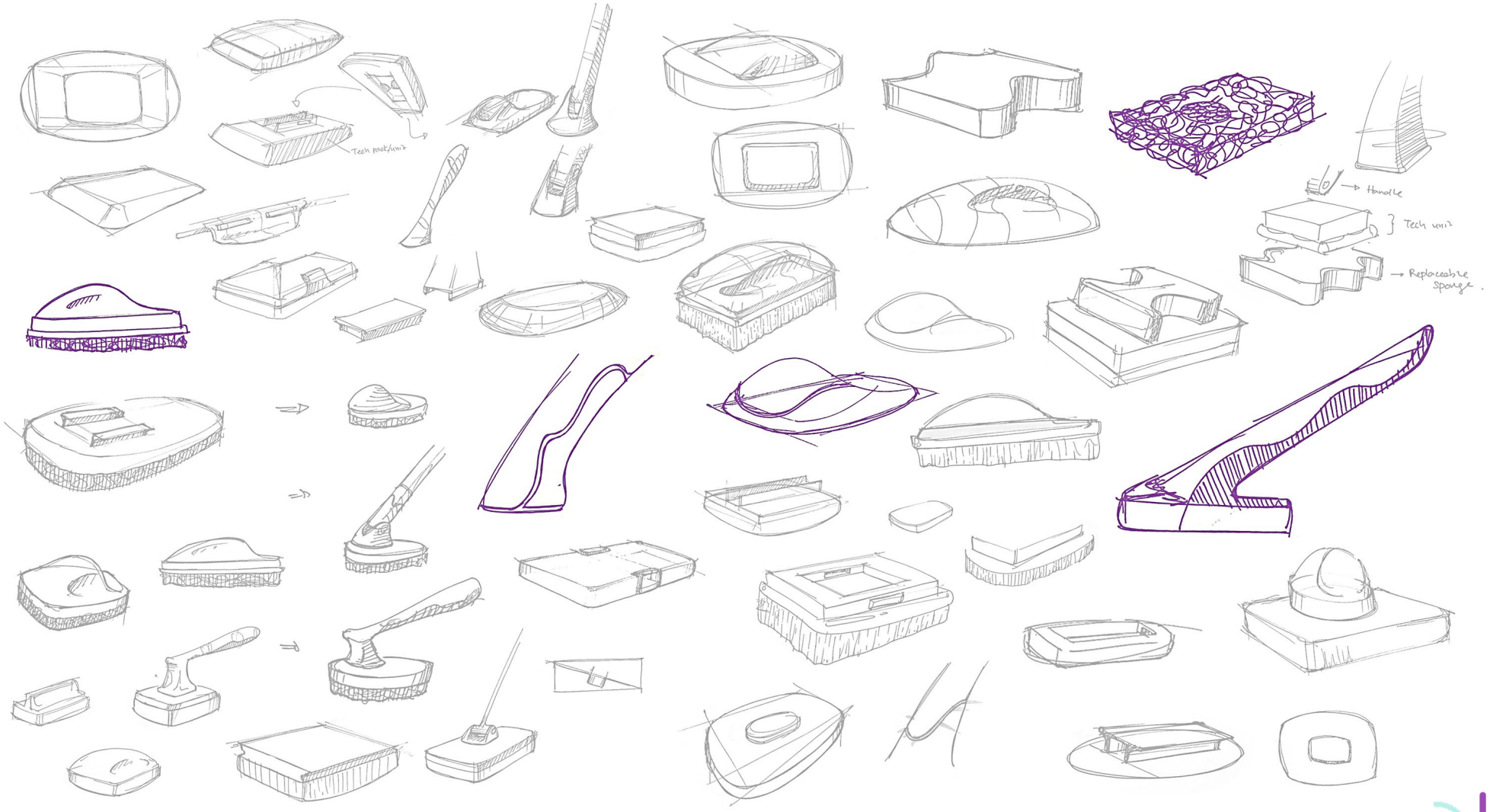
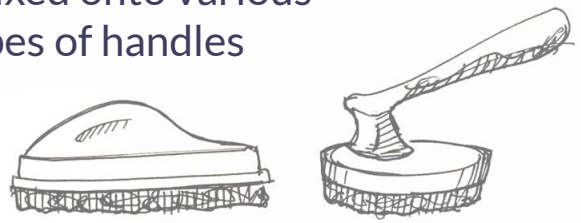
Design Process: Form Exploration

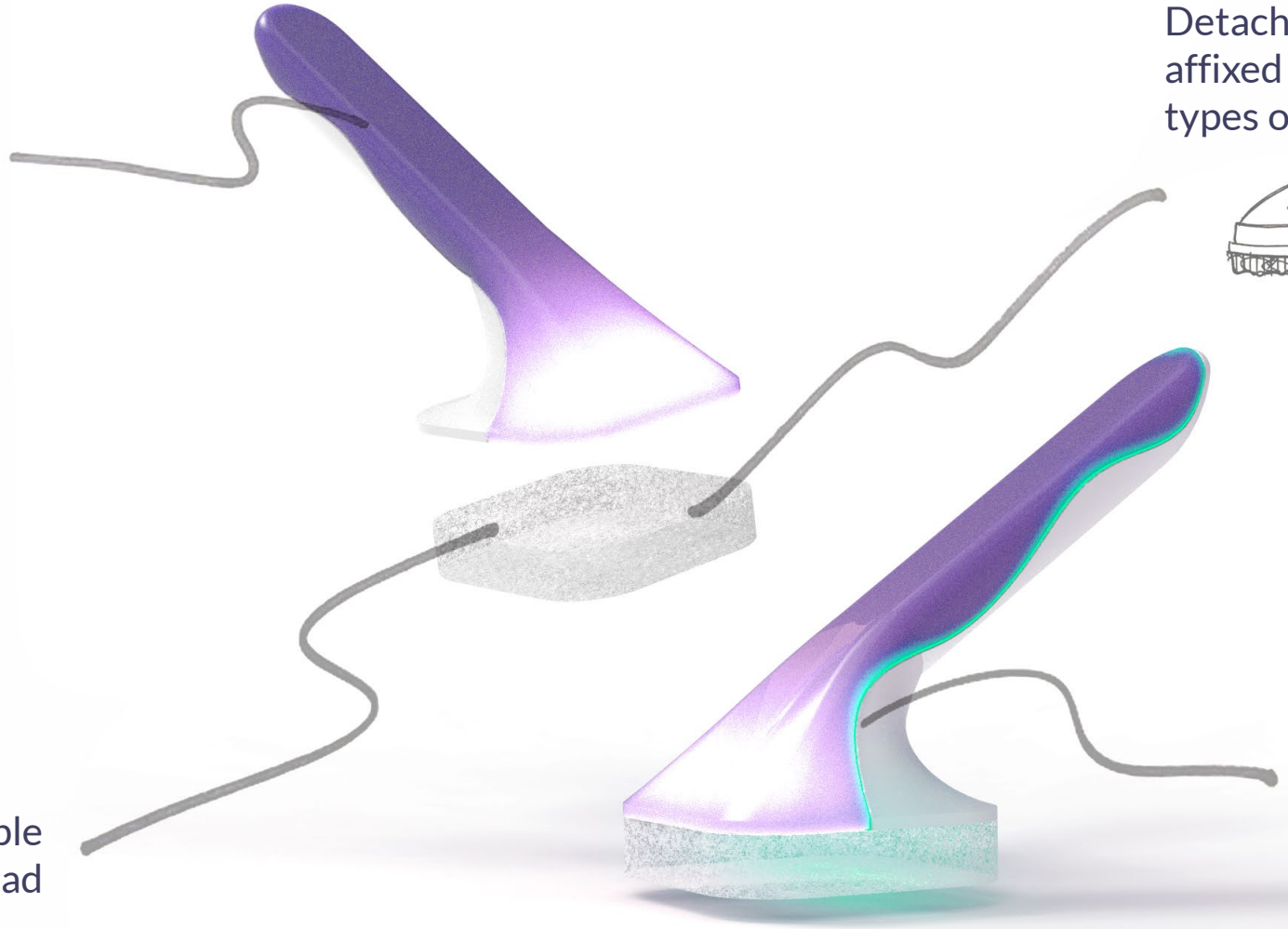


Design Process: Embodiment of Concept

Dishwasher-safe acrylic handle

Detachable pad can be affixed onto various types of handles





Disposable/recyclable scrubber pad

UV activates when pressure is sensed by the pad

Intellectual Property Research

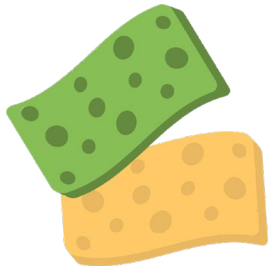
Non-woven fiber manufacturing patents

- The production of Scotch Brite scouring pads, and another method of producing multilayer, non-woven, fibrous structures are patent protected.

UV-C LED patents

- Some patents protect the combination of chemicals used in manufacturing certain types of LEDs that produce UV light.

Scour pad form design patents



- The shapes of some sponges and scour pads are protected by design patents.

UV cleaning patents

- Multiple devices that use UV-C light to kill bacteria have been patented.

- **None of these apply to Luma, as it uses a novel manufacturing technique, combines manual scrubbing with UV sanitation, has a unique form, and uses UV-C wavelengths unprotected by patents.**

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Scouring Fiber Material Selection

- **Given that the scouring pad requires the most performance attributes, it demanded an in-depth material selection process.** See Appendix B for CES EduPack analysis.
- Environmental resistances to maintain usability over lifetime:
  - Ultraviolet Light
  - Water
  - Salt water
  - Weak acids and alkalis
- High hardness to create an effective abrasive that will wear down slowly.
- High fracture toughness to prevent cracking/ crumbling during use.
- Transparency to conduct light through fibers.
- Recyclability to decrease production of waste from disposable pieces.
- **PET was selected as the best scour pad material.**

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Materials Selection

Li-ion (battery)

- Cannot be recycled.
- Can be dishwasher safe if designed correctly (encased in silicone housing.
- Wirelessly chargeable via induction.
- Can be charged/discharged for 500 cycles before needing to be replaced.

Silicone (grip)

- Good insulator, will not conduct heat when in contact with hot objects.
- Stable until 227°C, i.e. dishwasher-safe.
- Water resistant, can create water-tight seals to protect the battery in a visually appealing manner.

PET (scour pad)

- Stiff, strong material.
- Glass transition temperature of 74°C.
- Good for mechanical cleaning, dishwasher safe
- High refractive index of 1.575, ideal for internal reflection of UV-C light.
- Nonreactive and food-safe.

Acrylic (handle)

- Rigid material with good impact strength.
- Glass transition temperature of 84°C.
- UV-resistant.

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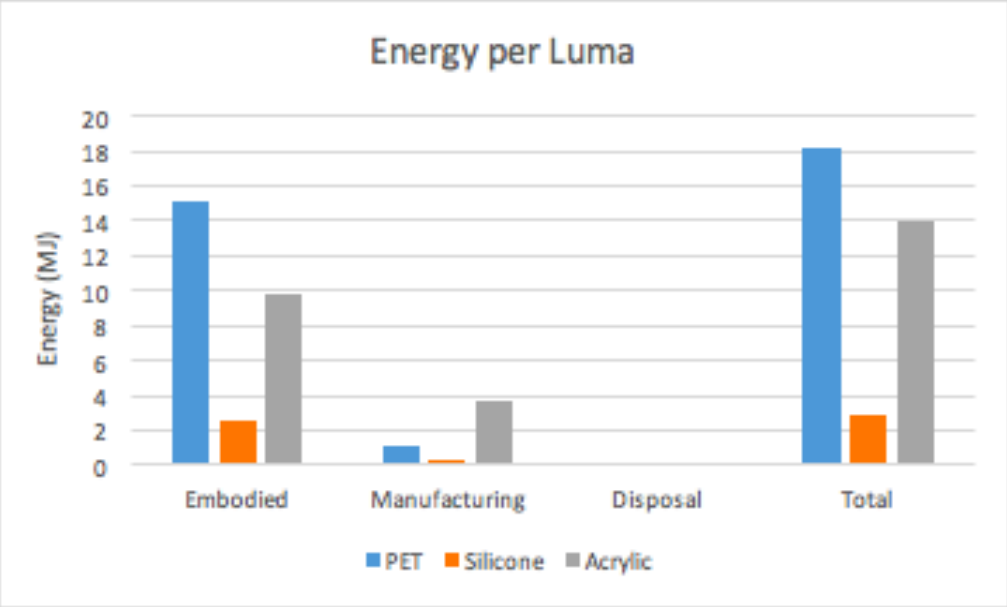
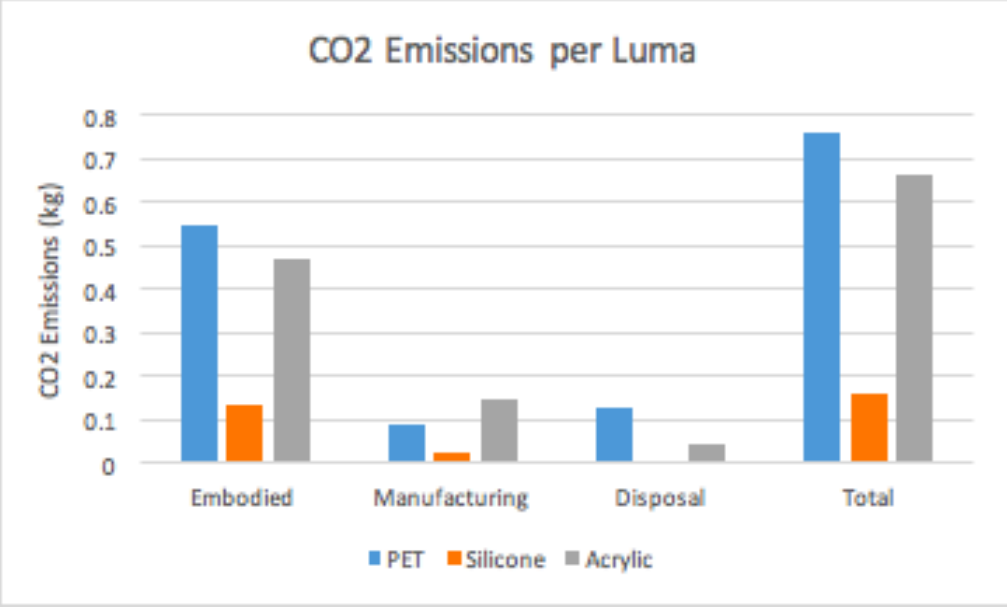
Life Cycle Analysis per Luma





Energy (MJ)				
	Embodied	Manufacturing	Disposal	Total
PET	15.121	1.178	0.126	18.096
Silicone	2.540	0.303	0.003	2.871
Acrylic	9.862	3.693	0.044	13.923

CO2 Emissions (kg)				
	Embodied	Manufacturing	Disposal	Total
PET	0.543	0.088	0.126	0.758
Silicone	0.133	0.024	0.003	0.160
Acrylic	0.471	0.145	0.044	0.660

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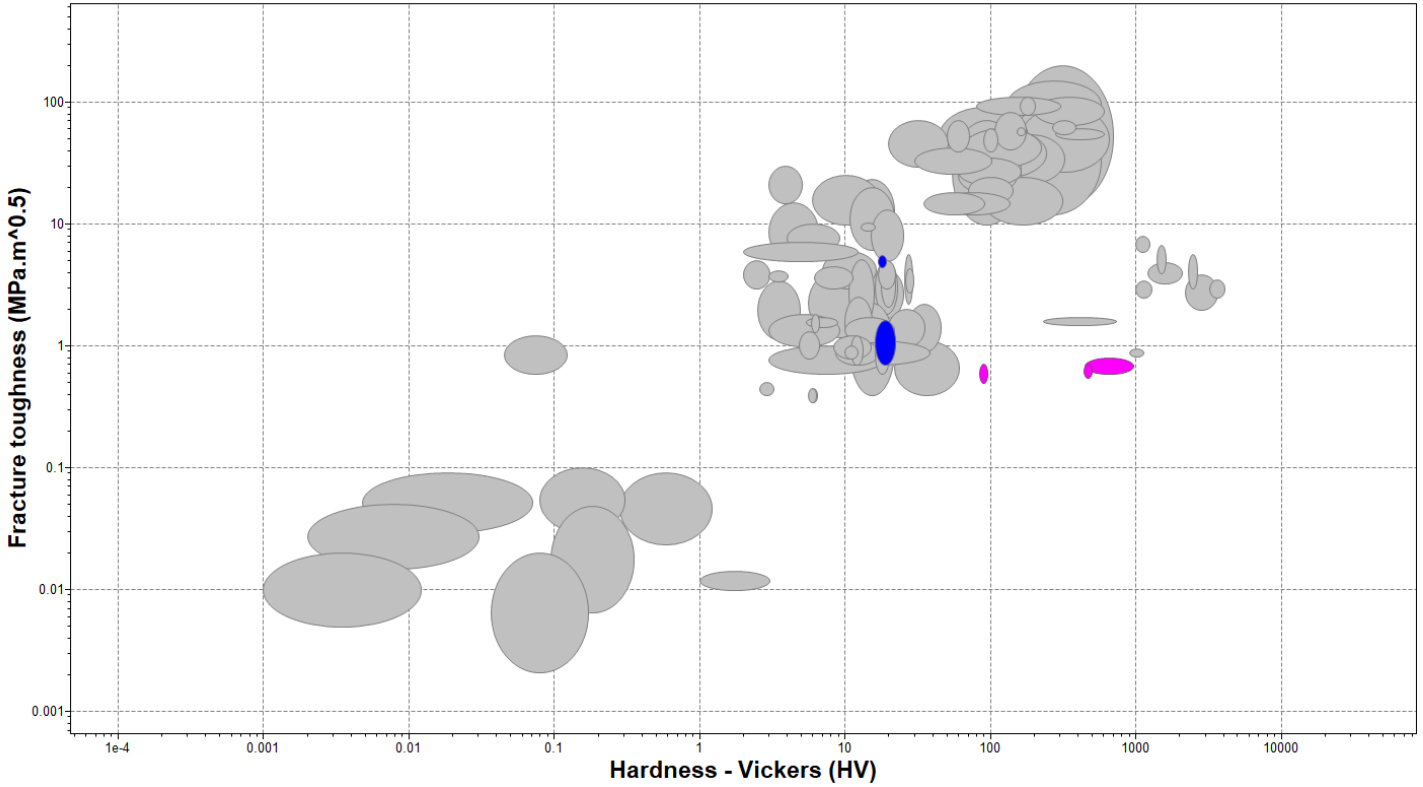
Thank you

Appendix A – Exit Interview Questions

1. Why did you stop when you stopped?
2. How did you know when a surface was clean?
3. Why did you choose each cleaning tool for each task?
4. How would you feel if we asked you to clean with a sponge that had a special antibacterial surface that did not require soap or water?
5. Would you still want to use it with soap? Or just wet it maybe?
6. How often do you clean your (house/dorm/kitchen/workplace)?

Appendix B – Scouring Fiber Material Selection

- Using CES EduPack 2018, the team conducted a materials selection in which finalists were found using the previously listed requirements and then evaluated.



Finalist Materials

- Borosilicate glass
- Polyethylene terephthalate (PET)
- Polymethyl methacrylate (Acrylic, PM...
- Silica glass
- Soda-lime glass

Appendix B – Scouring Fiber Material Selection

- Of the finalist materials, our team decided to pursue a polymer due to their superior manufacturability, low cost, and high durability.
- This left acrylic (PMMA) and PET, which were compared in terms of maximum service temperature for use and cleaning, index of refraction for efficacy as an optical fiber, and price. Of the two, PET was superior across the criteria.

	Max Service Temp (°C)	Index of Refraction	Price per Weight ($/kg)
PET	74	1.575	$1.20
Acrylic	48	1.535	$2.82

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