FALL 2020

PRODUCT DESIGN SPECIFICATION

ADDITIONAL PRODUCT

PREPARED BY

ASCEND

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PRODUCT DESCRIPTION

1.1 PRODUCT NAME

Introducing: the ErgoPad, a high-end lattice-based seat cushion and backrest with embedded optical pressure sensing.

1.2 BASIC FUNCTIONS

At its core, the ErgoPad must serve as a comfortable seat cushion, with the additional features coming in as an added benefit. The core functions include:

- Provide support to the user while seated, to reduce fatigue and pain
- Must be able to be retrofitted onto existing chairs
    - Or, built-in to chairs during production (more info on this later)
- Promote good ergonomics while in-use

1.3 SPECIAL FEATURES

What sets ErgoPad apart from other products on the market are these special features:

- Embedded fiber optic sensors to detect the user's seating position
- VIbration motors to alert the user when they are seated improperly
- Various alert scenarios and the option to turn these off if desired
- Aesthetic/interesting design
- Highly-durable
- Easily cleanable
- Excellent ventilation / thermal properties

1.4 KEY PERFORMANCE TARGETS

The ErgoPad meets the following key performance targets:

- Both pads must remain firmly attached to the chair under normal use - including shearing loads from the user moving around
- The pads must be comfortable to use for up to 8 hours
- The cushion must support users up to 250 lbs. For potential users above that weight, a larger size would need to be manufactured
- The light guide pressure sensing system must alert the user within 30 seconds of detected improper positioning
- The light guide system must not "saturate" under loading from users with high bodyweight (>200 lbs), or fail to sense with low-weight users (<100 lbs)
- The electronics must not get in the way of the user while seated
- The battery must last approximately 1 month or greater on a charge
- The EPU lattice must last 10 years of daily use at a typical room/body temperature, and must not degrade with continuous exposure to sunlight

1.5 SERVICE ENVIRONMENT CONDITIONS

The ErgoPad is expected to be used within an indoor setting, for households and offices. Since this environment tends to be temperature-controlled, the ErgoPad does not necessarily need to be designed for temperatures outside the range of approximately 50 to 100 degrees Fahrenheit (between the low bounds of room temperature and upper bounds of body temperature), though it likely could be used in a much wider range of temperatures. When being used, the pad will be under constant compression for extended periods of time, and depending on the user, this could be upwards of 12 hours a day

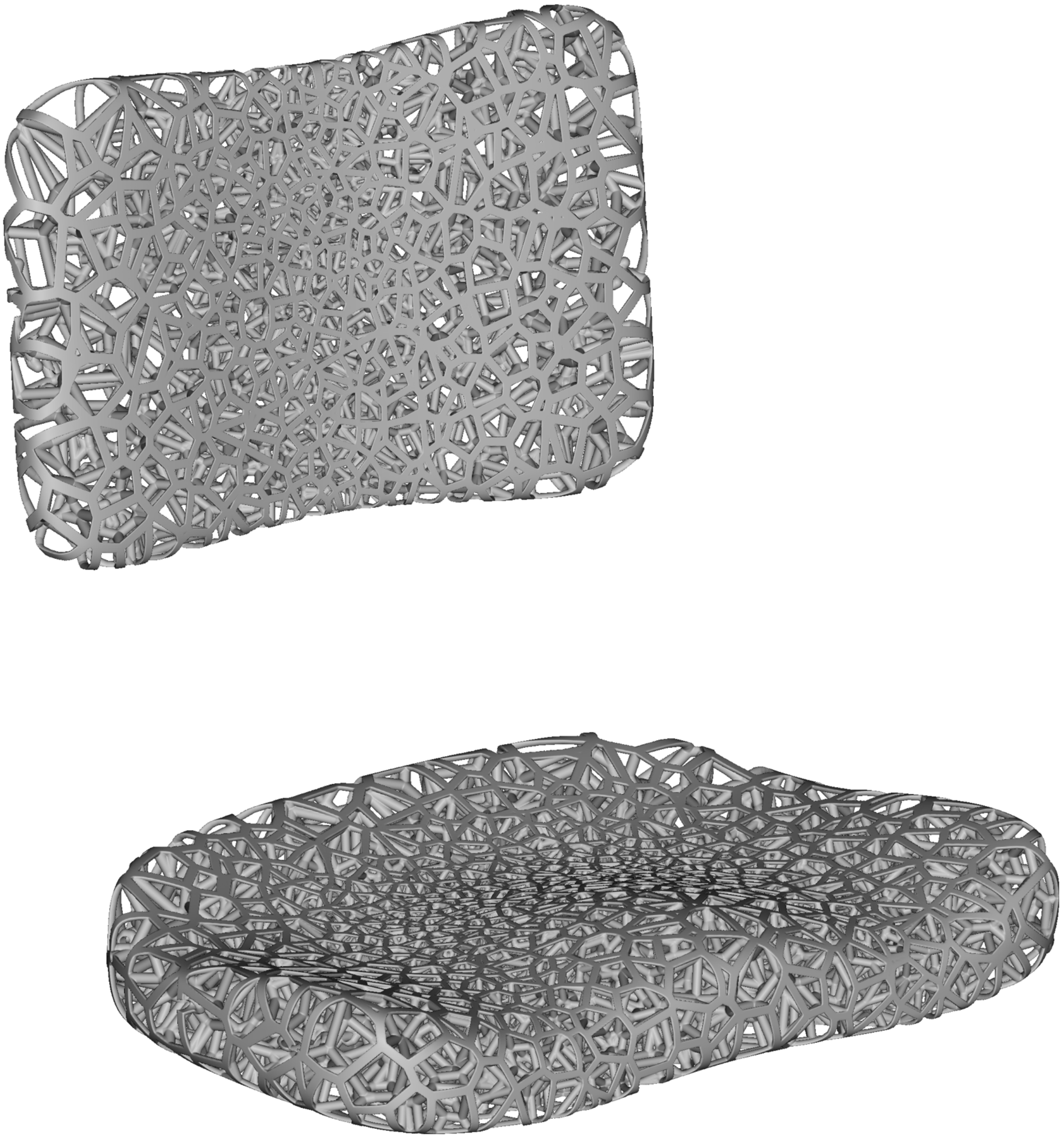
When cleaning the product, this can be done by simply detaching the cables leading from the electronics hub to the cushion. The rest of the product is entirely waterproof (the main electronics in the seat are the vibration motors, which are sealed shut) and can be submerged in soapy water and scrubbed

1.6 PREDICTION OF MISUSE CASES

Although the ErgoPad has been designed to provide a comfortable user experience in a variety of situations, the following misuse cases have been identified:

- A user exceeding the weight range for the product
- A user installing the pads in the improper position on the chair
- Forgetting to detach the electronics hub before washing the product
  - Or, improperly re-connecting this after washing
- Using this product for outdoor seating
- Using this product on a chair with a non-firm base (such as a couch)
- Failing to charge the battery

1.7 PICTURES OF CONCEPT



Render of the full system, with the backrest and the seat pad. Note that for the purposes of this render, the light guides are not shown - but more information on these and how they are positioned is included in later sections

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CUSTOMER / ENGINEERING CHARACTERISTICS

2.1 HOUSE OF QUALITY

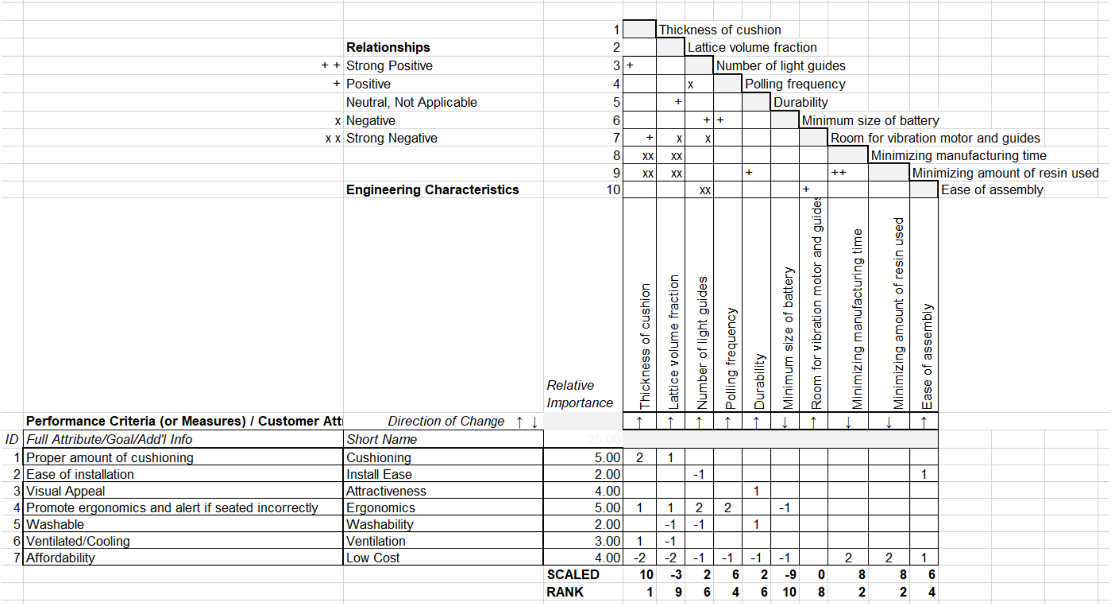
The House of Quality was used to translate the customer requirements for the ErgoPad into engineering characteristics. More information on HOQ is provided in the 4340 (VenturePak) section of this report - this section will focus mainly on how it applies to the ErgoPad specifically

The following is a summary of key trends from the engineering characteristics section:

- Increasing the thickness of the cushion allows for space for more light guides
    - However, increasing the volume fraction of the lattice decreases this space
- A higher lattice volume fraction will result in a more durable product (since there is more rubber bearing the loads)
- As the number of light guides and the polling frequency is increased, the battery will need to be increased as well due to the higher power draw
- Increasing the cushion thickness and volume fraction strongly increases both the manufacturing time and the amount of resin used
- Increasing the number of light guides makes it harder to assemble

And in the crossover between the engineering characteristics and customer attributes:

- The amount of cushioning can be improved by increasing the thickness of the cushion, and the lattice volume fraction to a smaller extent
- Increasing the number of light guides will make installation slightly more difficult
- Visual appeal will improve if the product is more durable (it will look good for longer)
- Increasing the number of light guides and the polling frequency will give better pressure sensing, make the alert system more robust
- A more durable system will be more washable
- Increasing the lattice volume fraction decreases breathability
- Affordability depends on nearly all of the engineering factors, with the amount of material / manufacturing time being the major factors



Relationships
+ + Strong Positive
+ Positive
Neutral, Not Applicable
x Negative
x x Strong Negative

Engineering Characteristics

	1	2	3	4	5	6	7	8	9	10
1 Thickness of cushion										
2 Lattice volume fraction										
3 Number of light guides	+									
4 Polling frequency			x							
5 Durability		+								
6 Minimum size of battery			+	+						
7 Room for vibration motor and guides	+	x	x							
8 Minimizing manufacturing time	xx	xx								
9 Minimizing amount of resin used	xx	xx			+			++		
10 Ease of assembly			xx				+			

ID	Performance Criteria (or Measures) / Customer Att Full Attribute/Goal/Add'l Info	Direction of Change ↑ ↓ Short Name	Relative Importance	Thickness of cushion	Lattice volume fraction	Number of light guides	Polling frequency	Durability	Minimum size of battery	Room for vibration motor and guides	Minimizing manufacturing time	Minimizing amount of resin used	Ease of assembly
				↑	↑	↑	↑	↑	↓	↑	↓	↓	↑
			25.00										
1	Proper amount of cushioning	Cushioning	5.00	2	1								
2	Ease of installation	Install Ease	2.00			-1							1
3	Visual Appeal	Attractiveness	4.00					1					
4	Promote ergonomics and alert if seated incorrectly	Ergonomics	5.00	1	1	2	2		-1				
5	Washable	Washability	2.00		-1	-1		1					
6	Ventilated/Cooling	Ventilation	3.00	1	-1								
7	Affordability	Low Cost	4.00	-2	-2	-1	-1	-1	-1		2	2	1
			SCALED	**10**	**-3**	**2**	**6**	**2**	**-9**	**0**	**8**	**8**	**6**
			RANK	**1**	**9**	**6**	**4**	**6**	**10**	**8**	**2**	**2**	**4**

House of Quality with customer attributes (left) and engineering characteristics (top)

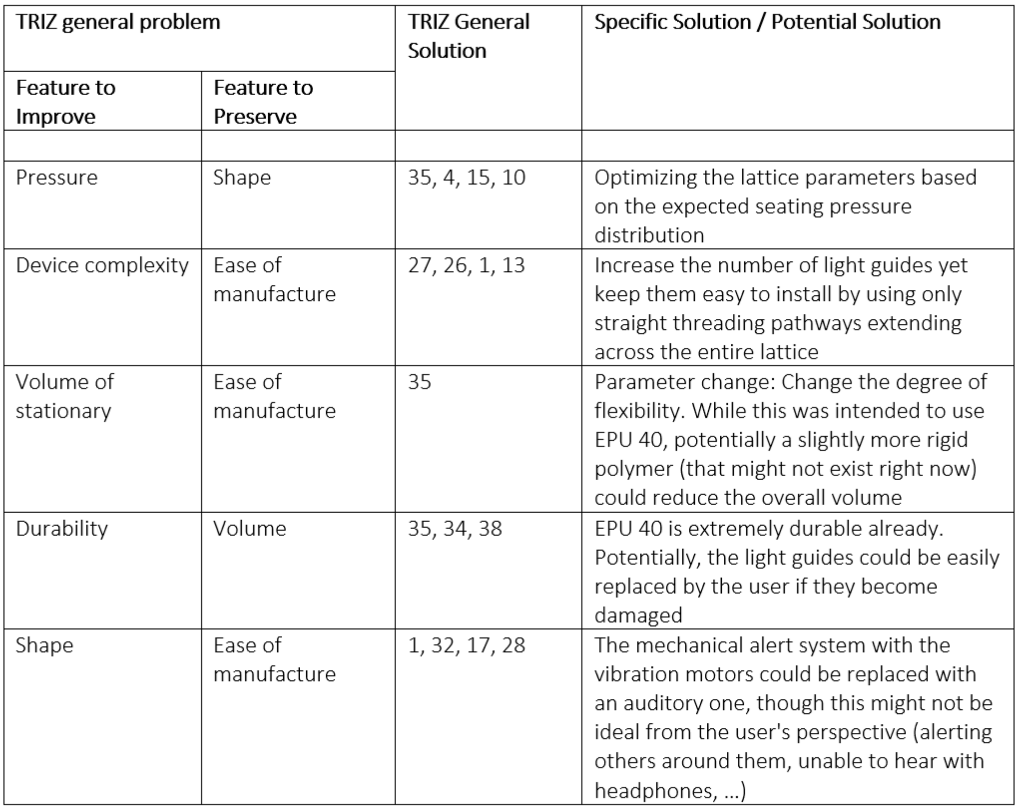
Considering the ranking of the engineering characteristics with the customer requirements, the key characteristic to design for is the cushion thickness, followed closely by the manufacturing time and the amount of resin used. This makes sense - some of the most important factors to the customer are the amount of cushioning and the total cost, of which these are a key element.

Coming in last is the minimum size of the battery, then the lattice volume fraction. The battery makes sense, the customer does not care how large the battery will need to be as this will be located out of view. The volume fraction is a very interesting one - being ranked so low, it means there is a lot of flexibility with optimizing the cushion's height versus the amount of resin used (the most important engineering characteristics).

2.2 TRIZ

The following table highlights a summary of some potential TRIZ considerations for this project. Note that many of the suggested changes from TRIZ are not possible given the predefined manufacturing requirements (additive manufacturing with Carbon DLS) and the desired goal of integrating the optical lace sensing into a consumer product.

The only TRIZ solutions that became a part of the final product were the first two in the table below, the implementation of which will be described in the next section.



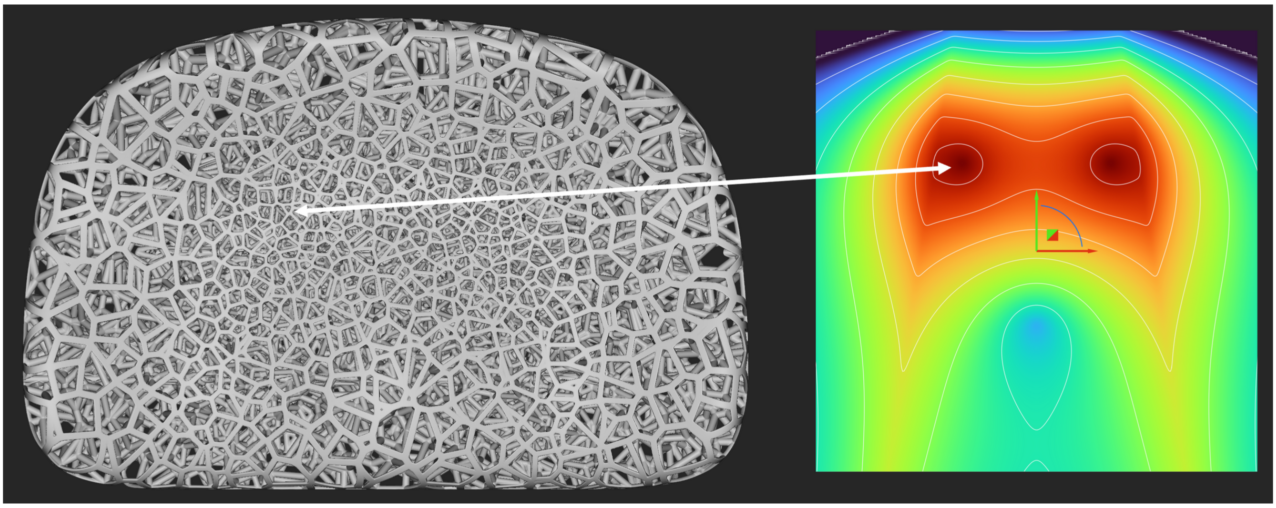
TRIZ general problem		**TRIZ General Solution**	**Specific Solution / Potential Solution**
Feature to Improve	**Feature to Preserve**		
Pressure	Shape	35, 4, 15, 10	Optimizing the lattice parameters based on the expected seating pressure distribution
Device complexity	Ease of manufacture	27, 26, 1, 13	Increase the number of light guides yet keep them easy to install by using only straight threading pathways extending across the entire lattice
Volume of stationary	Ease of manufacture	35	Parameter change: Change the degree of flexibility. While this was intended to use EPU 40, potentially a slightly more rigid polymer (that might not exist right now) could reduce the overall volume
Durability	Volume	35, 34, 38	EPU 40 is extremely durable already. Potentially, the light guides could be easily replaced by the user if they become damaged
Shape	Ease of manufacture	1, 32, 17, 28	The mechanical alert system with the vibration motors could be replaced with an auditory one, though this might not be ideal from the user's perspective (alerting others around them, unable to hear with headphones, ...)

3

PHYSICAL AND MECHANICAL DESCRIPTION

3.1 PHYSICAL DESCRIPTION

3.1.1. Lattice Generation

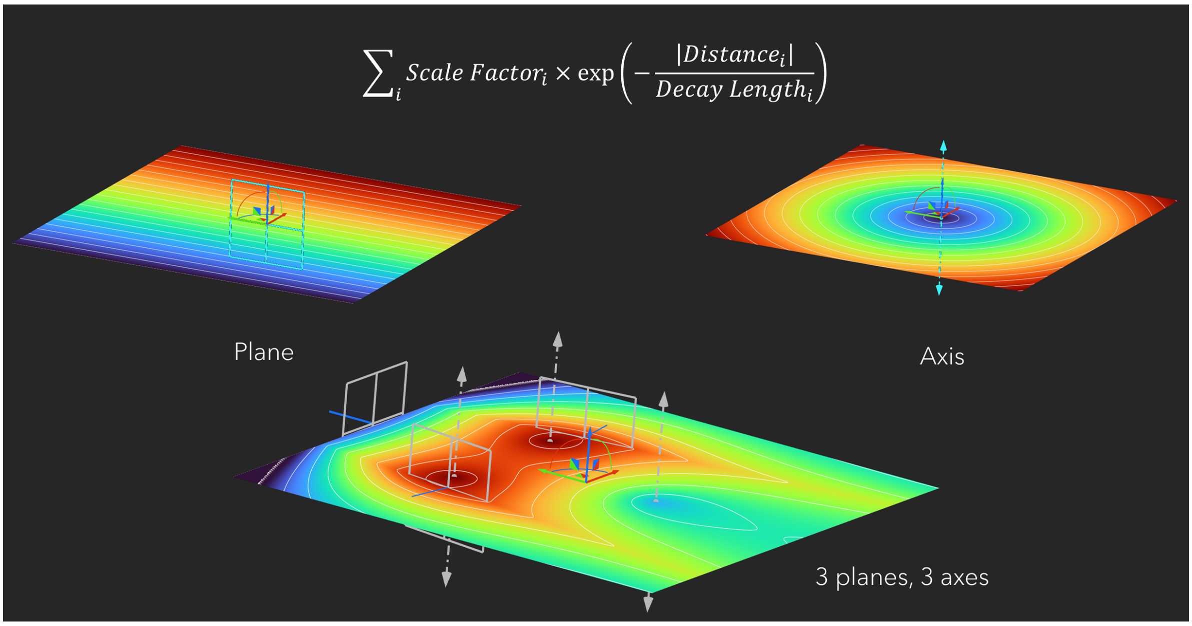


View of the seat pad lattice with the corresponding field used to scale the lattice parameters based on the expected pressure distribution

Since when seated, the user's weight is not evenly distributed over the surface of a cushion, an approximate field was generated to replicate the seating pressure distribution. This field was then used as a scaling factor for the Voronoi lattice parameters – namely, the node spacing and beam thickness. At the regions of the highest loading, the lattice was scaled to have a tighter node spacing with lower beam thickness – this improves the lattice's conformity at the pressure points, while still being strong enough to support the weight. As the lattice extends further outwards towards the sides of the cushion, both the node spacing and the beam thickness increase, to improve the support around the side and to encourage the user to remain properly centered in the seat (the most ergonomic position).

The lattice for the backrest was generated in a similar way, but with a much simpler overall field. The lattice towards the centerline of the user's spine has tighter node spacing and lower beam thickness, which both increase as the cushion extends outwards to the user's left and right sides.

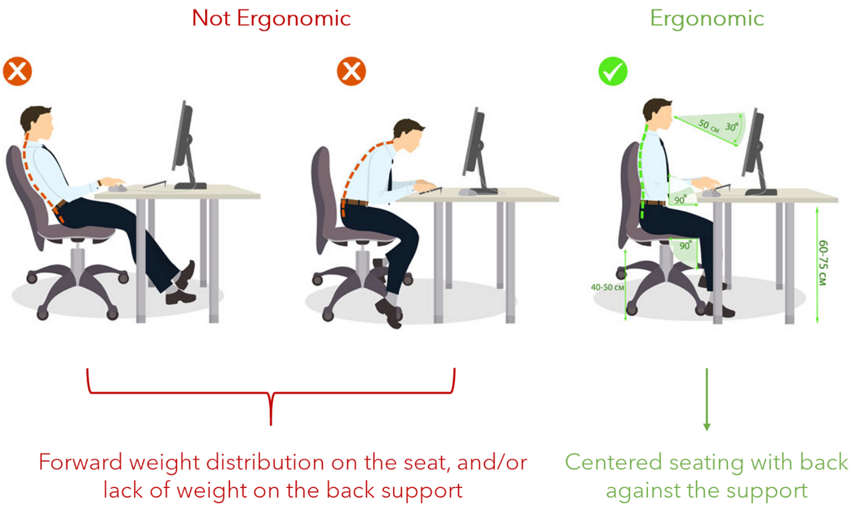
Both lattices were generated within the bounds of two freeform bodies, made to replicate a typical seat cushion and back rest.



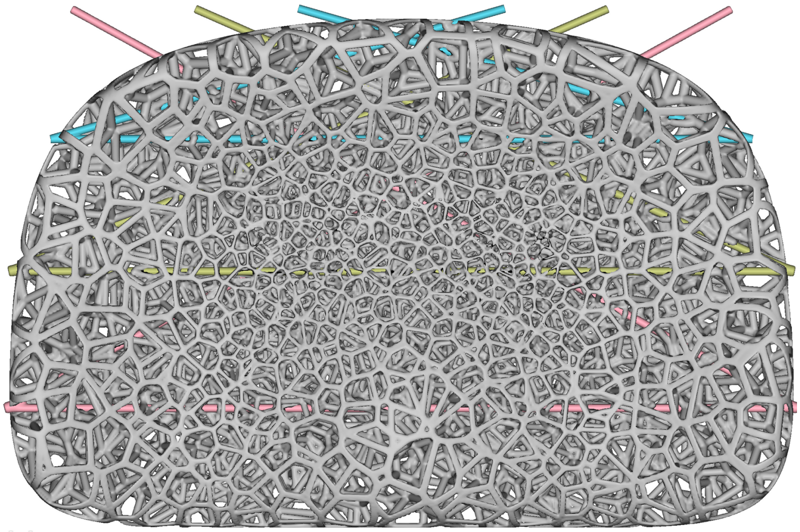
An example of the planar and axial distance fields and how these were rescaled using an exponential decay model to produce the field

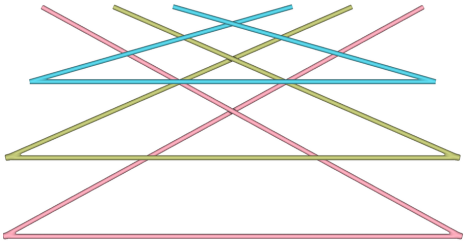
To generate this field, 3 planes and 3 axes were aligned in space, and a scaled exponential decay model was applied to each element's respective distance fields. These modified fields were then summed together to obtain the field as seen above, with the maximum pressures occurring at the user's ischium, or the "sitting bones", and with a slightly lower pressure distributed over the bottom of the legs.

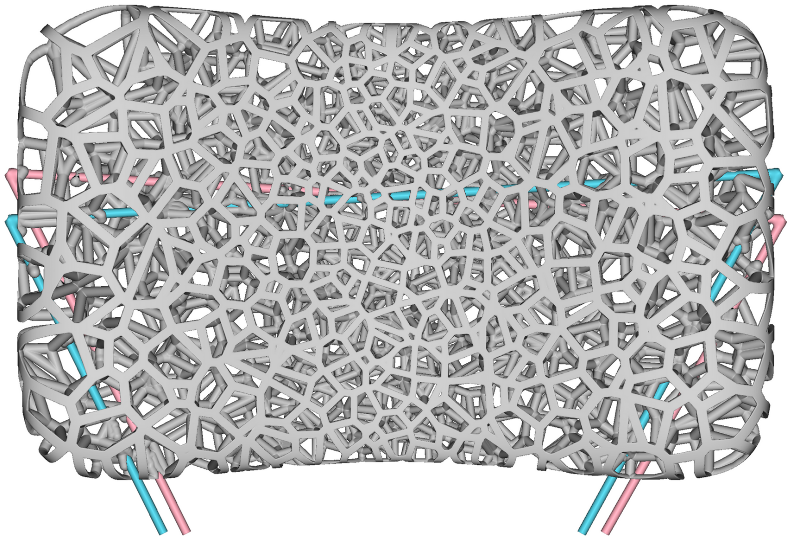
3.1.2 Sensing / Optical Lace Overview

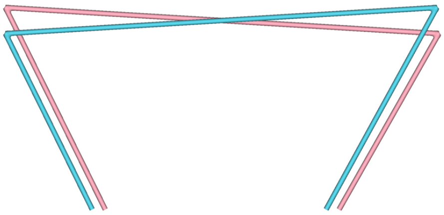


The basis for detecting improper posture depends on where the user's weight is distributed on the seat while using it. As seen in the figure above, non-ergonomic cases are characterized by a forward weight distribution and/or a lack of weight on the seat back, whereas the weight is properly distributed in the ergonomic case. A system with distributed pressure/deformation sensing will be able to tell the position of the user, and then be able to alert them of this.



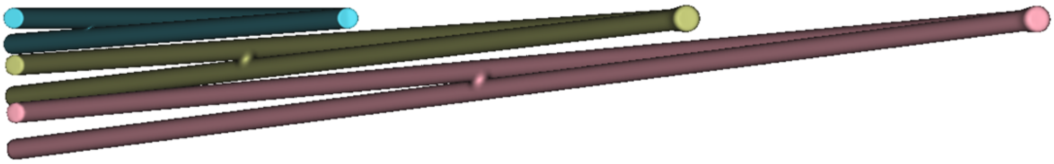




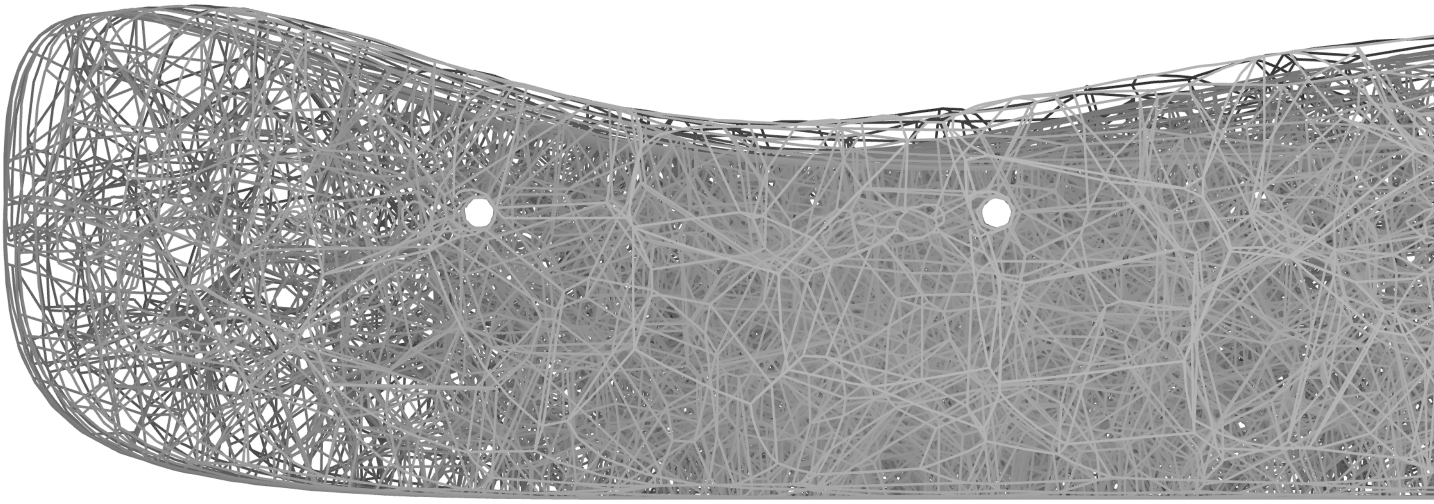


Shown above are both the seat pad (top) and the backrest (bottom) along with their corresponding light guide pathways. Different colors are shown for visual effect; the frequency of light used in the guides in the final version of the product may vary

Each light guide contains an LED at one end, and a photodiode at the other. Coupling between the guides upon compression of the lattice re-routes light and changes the signal at the photodiodes, which can be used to determine the pressure distribution. For more technical information on these, refer to (Xu, 2019) - this report primarily focuses on the product design application of this.



The routing pathways were designed so that the light guides will overlap but only contact each other once a load is applied. Above is a side view of the light guide pathways in the seat pad, where this overlapping design is most visible. Additional empty space was included in the lattice at these overlap areas, to ensure that they would properly couple.



And lastly, the lattice was also designed with the knowledge of these routing paths within the overall domain – the seed points determining where the beam elements of the Voronoi lattice are located were created such that none fell within the negative space required for the light guide paths. The figure above shows an unthickened view of the lattice, with paths clearly visible

3.1.3. System Integration

The ErgoPad system was designed for easy attachment to a user's preexisting desk chair. The seat pad can simply rest on the chair and the friction between the rubber and their chair will hold it in place, and the backrest pad can attach to the chair via straps. All wires are fed under the chair to the electronics hub, which contains the battery, LEDs, sensors, and microcontroller.

If this was built-in to a chair in production, the setup would be the same, but with these pads permanently attached.

3.1.4. Alert Functionality

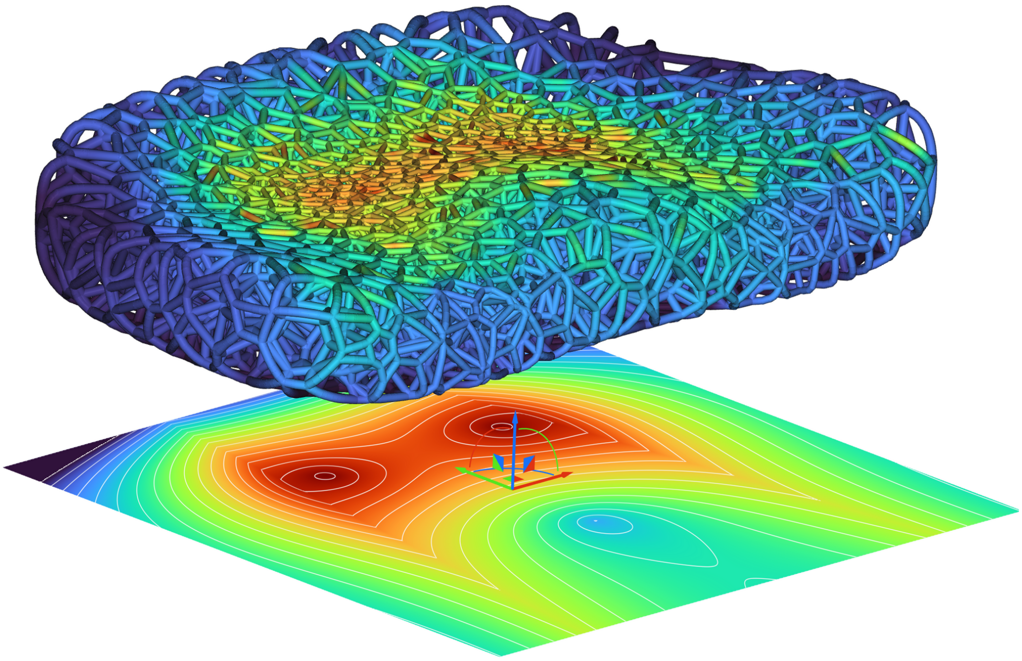
Slouching / leaning forward? → Both left and right sides vibrate

Putting too much weight on one side? → Side with most pressure vibrates

Sitting for too long without a break? → Both sides alternate vibration

The above diagram gives an overview of some possible improper seating positions, and the corresponding behavior of the vibration motors to alert the user of how to correct this. The vibration motors will both be located at the front end of the seat pad, underneath each leg. This is the optimal location for these as even if the user is slouching forward in the seat, their legs will still be positioned over these motors, and they will still feel the alert. Any of these alerts can be turned off as desired by the user.

3.2 MECHANICAL ANALYSIS



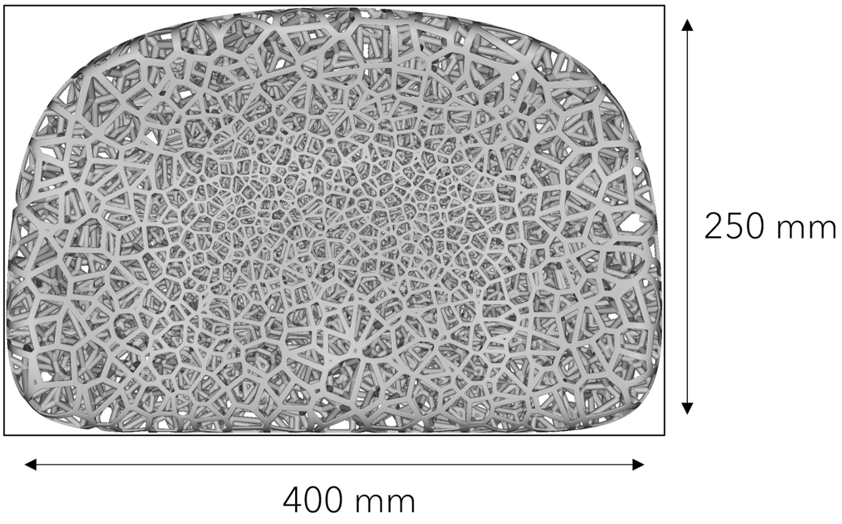
An FEA model was run to test the displacement of the lattice structure under the expected pressure distribution from an average 150 lb user. To create the model, the finite elements were discretized by the lattice beam elements (rather than with a tetrahedral mesh), to dramatically simplify the computation process. The material in the analysis used the same elastic modulus and Poisson's ratio as EPU, but considered it strictly linear elastic rather than nonlinear - another simplification to ease the computations.

Under this load, a maximum displacement of 30 mm out of the maximum cushion thickness of 50 mm was observed. Failure by stress is not a concern with EPU under loads of this magnitude. The lattice deformed as expected, with no uneven areas which would cause discomfort

4

MANUFACTURING

4.1 MANUFACTURING OVERVIEW



Above: the ErgoPad overlaid on the Carbon L1 printbed

The ErgoPad has been specifically designed with the Carbon L1 printer in mind. The only way to manufacture a lattice such as this is through additive manufacturing, and Carbon's EPU 40 (elastomeric polyurethane) is the perfect material for this lattice, being highly elastic and tear resistant. Carbon's L1 is the mass-manufacturing version of their DLS (digital light synthesis) printers which cure the resin with light for an extremely high surface accuracy. Along with the L1, their Smart Part Washer will be used to easily clean the lattice with less manual labor.

Additional orientations of the ErgoPad on the printbed were considered, but the flat bottom on the printbed is likely the optimal way of manufacturing this. The alternative would be rotating it such that the part's shorter edge is towards the printbed (with support material), which has the advantage of being able to print about 4 parts at once, but at the significant disadvantage of EPU "wobble" when printing long lengths of EPU.

The backrest pad is smaller than the seat pad (approximately 350x200x30 mm) and will fit on the printbed easily, though not at the same time as the seat pad. So, two prints would be required to produce the full system.

For the light guide assebmbly process, all pathways through the lattice for the guides are straight and pass through the entirety of the structure. Because of this, the light guides can be temporarily attached to a threading tool and easily routed through the lattice. If these pathways were curved or terminated within the cushion, this process would be significantly more difficult.

4.2 MANUFACTURING COSTS

At Carbon's current price of $250/L for EPU 40:	
Seat	$239.40
Back	$102.24
Total	**$341.64**

At Carbon's target price of < $100/L for mass-manufacturing:	
Seat	$96.00
Back	$41.00
Total	**$137.00**

Material costs for the ErgoPad. This assumes part volumes of 0.96 L for the seat pad and 0.41 L for the back pad

The manufacturing costs and consumer pricing are driven almost entirely by the EPU resin and the annual operating costs of the Carbon L1 printer. As seen in the table above, currently it would cost $341.64 to purchase just the resin necessary for the parts. However, Carbon has mentioned that they are trying to get their prices down below $100/L for mass-manufacturing, which would bring the resin costs down to $137.

But, this does not yet consider the operating cost of the L1, which Carbon has currently set at $250,000/year. Distributing this cost on a per-part basis depends wholly on the number of ErgoPads that one machine can produce in a year. Under the generous assumption that it would take 4 hours to print both the seat and back pads, one machine could print 2190 ErgoPads per year, meaning there is a minimum $114 addition to the production cost because of this.

Considering the few additional parts (light guides, LEDs, photodiodes, microcontroller, battery, wiring, and electronics housings), these are estimated to cost (from Alibaba):

4 LEDs	$0.12
4 photodiodes	$1.20
Microcontroller and custom PCB	$5.00
Battery	$6.00
Light guides and wiring	$1.00

Labor costs will be minimal as this has been designed to be extremely easy to assemble, and Carbon's Smart Part Washer will help with this as well. An estimate of 20 minutes of total labor per part would add $6.67 at an hourly labor rate of $20.

Including all of these, the total manufacturing cost, assuming Carbon's targeted mass-manufacturing resin prices, will be at minimum **$271**.

5

MARKET ANALYSIS

5.1 COMPETITORS

The primary competitor for this product is "LifeChair: A Conductive Fabric Sensor-Based Smart Cushion for Actively Shaping Sitting Posture," a research project out of the University of Tsukuba, Japan. While this appears to not be a consumer product as of yet, their use case and vibration alert system is extremely similar to the one presented in this report. (Note: this was discovered after all of the design work for this project was completed). They do have a patent on this application, but only in Australia - see AU2017101323B4. The primary difference here is that they are using conductive fabric for pressure sensing, rather than lattices and optical lace.

The Purple Double Seat Cushion ($99) is similar to a lattice with a flexible rubber material, but this does not contain any means of pressure sensing or alert

The Smart Check® by ROHO® is a cushion feedback system for inflatable wheelchair cushions. This is currently being sold on Amazon for $498.

5.2 PRICING

Given these reference prices and the cost to manufacture the ErgoPad, a target price would be $499 for direct-to-customer distribution, or selling to retailers for $450 with a MSRP of $600. Another alternative would be licensing this technology to a company such as HermanMiller, which deals in high-end furniture with prices upwards of $2000. Whereas the profit margin for a standalone product is 40-45%, this can be significantly higher in a fully integrated chair, which may cost $300 to manufacture (estimated) on top of the $271 of the ErgoPad. Selling this at $2000 would yield a profit margin of around 71%.

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