

NEST

Shapeable Magnetic Wireless Charger

Prototype documentation and research report: architecture, core material, wireless charging, thermal behaviour, load and stability, top-ring thermoforming, manufacturing.



Project

ABK Stuttgart, Industrial Design, Summer Semester 2026

Brief

Refill — Designing Energy Rituals

Object

NEST — a shapeable MagSafe wireless charger

Document

Technical documentation and research report, 7 sections

Date

3 August 2026

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Key Specifications

Table 1 Prototype key data.

Parameter	Value
Total mass (measured)	340 g
Core	250 g microcrystalline wax + 30 g mineral oil = 280 g
Default shape, L × W × H	105 × 100 × 68 mm
Base contact diameter	82 mm
Charging module	Ø 65 mm, 9 mm thick, USB-C input
Charging power / power adapter	10 W / USB-C PD ≥ 20 W
Coil cover (housing wall + fabric)	1.0 + 0.8 = 1.8 mm
Temperature limits	wax bladder ≤ 55 °C, coil surface ≤ 55 °C, touch surface ≤ 43 °C
Top ring	PLA, Ø 54 / 50 × 2.5 mm, thermoformed at 65–70 °C

1

Product Architecture

NEST consists of three sub-assemblies: a charging module, a wax–oil core and a textile skin. The charging module at the top provides magnetic alignment and wireless charging; the core adds weight and can be reshaped by hand; the textile skin covers both and holds them together.



Figure 1 Parts and iterations. **Figure 2** Assembled units, opened module.

1.1

Bill of Materials

Table 2 Parts list of the prototype.

No.	Part	Material and process	Mass g
P01	Charging module housing (incl. USB-C tab)	PLA, FDM printed	10
P02	Transmitter coil	Flat copper litz coil, supplied with charging board	6
P03	Magnet array	NdFeB arc magnets in a ring around the coil	8
P04	Charging control board	Generic wireless transmitter board, marked “15W”, on-board USB-C	6
P05	White top ring	PLA, FDM printed, thermoformed; clamps fabric edge	1.0
P06	Top fabric cover	Same fabric as P09, 0.8 mm	1
P07	Inner bladder	PET film bag, sealed	3
P08	Filling	250 g microcrystalline wax + 30 g mineral oil	280
P09	Outer skin	Two-way stretch knit, cut, sewn and overlapped	22
P10	Adhesive	Textile glue	2
Total (measured)			340

The mass of P05 is calculated from the STL dimensions: $\pi \times (27^2 - 25^2) = 327 \text{ mm}^2$, $\times 2.5 \text{ mm} = 817 \text{ mm}^3$, at a PLA density of $1.24 \text{ g/cm}^3 = 1.0 \text{ g}$. The other part masses are reference values, not weighed individually, allocated from the measured total of 340 g; their sum is 339 g.

1.2

Section

Figure 3 shows the default shape in section. The charging module rests on top of the core; the white top ring (P05) clamps the edge of the fabric cover (P06) onto the module face; the inner bladder (P07) separates the wax–oil mixture from the fabric and the electronics.

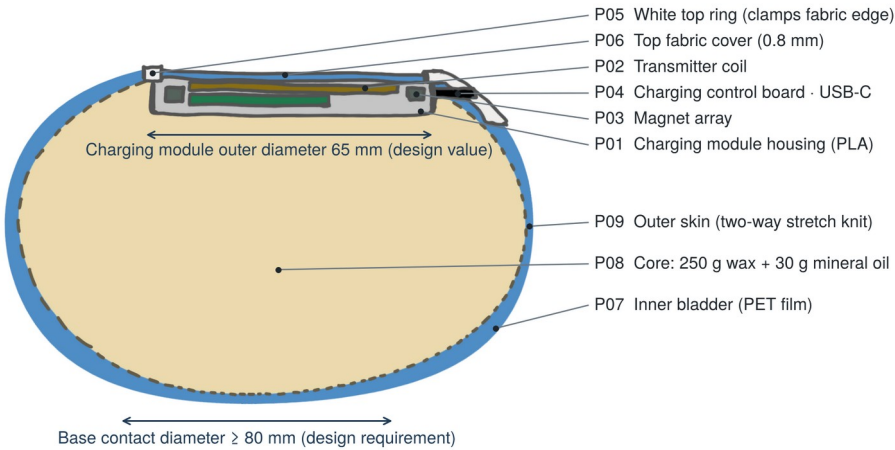


Figure 3
Hand-drawn section of the default shape, not to scale. Part numbers as in Table 2.

1.3

Main Dimensions

Table 3 Main dimensions of the prototype.

Parameter	Value
Charging module diameter / thickness (incl. cover)	65 / 9 mm
Housing wall above coil	1.0 mm
Transmitter coil diameter	43 mm
USB-C tab, length × width	14 × 12 mm
Top ring, outer Ø / inner Ø / thickness	54 / 50 / 2.5 mm
Top ring arc height after bending	6 mm
Default shape, L × W × H	105 × 100 × 68 mm
Base contact diameter, default shape	82 mm
Cover fabric / skin fabric thickness	0.8 / 0.8 mm

2

Core Material and Forming

2.1

Formulation

The core is a mixture of **250 g** microcrystalline wax and **30 g** mineral oil: 280 g in total, a mass ratio of 25 : 3, i.e. 89.3 wt% wax and 10.7 wt% oil.

The wax forms the structure of the core; the oil adjusts the resistance to pressing. More oil makes the core easier to shape but can also increase slow deformation when the core carries a phone for a long time. The oil content is set so that the core can still be shaped by hand but keeps its shape under the phone. The actual feel also depends on the raw-material grade and on processing; the wax grade and its drop melting point are still to be confirmed.

2.2

Forming Resistance

Three terms are used here. **Forming resistance** is the reaction force felt when the shape is changed. **Forming force** is the force needed for one specific press. **Shape retention** is the ability to keep holding the phone after release. At material level, needle penetration describes empirical hardness, and yield stress is the stress at which clear irreversible deformation begins. They relate to the feel, but they do not give the forming force of the whole product.

The mean contact pressure of a hand press is:

$$p_{\text{avg}} = F / A_{\text{contact}} \quad (1)$$

For a hand force of 20–40 N on a contact area of 2 cm², the mean pressure is **100–200 kPa**.

2.3

Strength Window

A 220 g phone weighs 2.16 N. Spread over a 65 mm charging face this gives a mean pressure of 0.65 kPa, about 1/150 to 1/300 of the hand pressure. The core must keep its shape under the phone and deform plastically under the hand. With safety factors of 5 and 2 on each side, the yield stress of the wax–oil mixture at 23 °C should lie between **3.3 kPa** and **50 kPa**.

2.4

Enclosure

The inner bladder (P07) is a PET film bag; the outer skin (P09) deforms with the core and limits its outward expansion. The bladder seal and the skin seams are offset so that the bladder seal does not lie directly under a seam. The felt forming force also depends on bladder tension, fabric stretch and contact friction, so the formulation cannot be judged without the enclosure. The sealing method of the bladder (heat seal or adhesive) is still to be confirmed.

3

Wireless Charging System

Power from the USB-C input drives the transmitter coil via the control board; the receiver coil of the phone converts the alternating magnetic field into charging power. The magnet array aligns and holds the phone.

Table 4 Charging system of the prototype.

Item	Specification
Charging board	Generic wireless transmitter board, marked “15W”; model to be confirmed
Input	USB-C: VIN, GND, CC1, CC2, DP, DN
Operating power	10 W
Power adapter	USB-C PD fast charger, rated ≥ 20 W
Phone alignment	Magnet array (P03) in a ring around the coil
Cover above coil	Housing wall 1.0 mm + fabric (P06) 0.8 mm = 1.8 mm
Over-temperature protection	Built into the board, 85 °C

3.1

Coil Distance

Whether charging starts depends on the distance between the transmitter coil surface and the receiver coil of the phone. The datasheet of the comparable Qi transmitter module QST QPT-0036A specifies 4.0–6.0 mm. In the prototype this distance has three parts:

$$d_{\text{Tx-Rx}} = t_{\text{wall}} + t_{\text{fabric}} + d_{\text{phone}} \quad (2)$$

The phone-side distance depends on the phone back and case and cannot be controlled by the design. Taking 5 mm as the upper limit, reserving 2.5 mm for the phone side and keeping a 0.5 mm margin, the module side must not exceed 2.0 mm. The prototype has 1.0 mm + 0.8 mm = **1.8 mm** and meets this requirement.

3.2

Further Development

The prototype uses a generic charging board. In further development it can be replaced by a certified Qi2 15 W module mounted on bosses in a moulded base shell; the effect of the higher power on heat is discussed in 4.1.

4

Thermal Behaviour

Heat from charging flows into the core, and the stiffness of the core changes with temperature.

4.1

Heat Loss

The loss is calculated with an end-to-end efficiency of $\eta = 60\text{--}75\%$:

$$P_{\text{loss}} = P_{\text{in}} (1 - \eta) \quad (3)$$

- Prototype: 10 W input, 6.0–7.5 W to the phone, loss **2.5–4.0 W**.
- Qi2 15 W option: 20–25 W input, loss **5.0–10.0 W**, 1.3 to 4 times the prototype.

Part of the loss occurs inside the phone and does not reach the core. With higher power, however, the prototype temperature data no longer apply and must be measured again.

4.2

Temperature Limits

- **Wax bladder top surface $\leq 55\text{ °C}$:** limits softening and slow deformation of the wax–oil mixture.
- **Coil surface / PLA housing $\leq 55\text{ °C}$:** the PLA used has a glass transition temperature of 60 °C , a Vicat softening temperature of 57 °C and a heat deflection temperature of 54 °C at 1.8 MPa .
- **User touch surface $\leq 43\text{ °C}$:** conservative limit for prolonged contact.

The board's over-temperature protection only trips at 85 °C , above the softening range of PLA, so it cannot protect the housing and the core. The prototype therefore uses 55 °C as its check value; if it is exceeded, a lower-power adapter or shorter charging sessions are used.

4.3

Heating Model

Treating the core as a body of near-uniform temperature, with constant heat input and cooling, starting from ambient temperature:

$$T_c(t) = T_a + Q_{\text{in}} R_{\text{th}} [1 - \exp(-t / \tau)], \quad \tau = R_{\text{th}} C_{\text{eff}} \quad (4)$$

T_c is the representative core temperature, T_a the ambient temperature, Q_{in} the heat input into the core, R_{th} the equivalent thermal resistance to the surroundings and C_{eff} the equivalent heat capacity. Heat input and heat capacity set the initial heating rate; heat input and cooling together set the final temperature rise $Q_{\text{in}} R_{\text{th}}$.

4.4

Temperature and Forming Force

The heating curve gives the core temperature over time; the forming force follows from the yield stress of the wax–oil mixture at that temperature. A press changes the shape once the contact pressure (1) exceeds the yield stress; the enclosure adds its own resistance:

$$F_{\text{form}}(t) = \sigma_y(T_c(t)) \cdot A_{\text{contact}} + F_{\text{encl}} \quad (5)$$

$$\sigma_y(T) = \sigma_{y,23} \cdot \exp[-\beta (T - 23\text{ °C})] \quad (6)$$

$\sigma_{y,23}$ is the yield stress at 23 °C, which must lie within the strength window of 2.3. β is the softening coefficient of the mixture; it is determined by press tests at two or more core temperatures. F_{encl} is the resistance of bladder and skin (2.4). Inserting $T_c(t)$ from (4) gives the forming force at any time during charging. Oil content, pressing speed and earlier heating also change σ_y ; they are held constant in this model. The feel of the prototype while charging at different ambient temperatures was observed as follows:

Table 5 Observed feel of the prototype during charging (subjective, no force measurement).

Ambient	Start	1 h	2 h	4 h
15 °C	firm	fairly firm	medium	slightly soft
26 °C	fairly firm	medium	slightly soft	soft
32 °C	medium	slightly soft	soft	very soft

NEST is intended to be shapeable by hand at room temperature; the temperature rise during charging is a secondary factor for feel and support. A softer core is easier to shape, but it also holds the phone less firmly.

5

Load and Stability

5.1

Load

The phone load passes through the rigid charging module, the fabric cover (P06) and the inner bladder (P07) into the core and on to the table. With a 340 g device, a 220 g phone and a 65 mm charging face, the phone weighs 2.16 N and the mean pressure is 0.65 kPa. The design goal is no visible permanent deformation of the core under this normal load. The value indicates the order of magnitude of the load, not the local stress inside the core.

5.2

Tipping

With the effective base width b , an offset x of the combined centre of gravity towards the tipping edge, and a horizontal force F_h acting at height h :

$$M_{\text{restore}} = (m_{\text{NEST}} + m_{\text{phone}}) g (b/2 - x) \quad (7)$$

$$M_{\text{tip}} = F_h h \quad (8)$$

A 1.5 N tap applied perpendicular to the screen at the top of a phone tilted at 60° has a horizontal component of $1.5 \times \sin 60^\circ = 1.30$ N. At a height of 130 mm this gives a tipping moment of **0.169 N·m**.

Table 6 Tipping check for three support conditions.

Support condition	M_{restore} (N·m)	$M_{\text{restore}} / M_{\text{tip}}$	Result
$b = 60$ mm, centred	0.165	0.98	tips
$b = 80$ mm, centred	0.220	1.30	stable
$b = 80$ mm, 10 mm offset	0.165	0.98	tips

The base contact diameter of the prototype in its default shape is **82 mm** and meets the 80 mm requirement. A wide base alone is not enough: the higher the posture and the further the charging module projects, the larger the offset and the easier the same lateral force tips the device. The user should therefore spread the base so that the charging module sits directly above the support area.

6

Top-Ring Thermoforming

The white top ring is printed flat and then thermoformed into an arc. Bending it to the target arc at room temperature brings the stress close to the flexural strength of PLA (6.2), so it is formed hot.

6.1

Geometry and Boundary Conditions

The ring has an outer diameter of 54 mm, an inner diameter of 50 mm, an axial thickness of 2.5 mm and a radial band width of 2 mm. For the analysis, both sides of the ring are treated as supports 54 mm apart; a punch loads the ring normal to its plane between the supports, and the mid-span deflection is δ . A narrow punch would create a stress concentration and could leave dents or cause layer separation, so a wide punch with a matching curved support is used to spread the load over an arc.

6.2

Bending Force

The ring is simplified as a simply supported straight beam with span $L = 54$ mm and cross-section $b = 2$ mm, $t = 2.5$ mm, bent out of plane. The flexural modulus of PLA at room temperature is $E = 2750$ MPa (XY).

$$I = b t^3 / 12 = 2.60 \text{ mm}^4 \quad (9)$$

$$F = 48 E I \delta / L^3, \quad M_{\max} = F L / 4, \quad \sigma_{\max} = M_{\max} (t/2) / I \quad (10)$$

Table 7 Bending force and stress for three arc heights (small-deflection linear-elastic beam).

Arc height δ	Force F	Moment $M_{\max}$	Nominal stress $\sigma_{\max}$
2 mm	4.4 N	0.059 N·m	28 MPa
5 mm	10.9 N	0.147 N·m	71 MPa
10 mm	21.8 N*	0.295 N·m	141 MPa*

5 mm is close to the limit of the small-deflection model. * Extrapolated values; not valid as actual load or stress.

The flexural strength of this PLA at room temperature is 76 MPa (XY). At an arc height of 5 mm the nominal stress already reaches **71 MPa**, about 93 % of the strength. The design arc height is 6 mm; extrapolated linearly, this gives about 85 MPa, above the flexural strength. Bending to the target arc at room temperature would therefore crack the ring, so it is formed above the glass transition temperature.

6.3

Temperature and Formability

The PLA used has a glass transition temperature of 60 °C, a Vicat softening temperature of 57 °C and heat deflection temperatures of 54 °C (1.8 MPa) and 57 °C (0.45 MPa). At **65–70 °C**, 5–10 °C above the glass transition, the ring is pressed to the stop contour of the fixture and keeps this shape after cooling below 40 °C.

6.4

Thermoforming Procedure

- 1. Preparation.** Remove the ring from the assembly, deburr it and sand the flat faces smooth.
- 2. Fixturing.** Support both sides on blocks matching the target contour; use a wide punch in the bending zone and a stop contour to define the final shape.
- 3. Even preheating.** Support the full ring and place it in a convection oven; hold for 2 min once the part reaches 65 °C.
- 4. Slow forming.** Transfer immediately to the fixture and press steadily with the wide punch to the stop contour.

5. **Cooling under load.** Keep the ring against the fixture until it is below 40 °C before release; do not twist it, so that the fixture defines the final shape.
6. **Inspection and assembly.** Check arc, joint faces and central opening against a contour template, then trial-fit with the charging module.

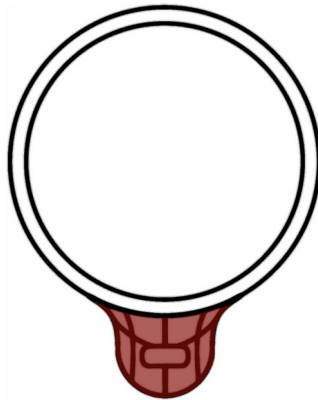


Figure 4

Top ring. The red area is the bending zone, 28 × 32 mm.

7

Manufacturing and Assembly

The prototype is built and checked as three sub-assemblies (charging module, sealed core and textile skin) before final assembly. The electronics are tested under power first, and the core enters assembly only after sealing and cooling, so the electronics never come into contact with the hot filling.

7.1

Prototype Process

1. **Printing.** FDM-print the module housing (P01) and the top ring (P05); remove supports and burrs.
2. **Ring thermoforming.** Form according to 6.4; check for cracks, delamination and twist.
3. **Electronics assembly.** Fit magnet array, coil and control board; align USB-C with the tab opening; fix the wiring. Confirm uniform magnet polarity with a phone attachment test.
4. **Power test.** Supply via USB-C and place a phone; confirm that charging starts and that an offset phone snaps back into alignment.
5. **Weighing and filling.** Weigh 250 ± 1 g wax and 30 ± 0.5 g oil, melt and mix, then fill the bladder.
6. **Sealing and cooling.** Clean and seal the opening, cool to room temperature; check for trapped filling and leakage; net mass 280 ± 1.5 g.
7. **Skin.** Cut the fabric to pattern, overlock, and make the top cover (P06) with the stretch direction as marked on the pattern.
8. **Final assembly.** Insert the core into the skin; glue the cover and skin edges to the top ring and module, keeping glue and wires away from the coil area.
9. **Final inspection.** Weigh, measure, and check charging, support posture and appearance.

7.2

Thermal Constraint

Chapter 6 shows that PLA deforms plastically at 65–70 °C, while the board's over-temperature protection only trips at 85 °C. PLA housings are therefore suitable for the prototype only, and the prototype uses a coil-surface check value of ≤ 55 °C; the textile glue and the bladder seal must also hold at this temperature.

7.3

Path to Series Production

Table 8 Prototype process and proposed series process.

Part	Prototype	Series production
Housing and top ring	PLA, FDM, thermoformed	PC/ABS (UL 94 V-0) injection moulded, bezel and base shell; wall 1.5–2.0 mm, draft $\geq 1^\circ$, USB-C opening on the parting line
Skin attachment	Textile glue	Fabric edge clamped between bezel and base when the snap fits close; no glue, removable and washable skin
Electronics	Generic charging board	Certified Qi2 15 W module on bosses in the base shell
Bladder	PET film bag	PET/PE laminate pouch, impulse heat-sealed after filling
Skin	Hand cut and sewn	CNC knife cutting and overlocking, or seamless 3D flat knitting