Empathetic Design in Advanced Humanoid Robotics

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Amber
GLADE CREATIONS

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Timothy J Drury

ABSTRACT

The successful integration of humanoid robots into domestic environments hinges not only on their technical performance but critically on their acceptance by human occupants. This report investigates how strategic application of colour, material, and finish in a robot's cladding can foster human comfort, trust, and emotional connection, moving beyond traditional industrial aesthetics. Current CMF strategies, while effective for factory settings, often present safety concerns and perceptual barriers in the home.

Analysis of surveys, interviews, and in-person observations including a live encounter with a Unitree G1 humanoid robot reveals a strong preference for advanced textiles, natural elements, and modular materials. These approaches made possible through modern additive and subtractive manufacturing methods, allow complex geometries and tactilely rich surfaces.

Ultimately, an empathetic CMF strategy, informed by psychological principles and leveraging cross-industry innovations, is essential to design robots that are not merely functional tools; but accepted, comforting presences within the household.

ABBREVIATIONS

- **AM** – Additive Manufacturing
- **ABS** – Acrylonitrile Butadiene Styrene
- **AI** – Artificial Intelligence
- **AV** – Autonomous Vehicle
- **BMW** – Bayerische Motoren Werke
- **CAD** – Computer-Aided Design
- **CFRP** – Carbon Fiber Reinforced Plastics
- **CMF** – Colour, Material, Finish
- **CNC** – Computer Numerical Control
- **EDM** – Electrical Discharge Machining
- **EMC** – Extracellular Matrix
- **ERP** – Enterprise Resource Planning
- **E-Skin** – Electronic Skin
- **HRI** – Human-Robot Interaction
- **LSR** – Liquid Silicone Rubber
- **PPS –** Polyphenylene Sulfide
- **PEEK** – Polyetheretherketone
- **ROBO** – shorthand for "robotics"
- **TPE** – Thermoplastic Elastomers

1.0 INTRODUCTION

The presence of humanoid robots is rapidly increasing as advances in AI and robotics make them more accessible to the public. Companies such as Unitree, 1X, Tesla, and Boston Dynamics are already producing humanoids, with several models now entering homes and public trials. Robots from Figure AI, for example, have been shown folding laundry in live demonstrations, while Unitree's affordable G1 is already being shipped worldwide.

Despite this progress, robotic technology requires further refinement to become less alien and more approachable. Some current prototypes move either too slowly, too rapidly, or in jarring ways causing discomfort in customers. This underscores the importance of movement and design harmony.

During an in-person observation at QUT's Centre for Robotics, I witnessed a Unitree G1 robot walking autonomously. Its exposed actuators and agile mechanics conveyed strength, but also highlighted risks. Researchers noted that if robots were dressed in human clothing, they could create security and identification challenges. This encounter reinforced how CMF decisions are not merely aesthetic but central to trust, safety, and long-term acceptance.

1.1 BACKGROUND

As humanoid robots become a fixture in domestic spaces such as kitchens and living areas, their success depends on more than technical performance. Movement fluidity and AI competence matter, but acceptance ultimately rests on how humans feel about them; CMF strongly influence these feelings.

Theories such as Masahiro Mori's uncanny valley (1970) show that robots which appear almost human can trigger unease when appearance and behaviour do not align. Hanson (2006) extends this with the idea of an aesthetic continuum, where design can strategically balance realism and abstraction to maintain trust.

Other scholars emphasise tactile interaction: Sabanovic (2010) demonstrates how soft silicone skin, textile joints, and layered surfaces enhance warmth and empathy in human-robot interaction. DiSalvo et al. (2002) further highlight the need for alignment between physical form and behavioural cues.

1.1 BACKGROUND

Industrial examples illustrate diverse approaches. Robots like Ameca adopt expressive facial features, while Figure AI opts for minimalist neutrality to signal reliability.

By contrast, Unitree's exposed actuators emphasise mechanical honesty, appealing to developer communities, but appearing less domestic. These contrasting strategies illustrate the gap this research addresses, few companies systematically integrate CMF for emotional acceptance in homes.

In summary, while technical literature focuses on function and AI, a gap remains in understanding the role of CMF in shaping trust, comfort, and emotional resonance. This study seeks to fill that gap by analysing how empathetic material and form decisions can foster household acceptance.

1.2 BENCHMARKING

Unlike many competitors that emphasise either mechanical transparency (exposed actuators, visible gears) or neutral minimalism (appliance-like shells), this project prioritises emotionally intelligent CMF. The design concept blends biomimicry with soft-touch textiles and flexible connectors, encouraging tactile interaction "touch to trust" and aligning form with movement. This CMF-driven expressivity remains underexplored in current benchmarks.

Key theoretical grounding:

• Masahiro Mori's uncanny valley (1970) shows that robots falling between human and machine appearances evoke unease.
• David Hanson (2006) demonstrates that expressive facial features (e.g., Sophia, Pepper) increase bonding and trust.
• DiSalvo et al. (2002) highlight the need for alignment between materiality and behavioural cues.
• Sabanovic (2010) provides evidence that tactile softness (e.g., textile joints, silicone skins) enhances warmth and social acceptance.

Personal observation:

Seeing the Unitree G1 in person reinforced this benchmarking: while its exposed mechanical design inspired admiration for agility, it lacked the approachable warmth of textile-based or softened CMF strategies. This aligns with Mori's and Sabanovic's warnings on trust and acceptance.

1. 2

BENCHMARKING


Optimus - Tesla


Figure 1 - Figure AI


Apollo - Apptronik


Neo - 1X Technologies


Phoenix - Sanctuary AI


Digit - Agility Robotics


R1 - Unitree


G1 - Unitree


Walker S2 - Ubtech


Abi - Andromeda

Robot	CMF / Exterior	Design Intent	Notes / Applications
Optimus – Tesla (USA, 2022)	Matte black & white shells	Minimalist, appliance-like utility	Mass-production goal; logistics, household tasks
Figure 01/02 – Figure AI (USA, 2023–25)	White matte curved shell	Neutral, trustworthy, product-like	Workforce roles (retail, warehouses); BMW partnership, >5h runtime
Neo – 1X Technologies (Norway/US, 2023–25)	Smooth white shell, knit fabric	Calm, safe, domestic presence	Security + household chores; expressive black visor
Apollo – Apptronik (USA, 2023)	Sleek modular body, LED interface	Collaborative, modular workforce design	Mercedes-Benz trials; warehouse & care applications
Phoenix – Sanctuary AI (Canada, 2023)	Polymer/metal hybrid, modular	Safe dexterity + cognition	Advanced Carbon AI platform; healthcare & logistics
Digit – Agility Robotics (USA, 2023)	Plastic/metal functional limbs	Task-flexible, industrial utility	GXO live warehouse pilots, tote handling
R1 – Unitree Robotics (China, 2023)	Compact, 26 joints, mechanical finish	Affordable, agile humanoid	Education, entertainment, low-cost entry to humanoid field
G1 – Unitree Robotics (China, 2023)	Exposed actuators, color accents	Industrial aesthetic, agility	Developer/maker appeal; viral demos, strength + agility
Walker S2 – UBTECH (China, 2023)	White polymer humanoid casing	24/7 industrial + home use	Battery swapping; factory floor trials
Abi – Andromeda Robotics (Australia, 2023–24)	Expressive Pixar-style face	Aged-care empathy + interaction	Human-robot social trials in Melbourne aged care

2 . 1

The central aim of this study was to explore how CMF influences emotional acceptance of humanoid robots in domestic environments. To achieve this, a mixed-methods approach was adopted, capturing both large-scale perceptual trends and in-depth qualitative insights.

Surveys (Qualtrics & Google Forms)

Surveys were deployed via Qualtrics and Google Forms to gather quantitative data from a diverse participant pool. Questions addressed perceptions of safety, comfort, trust, and aesthetic appeal in relation to robots with varying CMF characteristics. This method was selected for its ability to standardise responses and provide clear statistical breakdowns, while enabling participants to reflect on hypothetical domestic scenarios without direct exposure to prototypes.

Archival Observations

Archival observations were collected from movies clips on youtube. The clips came from movies such as iRobot, Chappy, and The Bicentennial man. Observations were to see how fashions developed over time, and how the population perceived the way humans lived in the future and how heavily we relied on robots.

Observations were also conducted on youtube videos of interviews and general information clips about robot companies. Notes were taken on what they are developing, and how they are planning on integrating their designs and products in to the everyday lives of people.

Expert Interviews with Dr. Saminda Balasuriya

A semi-structured interview with Dr. Saminda Balasuriya (QUT) provided qualitative insights into CMF perception, including how materials (e.g., textiles vs. rigid plastics), finishes (matte vs. gloss), and colours (warm vs. cool tones) to influence trust. This echoed prior HRI research, particularly for populations with heightened sensitivity to material cues.

In-person Observation: Unitree G1 and Prof. Johnathan Roberts;

Observing Unitree's G1 robot at QUT's Centre for Robotics offered direct experiential insight. While its mechanical agility was impressive, discussions with Prof. Roberts and Dr Balasuriya, highlighted potential risks if robots were dressed in human-like clothing—raising safety and identification concerns. This encounter underscored how CMF strategies must balance warmth and familiarity with transparency and security.

2.2

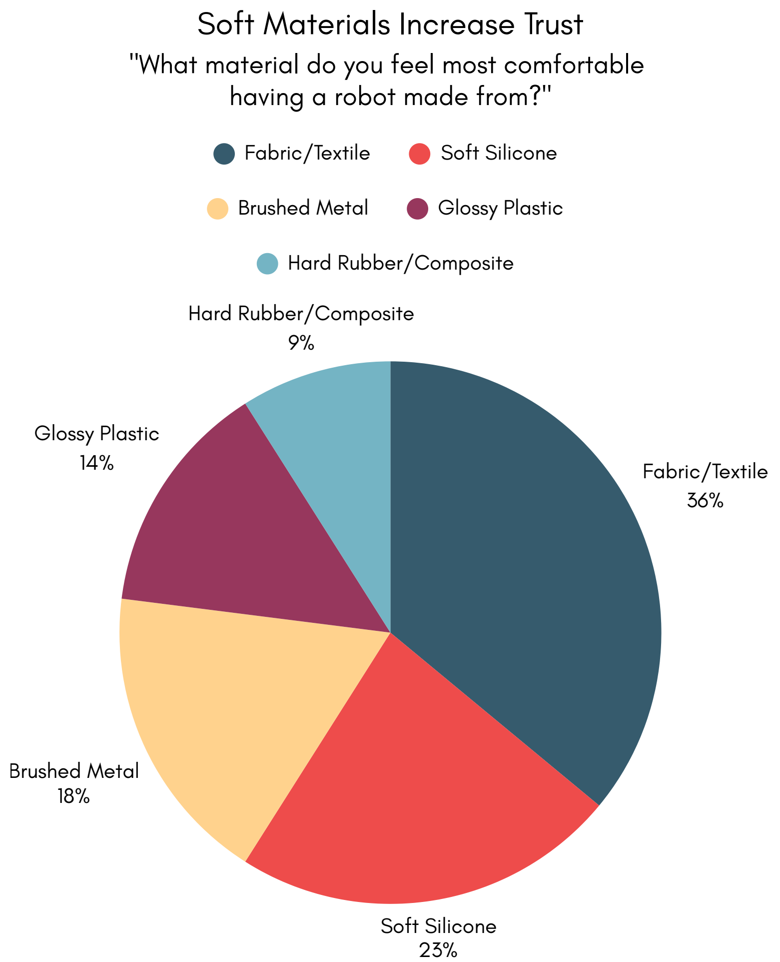
ANALYSIS & FINDINGS

Findings were organised around three research questions, integrating survey data, archival observations, interviews, and first-hand observations.

CMF Combinations and Emotional Comfort

Participants showed strong emotional reactions to CMF choices. Metallic and industrial finishes were the most frequently rejected (~30% of comments), associated with discomfort, coldness, and lack of warmth. Glossy plastics were similarly distrusted, often described as “aggressive” or “cheap.”

By contrast, participants preferred soft materials, muted tones, and textile elements, often described as “safer,” “warmer,” and more comfortable. In design trade-offs, pastel colours, fabric accents, and rounded forms scored highest for approachability and comfort.



Congruence Between Material and Movement

Observations revealed that robots with aligned movement and external materials/cladding (e.g., soft gestures and textile coverings) elicited more positive responses than those with incongruent traits (e.g., hard plastic and jarring movements). This supports Sabanovic (2010), who argued that tactile and visual softness enhance perceived safety in HRI.

Personal link: My G1 observation confirmed this pattern; its exposed actuators conveyed capability, but limited warmth, which would likely hinder acceptance in domestic settings.

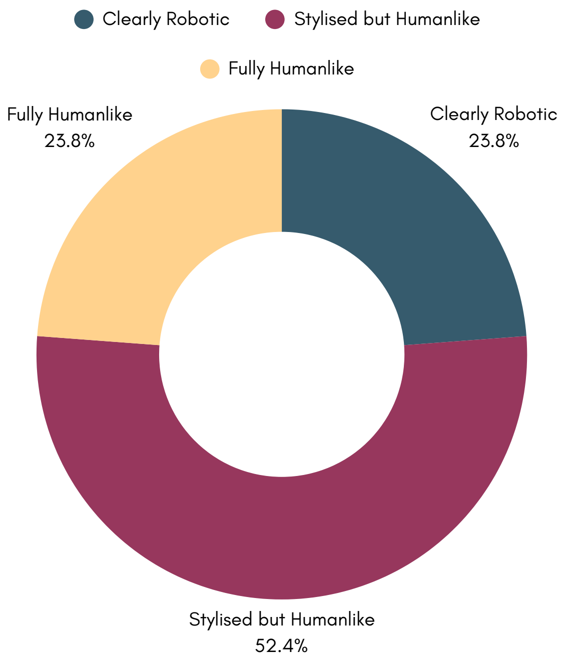
2.2

Safety, Reliability, and Long-term Integration

Survey participants expressed concerns about data privacy (~22%), reliability, and discomfort with overly human-like features. However, there was strong interest in customisable CMF (e.g., swappable panels, soft "skins") to match home aesthetics and extend product lifecycles. This aligns with broader sustainability concerns and supports modular, upgradable design as a pathway to acceptance. The data was thematically coded across eight key emotional and perceptual themes, supported by literature and user response patterns.

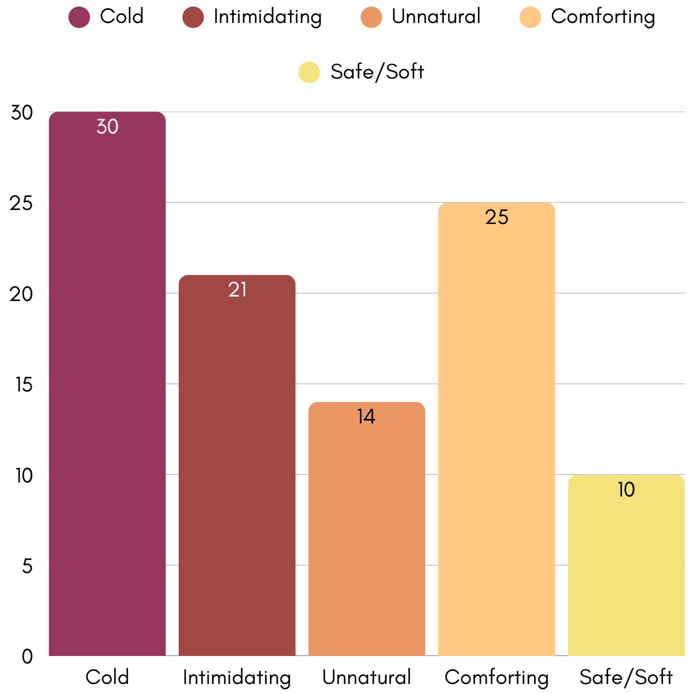
Clear Robot Identity Over Realism

"Would you rather your home robot look...?"



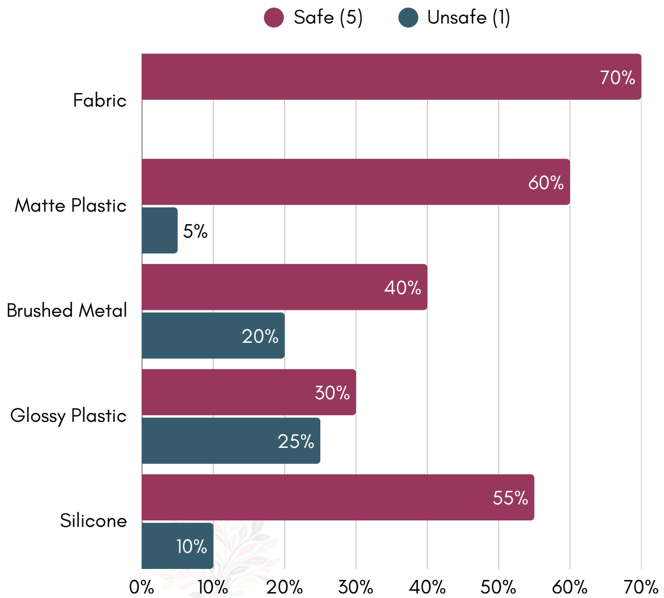
Emotional Reactions to Robot Surfaces

Avoidance of Cold/Industrial Finishes

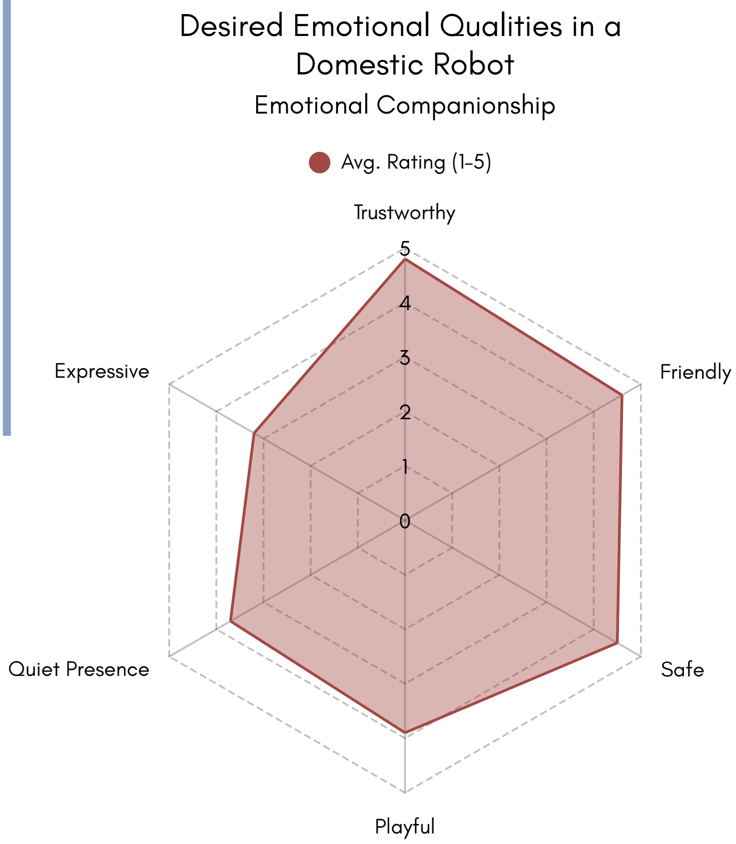


Emotional Reactions to Robot Surfaces

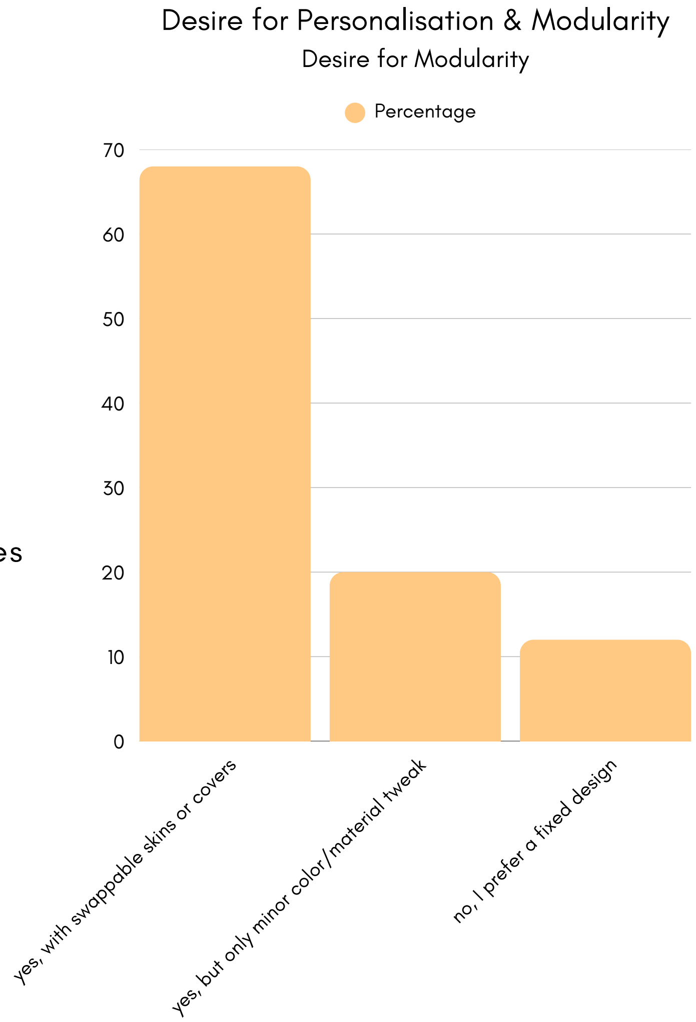
Perceived Safety Is Tied to CMF



- Avoidance of cold/industrial finishes
  - Participants rejected exposed metal, harsh edges, and gloss plastics.
  - Described these features as "cold," "intimidating," or "machine-like."
- Soft materials increase trust
  - Fabric, silicone, and matte finishes were associated with safety and comfort.
  - Respondents were more willing to "live with" robots featuring these textures.
- Clear robot identity referred over realism
  - Most participants preferred robots that look like robots, not mimics of humans.
  - Realistic "skin" or eyes triggered feelings of discomfort — consistent with Mori's Uncanny Valley (1970).



- Perceived safety is tied to CMF
  - Transparency in design (e.g., visible cameras or sensors) raised concerns about surveillance.
  - Softness, simplicity, and rounded forms increased perceived emotional safety.
- Form and movement must align
  - Robots with soft gestures but hard materials caused confusion.
  - Robots whose movement matched their surface (e.g. smooth with soft) increased emotional coherence were preferred.



- Desire for personalisation & modularity
  - Participants wanted robots they could style or skin to match their homes.
  - Industry interviews confirmed rising interest in modular exteriors and culturally adaptable “skins.”
- Emotional Companionship
  - Some respondents valued companionship roles for robots, especially with emotionally soft finishes (e.g. knitted textures, pastel tones).

The results from research in the psychology, haptics, and human-robot interaction, when benchmarked against existing robotic identified how visual and tactile design elements communicated warmth, safety, and sociability. It was also identified that more people were accepting of these features.

DISCUSSION

3.1

The findings highlight a consistent preference for humanoid robots that embody warmth and emotional accessibility through CMF choices. Participants rejected glossy plastics and metallic finishes as cold or untrustworthy, while soft materials, muted tones, and fabric accents were consistently described as safer and more comfortable. These insights align closely with Mori's uncanny valley (1970), Hanson's aesthetic continuum (2006), and Sabanovic's work (2010) on tactile design, confirming that congruence between form and behaviour is essential for trust.

This research enriches current understanding by drawing on first-hand experiences from everyday home environments. Unlike laboratory studies or industrial trials, the surveys and interviews in this project situate CMF within everyday household spaces, where aesthetics intersect with emotional comfort. The observation that participants preferred robots that looked robotic but friendly rather than overtly human supports DiSalvo et al.'s (2002) findings on the importance of material-behaviour alignment.

The findings also support a shift toward modular and personalizable CMF strategies. Participants expressed a desire to style their robots similarly to furnishing a home; choosing materials, colour palettes, or even cultural overlays. Interviews with experts suggest that this type of visual flexibility could help increase adoption by allowing robots to evolve with user preferences and interior trends. This opens the door for repairable, upgradable, and culturally adaptive surfaces, promoting both sustainability and deeper emotional attachment.

Furthermore, concerns about privacy, safety, and control point to the importance of visible design honesty. Robots with hidden sensors or ambiguous features were often seen as deceptive or threatening. Transparent joints, visible functionality, and clearly non-human facial zones all contributed to greater comfort, even when the robot looks less attractive.

DESIGN IMPLICATIONS

3.2

Based on the analysis, several implications for future humanoid robot design emerge:

- Clarity of form: Robots should avoid hyper-realistic human mimicry. CMF should balance familiarity and transparency, signalling both capability and approachability. Designers should use stylised, simplified shapes that imply friendliness without mimicking humans.
- Material softness: Soft-touch textiles, matte finishes, and muted colours can communicate warmth and safety, supporting trust in domestic settings. Designers should include fabric sleeves, soft silicone zones, and matte surfaces to invite touch and convey warmth. These materials should be durable but emotionally gentle.
- Layered CMF swatches for modularity: The idea of interchangeable CMF panels that demonstrate movement, emotion, or functionality is unique. This not only allows user customisation but becomes a tool for expressing intent through surface.
- Matching motion to material: If a surface looks soft, the robot must move softly. The prototype should integrate servo behaviours that support the feel of each CMF choice.
- Ethical transparency in form: Consider leaving some internal systems visible. A controlled exposure of the robot's internal mechanics can build trust, particularly if those systems are framed as safe, accessible, or even decorative.
- Colour strategy: Colours with low-saturation, warm tones scored highest in user trust and approachability. Avoid high-gloss or overly saturated finishes unless for specific utility purposes (e.g. caution markings).
- Customisation & modularity: Offering swappable "skins" or CMF panels enables users to personalise robots, aligning with sustainability principles and prolonging product lifecycles.
- Cross-disciplinary integration: Designers should draw from biomimicry, emotional ergonomics, and fashion/wearable design to enrich tactile and visual presence.
- Safety should be considered in design language: If a robot is dressed in human clothes it becomes a safety risk. A robot can be used to conceal weaponry. Tis represents great risk to the human population.

3.3

CONCLUSION

As humanoid robots move from labs and factories into everyday domestic spaces, their success will depend not only on functionality, but on how they look and feel. Interaction depends on how we as humans connect visually, emotionally, and physically to the robot. This research confirms that users form strong emotional responses to colour, material, and form (CMF) and that these design elements deeply influence perceptions of safety, trust, and long-term acceptance.

Through mixed-methods research including surveys, interviews, and observational analysis this project uncovered key user preferences. Soft materials, matte textures, and warm tones inspire emotional comfort. while hard, glossy, or hyper-realistic features often cause discomfort or distrust. Trust is not just built through appearance, but through alignment between surface, movement, and behaviour. Competitor benchmarking revealed that many current robots focus either on cold minimalism or hyper-functional aesthetics, neglecting the emotional needs of users.

In contrast, this project proposes a design direction grounded in empathetic robotics; one that uses CMF to communicate emotional clarity, invite touch, and encourage long-term cohabitation. By introducing modular, expressive CMF swatches that can be layered, swapped, or animated, this project lays the groundwork for robots that are not just tools — but companions designed for real human spaces. These findings provide a foundation for the next design phase, where physical prototyping and expressive surface ideation will bring these ideas to life.

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