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The aesthetics of robot design: towards a classification of morphologies

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Abstract

Robots are becoming increasingly prevalent in the workplace. As Industry 5.0 pursues human-centric technologies, a greater understanding of what effects aesthetics has on those interacting with robots is needed. This paper sets out robot morphology as a way to characterise key form types, and proposes seven classifications: anthropomorphism, zoomorphism, phytomorphism, artemorphism, functiomorphism, amorphism, and neomorphism. Through an assessment of the current robot aesthetic landscape, design dimensions are identified with examples that can inform future robot design.

Keywords: industrial design, aesthetics, design aesthetics, robot aesthetics, morphology

1. Introduction

Robots have increased hugely in prevalence in recent decades and this trend can be expected to continue with the drive towards digital and automated workplaces. The more human-centric approach inherent in Industry 5.0, and the increase in variety of robot solutions, requires consideration from a design perspective. An important aspect of robot design is aesthetics as form, experiences, and meaning. Hanson (2006) proposed that principles of robot aesthetics need to be determined to increase their success. Morphology, the characteristics and categorisation of overall form, is a key element of robot aesthetics, as it represents the first aesthetic interpretation and conveys the purpose and functionality. The dimensions, are the result of the overall styling. The literature review covers Industry 5.0 and how the addition of human requirements relates deeply to aesthetics and then to robot design aesthetic; determining robot aesthetic morphologies and dimensions. A narrative approach was taken to the literature review, with the categories of robot aesthetics emerging from reflection and synthesis across the sources consulted. A test of the morphologies and dimensions was done with two sets of images of robots, five real and five conceptual to determine the applicability of both the morphologies and the dimensions.

2. Literature background

2.1. Industry 5.0 and robotics

Industry 5.0 aims to make humans and robots collaborators, where robots help with repetitive tasks (Akundi, et al. 2022). Industry 5.0 technologies and social systems could use information inputs from observations, exchange, data interpretation, and intelligent agents in robots resulting in collaboration with humans. Termed collaborative robotics (Co-Botics/Cobots) they allow for this 'symbiotic' relationship between human, machine, and system. These are part of 'smart' devices that increase productivity, yet increase cyber security issues, and human isolation. They also require careful planning of the Socio-technical system to work (Bednar and Welch, 2020).

If we look back to the first industrial revolution; manual machines became powered by steam. The second; added production lines with electricity which resulted in higher productivity. The third; computerised machines, added communication technologies allowing for automation. The fourth; digitised machines creating cyber-physical systems with intelligent decision-making, in turn increased flexibility and high-quality personalized mass production. The fifth intends to add human values to industrial production (Xu, et al. 2021). Industry 5.0 was introduced by the European Commission in 2021, and proposed to be human centric, resilient, and sustainable (European Commission, 2021), The term of Industry 4.0 was first used in the Hannover Fair in 2011 (Vogel-Heuser and Hess, 2016). Conceptually the fourth industrial revolution and Industry 4.0 are different yet linked. 4.0 is an initiative that occurred in Germany from 2011 to 2015. Then Klaus Schwab the founder of the World Economic Forum, in his book 'The fourth Industrial revolution' propagated it further (Thomas and Nicholas, 2018). The industrial revolutions are shifts in industry by way of technological change and the effects on humanity. The '.0s' are theoretical framings. 4.0 and 5.0 were instigated by a state and a supernational organization and popularised by another respectively rather than occurring naturally. Given that 5.0 intends to apply human-centric principles to robots or can be framed as taking account of human requirements. This means that they will, if successful, be more prevalent in humans' lives. As such their aesthetics will have a great impact on both their technical success and their acceptance as useful tools.

2.2. Industrial, collaborative, and social robots

Myths of robots exist from the Titan Prometheus creating man from clay. Talus, a giant bronze slave was created by Hephaestus in 3500 BC. Egyptian priests hid in oracle statues in 2500 BC. With many other ancient robot-like ideas. The term 'robot' itself comes from 'robota' meaning forced labour in Slavic languages first seen in Rossum's Universal Robots by Karel Capek in 1920. (Siciliano, et al. 2008).

In modern times, industrial robots have become important as they can execute heavy and repetitive tasks which then removes the work from humans. The first generation of industrial robots from 1950-67 machines became programable. The second from 1968-77 added adaptive behaviour to the environment. The third 1978-99 had greater interaction for users through a complex interface and limited self-programmability. The fourth starts in the year 2000 and is ongoing aiming to add high-level intelligence, deep learning, and collaborative behaviour (Gasparetto and Scalera, 2019). These industrial robots tend to be application specific, large, heavy, and rigid. A new counterpart is the collaborative robot or 'co-bots' (Sherwani, et al. 2020). These are specific phases in the development of robots essentially starting from the third revolution.

The concept of cobots was invented by Colgate et al. (1996) and Peshkin, et al (2001). The form of these original cobots were vastly different from current designs being reactive robotic hand tools. As for the application of robots and humans generally, robots are less dexterous and flexible whilst human are more so and are better suited for lower weight tasks. This is due to human level dexterity and flexibility being an unreachable characteristic for traditional robots (Matheson, et al. 2019). The original cobots were robotic devices that manipulated objects with humans operating the robot in a digitally restricted workspace and were assisting humans (Colgate, et al. 1996). Recently cobots are designed to be in proximity with humans in a shared area. Usually, this is organised in terms of the timing of the work between the cobot and human (continuous, synchronous, alternate, etc). Ultimately, cobots are intended to help and enable humans to perform tasks, aiding with flexibility, quality, cognitive, and ergonomics. There were much earlier studies (see ref. 3-11 in Vicentini, 2021) from the 1980s interested in the interaction controls with robotic systems. These could be considering the initial foundation of modern collaborative robots describing ideas of force control, compliance actuation, and others. As for, physical Human-Robot Interaction (pHRI) it is limited to low powered tasks, and in terms of physical interaction, it is separated into accidental (requires safety consideration) and voluntary contact (greater consideration). (Vicentini, 2021). As for their use cobots are preferred over industrial robots due to their lower cost and ease of implementation into a system without serious modification to that system (Pizoń, et al. 2022). Continuing with this relationship perspective, Human Robot Interaction (HRI) has been mostly explored with an anthropomorphic approach with direct/contact interaction. The anthropomorphic paradigm in HRI is based around imitating how humans interact with each other. Although this paradigm has not been as successful as expected due to many robots not being optimised for human factors for a variety of situations and the technology for robots to recognise human interaction and intention is limited. Specifically, when these anthropomorphic interfaces let down users with their less than 'human-like' responses causing disappointment and confusion (Park and Kim, 2009). Anthropomorphic interaction can be interpreted as a Human-Human Collaboration Model with three components. Firstly, the collaboration is achieved through the available communication channels (audio, visual, environmental). Secondly, through cues (verbal and non-verbal) from each channel. Thirdly, the affordances in the technology affect the display, and reception of cues. (Green, et al. 2008).

Some suggest that collaborative robots must become social because they exist in the social space of humans (Fischer, 2019). These social robots or 'so-bots' can fall in line with the social behaviours of humans and make decisions autonomously. Typically, cobots and so-bots are separated but as collaboration has social elements, they are closely related typologies (Cusano, 2022). So-bots can be used for health care and therapy, work and in the public, education, or at home. The aesthetics of such robots has a great effect on how they are perceived, their acceptance, and functionality. In addition, simply adopting anthropomorphic morphology will result in failed expectations due to limited technology. As such the aesthetics of these robots must not only consider its behaviour and social functions but also its' context and practical functions (Leite, et al. 2013) As such so-bots could be characterized as a robot with a social interface resulting in it being a social robot. The aesthetics of the form broadcasts' the social cues and behaviours of the robot. As such they have social functions, a social form, and a social context (Hegel, et al. 2009).

Essentially the robot can be formed into three main categories of Industrial, Collaborative, and Social. In line with the description of a robot plus a social interface makes it a social robot. The type of interface determines its type, an industrial interface is on an industrial robot. With that there is the type of interactive paradigm that the robot is based on, e.g., anthropomorphic. Interactively the cues are audio, visual, environmental, and physical. Before addressing robot aesthetics specifically, we need to review the change and context of design aesthetics more broadly.

2.3. Design aesthetics

Design aesthetics can be seen be through perceived affordances and visual feedback (Norman, 2004). It is a method of communication and core to design. The ideas driving the object, how much the idea is displayed, and the appearance affecting the degree of self-reflective aesthetic function. This becomes a wide-ranging area of exploration and challenges rather than a series of problems. It presents ideas embedded overtly or covertly in objects and the aesthetic aims to achieve a purpose whether wanting to be purely functional or experimental (Folkmann, 2010). With that there is a relation to the wider context which it is introduced in, its symbolism, or product semantics (Krippendorff, 1989). As well as 'higher' spiritual meaning and understanding. Although currently objects are typically absent of higher meaning (Walker, 2001). Though these experiences can be in the form of complex cognitive and behavioural activities flowing from and into our subconscious emotions, perceived emotions, conscious judgement, and internalised preferences (Haug, 2016). These 'aesthetic emotions' are seen as discreet emotions upon exposure to aesthetic experiences and motivate us towards wanting and owning aesthetically pleasing objects and exposure to pleasing events. They always involve aesthetic evaluation, appreciation, and are distinct from art-elicited emotions (Menninghaus, et al. 2019). Xenakis and Arnellos (2013) argue that this complex whole is indistinguishable from any element of an object, whilst not necessarily being in the pursuit of beauty. It emerges through interactions with objects as emotions exciting other processes such as semiotic chains, anticipation, detection of affordances, as well as those previously mentioned, and others; termed 'Interaction Aesthetics' (Xenakis and Arnellos, 2013). The inverse of that name is 'Aesthetic Interaction' which is more related to the interaction, and is where the aesthetics are intrinsically valuable, has a social dimension, a pleasing and dynamic form, and involves the body, cognition, emotion, and social abilities. This uses aesthetics as a mechanism for design (Ross and Wensveen, 2010). A design aesthetics approach can be applied to any element of an object and various elements have been researched. Line: through principles of form rhythm and direction (Poffenberger and Barrows, 1924). Pattern: through curved and angular repeating motifs (Urquhart and Wodehouse, 2021). Form: through curvature, sharpness, and emotive composition (Mothersill, 2014). Colour: affecting how beautiful something is considered, cultural and personal expression affecting our

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physiology, and perception (Wilson, et al. 2001). Texture: affects attraction and aversion of a design as well extending its functionality (Şener and Pedgley, 2021). Movement: can enhance the expressiveness, and emotions making them more tangible through thematic movement and interaction (Weerdesteijn, et al. 2005). Interaction: as an aesthetic driving force for a design enhancing the value of a design beyond functional requirements, but as a pleasing and meaningful one (Ross and Wensveen, 2010). Light: causes reactions in our brains and changes in our emotion. It could enhance the qualities and perception of forms and change the expressiveness of a design (Trivyzadakis and Zisi, 2016).

Generally, it seems that design aesthetics has three dimensions of angularity to curvature from Urquhart et al. (2021), chaos to unity from Poffenberger et al. (1924), and accurate to iconographic embodiment of the idea from Folkmann, (2010). As well as these factors there is the idea embodiment, purpose, and context. Along with the design elements there are line, pattern, form, composition, colour, texture, movement, interaction, and light. This results in the meaning the object embodies with the affordances conveying its functionality and purpose.

2.4. Robot design aesthetics

When robots were first conceived designs typically imitated biology, in particularly the anthropomorphic form. The first being robotic anthropoids. Whilst today they use more "synthetic aesthetics languages" and are designed around their context. Given the rising use of robots the relationship between robotics devices and humans should be investigated, the ethical dimension should be prioritised and result in a positive outcome for humans. Humans have three fundamental dimensions: biological, social, and ethical which creates a cultural life. Thus, HRI and the reasons why humans could accept a robot are important. The first point of contact would be the expressive or aesthetic element and then the usability becomes relevant. HRI should have five main factors: advantage, compatibility, complexity, trialability, observability, and physical appearance. Germak et al. (2015) suggest that there are only two morphologies of robots that exist: mechanical, and anthropomorphic. Where the first in its pure form is focused on performance and functionality, the second in its pure form is used for personal robots. This 'human' robot tends to make humans interaction to it more empathetic. In terms of interplay of acceptance and expressiveness there are three main factors. Facial expression, where it can show emotion, personality, and intention, resulting in better engagement. Fluidity of movement, through smooth articulation that adapts to its environment and can vary the paths it takes to avoid a mechanistic feeling. Formal synthesis is how the purpose and functionality of the design is conveyed in its form (Germak, et al. 2015). Given the rise of robots interreacting with humans the aesthetics of these robots deeply affects the ultimate success of their deployment. We therefore need to identify fundamental principles of robotic aesthetics. One range is from abstract to realistic humanoid robotic head forms. More realistic humanoid designs can appear like "dead matter" due to the movement not corresponding to the appearance. Better aesthetics results in better engagement, which results in greater success of the robot. One can theoretically replace the uncanny valley with the theory of paths of engagement where the aesthetics can improve engagement if done well, overcoming the valley (Hanson, 2006). The uncanny valley was proposed by Masahiro Mori in 1970 and has remained of interest in HRI. It posits that the more human-like a robot is physically and in movement there will be a proportional increase in positive emotion until those emotions suddenly become negative. Although the valley could be a cliff where the positive emotion never matches those when seeing a real human. This might be related to framing theory, easily summarised as using our memories to apply context of our environment (Bartneck, et al. 2007). The human element of HRI has evolved to interpret and react to sensory cues affecting our thinking and emotions. Aesthetics have a great impact on the level of trust a human has with a robot. A lack of trust can result in the robot never being used yet pursuing expressiveness and a cartoon style in robot design can create an emotional connection that fosters trust. Other design elements also affect the aesthetics of the interaction, such as colour, design elements, design principles which will change the level of trust. (Pinney, et al. 2022) The qualities of the materials that robots are made from are also a part of the aesthetic experience. Soft robots appear less natural but are more willing to interact with them than mechanical design. Thus, mechanical designs seem more natural/normal, possibly due to a mechanism being visible (Jørgensen, et al. 2022).

Humans anthropomorphise real, or embodied robots as well as processing physical objects differently to two-dimensional objects. They also anthropomorphise more and prefer real objects compared to

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digital objects (Kiesler, et al. 2008). Tondu et al. (2009) state that for robotic design, two design principles affect the resultant design of an anthropomorphic form, one being positive (the form having human qualities) and the other principle being negative (the association of human-like qualities onto non-human objects). These are inseparable to the aesthetic perception of robots and are in turn are inseparable from the social perception and so robots should be anthropomorphic. Yet industrial robots can be seen to lack aesthetic characteristics due to being designed around the required working envelop and positioning system (Tondu and Bardou, 2009).

2.4.1. Anthropomorphising objects

Other objects are also anthropomorphised. Rational theory for pareidolia (meaningful interpretation from vague information) is that we understand the world by referring to something we know. Emotional theory posits that it is due to the social nature of humans and a need to reduce perceived threats. Both theories refer to the self and perception. This related to the 'uncanny valley' where highly representational faces are noticeably artificial and thus repel user as mentioned previously. Robot aesthetics and facial phenomenon can be categorised into six types of robots. Functional: a robot designed for a precise typical industrial function. Assistant: typically, zoomorphic and can act as cute companions. Humanoid: where simple forms are used to allude to the human form. Android: where a complex humanoid design is present but is still clearly mechanical in nature. Uncanny: the attempt to be realistic yet failing aesthetically or in motion causing an artificial and repellent sense. Cyborg: a mix of human and mechanical elements yet has an overall human quality. For anthropomorphic designs high levels of detail and geometric complexity convey intelligence and functional sophistication, with roundness conveys cuteness (Wodehouse, et al. 2018). DiSalvo and Gemperle (2003) posit anthropomorphic design consists of the form and behavioural design of the object. This falls on a two-dimensional range of the quality of anthropomorphism. Seduction: when anthropomorphism acts as a lure to encourage purchase and use of the design but being unrelated to its purpose or experience. Fulfilment: when anthropomorphism is not separate from purpose and leads to meaningful understanding of the products' purpose and resulting in appropriate engagement with it. They also claim to have identified four uses of anthropomorphic form; First is 'Keeping Things the Same', which is maintaining preestablished conventions. Second is 'Explaining the Unknown', which explains and introduces new functions and/or technologies. Third is 'Reflecting Product Attributes', which structures the relationship and interaction with objects based on how they operate. Fourth is 'Reflecting Human Values', which focuses on the sociocultural attributes of the experience of the product and its human context. Anthropomorphism is typically used to appeal to innate human instinct, to be seductive. This interpretation is intended to help understand and realise an appropriate use of anthropomorphic forms to fulfil meaningful design goals and encourage a design approach as anthropomorphic designs have existed since the earliest of human objects (DiSalvo and Gemperle, 2003).

2.5. Robot aesthetic morphologies and dimensions

Constructing categories of morphologies and dimension would shed light on robot design and give further avenues of inquiry into the effect of these. The morphology can be organised by what inspired the design, whether real or imaginary; artifact shaped, functional, or bioinspired. The bioinspired can be human, animal, plant or fungi. Anthropomorphism can result in inappropriate social expectation due to limited technology or an uneasy feeling due to realism. Zoomorphic designs can be made with familiar or unfamiliar animals. The familiarity against strangeness affects the interaction deeply, for example someone plays with a robot dog and it acts like one. Dog robots can increase bonding but technological limits result in users ending the interaction (Löffler, et al. 2020). An evolutionary robot morphology aims at evolving the design and software of the robot autonomously (Jelisavcic, et al. 2017). By using evolutionary principles to solve problems by changing the morphology, software, etc. of the robot (Doncieux, et al. 2015).
There are a few aesthetic morphologies that as stated previously can be inspired physically, interactively, and in the method of interaction. Anthropomorphism, where the robot is inspired by humans was coined by Hanson (2006), Park, et al. (2009), Green, et al. (2008), Wodehouse, et al. (2018), as well as others in this paper. Zoomorphism, where the robot is inspired by a fauna. Phytomorphism is where the robot is inspired by flora. Artemorphism is where the robot inspired by an object. Functiomorphism is where the robots' form is based around its function. These four are mentioned by Löffler, et al. (2020) although we termed them as

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morphologies. Amorphism is where the robot is designed with a lack of order or changes over time akin to evolutionary robots mentioned by Jelisavcic, et al. (2017). One morphology not previously identified is Neomorphism which applies where the morphology of the robot feels new or is a combination of multiple. The aesthetic dimensions of robots are theme from the design aesthetics. As robots with the same morphology can result in a different experience due to the details. These are, the uncanny valley, and others relate to a dimension of natural to mechanical by Hanson (2006). Another dimension is from familiar to strange by Jørgensen, et al. (2022). The final dimension is from abstract to realistic discussed by Wodehouse, et al. (2018). The inspiration of the morphologies does not have to be real but could be imagined or a combination of morphologies. As such these morphologies are not strict categories but ranges in which a robot design may inhabit one, a few, or all categories to varying degrees. These aesthetic dimensions and aesthetic morphologies are driven by aesthetic philosophies suited for the project as well as the different design elements that make up any object to communicate what it ultimately is and how it can help the user.

3. Methods

Tentatively testing whether the morphologies functioned as categorical ranges. From positive (strong) to the right and negative (weak) to the left. Past the middle point establishes the design in that morphology. A smaller image of the same design was placed the negative side if it seemed link to another morphology. Two sets of five robots were mapped onto the morphologies. Images were selected when they were sufficiently different from each other to ensure no repetitive designs. Five are real robots in the market, and five are conceptual, to ascertain where robot morphologies are now and where they could be. The limited number was to ensure legibility of the designs on the morphology and dimensions figures. The images were interpreted and placed on the morphological spectrum that best suits it. The images of a real robot have full lines encircling them and the conceptual robots have dotted lines encircling them.

4. Results

4.1. Plotting aesthetic morphologies

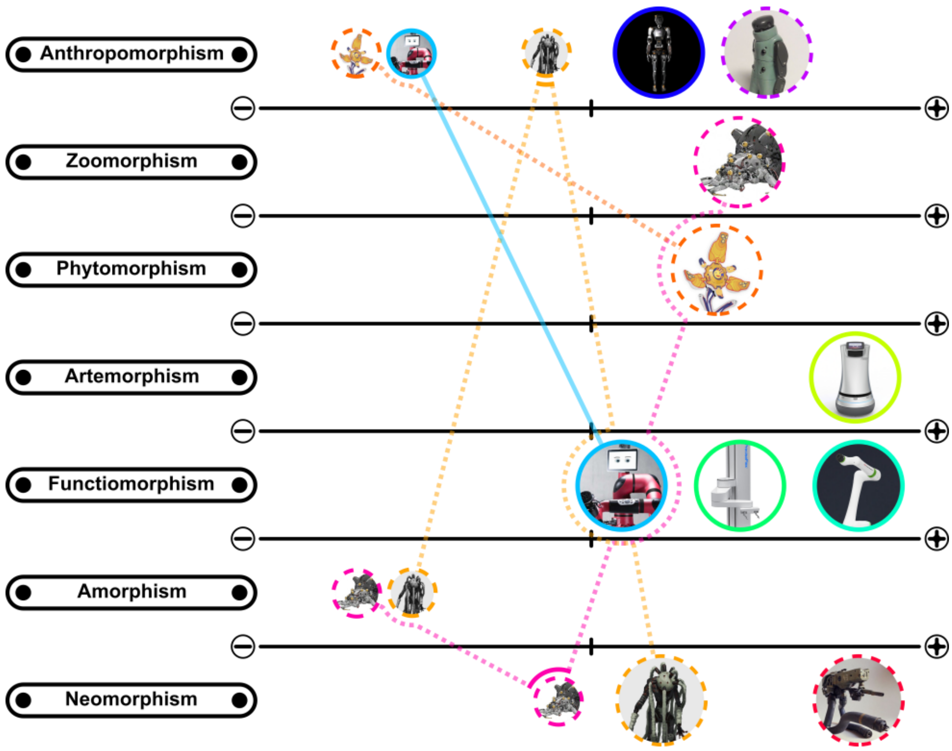

Figure 1. Two sets of five robot designs applied to the morphologies; Images with full lines: Real robots; Images with dotted lines: Conceptual Robots

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4.2. Plotting robot aesthetic dimensions

For a more detailed analysis of the individual robots, they were plotted on the three dimensions giving a picture of how the two sets differ in term of their details. These dimensions are based off the robot aesthetic dimensions and the design aesthetic dimensions established previously in 2.6 for robots and in 2.4 for design. The contrasting themes of the dimensions do seem applicable and given the simplicity of modern robotic design. Yet reducing design aesthetics to simple dimensions does seem reductive. It does appear to help analyse the details of multiple design and contrast them to others. In a sense a more complex mood board that give the general mood and the individual mood of each design. The top names of the dimensions of robot aesthetics; natural to mechanical, familiar to strange, abstract to realistic. The bottom names are the design aesthetics dimensions, angularity to curvature, chaos to unity, and accurate to iconographic. These do appear relatively interchangeable but it seems appropriate to combine the two as the majority of robot aesthetic is contained in the general rules of design aesthetics.

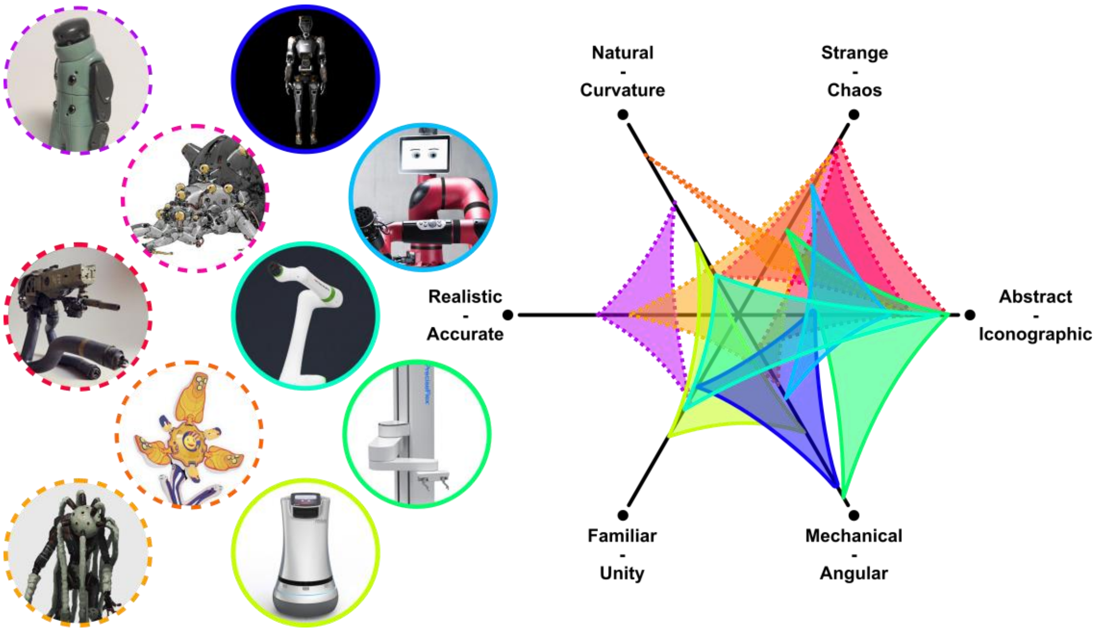

Figure 2. Overlaying all real and conceptual robots on the three dimensions of robot aesthetics and design aesthetics

The real robots clearly sit more in the mechanical, iconographic, and somewhat familiar territory (Figure 2). This could be due to the technological limitation and application of the robot as they need to solve a problem to attract customers. The conceptual robots sit more in the strange and curved dimension whilst varying in abstraction and humanoid appearance. This could be due there being no technological limit. There are also more novel forms that are clearly more attractive. The functiomorphic and artemorphic designs generally used more mechanical and iconographic design aesthetics.

5. Conclusion and future work

This paper has reviewed the literature in relation to robot aesthetics and has identified six morphologies and added a new one that supports classification and interpretation of this domain, with three robot aesthetic dimensions. These essentially act as general classifications of what the form of the robot reminds us of the most and where generally the aesthetics details can sit. For the aesthetic dimensions in robotics and design there is a degree of conceptual overlap due to design aesthetic conceptually containing robot aesthetics. Morphologically, the real designs prefer curvature and bias toward anthropomorphic or functiomorphic. The conceptual designs lean towards strangeness, curvature, and more abstract yet zoomorphic or neomorphic designs. More detailed comparative analysis of different aesthetic robot morphologies is needed, given most research focuses on anthropomorphic morphology. More design research involving the act of designing is also desirable. The aesthetic review has demonstrated that the robotics industry relies on functionmorphism and anthropomorphism. The

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addition of neomorphism is a novel contribution, acting as a way determine the novel morphologies. Creative processes such as sketching and modelling shows potential to explore different aesthetic morphologies and expand existing ones. For design and robot aesthetic dimensions there is overlap due to design aesthetic guiding aesthetics for objects. There also seems to be a link between certain morphologies and certain dimensions such as curvature and phytomorphism. How much the design details can be pushed until the aesthetic dimensions flip, or the morphology changes need to be explored? The creation and limits of the morphologies and dimensions needs to be further explored. In the future this could give clarity to designers on how to play with their designs to best fit the user, and solve problems with robotics. This could form a basis to for categorising and evaluating robot aesthetics.

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