ON THE FUNCTIONS OF PRODUCTS

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ABSTRACT

Understanding the performance and manner of functioning of existing products is at the base of new product development activities. In engineering design the term function is generally used to refer to the technical actions performed by a product. However, products accomplish a wider range of goals. This research explores the opportunity to describe and model, through the concept of function, product actions across four dimensions including technical, aesthetic, social and economic. The research demonstrates that non-technical functions can be represented through active verbs and nouns and modelled using a method known as the Function Analysis Diagram (FAD). The research argues that when technical, aesthetic, social and economic perspectives on product development are considered as different types of function, stakeholders have a common language to communicate which can benefit design collaboration.

Keywords: Product design; Product function; Function analysis; Function Analysis Diagram

1   INTRODUCTION

Every year new products are designed, manufactured and launched in the market. The reasons why consumers buy and own products are linked to the fulfilment of needs or goals. Consumer behaviour is studied to understand these reasons and to inform product development.

From an engineering perspective these reasons are associated with the performance of technical actions which are generally referred to as product functions. As an example, a kitchen knife can be considered in terms of how it fulfils the action of cutting food. Technical functions have been extensively studied. In engineering design, numerous methods have been proposed to analyse functions [1, 2] and to organise them on a formal basis [3].

From a social perspective, products transmit messages about themselves, and their owners and makers. This feature makes products more or less desirable. It can be argued, for example, that consumers of Apple products are attracted, among other factors, by the resulting social recognition. The social actions of products have been researched at a theoretical level but no formal method to integrate this aspect in product development has been suggested.

From an aesthetic perspective, consumers buy and own certain products rather than others as these better meet their sensory values. In other words, consumers, before purchasing products, judge them to establish if they satisfy their sentiment and taste.

From an economic perspective products are traded within a market. The reasons to buy and own products are, therefore, also related to the performance of commercial actions. As an example, buying a product can be considered as a form of investment.

The primary aim of this research is to explore the actions performed by products across technical, social, aesthetic and economic dimensions. In particular, the research investigates the value of describing these actions as different types of product functions. In this way the research intends to reflect on the opportunity to generate a shared language for the stakeholders in the design process that facilitates collaboration and avoids undue prioritisation of any single functional area.

The secondary aim of the research is to investigate a method, known as Function Analysis Diagram, to graphically represent product functions. The focus is on understanding actions performed by products during consumers' ownership and use. Products, however, perform actions for all the stakeholders involved in the development process and these will be at times considered.

The research is based on the review of literature from the fields of engineering design, aesthetics and user experience. In order to ground concepts and issues in an empirical example, the functions of a

well-known product, the Alessi's Juicy Salif Lemon Squeezer by Philippe Starck, have been extracted from textual descriptions in published articles and modelled using the FAD method.

2 BACKGROUND

The Oxford Dictionary of English (ODE) defines *function* as the purpose of a thing [4]. Other terms that are generally used to define *function* are aim, objective and intent. In product development the function of a product is usually expressed in technical terms. This section builds on this by reviewing the technical, aesthetic, social, economic and emergent functions of products. These dimensions of product functionality are important to understand consumer behaviour. The categories were selected as a coherent starting point for discussing functions and illustrating the value of diverse perspectives. A framework for better understanding the existing *flexible menu* of function categories is presented in [5]. This work highlights key considerations that are constant across divisions of function:

- functions are subjective: the value and even existence of a function depends greatly on point of view and context – users, designers and others;
- functions are normative: certain functions are given precedence when describing a designed artefact, even if this does not follow how things are actually used (thus it is not always adequate to rely on stakeholder's descriptions but also observation);
- new understanding can come from any category, not necessarily the ones given precedence because they are more easily described (technical vs. social); along similar lines, the characteristics of tangible categories can inform us about the less tangible ones.

Functions are powerful mechanisms for exploring the relationship between people and the artefacts of their environment. The following sections examine representative examples of functions that are important to design activity.

2.1 Technical function

The history of the systematic analysis of the technical function of products can be traced back to the pioneering work of Lawrence Miles on Value Analysis, conducted at General Electric during the Second World War [6]. Function is defined by Miles as the basic purpose of each expenditure, whether it be for hardware, the work of a group of men, a procedure or whatever [6]. A key idea of the Value Analysis method was to list the functions performed by a product, each function being simply represented by the two words combination of an *active verb* and a *measurable noun*. The objective was to see how a product design could be modified to improve overall value by eliminating unnecessary functions, and minimising the resources required to perform those confirmed to be necessary. It is noteworthy that while functional analysis was conceived as an answer to the rigor and constraints of war, with the onset of peace Miles soon appreciated the need to consider the aesthetic function that aims simply to please the customer. Miles, therefore, made a distinction between *use function* and *aesthetic function*. In this section the focus is on the use function. The use function is subdivided by Miles into basic function and secondary function.

Basic

Basic functions are those necessary to the customer and for which the user or buyer purchases the product. A light bulb, for example, has the basic function of providing light.

Secondary

Secondary functions merely allow the designer's choice of means to perform the basic function and to do so effectively. These functions are not of interest for the customer as he or she will pay attention to the basic function only. The designer of a light bulb may choose various modes of molecular excitation to produce light. Incandescent light bulbs rely on high temperatures to release a range of light through blackbody radiation. The secondary function of that light bulb thus becomes to resist high temperatures (ca. 2000 K at the filament, a bit below the melting point of tungsten). Fluorescent light bulbs rely on more selective excitation of gas with high voltage to release a more narrow range of light with less heat losses. Their secondary functions then revolve around the containment of potentially dangerous gases (mercury) and enduring high voltages (kV range) involved in their mechanisms. The user is not concerned by these thermal, safety or electrical considerations until something goes wrong.

2.2 Aesthetic function

Aesthetics is generally used to refer to a response or reaction to an object, artefact or system, which is manifested through the senses [7, 8, 9]. Aesthetics involves all of our senses, i.e. vision, hearing, touch, taste and smell, which contribute to our perception of a product or system. Considering aesthetics just as the perception of an experience, reflection is by-passed [10]. Some authors argue that this definition is limiting and aesthetics involves more than a sensorial response [11]. Responses to an object can be pleasing, displeasing and indifferent. In this review we are concerned primarily with positive responses but we acknowledge that the range of possible responses is more complex.

Pleasant aesthetic

A positive aesthetic response can be classified according to a number of pleasure subdivisions including [12]:

- Physio-pleasure, the pleasure derived from the senses of, for example, touch, smell, sensual or sexual pleasure;
- Socio-pleasure, the pleasure gained from interaction with others;
- Psycho-pleasure, the pleasure derived from the satisfaction felt when a task is successfully completed; and
- Ideo-pleasure, the pleasure derived from interactions with books, art and music.

The physio-pleasure derived from viewing products is linked to form. Styling, a typically visual embodiment of aesthetics, involves developing and giving a product an attractive visual form. Styling usually refers to the development and realisation of an attractive and innovative visual form for a product that embodies the functional and social requirements. Although the appreciation of a product's aesthetic appeal is subjective and each person will judge it individually, there are a number of principles that are helpful in the development and realisation of style and form. These include: exploration of the design space; consideration of human behaviour; ergonomics; technology selection; colour; use of organic and inorganic form; development of relationships between form and function; use of metaphor in design; visual identity or branding; material selection and finish.

2.3 Social function

Before consuming a product, individuals have to recognize the category it belongs to, e.g. tool, domestic appliance, furniture, etc. They may end up selecting the product that looks more *professional* or the one that fits better with their personality. Once they are interacting with the product, they have to recognize its affordances, feedback, and so forth [13, 14]. All these aspects embody the idea of social functions. In [5] Crilly explains that social functions depend on the collective understanding and agreement of the agents that make up the relevant community; they are social-status functions. Social functions are related to people's manner of thinking of and talking about artefacts [15, 16, 17, 18]. In particular, individuals appear to speak about certain products as if they have a character and interact with them accordingly. The theory that supports social functions is extensive [13, 19, 20]. This section outlines three types of social function, namely association, communication and identification, and memento.

Association

People connect with product features that guide them into appropriate use through affordances, e.g. a circular handle affords grabbing [13]. Crilly names this semantic association: what a product is seen to say about its function, mode-of-use and qualities [21]. The association process is also related to intuition, a cognitive process that utilises knowledge gained through prior experience to intuitively interact with a product [22]. In other words, an *intuitive* product is somehow like one that a consumer is already familiar with, e.g. adding a green button to turn on a photocopy machine or mobile phone. Guidelines to design product features were defined by Norman in [14] and are a relevant aspect of usability.

Communication and identification

In [19] Belk affirms that our possessions are a major contributor to and reflection of our identities. Identification is linked to the idea that individuals express their selves through physical objects, e.g. one buys an elegant product to show how elegant he is [17, 18, 19, 23]. This is what in [21] Crilly has termed symbolic association, which is the perception of what a product says about its owner or user. Communicative and identification processes not only help build an identity, but also know other

people as they enable identifying both differences and similarities between people [24]. They are, therefore, also related to group affiliation, e.g. Harley Davidson Motorcyclists [25].

Memento

An object can be a reminder of another person or an event e.g. a photograph that symbolise a loved person [26], or a souvenir that brings nostalgic memories from wonderful holidays [27]. These actions generally have little to do with the shape, or the visual references of a product. Moreover, these products are not used to communicate success or status. In [26] Csikszentmihalyi reported that people establish a very personal relationship with the objects embodying the memento. Equally relevant, there is no substitution for these objects. McLeod confirms this suggestion by reporting strong feelings of loss when people loose symbolic objects because of natural disasters [28]. Mementos are a good example of how consumers continue meaning-making during product ownership [29]. During recent years scholars have paid attention to this phenomenon and research has been carried out to understand how bonds are developed with the intention to stimulate it as a sustainable design strategy [25, 30, 31].

2.4 Economic function

Commercial activities impact a wide range of aspects from profit and share-holder value to personal status and societal well-being. In order for human activities to become sustainable however, systemic considerations beyond traditional economic models must become an intrinsic part of how artefacts are designed. Traditional economic models that focus solely on monetary profit are increasingly seen as inadequate. This gap has become particularly acute during recent economic crises. There is a need for a less simplistic model and triple bottom line (TBL) economics is one of these [32]. The flow of value is a very complex subject. This section very briefly reviews examples to create a starting point for modelling function by adopting some of the basic ideas behind TBL, dividing economic functions across components like profit, ecology and fairness.

Profit

Traditional measures of economic performance seek to measure all changes in value in a uniform currency. This enables numerous forms of control and optimisation across various parts of economic systems. Since commercial activities are dependent on profitability, the maximisation of profit is a key decision driver in commercial product design. This maximisation results from decisions throughout the design process. A critical goal is often sustaining adequate revenue streams. An option that may be considered in the development of an idea is whether the product represents a one-off sales opportunity or whether it is possible and desirable to develop a system that enables repeat sales opportunities or even continuous services. As an example, printers can be considered where the initial sale of the printer may be at a discounted rate and future profit is principally based on the purchase of ink cartridges. The product-system must be designed so that the host product has sufficient reliability and functionality to retain customer loyalty and engagement and to encourage the customer to continue using the device or system and purchasing additional refills or service time.

Exclusive dependence on profit to assess overall economic benefit is potentially dangerous. Externalised costs such as losses of ecosystem services or societal stability may be invisible to profit measures yet incapacitating to commercial activities. It is, therefore, important to consider other aspects of economic function as well. These are treated in the following subsections.

Ecology

In contrast to the way that profit aims to maximise aggregated returns, ecological considerations focus on balancing individual resource use. Renewable energy use and balanced material cycles are required to insure sustainable product industries. Unfortunately, the nature of this functional area is often misunderstood. Simply maximizing efficiency in the use of resources is helpful in the short term but ultimately ineffective where a resource is finite and non-renewable. The resource will eventually run out and no amount of efficiency will sustain effectiveness. As a metaphor one can imagine driving from London to Liverpool. If the destination changes to Paris, no amount of slowing down will ever get you there: not 10%; not 99%. You have to stop, turn around and probably change vehicle. This is the way in which a great deal of *green* design fails to fulfil the ecology functions.

Since it is not acceptable to deplete limited resources by discarding or rendering materials unusable, McDonough introduces the concept of designing *technical nutrients*. Product materials should be selected for perpetual reuse [33]. They can thus feed human technological activity through infinite lifecycles.

Most current products probably still fail to meet this benchmark of sustainability and it is proposed that this is a failure in design [33]. For example, although the iron in cars appears widely recyclable it is usually contaminated with numerous heavy metal additives from paint coatings that make it unsuitable for actual reuse in cars. Instead, that metal can be *down-cycled* into building steel but this simply delays the loss of this technical nutrient from the global human system. If designing for ecological economic function, better paint choices can be made and the steel can remain a technological nutrient across product manufacture. In order to succeed, this design choice must be made when initially establishing the functions of a system.

Fairness

The value of human wellbeing is perhaps even more difficult to quantify than the value of ecological systems balance. One thing that is known is that happiness is strongly correlated with the fulfilment of basic needs (food, shelter, relationships). An example of minimum thresholds for human wellbeing is the Fair Trade Minimum Pricing (FTMP) scheme for coffee [34]. FTMP seeks to insure that goods sourced from less economically powerful areas of the world are protected from detrimental free-market variation. It asks "What is the minimum cost of this product to the producer?" Without this protection, there is a danger of de-stabilising the producer's livelihood due to free-market variation and minimisation of product prices. A key example is coffee, the second most traded commodity besides oil. Establishing a fair price is a complex, political-charged negotiation. Everyone has different costs and there are fears that artificially raising costs beyond a certain threshold will diminish demand and eliminate the benefit of the higher price. Nevertheless, FTMP contributes to market sustainability by safeguarding those that have the most to lose from market forces. It does so by creating a residual social connection between users and producers and by making key political struggles visible and therefore manageable. Thus, in functional terms, *fair* economics seeks to insure understood minimums in terms of basic needs.

2.5 Emergent function

It is important to allow for a residual category when classifying information. This allows effective adaptation to new or unpredictable entities [35]. There are a number of ways a product can perform unexpected functions and understanding these provides a number of benefits.

Emergent functions only come to exist in a specific context. Given that this can make them unpredictable, they may not be part of original *designerly* intent. Their value lies in potential learning. Examining emergent functions teaches designers about human behaviours and provides novel signals for future innovative design directions. An example of a framework for these emergent functions can be found in [36]. This framework looks at how people interact with their environments and it is intended to train observation for design work. These interactions include: reacting, responding, co-opting, exploiting, adapting, conforming and signalling.

A prime example is how it was found that a Bic pen can be used to open some models of bike locks [37]. Locks are about security. Technical security functions involve resisting brute mechanical force and other forms of un-authorised entry such as lock-picking. Economically, the product provides additional security with a substantial cash guarantee against technical failures. Being a brand name product with a conspicuous logo, they are also designed to meet the social aim of communicating security status to the owner and deterring potential thieves. Yet this all fails against a pen stem inserted into the lock and rotated in a particular manner. While complex operating environments are not predictable, awareness of these sorts of issues opens a whole set of design issues. Better ways of looking for these *surprises* should aid at least in speeding reaction and design revision.

Beyond the negative side of repairing failures, the identification of successful emergent functions is a powerful way to inform future design work.

3   RESEARCH APPROACH

The actions performed by products were initially researched by reviewing literature in the fields of engineering design, aesthetics, user experience and economics. The review indicated that product functionality is linked to the following dimensions: technical, social, aesthetic and economic. In order to ground the concepts and issues emerging from the research, the decision was made to analyse a commercial product. The Alessi Juicy Salif Lemon Squeezer by Philippe Starck was selected on the basis that all the aforementioned aspects are prominent. To identify the functions of the Lemon Squeezer, research articles, books and product reviews were analysed. The product was also tested

with a group of undergraduate students involved in the Mechanical Engineering degree at Imperial College London. A total of approximately 50 functions (22 technical; 9 aesthetic; 6 social; 10 economic; 4 emergent) were identified. These were initially logged into a spreadsheet and subsequently sorted by group and mapped using a modelling method known as the Function Analysis Diagram.

4   MODELLING PRODUCT FUNCTIONS

In Value Analysis, the list of functions has traditionally been generated in the abstract then linked to product parts or features performing these functions using a matrix, to enable value metrics to be calculated. However, it has long been recognised that the separate generation of the function list is a challenging task. Miles acknowledges that the naming of functions "is so difficult and requires such precision in thinking that real care must be taken to prevent the abandonment of the task before it is accomplished" [6]. This problem was addressed through the development of a range of diagram-based formalisms to represent product functions. The first to appear was the Function Analysis System Technique (FAST), a graphical way of structuring the generation of functions using a top-down decomposition process based on simply asking the questions: How? Why? and When? [1]. FAST was followed by the Function Structure, which consists of drawing a flowchart with blocks describing the sub-functions of a product connected by arrows describing flows of matter, energy and signals [2]. The FAST technique and the Function Structure benefit from their graphical presentation, but they remain methods representing just the technical function. A type of functional diagram that directly links the parts and features of a product with the functions that they perform and the parts acted upon, was published as part of a patent application filed in 1997 by the TRIZ vendors Invention Machine Corporation [38]. It was then implemented in their TechOptimizer software, later renamed Goldfire Innovator. These diagrams are a specialised form of concept map [39]. The mapped relations are useful actions or functions between product elements, which are coloured green, but also harmful effects which are coloured red. In a multinational power systems company effective use has been made of them in engineering design for some years, generally in the context of TRIZ workshops convened to address some particular problem [40]. They are generally created in Microsoft PowerPoint with the aid of a simple template and referred to as Functional Analysis Diagrams or simply FADs. Despite the development of above diagram-based methods, matrices have continued to attract engineers as an instrument for functional analysis and methods like Quality Function Deployment and Design Structure Matrices have emerged [41, 42]. It has been suggested that for sparsely linked structures, node-link diagrams (like concept maps) are faster to use and less error-prone than matrices [43]. A common complaint heard of matrix-based methods like QFD in practice is also that they are tedious to complete in full in order to get to the next stage (possibly due to diminishing returns after key areas of interest are modelled).

Here we will combine the concept of FADs with the multiple dimensions of functions in order to augment the study and understanding of product functions. A concept-map style node-link representation was deemed most appropriate for capturing the interrelated functions. Concept mapping thus embodies a rich medium that allows a practical focus on key functional areas of interest.

4.1 Application to an example: the Alessi Juicy Salif Lemon Squeezer

A simple, successful commercial product was selected to demonstrate the functional analysis. Many of the points here are based on discussions about the product in [44, 45]. The following maps use the legend presented in Figure 1 to capture each functional dimension.
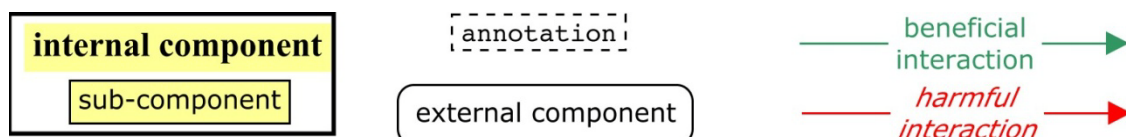
Figure 1: Functional Modelling Diagram Legend

The product has been modelled as internal components and sub-components. This simplified hierarchy is used because functions are often only rooted in a particular aspect or feature of a product. The decomposition allows more accurate mapping. Beneficial and harmful interactions are clearly distinguished to help highlight the complexity of interactions. For example, Preston describes the

value of studying both function and malfunction [46]. External components are sometimes necessary to model product functionality and thus are included. An annotation node has also been included to augment the map descriptions. Colour, font and outline selections allow this map design to work both in colour and monochrome printing.

Figure 2 presents a view of the design problem that allows designers to directly state what they seek to improve while maintaining key local functions. After some experimentation, a clear layout was found that separates all the external components (left) from the product itself (right). Technical functions are easily modelled because this product is fairly mechanical in nature. Each part has very few features and intended functions. The harmful interactions still highlight that the lemon squeezer is not very good at a number of things, including containing unwanted bits of the lemon and efficient scraping of all the juices. Referring back to the technical use functions, it would appear that almost all of the functions are secondary functions – dependent on the user to provide crushing force, balancing hold and even some of the filtration one might hope to get from a juicer. Given that a juicer ostensibly separates the juice from the fruit, the tendency of pulp and seeds to end up in the glass suggests a bit of a design failure. These seeming failures did not, however, prevent the product's success. Reasons for this become apparent from the other functional dimensions.
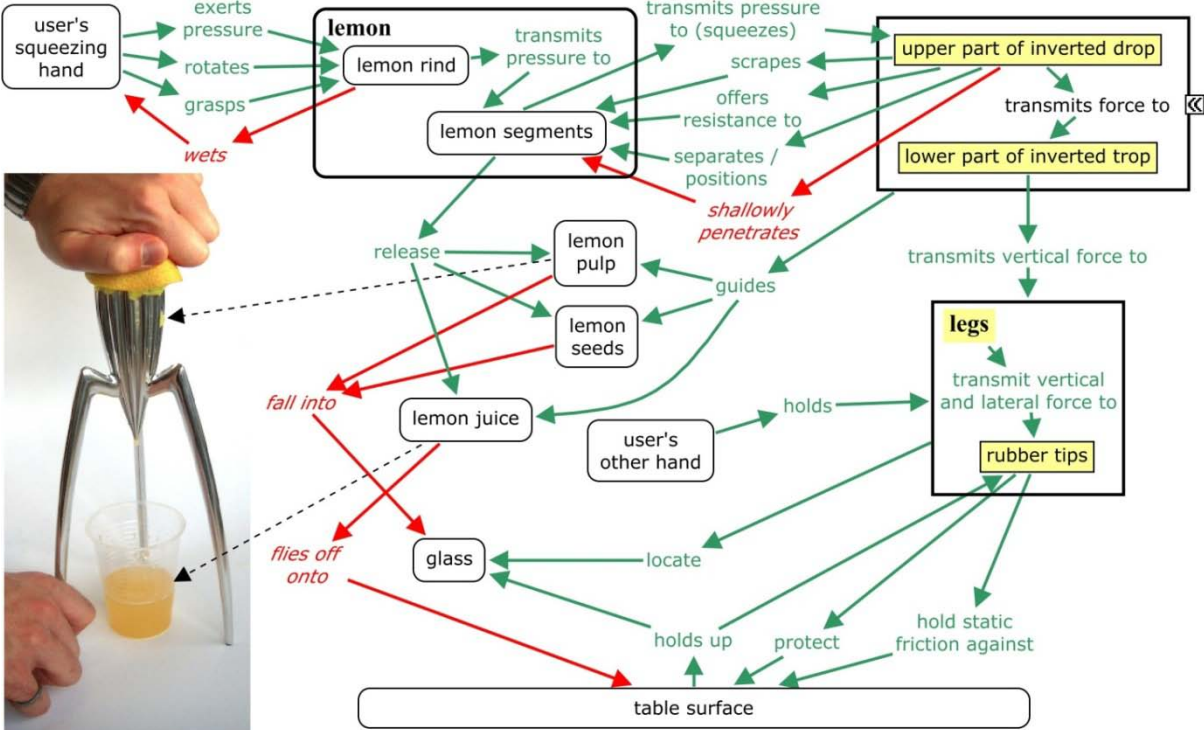
Figure 2: Technical Functions

Figure 3 provides a few examples of aesthetic functions of the lemon squeezer. The excitement caused by the inadequate technical functions is one of the key factors that sustained the economic functions. Since aesthetics is partially a sensory attribute, one might imagine a template of the senses that at least prompts designers to consider the whole experience of an artefact.

As an extreme example, at the tenth anniversary of its launch, 10000 lemon squeezers were numbered and gold plated. The gold plated version was described as an ornament because the citric acid in a lemon discolours and erodes the gold plating [45].
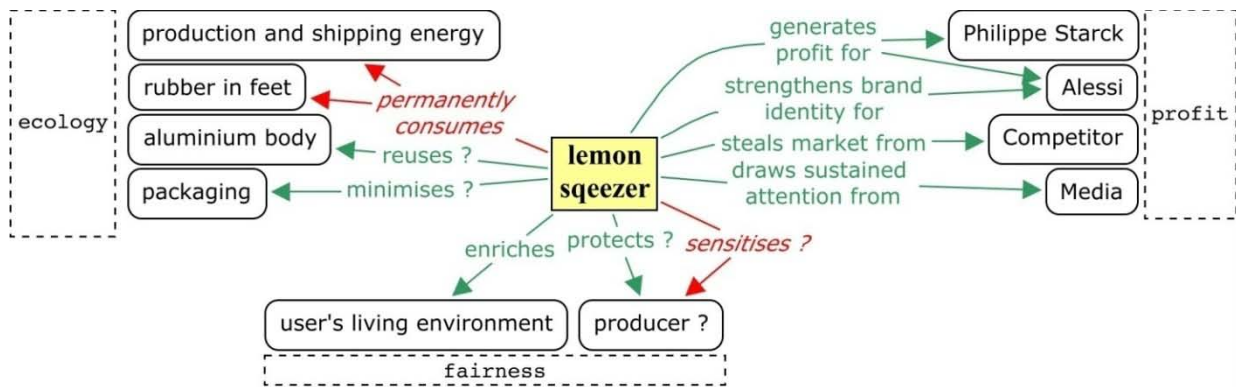
Figure 3: Aesthetic Functions

Figure 4 presents a few examples of social functions of the lemon squeezer. Stated functions emerged when looking for association, communication and mementos between social actors. In particular, the function to start memorable conversations between users is attributed to Philippe Starck himself who is rumoured to have said that his juicer is not meant to squeeze lemons. This diagram is more heavily annotated because social functions are more implicit.

Figure 4: Social Functions

Figure 5 is organized according to the three dimensions of interest in economic function: profit, ecology and fairness. Note that a number of points retain '?' marks due to a lack of information about the product. They are included to demonstrate more examples of what should be considered.

In the ecology dimension, for example, it is not clear where the aluminium was sourced and this has a significant effect on the planet considerations. Aluminium requires significant energy to produce (ca. 200 MJ/kg for virgin material, ca. 30 MJ/kg for recycled aluminium). If this is done with fossil fuels or nuclear generators, the overall balance is quite different than if it is produced using hydro-electric power. It is highly unlikely that it is produced entirely from wind, wave or solar power. Fortunately it is highly durable and recyclable.

Profit-wise, the product has clearly been a success. It has maintained some degree of attention to this day despite being twenty years old. Unorthodox aesthetics, Starck's character and Alessi's brand identity have all come into play here.

From a fairness perspective, it is less clear how this artefact functions. Casting is a relatively simple production process so it could be produced anywhere in the world with inexpensive labour or at volume with mechanisation.

Figure 5: Economic Functions

Figure 6 shows a few of the functions that were not necessarily intended in the original product design but that come to exist in its context of use. Having a few around the office for teaching purposes, the authors have put them to various non-juicing uses.
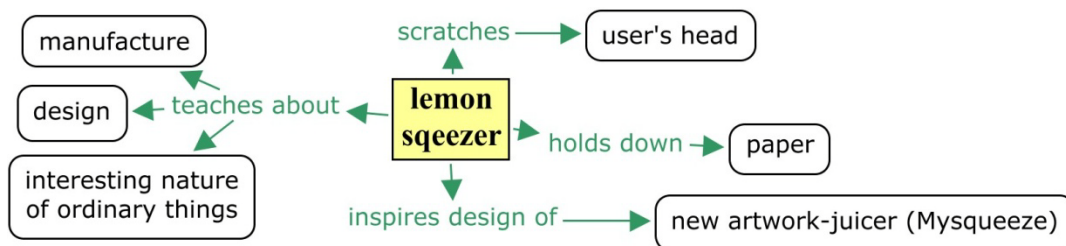

Figure 6: Emergent Functions

4.2 Discussion

The discussion focuses first on the importance of the various sets of functions in new product development and then on the graphical representation of functions.

Product functions and New Product Development

Technical functions are not a static set; rather they evolve with scientific and technological development.

In developing product form, attention needs to be paid to the consideration of the aesthetic function and the type of response evoked by the form. Consideration of the aesthetic function, therefore, represents a critical aspect of the design process and several scholars have pointed out its importance. Bloch affirms that product form can address attention from consumers and make a product stand out in a mature market [7]. Furthermore, Bloch points out that product appearance is the first thing about a product that connects with a potential buyer, and regardless of product class, judgments follow from this sensory experience [47]. Aesthetics, therefore, is one element that can stimulate product purchase. As Hektner has pointed out [48], it is not expected that individuals can always choose to do what they find most enjoyable, i.e. to buy the most aesthetically pleasing product. However, because attention and psychic resources are limited, it is expected that people prefer to spend their resources and time in activities and social relations that they associate with a positive experience, trying to avoid those perceived as negative [48]. Besides drawing the consumer's attention, aesthetics also creates long-lasting relationships with the consumer [26, 31]. An aesthetic product often has a higher economical value. Sometimes cost accepted in the aesthetic area brings the best return [6]. A consumer may pay more for a beautiful product than for an ugly one. This effect, however, is moderated by the personal aesthetic orientation of the person [47], as well as, situational aspects such as task and efficiency-oriented contexts. These may lower the importance of beauty [9]. Although the appreciation of a product's aesthetic appeal is subjective and each person will judge it individually, there are a number of principles that are helpful in the development and realisation of form [8, 49].

Designers should be aware that successful products are inscribed with meanings as well as uses [29]. The social dimension of products has to be carefully considered and fulfiled. New product development can benefit from communication and identification processes because it has been suggested that designers are good at embodying meaning onto products that consumers can disclose

[29] and that no design works unless it embodies ideas that are held in common by the people for whom the object is intended [50].

In [51] Tractinsky mentions that, as opposed to aesthetics per-se, effective symbolism depends on a cognitive process in which the individual recognizes a denotative meaning (the content of the formal structure) and infers connotative meaning about it. Moreover, Eisenman suggests that the symbolic properties of products are determined in the cultural and institutional environments in which consumers and producers are embedded [52].

In traditional societies consumption is linked to and grows proportionally with status [53]. Social functions have been used to build images of success and luxury. If a person wants to be recognized as successful, one strategy is to upgrade gadgets as soon as new ones are in the market. Communication and identification processes, however, can also be used for constructing images of sustainability, e.g. consumers have to recognize *green* products. Furthermore, people may want to be affiliated to the responsible consumption group.

The economic dimension will always be a determinant. However, this has been shown to be made of three facets: profit, ecology and fairness. Products exert several effects on the planet and people involved in its lifecycle. A world in which supplies are limited and where economic models are based on unlimited consumption is not sustainable. For example, planned obsolescence is no longer the path to follow. Deeper consideration of the actions of products and their development is required to save our planet. Product attachment, defined as the strength of the emotional bond a consumer experiences with a specific product, offers a promising area to tackle the actions of products on our planet [54]. The idea is to establish strategies for stimulating bonds between people and products. Chapman mentions that over ninety percent of the resources taken out of the ground today become waste within only three months [30]. This example illustrates the importance of understanding product attachment. Mugge identified that aspects of functionality and appearance are relevant to stimulate product attachment [31]. Another reason to consider is the different functions of products. As in [27, 17] we acknowledge that the different functions of a product are deeply intertwined, for instance, when designing product's form all the functions suffer an impact; this impact should be carefully designed.

Not all products require embodiment of technical, aesthetic, social and economic functions. Some succeed by satisfying only the technical and economic ones. Compressors and pumps are examples of engineering products that fit in this category. Fast moving consumer goods, however, are increasingly characterised by the need to satisfy more than the technical and economic functions. The aesthetic and social functions have long been neglected and require more consideration as they have a significant impact on consumers. The Juicy Salif Lemon Squeezer, commissioned to Philippe Starck by Alessi, has been shown to embody all four types of function. However, the Juicy Salif has become successful without fully addressing the basic technical function. This is highlighted by the number of secondary functions in the design that directly involve the user. The product is currently better known for its aesthetic and social functions rather than the technical one. This shows that balance between the four function types may be desired but is not necessary for success. Since we have exposed the particular impact of each dimension on product success we propose that it is not convenient for stakeholders to neglect these any longer.

The modeling method: Function Analysis Diagram

The litmus test for any new representation is whether it reveals solutions to new kinds of problems. What is visible that was not visible before? Here, we suggest three important possibilities: learning, re-design and creativity.

In order to apply the conceptual descriptions of functions from the literature, designers need a flexible way to match product observations to theories. The messy, networked nature of that exploration is probably best supported by a diagrammatic representation. Through a node-link representation, the initial fragmented components and relationships can be incrementally organized into coherent views of a product. Throughout our experimentation, we have yet to find clear rules for this clarification process. Unlike a highly formalized tool such as TRIZ, there may not be very widely generaliseable patterns to functional layout. FADs at least enable an accessible tool that encourages immediate interaction with concrete examples. This contrasts with the time it takes to learn and apply many other modelling techniques. FADs also create a more neutral view through which to compare multiple products with similar functions. The end result is a smoother learning curve, and, hopefully, more rapid and thorough understanding of the system under study.

Redesign is performed to reduce costs, eliminate harmful functions or extend the range of existing functions. As an example, the Juicy Salif juicer could be redesigned to manage a grapefruit or reduce, in a fit of post-post modernist utility, the spillage and mess created when using it. These functional diagrams give designers a context to put those ideas in order to find paths to those new solutions. A concept diagram excels here because it does not commit a designer to geometry from the get-go. The FAD thus provides the basis for a form of *pre-geometric* concept visualisation that would not otherwise exist.

The role of a FAD in creativity follows from the preceding point on re-design. There seems to be a perception within some of the design disciplines that creativity requires unbounded freedom – unfortunately this creates a danger in having to start from scratch to be truly innovative. Through a clearer understanding of interacting functions and a more flexible, abstracted starting point for design work, it is proposed that FADs can provide an appropriately balanced framework for *system-wide* creativity. Many of the systems mapped lack multi-directional relationships. This is not a limitation of the method but due to a lack of information on the products by the mappers. Future work on more complex products will address this.

5   CONCLUSIONS

Product development involves stakeholders from several disciplines who are concerned with understanding the needs and goals of consumers and planning the actions of new products. These stakeholders have different background and use different language to describe consumer needs and product actions. This study has proposed the description of product actions as interwoven concepts of function. Using a successful language from technical function, the research has delivered a consistent representation across disciplines, which has the potential to enable stakeholders to collaborate more successfully earlier in the design process and to improve product designs. Technical, aesthetic, social and economic functions were found to provide an improved description of product functionality. These augment typical technically-focused perceptions of functions so that wider influences on consumer behaviour are taken into account. The four dimensions of product functionality were demonstrated on a consumer product that has been very successful despite its technical failings. The Function Analysis Diagram technique, used to represent product functions, was shown to provide an accessible perspective that engenders new understanding of the complexity of products as well as opportunities for improving future designs. Further work is required to evaluate the advantages of FAD modelling method.

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