Product design strategies in technological shifts: An explorative study of Italian design-driven companies

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1. Introduction

In a period of technological shift that spans many different industries, "being first to launch a new technology is less important than being first to envision its greatest untapped market potential" (Verganti, 2011b). In other words, a product design that applies a new technology is more relevant than the technology itself. This widely shared view has attracted the attention of a growing number of scholars (Clark, 1985; Hargadon and Douglas, 2001; Rindova and Petkova, 2007; Talke et al., 2009; Verganti, 2011a, 2011b; Tran, 2010; Candi and Saemundsson, 2011) who are interested in the relationship and interplay between technological change and product design strategy. According to some scholars, design-driven innovation (Boland and Collopy, 2004; Borja de Mozota, 2003; Noble, 2011; Verganti, 2003, 2008, 2009; Luchs and Scott, 2011; Roy and Riedel, 1997; Filippetti, 2011; D'Ippolito, 2014; Johansson-Sköldberg et al., 2013; Ravasi and Stigliani, 2012) is progressively supplementing and partially overtaking the consolidated paradigm that considers innovation as resulting from "technology-push" or "market-pull" strategies (Dosi, 1982).

In other word the traditional view of technological innovation as a driver of advancement in product performance and functionalities (Abernathy, 1978; Abernathy and Utterback, 1978; Abernathy and Clark, 1985; Christensen, 1997; Freeman, 1982; Nelson and Winter, 1982; Nelson, 1994) has been complemented by the view of design-driven innovation as a means to convey the meaning of the technology to customers (Verganti, 2009; Verganti, 2011a, 2011b). Including the aesthetics, style, function, ergonomics, and overall gestalt of a product (Noble and Kumar, 2008), product design innovation differentiates offerings and maintains consistency with emerging social and cultural trends, enabling companies to cope with demographic, social, cultural and economic change (Berkowitz, 1987). Product design allows companies "to compete through design means to develop new design languages and signs that allow products to convey meanings and values to the users" (Dell'Era and Verganti, 2007).

Scholars have thus highlighted the factors that affect product design choices such as the breadth of the product portfolio (Monö, 1997), the type of competition (Monö, 1997), the phase of the product lifecycle (Monö, 1997; Berkowitz, 1987; Person et al., 2008), the brand identity (Karjalainen, 2003; McCormack et al., 2004; Olins, 1989), the maturity of the market (Karjalainen, 2003), the innovation orientation of a company (Dell'Era and Verganti,

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2007), the market segments being targeted and the emergent lifestyles of consumers (Sanderson and Uzumeri, 1995).

In particular, two design choices have been considered as particularly relevant to achieve a product design-based competitive advantage: the stylistic differentiation and stylistic heterogeneity (Cautela and Simoni, 2013).

Regarding stylistic differentiation literature recognizes a tradeoff between product design differentiation and product design sharing. Product design differentiation focuses on product language and style as a means of differentiating firm's offering (Verganti, 2009; Ravasi and Lojacono, 2005; Karjalainen, 2003; Tran, 2010). Conversely product design sharing involves the cooperation between companies that, sharing the evolution of sociocultural models and consumption patterns, converge on a common product language frame to minimize the risks and efforts in establishing certain product languages and meanings (Dell'Era and Verganti, 2007, 2011).

Regarding stylistic heterogeneity scholars consider the tradeoff between product portfolio language homogeneity and product portfolio language heterogeneity (Dell'Era and Verganti, 2007).

With a homogeneous product portfolio, companies use their product design and language traits to create a compact and consistent brand identity. By contrast, with a heterogeneous product portfolio, companies shape their product portfolios with high language variety to target different market segments.

Firms tend to address both tradeoffs – i.e. between product design differentiation and sharing and between product portfolio language homogeneity and heterogeneity – whenever they have the opportunity to develop relevant design-driven innovations and to promote new product languages. In particular during a technological shift scholars have observed that the need for firms to synchronize the new product languages with the new technology becomes particularly intense and that the discontinuity between the design of products based on the old technology and products based on the new technology has to be carefully managed (Hargadon and Douglas, 2001; Rindova and Petkova, 2007; Verganti, 2011b).

However extant studies have restricted their analysis to the sole interplay between technological innovation and design-driven innovation without inquiring the different design strategic choices of firms. To date there are no studies that have explored whether firms adopt different product design strategies to leverage the opportunity created by a technological change and whether they change their approach when shifting from the old to the new technology. This article aims to fill this gap in the literature by attempting to understand (i) whether different approaches to product design coexist within an industry among firms that are developing products based on a discontinuous technological innovation and (ii) whether these firms adopt a design approach that is consistent with the approach that was employed with the old technology.

A conceptual framework is proposed to investigate these research questions. The framework combines the two aforementioned dimensions of product design strategy (i.e., product design differentiation versus product design sharing and product portfolio homogeneity versus product portfolio heterogeneity).

We consider both dimensions in analyzing the design strategies of firms with old and new technologies. This approach allows us to highlight the differences between the firms within each technological trajectory and to assess the consistency of the design approaches used with old and new technologies for each firm.

The conceptual framework has been used to analyze the lighting industry. This industry is an interesting research subject for many reasons. Product design and style are relevant factors in the competition among the firms in the lighting industry, playing a fundamental role in shaping customer preferences. In this historic phase, the introduction of a discontinuous technology – i.e. LED (light emitting diode) – is observed as having stimulated a need for firms to either change or confirm the stylistic approach that they employed with previous technologies. Competitors in this industry show a high degree of variety in terms of their characteristics and behaviors, which may encourage different product design strategies.

Focusing on the Italian lighting industry, we selected a sample of 12 firms, including design innovators, and conducted an in-depth analysis of the styles of their product portfolios for a total of 484 different references. Considering the stylistic heterogeneity and differentiation of firms with respect to halogen and LED lighting sources, we determined their product design strategies during a technological shift from an old to a new discontinuous technology.

This article has seven main sections. First, the theoretical background for the study is presented; product design strategy and its relationship to technological shifts are discussed. At the end of the theoretical section, two research questions are proposed.

Next is the development of the conceptual framework, which presents the two main theoretical constructs – stylistic heterogeneity and differentiation within product design strategies – as its foundation.

Next, the methodological process employed in this research is described. The research setting, the style mapping tool and the measures used to assess stylistic heterogeneity and differentiation are presented.

The findings and results are presented and analyzed in the fourth section. Following a discussion section is presented where four propositions are outlined. Then theoretical and managerial implications are depicted.

The conclusions at the end of the article describe the limitations of the research and propose suggestions for further research that could more deeply consider how product design strategy intersects with technological shifts.

2. Theoretical background and research questions

Product design choices are increasingly becoming strategic decisions for several reasons. Aesthetics and product design are increasingly responsible for user preferences and behaviors (Bloch, 1995, 2003; Chitturi et al., 2008; Hirschman and Holbrook, 1980). The symbolic and emotional dimensions of consumption (Baudrillard, 1968; Noble and Kumar, 2008; Norman, 2004; Schmitt and Simonson, 1997) have made product design strategies a top concern for management (Le Masson, Hatchuel and Weil, 2011; Chiva-Gomez, 2004; Chiva and Alegre, 2007; Drejer and Gudmundsson, 2002; Dumas and Mintzberg, 1989; Filippetti, 2011; Ravasi and Lojacono, 2005; Krippendorff, 2011; Verganti, 2009; Lee and Evans, 2012) and policy makers (Hobday et al., 2012). Regardless of sector-specific idiosyncrasies, product design choices generally affect a company's profitability (Hertenstein et al., 2005; Carayannis and Coleman, 2005; Walsh et al., 1992; Moultrie and Livesey, 2014) and its potential for "strategic renewal processes" (Ravasi and Lojacono, 2005).

Moreover, product design strategies facilitate firm-level efforts at differentiation (Porter, 1980). Today, companies employ product style and design to distinguish their products from those of their competitors (Karjalainen, 2003; Karjalainen and Snelders, 2010; Monö, 1997; Candi and Saemundsson, 2008; Verganti, 2009).

Third, product design and style are employed strategically to develop brand identity and imbue it with meaning (Karjalainen, 2003; Karjalainen and Snelders, 2010; McCormack et al., 2004; Olins, 1989).

Companies such as Philips, Swatch, Nintendo, Alessi, and Apple are acknowledged as top players that generate an untapped market potential for technology via dramatic breakthroughs in product design.

The management innovation literature has analyzed the factors that affect the selection of a product design strategy.

Two main tradeoffs in selecting a product design strategy have been highlighted:

- product language differentiation versus product language sharing;
- product portfolio language homogeneity versus product portfolio language heterogeneity.

Regarding the first tradeoff, studies on product language differentiation indicate that product design choices are a means to differentiate a firm's products from those of its competitors and thus to achieve a distinctive position in the market (Verganti, 2009). Factors both external and internal to a firm have been explained to affect the firm's decision to differentiate its product language from that of competitors.

Focusing on external factors, scholars have argued that whether a firm uses its product designs to differentiate its offerings from those of its competitors depends on the characteristics of the firm environment. In this vein, Noble and Kumar (2008), who relate design strategies to functional differentiation and emotional value creation, identify three main strategic design options: (i) utilitarian design, in which functional differentiation is achieved by increasing the overall product performance and adding new functionalities; (ii) kinetic design, in which user-product interaction and product ergonomics are enhanced; and (iii) visual design, in which "product personality" is generated using design elements – mainly form, style, and aesthetics – to generate impressions and user emotions. In the same vein, other authors relate product language differentiation to the stage of the product in the product lifecycle (Berkowitz, 1987; Person et al., 2008). These authors point out that during the introduction and growth phases, product design emphasizes basic functional and structural changes, whereas in the maturity and decline stages, decoration, new visual appeal, and cost-reduction goals are emphasized.

Considering not only external factors but also internal factors, Karjalainen's (2003) analysis of Nokia and Volvo explains how stylistic and design decisions are influenced by factors such as brand identity, values and market maturity. Similarly, in a more recent study (Person et al., 2008), stylistic and design decisions were found to be affected by three internal and external factors: (i) the product's stage in its lifecycle, (ii) the number of products that a company has in its portfolio, and (iii) the company's positioning in the market. First, regarding the product lifecycle, when a product is well known, the market is mature and companies do not compete with regard to functionality and technological innovation different product designs are developed to target other customer segments or to stimulate repurchasing.

Second, a limited product assortment is more strongly associated with similarity between current products with regard to stylistic decisions, whereas a wide product assortment will include more diversity with regard to styling as a means to simultaneously reach several market segments. Third, whereas functional positioning is associated with stylistic continuity, symbolic positioning requires differentiation from existing and previous product generations (Monö, 1997).

By contrast to product design differentiation, scholars have recently analyzed an alternative product design strategy based on the benefits of sharing the main features of a new product language.

This cooperative approach is defined by Verganti as "design discourse" (Verganti, 2006, 2009; Dell'Era and Verganti, 2007, 2011). According to the author, "by being part of the same design discourse innovators develop a continuous dialogue about socio-cultural models and patterns of consumption impacting on the adoption of specific product signs and languages" (Dell'Era and Verganti, 2007). Thus, companies adopting such an approach converge to a common product language frame (i.e., a shared set of symbolic and aesthetic patterns) that is used to orient the development of the associated single products and product families.

As a result, their products and product portfolios may appear very similar (i.e., sharing common shape traits, similar materials, the same colors, and/or convergent signs), which limits the capacity to use the product language as a means of product differentiation but reduces the costs and risks of developing and diffusing the new product language. On the one hand, firms reduce the efforts required to develop their product language by benefiting from the achievements of others. On the other, when a dominant product language is affirmed in the market, firms participating in the design discourse limit the risks that their products' design will be rejected by customers.

In the same vein, Cappetta et al. (2006), building on the framework described by Anderson and Tushman (1990), describe the tension between product language differentiation and product language sharing. Specifically their results show that periods of divergence, when firms develop a range of different product languages and profoundly differentiate from competitors, are followed by periods of convergence, when the majority of companies adopt very similar styles to affirm a mainstream dominant product language.

The second product design tradeoff relates to the product portfolio language.

The relevance of this strategic dimension has been noted in studies that consider the size of firms' product portfolio and the relationship between brand identity and product design to be the two main drivers of the tradeoff between product language homogeneity and product language heterogeneity.

Specifically, a recent work by Dell'Era and Verganti (2007) analyzing the stylistic heterogeneity of more than 2000 products launched by 210 firms explores how a variety of "product languages" is differently managed by design-driven innovators and imitators. Indeed, according to the authors, the decision of firms to proactively launch a new design language or to employ languages that already exist in the market is coupled with the decision to develop a compact and homogeneous product language or to explore various and heterogeneous product languages. The results of the study illustrate that an inverse relationship exists between the innovativeness of the product language and the heterogeneity of product signs and languages. The authors explain this relationship by arguing that innovators are interested in promoting their brand through a product language, which is homogeneous and immediately perceivable for its innovative identity traits. Conversely, imitators tend to adopt a variety of product languages that are associated with existing products, mainly because they lack the resources and capabilities to interpret the evolution of trends and socio-cultural models. In this way, they foster the product language heterogeneity of their product portfolio (Dell'Era and Verganti, 2007).

The two tradeoffs in product design strategy are particularly relevant during a technology shift. Indeed, as highlighted by recent research, discontinuous technological changes allow for relevant design-driven innovations but also pose serious challenges to firms' product language development.

As observed by Rindova and Petkova (2007), technological innovation and product design show continuous "synchronization"

because the underlying technological change and the outer product aesthetic jointly determine both the cognitive and the emotional customer assessments of the new product's value. Eisenman (2013) points out that when a new technology emerges, product design plays a central role in the acceptance of the new technology because the product design provides information regarding the use of the technology, extends the product functionalities and excites users through new product meanings. Similarly, Hargadon and Douglas (2001) state that when a breakthrough technology enters the market, product design, which is intended to be "the particular arrangement of concrete details that embodies an innovation," is responsible for mediating between innovations and preexisting institutions. According to the authors, design has to mediate between novel and existing signs and product languages, with the former used to exploit the opportunities provided by the new technology's trajectory and the latter used to generate stakeholder and customer acceptance. Invoking preexisting knowledge, through cues, schemas, and scripts that are immediately effective in the short term but are not limited to existing messages, "robust design" enables the exploration of new ideas and language components.

Whether to differentiate a product offering through a new product language or to participate to a design discourse and whether to develop a homogeneous product language or to explore different product languages are relevant decisions in product design and become even more relevant when the advent of a new technology changes the competitive market environment. Nevertheless, innovation management studies have only partially addressed this topic, and no study to date has comprehensively analyzed the design strategies adopted by firms during a technological shift.

We address this gap in the literature with the following research questions and an empirical study in a relevant design-intensive Italian industry.

R1: What are the main design strategies that firms adopt when facing a technological shift?
R2: Do firms tend to maintain their design strategies for previous technologies with new technologies, or do they tend to modify their strategies?

3. Conceptual framework

A conceptual framework is presented as a means to answer these research questions. If one considers product design as the manipulation of the languages and styles of single products and those of the product portfolio as a whole (Dell'Era and Verganti, 2007; Dell'Era et al., 2008; Noble and Kumar, 2008; Verganti, 2003), a firm's product design strategy can be framed according to two main dimensions. The first dimension, which relates to the existing product portfolio, is the stylistic heterogeneity of the firm's products (Dell'Era and Verganti, 2007; Karjalainen, 2003). The concept of stylistic heterogeneity addresses the strategic decisions that firms make in their attempt to convey the meaning of a certain technology, either through a homogeneous product language that acts as a marker of that technology or through a variety of styles that highlight the different features of the technology. At opposite ends of a continuum, these polar approaches allow us to distinguish firms that tend to focus on a homogeneous product style from firms that tend to explore multiple product languages within a given technological trajectory. The second dimension, which is related to inter-firm competition, is the strategic decision of style differentiation (Tran, 2010; Borja de Mozota, 2003; Karjalainen, 2003; Noble and Kumar, 2008; Monö, 1997; Verganti, 2009). Style differentiation refers to how a product language is used with a certain technology to differentiate a company's product from its competitors. There are two opposing design approaches regarding style differentiation. The first approach involves focusing on differentiated product language niches. The second approach involves sharing a common product language that may eventually define a de facto dominant style within a given technological trajectory (Dell'Era and Verganti, 2011, 2007).

Both dimensions are used to analyze the strategic design choices of firms during a discontinuous technological shift in which some structural and aesthetic aspects of product design are supposed to change (Clark, 1985; Hargadon and Douglas, 2001; Henderson and Clark, 1990; Rindova and Petkova, 2007; Verganti, 2011b).

According to the proposed framework, firms can take advantage of a technological shift by modifying the stylistic heterogeneity of their product portfolios and by changing the degree to which they differentiate their style from that of their competitors.

Firms might choose to employ a new discontinuous technology to change their approach to style in their product portfolio, offering products equipped with the new technology through languages that are more or less heterogeneous than those adopted for their past products. Increased heterogeneity may allow companies to test the market acceptance of the new technology using different product styles. Conversely, reduced heterogeneity may be used to mark the new technology with a specific product language that facilitates the promotion of the new offering (Karjalainen, 2003; McCormack et al., 2004; Olins, 1989).

Style differentiation, in contrast, allows companies to employ the new discontinuous technology to accentuate the differences between their style and that of their competitors. Alternatively, decreasing style differentiation can allow a firm to become more similar to its competitors in terms of style, especially in the preliminary launch phase.

By stressing stylistic differentiation from its competitors, a firm can gain and defend market niche positions within the new technological trajectory. Instead of using the most common styles and languages, companies can seek out new style patterns to position themselves in niche segments.

By reducing stylistic differentiation from its competitors, a firm, by contrast, can converge on particular style patterns to sustain and even facilitate the introduction of a new discontinuous technology (Abernathy and Utterback, 1978). As indicated in studies of the fashion industry (Cappetta et al., 2006) and design-driven industries (Dell'Era and Verganti, 2007), companies tend to share style patterns to be more effective in launching new stylistic trends and in diffusing new product languages and meanings.

This approach can be particularly helpful when the new technology represents a discontinuous shift, with certain technical, structural and aesthetic features that are inconsistent with current customer scripts and cognitive patterns (Creusen and Schoormans, 2005; Rindova and Petkova, 2007; Veryzer, 1998).

Stylistic heterogeneity and differentiation are operationalized according to "style-profile distance" (Chen and Owen, 1997), which is discussed further in the following methodological section.

4. Methodology

4.1. Research setting

For several reasons, this study of product design strategies is focused on the lighting industry. First, the lighting industry is part of the design-driven industry, in which competition is mainly

Table 1
Main characteristics of firms in the sample.

	Foundation year	Turnover 2010 €/000	N. of employees	N. of design awards	N. of designers	N. of halogen products	N. of LED products
Artemide	1959	123,000	500	3	18	51	44
Catellani and Smith	1998	7,871	23	0	1	0	94
Cini and Nils	1970	4,804	15	0	1	10	9
Danese	1984	1,800	15	1	13	13	51
Flos	1962	109,000	356	4	11	29	19
Fontana Arte	2004	19,516	59	0	13	21	0
Foscarini	1988	37,000	63	1	17	35	5
Ingo Maurer	1965	1,000[a]	10	1	4	23	12
Kundalini	1996	3,500	11	0	9	6	5
Luceplan	1978	19,000	104	3	8	12	12
Martinelli	1973	4,000	18	1	7	7	14
Nemo	1993	107,000[b]	305[b]	0	7	8	4

The data have been gathered from different sources: firm balance sheets, economics magazines (Il Sole 24 Ore), Archivio Compasso D'Oro of the ADI (Italian Design Association) and the companies' product catalogues.

[a] Estimated value.

[b] Nemo is a brand within the Cassina Group. The data reported for turnover and employees are those of the entire group.

based on product design (Dell'Era and Verganti, 2007). Second, the firms within the lighting industry employ a plurality of strategic approaches to product design and to the style of their product portfolios. Furthermore, in the current historical phase, different technologies occupy the same sphere: halogen bulbs, the compact fluorescent light bulb (CFL), and the light emitting diode (LED) are the main lighting sources that are employed in residential and outdoor markets (Collis and Furey, 2011). The existence of different technology options – associated with different levels of performance, cost and efficiency – allows us to analyze product design strategies in terms of stylistic heterogeneity and differentiation during a technological shift.

In particular, the lighting sector recently experienced the introduction and diffusion of a discontinuous technology. In fact, LED is considered a breakthrough technology not only because of its superior performance in terms of efficiency and lifespan but also because it is an "electronic light" (Koeppel, 2011) that marks the transition from an electrical–mechanical-centered competence system to an electronics-based one. This transition has influenced the design and management of the new product development processes, allowing the entrance of new players, such as Sharp, Samsung, and Panasonic, which had previously operated in the realm of electronic appliances but are now reconfiguring the competitive dynamics of some segments of the lighting sector (Collis and Furey, 2011).

These features of the lighting industry allow for a comprehensive analysis of the interplay between product design strategies and technological shifts.

This study investigates that interplay by analyzing 484 products from 12 representative Italian companies operating in the sector in question. Halogen and LED technologies were referenced to compare the product design strategies associated with an older product and a new discontinuous technological innovation.

The sample of companies has been composed using theoretical sampling principles (Eisenhardt, 1989; Glaser and Strauss, 1967; Yin, 1994). Firms with different structural, economic and innovation profiles have been included to increase the possible heterogeneity of the product design strategies.

The sample includes medium-large companies – relative to the average Italian size – such as Artemide, Flos, and Luceplan. These companies are characterized by strong brand heritage and are acknowledged to have contributed to the worldwide diffusion of Italian design as a result of their collaboration with design masters such as Ettore Sottsass, Vico Magistretti, Michele De Lucchi, and Achille and Pier Giacomo Castiglioni. Because of these companies' innovative products, these firms have been awarded the Compasso D'Oro many times over. This prize is the most prestigious international award in product design.

The sample also includes very small, younger companies that are characterized by limited turnover, economic resources and numbers of employees, such as Kundalini, Danese, Martinelli, and Ingo Maurer. These companies, notwithstanding their limited resources, guard niche markets and have sometimes achieved interesting design innovations.

Table 1 shows the main characteristics of the firms in the sample.

Despite their different sizes, handled resources, and awards, the analyzed companies represent "design innovators" or cutting edge "design-driven companies". In addition to sharing a common vision about the strategic power of design, these companies seem to even have a common way of managing and leveraging design capabilities, setting their design portfolios, and sharing an entrepreneurship culture that is rooted in the richness and productive atmosphere of the region where they are located (Dell'Era and Verganti, 2010, 2007; Verganti, 2006).

4.2. Style profile distance, product language heterogeneity and product language differentiation measures

We consider the heterogeneity of the product portfolio for a given technology and the differentiation of the firm's offerings from those of its competitors as the main dimensions of a firm's product design strategy.

These two constructs were operationalized by building on Chen and Owen's (1997) idea that stylistic features are psychological qualities that are perceived by an individual and that can be captured using a semantic differential analysis based on an appropriate set of polar adjective pairs (Osgood et al., 1957). According to the authors' methodology, a "style-profile distance" for products can be calculated as a function of the differences between the product design characteristics.

In particular, the product language of a physical object can be analyzed by assessing the multiple elements that concur to its design such as the form of the distinguishable parts of the object, the joining relationships among these parts, the details treatments of the object, the texture patterns exhibited by the object, the color treatments employed. Each of these elements can be assessed by using polar adjective pairs to measure the specific features of the object.

As our first step in using the style-profile distance measure, we adapted the assessment tool that was originally proposed by Chen and Owen (1997) to the lighting sector. At this aim, we asked a pool of experts (i.e. four professors in the field of product design) to evaluate the suitability of Chen and Owen's adjective pairs to assess lighting products. The experts suggested removing some attributes that were ambiguous in the context of lighting products.

The reliability of the modified tool was then tested on a set of 50 randomly chosen lighting products. Therefore using each polar adjective pair as extremes of a six steps Likert scale, two researchers in the field of design were asked to separately assess the style-profile of the 50 products. Their evaluations were then compared using Cohen's Kappa analysis to exclude that subjectivity biases may affect the evaluation process (Cohen, 1960). The inconsistent items were removed from the tool (see Appendix A for further details about Kappa measures of style-profile items).

After this adjustment, the tool contained five product design elements, as articulated by 14 polar adjective pairs.

Using Chen and Owen (1997) words, the polar adjective pairs of the tool can be described in terms of questions they answer to.

Form elements

(i) harmonious–contrasting: do the form elements match well or contrast with each other?
(ii) homogeneous–heterogeneous: are the form elements of one kind or of several different types?
(iii) geometric–biomorphic: are the form elements geometric, biomorphic or partially biomorphic?
(iv) simple–complex: do the form elements demonstrate the quality of simplicity or not?
(v) balanced–unstable: are the form elements in a balanced state or an unstable one?

Joining relationships

(vi) monolithic–fragmentary: do the joinings make the object look like a single piece or one that is fragmentary?
(vii) self-evident-hidden: are the joinings clearly visible or very subtle?
(viii) static-dynamic: does the construction of form elements result in a structure that seems static or one that seems dynamic?

Detail treatments

(ix) uniform–multiform: do the detail treatments given the object demonstrate the quality of homogeneity or heterogeneity?
(x) angular–rounded: how are the details of the object perceived? Sharp- cornered? Or soft and rounded?

Textures

(xi) harmonious–contrasting: do the textural patterns used match each other well or do they create a strong contrast?

Color treatments

(xii) harmonious–contrasting: do the colors used match each other well? Or do they create a strong contrast?
(xiii) single–multiple: How many different hues appear in an object? Just one or quite a few?
(xiv) cool–warm: do the colors used suggest a cool or warm image?

The two raters involved in the tool's reliability test were asked to assess all the products in the sample by using the tool. Therefore for each product a style-profile was obtained that consists of 14 different values, one for each polar adjective pair. These values are all comprised in the range from 1 to 6.

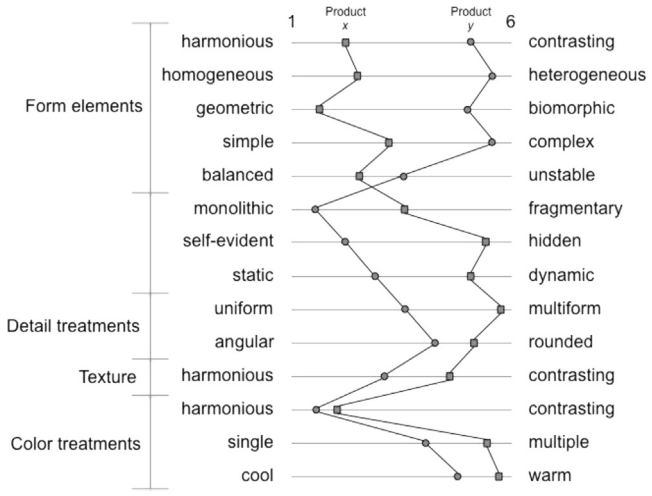

Fig. 1. Example of comparison between the style-profile of two products *x* and *y*.

By comparing a product's style-profile with that of another product the differences between their product languages can be analyzed and the distance between their style-profiles calculated. Fig. 1 provides a graphical example of the comparison between the style-profiles of two products.

The style-profile distance between two products was calculated according to Chen and Owen (1997). Thus, for each polar adjective pair, the difference among the scores obtained by the two products was calculated. These differences were then summed. Values of differences were squared and the sum was square rooted in order to obtain a value, which is independent on the signs of the differences between the scores of the two products.

Mathematically the style-profile distance was calculated as follows:

$$STdist_{x,y} = \sqrt{\sum_{j=1}^{n} (Ay_j - Ax_j)^2}$$

where $STdist_{x,y}$ represents the distance between the style-profiles of products *x* and *y*, Ay_j and Ax_j represent the values of the *jth* polar adjective pair for products *y* and *x*, respectively, and *n* represents the total number of polar adjective pairs.

Before calculating the style-profile distance for each of the 14 polar adjective pairs included in the style assessment tool, the values on the Likert scale were normalized in a range from 0 to 1.

Consequently, the range of $STdist_{x,y}$ values varies from a theoretical minimum of 0 for two identical products to a theoretical maximum of $\sqrt{14} = 3.7416$ for two products that show the maximum difference in all attributes. The same measure of style-profile distance was then used to assess the product language heterogeneity and the product language differentiation. Therefore the same theoretical minimum and maximum values can eventually be observed for both language heterogeneity and language differentiation.

The language heterogeneity of the firms' product portfolios was measured through the following procedure. First, the product portfolio of each firm was split between the two different technologies (i.e., halogen and LED) in order to calculate the product language heterogeneity for each technology. Then for each technology the style-profile distance among the products of each firm was determined. At this aim, the style-profile distance of each product from all other products of the firm's product portfolio was calculated and the minimum value was considered. In so doing for each product the minimum style-profile distance

from the other products of the firm was assessed. The mean of the minimum distances of the products in a firm portfolio was then calculated in order to obtain an estimate of the maximum degree of similarity (i.e. the minimum style-profile distance) among the style-profiles of the products of that firm for a given technology.

Therefore a firm with a low value of this indicator shows, for a given technology, a large number of products with highly similar style-profiles (i.e. a tendency toward a slightly heterogeneous product portfolio) whereas a firm with a higher value of the indicator shows a lower number of products with highly similar style-profiles (i.e. a tendency toward a more heterogeneous product portfolio).

In mathematical terms the product language heterogeneity was calculated as follows:

$$PLhet_{i,T} = \frac{1}{n}\sum_{j=1}^{n} min_{i,T}(STdist_{j,n})$$

where $PLhet_{i,T}$ represents the product language heterogeneity of the product portfolio of the firm i with respect to the technology T, n is the number of products in the portfolio of firm i and $min_{i,T}(STdist_{j,n})$ is the minimum style distance of the product j from all other n products in the portfolio.

The language differentiation among the product-portfolios of different firms was measured through the following procedure. Analogously to the language heterogeneity, the product portfolio of each firm was split based on the technology (i.e. halogen and LED). Then, given a firm and a technology, the distance was measured between each product in the portfolio of the firm and all the other products based on the same technology and developed by other firms. The minimum value was considered for each product. Minimum values were then averaged obtaining an estimate of the maximum degree of similarity (i.e. the minimum style-profile distance) among the products of one firm and the other products available in the market with a certain technology. Thus a firm with a low value of this indicator shows a large number of products with a style-profile, which is highly similar to that of the products available in the market (i.e. a tendency toward low levels of product language differentiation) whereas a firm with a higher value of this indicator shows a lower number of products with a style-profile, which is highly similar to that of the products available in the market (i.e. a tendency toward higher levels of product language differentiation).

Mathematically the product language differentiation was calculated as follows:

$$PLdif_{i,T} = \frac{1}{n}\sum_{j=1}^{n} min_{i,T}(STdist_{j,N-n})$$

where $PLdif_{i,T}$ represents the product language distance of the product portfolio of the firm i from the product-portfolios of competitors with respect to the technology T, n is the number of products in the portfolio of firm i, $N-n$ are the products of competitors; and $min_{i,T}(STdist_{j,\,N-n})$ is the minimum style distance of the product j from the other $N-n$ products of competitors that offer technology T.

An exemplifying figure is provided where different sampled products are shown to better understand the different cases that were measured according to the aforementioned formulas (Fig. 2).

5. Results analysis

Based on the measures of product language heterogeneity and differentiation, our empirical analysis was designed to evaluate whether multiple product design strategies coexist during a discontinuous technological shift and whether firms maintain a

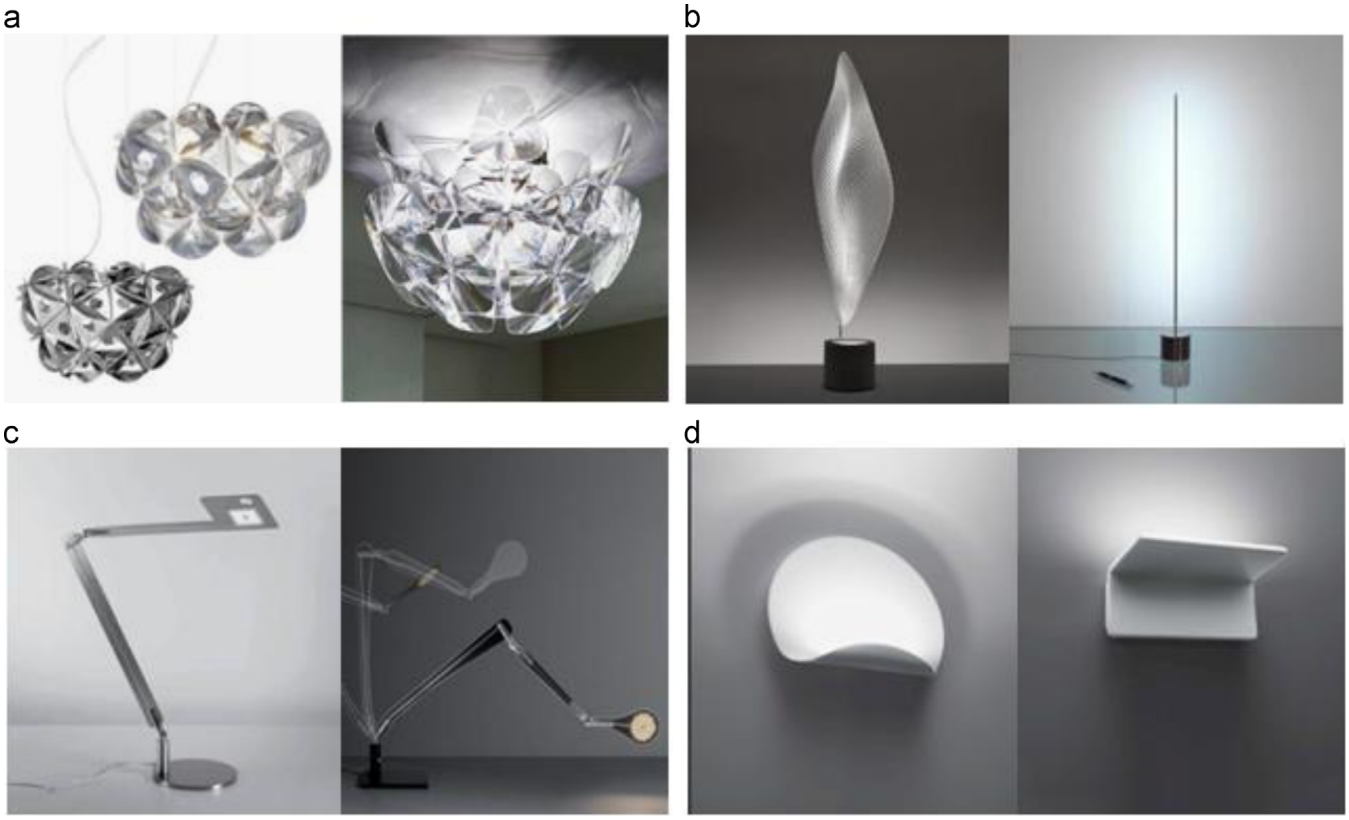

Fig. 2. Sampled product couples showing product language differentiation/similarity and product portfolio homogeneity/heterogeneity. (a) Example of products developed by different companies that share similar language and design traits (i.e. design discourse); (b) Example of products developed by different companies that do not share similar language and design traits (i.e. differentiation); (c) Example of products of the same company product portfolio that share similar language and design traits (i.e. product portfolio homogeneity); (d) Example of products of the same company that do not share similar language and design traits (i.e. product portfolio heterogeneity).

Table 2
Product language heterogeneity and differentiation in halogen and LED technologies.

	Product language heterogeneity		Product language differentiation	
	Halogen	LED	Halogen	LED
Artemide	0.4209	**0.4603**	0.6355	0.5978
Catellani and Smith		0.2313		0.5802
Cini and Nils	0.2189	0.2505	**0.7666**	**0.7663**
Danese	**0.6693**	0.3711	0.7118	0.5894
Flos	0.3414	0.2513	0.6221	0.6423
Fontana Arte	**0.5334**		0.6404	
Foscarini	0.4019	0.2517	0.6202	**0.8345**
Ingo Maurer	**0.4511**	**0.5243**	**0.7418**	0.7160
Kundalini	**0.4885**	**0.4737**	**0.7865**	**0.8749**
Luceplan	0.4323	**0.4891**	0.7118	0.6356
Martinelli	**0.4730**	**0.4186**	**0.8221**	0.6810
Nemo	**0.6057**	**0.5612**	**0.7712**	**0.8648**
Sample mean	0.4503	0.4052	0.7189	0.7203

Values in bold are above the sample mean signaling high product language heterogeneity and high product language differentiation.

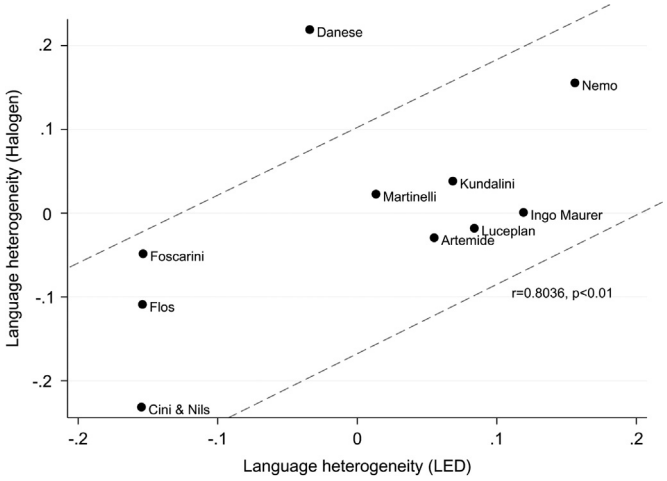

Fig. 3. Firms' approach to product language heterogeneity during a technological shift.

consistent product language approach while passing from the old to the new technology.

Table 2 summarizes the results in terms of both dimensions.

Fig. 3 shows the values of firms' product language heterogeneity (i.e., the variable *PLhet*) for the new technology on the *x*-axis (i.e., LED) and for the old technology on the *y*-axis (i.e., halogen). The firms show different product design approaches, with two main groups composing the greater part of the sample. The first group lies clustered in the lower left quadrant of the matrix. This group of firms tends to develop a product portfolio with low product language heterogeneity for both technologies. A second set of firms is grouped in the upper right hand quadrant of the matrix. This group tends to develop product portfolios with high heterogeneity for both LED and halogen lighting sources.

In addition, with the notable exception of the firm Danese, companies seem to maintain the same product design approach for both LED and halogen technologies. Once we had removed Danese from the sample, we found a Pearson correlation coefficient of 0.8036 for the heterogeneity of the firms' product portfolios for the two technologies, with a *p*-value that is significant at the level of $p < 0.01$. The higher the firm's stylistic heterogeneity in developing products using the old

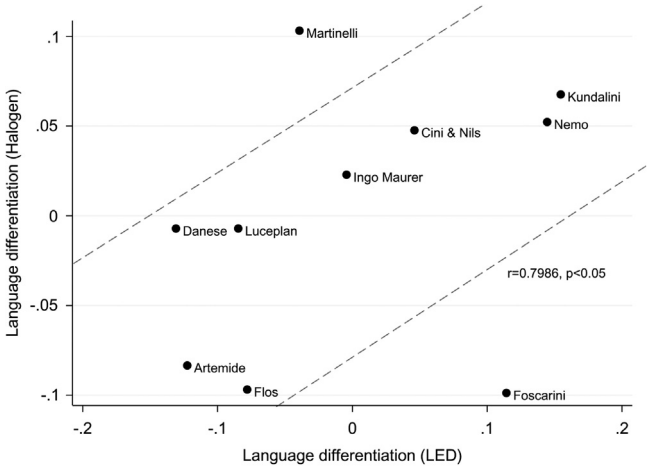

Fig. 4. Firm approaches to product language differentiation during a technological shift.

technology is, the higher it tends to be for the discontinuous new technology.

Danese differs from other firms because it changed its approach to stylistic heterogeneity during the discontinuous technological shift. Whereas heterogeneous style languages characterize its halogen product portfolio, its LED product portfolio shows a markedly lower level of such heterogeneity.

Fig. 4 shows the values for firms' product language differentiation (i.e., the variable *PLdif*) for the new technology (i.e., LED lights) and the old technology (i.e., halogen lights) on the *x* and *y* axes, respectively.

In addition, for this dimension of product design strategy, two main patterns appear to be relevant. One group of firms is clustered in the lower left-hand quadrant of the matrix. For both technologies, these companies tend to develop product portfolios that exhibit a low degree of differentiation from those of their competitors.

A second group of firms is clustered in the upper right-hand quadrant of the matrix. These firms tend to differentiate their product portfolios from those of their competitors for both technologies. Moreover, as with stylistic heterogeneity, firms show consistency in this design approach during the shift from halogen to LED technology. Indeed, with the exceptions of Martinelli and Foscarini, these companies show a high correlation between the degree of differentiation adopted in the LED and halogen technological trajectories, with a Pearson coefficient of 0.7986, which is significant at the $p < 0.05$ level. The higher the degree of differentiation for the old technology, the higher it tends to be for the discontinuous new technology.

Martinelli and Foscarini are two firms that have changed their design strategy with respect to stylistic differentiation. The former shows a high degree of differentiation from its competitors with regard to its halogen-based product portfolio, whereas its LED portfolio appears to be moderately differentiated from those of other companies that offer the same technology. Conversely, Foscarini has a halogen product portfolio that is characterized by a low degree of stylistic differentiation from those of its competitors, whereas its LED-based product portfolio is highly differentiated from those of its competitors.

The joint consideration of stylistic heterogeneity and differentiation allows us to identify and analyze the different product design strategies used during the technological shift from halogen to LED lighting sources. These strategies are discussed in the following section of the paper.

6. Discussion

The proposed framework considers product design strategy as the choice of expanding or reducing a product portfolio's stylistic heterogeneity and that of limiting or emphasizing the stylistic differentiation of the products from those of competitors. Style heterogeneity measures how companies compete within a technological trajectory through a product portfolio that is characterized either by a homogeneous language that clearly distinguishes the given technology or a heterogeneous language that proposes multiple stylistic options with respect to that technology. Stylistic differentiation indicates how companies compete by converging with other firms towards shared product languages in hopes of leveraging the diffusion of dominant languages and styles (Dell'Era and Verganti, 2007, 2011) or by differentiating themselves by protecting their market niches and micro-segments.

The first research question of this article addresses whether companies tend to adopt different or convergent product design strategies during a discontinuous technological shift.

As highlighted by the analysis of the results, a variety of product design approaches in terms of stylistic heterogeneity and differentiation have been used by firms facing the transition from halogen-based to LED-based products in the lighting industry. Combining these two dimensions yields four different design strategies. Fig. 5 shows the stylistic differentiation of firms on the *x*-axis and their stylistic heterogeneity on the *y*-axis, both with respect to the new LED technology.

The first strategy characterizes companies that retain a compact product portfolio language and seek to use the same product languages as their competitors at the expense of differentiation. The logic behind this strategy is twofold. On the one hand, focusing on a specific product language, these firms can achieve high levels of effectiveness in developing and promoting the new technology (Kim and Mauborgne, 2005; Meyer and Lehnerd, 2011). On the other hand, joining some common emerging product language principles, they can limit their investment in affirming the meaning of the new technology and its related offerings (Dell'Era and Verganti, 2011). Thus, these firms act as *language trend setters*. Having identified one style that can mark the new technology, they can establish this style as the dominant product language within the new technological trajectory. Language trend-setter firms are denoted by the letter A in Fig. 5 (Danese, Flos, Catellani and Smith).

The second strategy is that of firms that combine high product language heterogeneity with reduced differentiation from their competitors. These firms develop multiple product language options for a given technology; however, these firms use the most relevant styles that are being employed by other industry competitors. The logic behind this strategy is related to the idea of strategic flexibility (Aaker and Mascarenhas, 1984; Sanchez, 1995, 1997; Sanderson and Uzumeri, 1995). Indeed, proposing several product language options these firms are able to maintain tight control over the development of the product styles related to the new technology. When one product language option proves to be more effective, they can focus on that option and abandon other possibilities for product languages. Moreover, being aligned with the design choices of their main competitors, they reduce the investment necessary to affirm the styles of the new technology and diminish the risk of the chosen product language being made obsolete by the product language proposed by another firm. Thus, these companies act as *language trend diffusers*. Having selected their set of styles, they contribute to the diffusion of multiple design options that may end up with one or more dominant product languages related to the new technology. Language trend-diffuser firms are denoted by letter B in Fig. 5 (Artemide, Luceplan, and Martinelli).

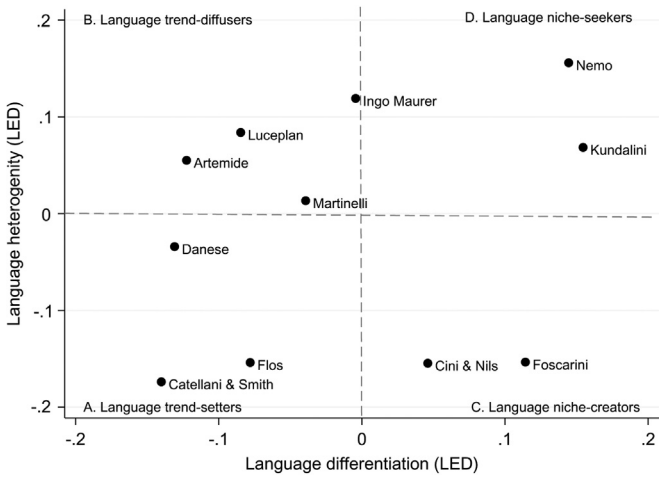

Fig. 5. Firms product design strategies in launching new LED technology.

Language trend setters and trend diffusers, as noted in the literature (Dell'Era and Verganti, 2007; Verganti, 2009), take part in and drive the "design discourse" that determines the meanings of products and new technologies by assigning languages, messages, and styles to them. These companies act as a sort of *language trust* that reduces the design-based competitive advantage of each participant but diffuses the main languages and styles and the associated socio-cultural models, thus generating collective advantages as occurs with the affirmation of a shared technological standard (Dell'Era and Verganti, 2007, 2011; Suárez and Utterback, 1995; Tegarden et al., 1999).

Overall, these firms are the drivers of the new trend in LED-equipped products, and most of the firms share some common features: the control of relevant economic resources that are invested in the exploration of new languages and efforts to diffuse them (Dell'Era and Verganti, 2007); innovation capacity as recognized by a long history of design awards; the ability to manage a large number of different product designers; and a large portfolio of product references.

In the third design strategy, companies jointly choose low stylistic heterogeneity and high differentiation from their competitors. These firms attempt to create a unique and distinctive style position that sustains the identity of the product offering by differentiating the firm from its competitors in other niches or in the dominant product language stream. As with language trend setters, the logic behind this strategy is related to more effectively developing and promoting a new technology-based offering by focusing on one single style (Kim and Mauborgne, 2005; Meyer and Lehnerd, 2011). Different from firms adopting the trend setters strategy, these firms aim to create their own product language within the new technological trajectory. This risky strategy may lead to disproportionate positive results for the firm if the design option proposed is accepted in the market overtime. Such a strategy may also lead to a progressive marginalization of the firm if its product language is not well accepted, and the efforts made to affirm it do not produce adequate returns. Thus, these firms act as *language niche creators*. Having selected one style, they contribute to the creation of product language proposals outside the mainstream design related to the new technology (Frenken et al., 1999; Wright, 1986). Letter C in Fig. 5 denotes language niche-creator firms (Foscarini and Cini Nils), which are characterized by compact product languages. These languages represent specific style identities that are deeply differentiated from the rest of the LED-based market offerings.

In the last strategy, companies seek high stylistic heterogeneity and high differentiation from their competitors. These firms

couple stylistic heterogeneity within their product portfolios with a systematic search for ways to differentiate their offerings from those of their competitors. As with the strategy for language trend diffusers, the logic behind this strategy is strategic flexibility (Sanchez, 1995, 1997; Sanderson and Uzumeri, 1995). Indeed, exploring multiple stylistic options, they are able to eliminate stylistic options that are less promising and shift investment to the product languages that are favored by the market. Different from firms adopting the language trend diffusers strategy, instead of aiming to diffuse one or many dominant languages within the new technological trajectory, these firms seek product styles that can be protected from competitors. In doing so, they increase the opportunities to find interesting market niches but still face the risk, similar to language niche creators, of being marginalized by the affirmation of mainstream design styles related to the new technology. Thus, these firms act as *language niche seekers*. Having adopted a set of styles, they increase the number of product languages that differ from those proposed by the main competitors. In Fig. 5, language niche-seeker firms are denoted by the letter D. This group includes firms (Nemo and Kundalini), which attempt to identify and protect interesting style niches in the market for LED-equipped lighting products.

Scholars recognize both language niche creators and language niche seekers as including firms that, given a certain technology, will expand the product languages within an industry by adopting styles that usually remain confined to a small portion of the market. It is rare for these firms to establish a new main stylistic trajectory through the substantial market growth of their language niche. When a new main stylistic trajectory is established, however, a market winner firm emerges that is able to not only master a new technology but also produce a differentiated product language that competitors may not be able to mimic.

Firms in both groups share some features, such as limited resources that can be invested in product design innovation, small creative networks of designers, and narrow product portfolios.

The second research question addresses whether companies tend to be consistent in their product design strategy when they switch from the old technology to the new discontinuous technology.

As noted in the analysis of the results, the data fundamentally show a certain strategic coherence or a form of "stickiness," indicating that companies tend to maintain the same strategic approach, whether it involves heterogeneity or differentiation.

Fig. 6 complements the data in Fig. 5 concerning the halogen technology. As shown in the figure, most of the firms maintain almost the same position in the matrix for both technologies, signaling the continuity between the product design strategy used for the old halogen technology and that used for the new LED technology. Indeed, Flos confirms that its language trend-setter approach to its LED products was also used for its halogen-based products. Similarly, Artemide and Luceplan confirm that their trend-diffuser approaches to their LED products are a continuation of the approaches that they adopted for the old halogen technology. The same can be said for Cini and Nils, which show continuity as language niche creators within the halogen and LED product trajectories and for Nemo and Kundalini, which show that their approach to the new technology as language niche seekers is consistent with their product design strategy for the previous technology. Finally, for Ingo Maurer the position in the matrix for its halogen products helps assuming that also its ambiguous position for LED products should be interpreted as that of a language niche-seeker.

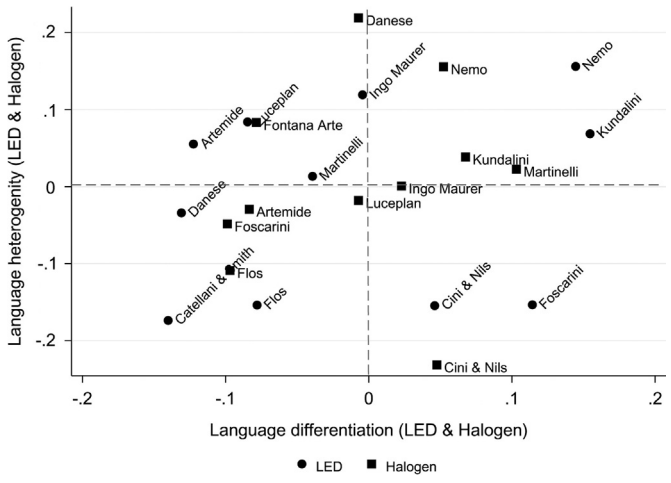

Fig. 6. Comparison of the product design strategies for LED and halogen technologies.

Two interesting general tendencies can be observed with respect to these firms. First, companies that engage in a "design-discourse" (Verganti, 2009) to establish the dominant languages of a technology tend to reduce their relative stylistic differentiation in the shift from halogen to LED lighting sources. In fact, the position of these firms in the LED portfolio matrix is to the left of their position in the halogen portfolio matrix. When facing a discontinuous technological innovation, these firms aim to converge on a set of shared product languages that is smaller than the set for a more mature technology. This evidence confirms the hypothesis in the literature that style differentiation increases with the maturity of technologies.

Conversely, as observed in the cases of Nemo and Kundalini, firms that attempt to establish product design niches tend to accentuate their differences from their competitors. Indeed, their position in the LED portfolio matrix is to the right of their position in the halogen portfolio matrix. In shifting to the new technology, these firms aim to accentuate their search for a distinct style from the earliest phases of technological development.

Two notable exceptions to this trend are firms that have changed their product design strategy in shifting from the old to the new technology. The most relevant case in terms of the magnitude of the change is Danese. This firm revised its approach to product portfolio languages during the shift from halogen to LED technologies. Whereas the firm acted as a language trend setter for LED technology, it appears to act more as a language trend diffuser for halogen products. The heterogeneity of the product portfolio was, in fact, significantly reduced when the firm launched its new LED-based products. Two drivers, one internal and one external, may have dictated this behavior. The internal driver may be the intention on the part of the firm's management to have a stronger impact on the formation of LED-dominant languages by focusing on a narrower set of stylistic options during the early phases of the new technology-based design discourse. This conjecture is highly realistic because of the very high degree of heterogeneity that actually characterizes Danese's halogen product portfolio. The external driver may be related to the absolute magnitude of the stylistic heterogeneity of the other relevant players that are involved in the collective design discourse about LED-based products. Indeed, these firms have lower levels of portfolio heterogeneity, and Danese's management should have brought its portfolio heterogeneity to such a level.

The second case is Foscarini, which changed its stylistic approach by increasing its stylistic differentiation in the shift from halogen to LED products. Once a language trend setter in the halogen market, the firm has now become a language niche creator. This move contradicts the portion of the literature that argues products should become more differentiated as technologies mature (Berkowitz, 1987; Monö, 1997; Person et al., 2008).

The firm seized the new technological opportunity by focusing its resources to create a specific product language that is distinct from the one used by the rest of the firms that offer LED-based products. This firm's strategic approach may be related to the propensity of its managers to accept higher levels of risk during the discontinuous shift from the halogen to the LED technology. Indeed, adoption of a single product language that is highly differentiated from the rest of the LED-based offerings may give a firm greater visibility than participation in the dominant product language discourse as one of the many players. Nevertheless, this strategic approach exposes the company to the risk of been confined within a small niche of the market if its style proposal does not match the primary sociocultural trend related to LED-based products.

The discussion of the empirical results can be summarized in four theoretical propositions about the relationship between technological change and product design strategies.

Proposition 1. During a discontinuous technological shift, companies tend to adopt different product design strategies.

Proposition 2. During a discontinuous technological shift, companies tend to adopt product design strategies that are consistent and coherent with the ones that the firm adopted for previous technologies.

Proposition 3. During a discontinuous technological shift, four main product design strategies are used: (1) product language trend-setters; (2) product language trend-diffusers; (3) product language niche-creators; (4) product language niche-seekers.

Proposition 4. During a discontinuous technological shift, companies that rely on past product design strategies tend to accentuate these strategies, whereas companies that change their product design strategies tend to modify their approach according to specific contingent factors.

Following theoretical implications and managerial implications are depicted in order to better show how these propositions contribute to innovation and strategy studies and to the managerial practice, respectively.

7. Theoretical and practical implications

The article has several theoretical implications.

First, the article shows that firms dealing with a technological shift adopt different product design strategies in developing and promoting products based on a new technology. These strategies rely on specific choices about the product language (i.e. form, joining relationships, detail treatments, textures, color treatments) that firms use to convey to users the meaning of the new technology (Sanderson and Uzumeri, 1995; Hargadon and Douglas, 2001; Rindova and Petkova, 2007; Verganti, 2011a, 2011b; Eisenman, 2013). However extant technology innovation literature, which is mainly focused on the firms' choices about new products technological features (i.e. functions and performance) and on the different types of technological innovation that firms can develop (Dosi, 1982; Henderson and Clark, 1990; Christensen, 1997), has deserved limited attention to product design strategies. This literature, therefore, could be improved by including product design strategies in the repertoire of the strategic options available for firms facing a technological shift (Verganti, 2008; Cautela and Simoni, 2013). That is, product innovation strategies could be rethought in terms of interplay between technological and product language innovation choices and the understanding of the affirmation or of the failure of new technologies in an industry could consider also issues related to the product designs strategies adopted by firms to convey the meaning of the new technology.

Second, the article highlights that the different product design strategies adopted by firms in a technological shift are based on different competitive logics that, in turn, lead to different roles in diffusing the product languages associated to the new technology. Such variety of strategic roles represents a factor that extant literature on technology-based competition could consider to better explain the competition among firms during a technological shift. Indeed the success of a firm could be dependent not only upon its capabilities to exploit the new technological trajectory but also on its ability to play a relevant role in the affirmation of new product meanings based on the new technology (Ulrich, 2011; Verganti, 2011a, 2011b). As a matter of fact, the different product design strategies that are highlighted in the article could be an additional antecedent or eventually a moderator of the relationships between the firm's technology strategy and its competitive success.

In addition, the aforementioned different product design strategies can have also implications for the literature that studies design capabilities of firms (Bruce and Docherty, 1993; Bruce and Morris, 1994; Dell'Era and Verganti, 2010; Ho et al., 2011; Jevnaker, 2000). Indeed this literature focuses on the type of capabilities that are required by firms to successfully design new products. However the choice about the capabilities to be developed by a firm may be well affected by the product design strategy adopted to exploit a new technology. Therefore the different strategies investigated in the article could represent a driver for firms to direct their effort towards the development of certain design capabilities instead of others. Literature on the topic could rely on these possible complementary explanations to better investigate the design capabilities of firms.

Third the article shows that firms tend to apply to new technologies the same product design strategies used for previous technologies. This sort of strategies' stickiness is relevant for studies about creativity in new product design (Cross, 1997; Dorst and Cross, 2001). Indeed these studies focus on the conditions under which new ideas flourish and novel design solutions are developed. However the observed path dependency of product language choices introduces an evolutionary perspective in creativity research. New design solutions emerge not simply as an outcome of designers' creative leaps but as the result of a precise design strategy, which, in turn, is largely affected by previous choices about product language (Cautela and Simoni, 2014). Such evolutionary view of new product design may also help in shading light on the roots of creativity in design, that to date is a very debated topic.

The article has also several managerial implications.

First the article shows that different product design strategies coexist in a technological shift and that these strategies respond to different competitive logics allowing firms to play different roles in diffusing product languages related to a new technology. Managers should therefore be aware of the different strategic options and analyze the impact of these options on firm's success.

In particular, in facing a technological shift, managers should consider two main tradeoffs. The first tradeoff concerns the decision between strategic flexibility and effective product language development. Managers can simultaneously explore different product languages to continuously fine tune their products' style based on the market and competitors, which may lead to increasing costs and a less clear stylistic identity of the product portfolio. By contrast, managers can adopt just one specific product language to mark the new technology, so providing a single consistent style to all their products. This choice allows the firm being highly effective in allocating resources and efforts to product design, but makes it difficult to adapt firm's product language to the changing market and competitive context.

The second tradeoff concerns sharing a common language with competitors to affirm a dominant language compared with the alternative option of creating a differentiated design niche. In the first strategic approach, risk and investment are minimized but at the cost of lacking differentiation from competitors; in the second, the benefits of product differentiation and the creation of new design niches are counterbalanced by higher costs and risk.

Second, the article highlights that product design strategies are highly path dependent. This path dependency should stimulate managers to carefully consider their decisions in two perspectives. On the one hand, managers should make their strategic choices by carefully assessing the validity of past product design strategies in the current situation. Indeed, to confirm strategies that proved to be adequate in the past could be not necessarily a correct choice for the future. On the other hand, managers should constantly evaluate the consistency of firm's design capabilities with the product design strategy selected for a new technology. The continuous alignment of firm's design capabilities and product design strategies could represent one of the most relevant challenges for managers in mastering technological shifts.

8. Conclusions

This article aims to contribute to the existing literature by exploring the relationship between technological change and product design strategies. Although the literature acknowledges that technological shifts provide new opportunities in terms of product design strategies, most studies do not analyze companies' actual strategic behavior during technological shifts. The article shows that companies – facing a discontinuous technological shift – tend to adopt different product design strategies. Furthermore they maintain their existing product design strategies during the transition from an old technological trajectory to a new discontinuous one.

This research and its results have certain limitations, which are mostly related to the explorative nature of the study. Indeed our focus on a limited number of firms that are geographically located in Italy, belong to a typical design-driven industry (i.e., the lighting industry) and are all design innovators, on the one hand, allowed us to conduct an in-depth analysis but, on the other hand, limited the generalizability of our results. Future research may thus explicitly address these limits. First, including a larger number of firms of the same type in the sample would provide a more comprehensive view of the studied industry. Second, the use of design innovator firms restricts the application of our findings to companies that achieve competitive advantage through design innovation. Imitators or firms with a weak design-driven innovation orientation may use different design strategies. Analyzing both innovators and imitators may provide insight regarding product design strategies of firms. Third, our results may have been affected by idiosyncrasies of the lighting sector, although this industry is considered a typical design-intensive industry in the literature. A multi-sector study could thus bolster our results. Finally, analyzing other countries where product design is still an emerging strategic weapon of firms would further improve the generalizability of our results.

Future research could extend our findings also by exploring related research questions.

The same study could be replicated by exploring industrial and competitive contexts in which the pace of technological change is more rapid than that in design-driven industries. Analyses of these industries could yield new evidence regarding the interplay between technological change and product design strategies.

Moreover, future research could study the relationship between design strategies and performance, providing further elements to elucidate the rationale of each strategy option and to clarify the generalizability of our results.

Finally, the key players in a design-driven environment are mainly represented by external designers who develop new product proposals. Studying how these companies compose and manage their designer networks during a technological shift could add another dimension to our knowledge of the relationship between product design strategies and technological change.

Acknowledgements

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Appendix A

The reliability test was conducted on a style assessment tool that consisted of five categories for a total of seventeen attributes describing a product style-profile. Following Chen and Owen (1997), the items were operationalized using a six-point scale between two bipolar adjectives (Table A1).

Two experts in product design were asked to assess independently the style-profile of a random sample of 50 lamp models. Their judgments were then compared using Cohen's Kappa analysis to evaluate subjectivity biases affecting the evaluation process (Cohen, 1960).

Indeed, the Kappa coefficient is directly interpretable as the proportion of joint judgments in which there is agreement after chance agreement is excluded. To avoid interpreting similar judgments as discordances, the importance of disagreements

Table A1
Style-profile assessment tool.

Category of product style-profile	Attributes of product style-profile	
	Adjective 1	Adjective 2
Form elements	Harmonious	Contrasting
	Homogeneous	Heterogeneous
	Geometric	Biomorphic
	Simple	Complex
	Balanced	Unstable
Joining relationships	Monolithic	Fragmentary
	Self-evident	Hidden
	Static	Dynamic
Detail treatments	Uniform	Multiform
	Angular	Rounded
Textures	Harmonious	Contrasting
	Single	Multiple
	Regular	Irregular
Color treatments	Harmonious	Contrasting
	Single	Multiple
	Cool	Warm
	Hard	Soft

Adjective 1 and adjective 2 are the two extremes of the semantic differential based on a six-point Likert scale.

Table A2
Cohen's Kappa results based on two experts' evaluation assessments.

Attributes	Agreement (%)	Expected agreement (%)	Kappa	Std. err.	Z	Prob > Z
Form element #1	92.08	84.02	0.5043	0.1204	4.19	0.0000
Form element #2	92.33	84.74	0.4973	0.1164	4.27	0.0000
Form element #3	95.04	82.72	0.7130	0.1380	5.17	0.0000
Form element #4	94.32	87.98	0.5275	0.1355	3.89	0.0000
Form element #5	91.12	85.78	0.3754	0.1267	2.96	0.0015
Joining relationship #1	91.76	87.42	0.3450	0.1247	2.77	0.0028
Joining relationship #2	83.52	73.39	0.3807	0.1121	3.40	0.0003
Joining relationship #3	89.84	82.06	0.4337	0.1405	3.09	0.0010
Detail treatment #1	90.56	86.52	0.2996	0.1117	2.68	0.0036
Detail treatment #2	92.00	85.71	0.4402	0.1131	3.89	0.0000
Texture #1	94.38	87.12	0.5631	0.1352	4.17	0.0000
Texture #2	81.88	79.81	0.1025	0.1363	0.75	0.2260
Texture #3	89.25	87.53	0.1383	0.1410	0.98	0.1633
Color treatment #1	88.96	85.90	0.2168	0.0866	2.50	0.0062
Color treatment #2	91.52	86.19	0.386	0.1067	3.62	0.0001
Color treatments #3	92.25	89.85	0.2365	0.1150	2.06	0.0199
Color treatment #4	89.36	87.10	0.1754	0.1140	1.54	0.0619

was weighted according to the following equation (Cohen, 1968):

$$wgt_{i,j} = 1 - \left(\frac{i-j}{k-1}\right)^2$$

where i and j index the rows and columns of the ratings by the two raters, k is the maximum number of possible ratings and $wgt_{i,j}$ is the weight of each agreement/disagreement.

As observed in Table A2, for all of the attributes except three, the agreement between the two raters was above the expected value at a high level of significance. For the three attributes, a value of $p > 0.05$ was observed (i.e., Texture #2, Texture #3 and Color Treatment #4) signaling a low level of agreement between the raters.

The attributes yielding unreliable results were removed from the tool to avoid ambiguous evidence that could lead to measurement errors of both firms' product language heterogeneity and product language differentiation.

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