New wine in old bottles or new bottles for new wine? Product language approaches in design-intensive industries during technological turmoil

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It is widely acknowledged that technological innovation affects the development of product lan-guage. Some scholars argue that technological innovation leads companies to develop radically different product language to emphasize novelty; conversely, others note that technological inno-vation pushes companies to recall previous technology product language in order to increase acceptance of the new technology. This article analyzes the rationale that guides firms to choose these alternative approaches when confronting technological innovations of different magnitude and identifies which of them prevails in a design-intensive industry. In particular, the study—through an analysis of 678 products in the Italian lighting industry—shows that light-emitting diode (LED) technology (a discontinuous innovation) involved more product language changes than did compact fluorescent lamp (CFL) technology (a continuous innovation) and that a differ-ent use of product materials contributed to this higher number of product language changes. By discussing the reasons behind these findings, this paper extends and better qualifies the literature on the relationship between technological innovation and product design innovation.

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1 | INTRODUCTION

Product language, defined as a set of symbolic and material product features—such as form elements, textures, colors, details, and joining elements—is increasingly becoming a competitive lever for firms in a growing number of industries. Following a semiotic framework, product language can be considered a code composed of elements, similar to the letters of the alphabet, that are joined together to produce an infinite number of combinations (Barthes, 1983; Eco, 1976).

The design and innovation management literature has highlighted the relevance of product language changes triggered by shocks and evolutionary dynamics in sociocultural models (Cappetta, Cillo, & Ponti, 2006; Chitturi, Raghunathan, & Mahajan, 2008; Cillo & Verona, 2008; Dell'Era & Verganti, 2007, 2011; Dell'Era, Buganza, Fecchio, & Verganti, 2011; Hirschman & Holbrook, 1980; Verganti, 2003). When technological innovation occurs, product language changes become even more relevant (Hargadon & Sutton, 1997). The decision to embed a new technology in product language that recalls the aesthetics code of the recent past or, on the other hand, to define a completely new aesthetic and styling paradigm is, indeed, a key choice for the fast diffusion and success of the products based on that technology. The rationale for this decision varies according to the magnitude of the technological change. As noted in the innovation management literature (Abernathy & Utterback, 1978; Anderson & Tushman, 1990; Christensen, 2013; Dosi, 1988), the extent of technological innovation is related to the performance of the new technology, the new functionalities enabled by the technology, the competences that firms need to employ the technology in their products, and the user experience of the products based on the technology. Some technologies represent discontinuous improvements because they dramatically increase product performance and have radically different functional attributes compared to previous technologies, both of which in turn lead to new types of product applications and user experiences. Moreover, these technologies require the mastering of new competences to be fully exploited (Christensen, 2013; Dosi, 1988). By contrast, some technologies represent continuous improvements of existing technologies in that they slightly increase the performance, share many functional attributes with previous technologies, do not require new competences to be employed by firms, and do not significantly alter the overall user experience.

In responding to discontinuous technological innovations, on the one hand, companies must face the risk of rejection of the new technology because of the perception of its radical novelty by the market; on the other hand, companies can exploit the new potentialities and features enabled by the technology to appeal to the market. Accordingly, the decision is whether the firm should develop new product languages, which recall the past languages, to *de-emphasize the technological discontinuity* and reduce the risk of rejection of the new technology, or whether it should propose radically new product languages, which largely depart from past ones, to *mark the technological discontinuity* and exploit the product design opportunities provided by the new technology.

Conversely, in responding to continuous technological innovations, on the one hand, companies can benefit from the low risk of rejection of the new technology because of the perception of its continuity with the past technologies by the market; on the other hand, companies face the risk of disappointing the market by providing new products with limited enhancements and poor new features. Accordingly, the decision is whether the firm should develop new product languages, which recall the past languages, in order to *mark the technological continuity* and sustain the seamless transition from the old to the new technology or whether it should propose new product languages, which largely depart from past ones, to *de-emphasize the technological continuity* and to stimulate market demand. Which product language innovation approach prevails is clearly dependent on the boundary conditions under which the alternatives are evaluated.

In this paper, we focus on a design-intensive industry in which market and competitive dynamics are largely driven by product language innovation (Cappetta et al., 2006; Dell'Era & Verganti, 2007). The aim of this paper is thus to understand which of the alternative product design innovation approaches identified in the previous literature is dominant in design-intensive industries. To answer this research question, this study is centered on the decorative lighting industry and investigates two main technological innovations characterized by different magnitudes.

In particular, the study focuses on the introduction of the light-emitting diode (LED) in the decorative lighting industry, which represents a discontinuity after a period of continuous technological change (i.e., from halogen light bulbs to compact fluorescent light (CFL) bulbs).

This study analyzes the product language of 678 decorative lamps equipped with halogen, CFL, and LED technologies in the first five years after the introduction of LED-based products into the Italian market (i.e., from 2007 to 2011).

Using the older technology (i.e., halogen) as the product language baseline, we measured the differences among the language solutions of products based on this technology and those of CFL- and LED-based products. In addition, we considered the materials used in lamps as moderators of the relationship between technological change and product language innovation. Indeed, as the literature has observed, the use of different materials in product design is key to modifying the main product language elements (Doordan, 2003; Karana, Hekkert, & Kandachar, 2008, 2009; Karana, Pedgley, & Rognoli, 2014), especially when a new technology unlocks the possibility to use the usual materials in totally different ways (as in the case of LED, a cold and miniaturized light source that extended the possibilities for using those materials).

By testing two specific hypotheses, this paper contributes to the literature on design and innovation management by showing the logic that links technological change and product language innovation in a design-intensive industry. In particular, the findings shed light on opposing scholarly perspectives of the use of design to leverage the opportunities offered by a new technology in terms of product language innovation and highlight the moderation role played by the use of product materials in designing new product languages. Moreover, the findings provide managers in design-intensive industries with empirical evidence of the prevailing logic in the decorative lighting industry. This logic could be replicated in other industries, or it could be used as a starting point from which to develop strategic reasoning about the product language approach to take during a technological shift.

The paper is divided into five main parts. The next part analyzes the literature on different product design approaches. In particular, this section highlights the extant literature on the existence of contrasting logics in product design, and it identifies two hypotheses about which logics prevail in a design-intensive industry. The subsequent part describes the research methodology, the product-sampling logics and the product language assessment method. The results of the empirical analysis are presented, followed by a discussion of their meaning in terms of theoretical and practical implications. The concluding section focuses on the study limits, which reveal avenues for further research on the relationship between technological innovation and design innovation.

2 | THEORETICAL BACKGROUND

Product language changes can be driven by different forces and pressures. A relevant literature stream has recognized cultural and social setting as the main drivers of product language innovation (Bloch, 1995; Chitturi et al., 2008; Chitturi, Raghunathan, & Mahajan, 2007; Dell'Era & Verganti, 2007; Hirsch, 1972; Verganti, 2003, 2008, 2009).

In a contribution from 1995, Bloch presented a theoretical model where “product form” and “consumer response” are connected. Specifically, according to the proposed model the product form is influenced by “design goals/constraints” given by the organization—such as performance, marketing program, designer, costs, etc.—“individual tastes” and “situational factors” that contribute with a moderating role to influence customer responses. Here the cultural and social forces are considered as specific references that influence the consumer personal tastes and responses, jointly with the innate design preferences, the level of design acumen, the experience with design, and personality variables (Bloch, 1995). According to Bloch indeed “*designers expect consumers to prefer product that communicates meanings that are desirable within a particular culture or subculture*.”

Also Verganti (2003, 2008, 2009) in various seminal works emphasizes how design-driven innovators change the product languages thanks to their ability to sense and leverage emerging socio-cultural models. In a contribution from 2007, Dell'Era and Verganti—analyzing the relationship between innovativeness and heterogeneity of product languages fostered by innovators and followers operating in design-intensive industries—claim that

> *successful Italian manufacturers in design-intensive industries […] have demonstrated unique capabilities to understand social needs and to develop systems of offering with higher value for the sociocultural environment. They have superior capability to*

understand, anticipate, and influence the emergence of new product meanings. The diffusion of sociocultural models and consequently their impacts on the interpretation of design languages depend on many interactions between several stakeholders; customers' interpretations are in line with what is happening today, and for this reason they can rarely provide interesting indications in terms of radical changes.

On the other hand, the same Verganti also recognizes a peculiar role of new technology in steering and impacting product language changes. In the words of the scholar:

there is a strong interaction between the linguistic and technological dimensions that underlines reciprocal influences: for example, the definition of a product language is typically not defined solely in semantic terms but is often influenced by technological opportunities such as the adoption of innovative materials. (Dell'Era & Verganti, 2007)

Here, and in other works, the advent of a new technology is considered as a driver to unveil "*quiescent meaning*" (Buganza, Dell'Era, Pellizzoni, Trabucchi, & Verganti, 2015; Dell'Era, Altuna, Magistretti, & Verganti, 2017; Verganti, 2017). The new technology is a means that offers an *opportunity* to change the product language and the relative meaning of the product. Notwithstanding, technology innovation does not call automatically for a product language change. There are companies—i.e. "design-driven innovators"—able to tap new technology as a way to launch and foster radical changes in product language; as there are companies approaching the technology innovation "reinforcing the current meaning" with actions of "*technology substitution*" or "*technology scanning*"; as to say that the new technology is respectively adopted without altering the extant product language or it is rejected because it is seen as a threat to the current meanings widespread in the industry (Verganti, 2016).

This is to say that if changing the product language on the basis of emerging socio-cultural trends seems to be a deep contingent necessity, as the change in socio-cultural patterns pushes out obsolete languages and meanings from the market, the product language innovation driven by a technology innovation seems to be more a possible strategic option specifically in the early phases of new technology development.

The innovation management literature has emphasized possible product design approaches to address a new technology in an industry (Eisenman, 2013; Hargadon & Douglas, 2001; Sanderson & Uzumeri, 1995; Verganti, 2011a, 2011b). However, there is no explicit evidence and consensus about the connection between the magnitude of the technology innovation and the potential eventual product language change.

The following literature review thus helps clarify the conflicting views of the relationships between continuous and discontinuous technological innovation and product language innovation and advances two hypotheses regarding the product design approach that should prevail under the specific boundary conditions of a design-intensive industry.

2.1 | The controversial relationship between technological innovation and product language

The innovation management literature identifies technological innovations by the magnitude of the discontinuity they produce with respect to the previous situation. Discontinuous technologies deeply alter the status quo because they dramatically increase product performance, introduce new functional features, require new competences in order to be fully leveraged by firms, and impact the overall user experience, sometimes by even asking for different knowledge to be fully exploited by users. Conversely, continuous technologies consolidate the status quo because they only slightly increase product performance, maintain the previous functional features, can be developed using current competences, and do not significantly alter the user experience (Christensen, 2013).

The main existing studies in the innovation management literature tackle the relation between technological innovation and product language from the side of discontinuous innovation, but they provide contrasting views.

Hargadon and Douglas (2001) study how the Edison lighting system—that is, a discontinuous technological innovation—has been arranged and diffused, highlighting the logic in design when a discontinuity in technology occurs. Specifically, they observed, "*Edison's system of electric lighting depended on the concrete details of its design to invoke the public's familiarity with the technical artifacts and social structures of the existing gas and water utilities, telegraphy and arc lighting*." They call this a "*robust design*" approach. The authors state that when a new discontinuous technology enters the market, product design—"*the particular arrangement of concrete details that embodies an innovation*"—is responsible for mediating between innovations and preexisting institutions and social structures. Indeed, 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. By 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 increases the likelihood of acceptance of a new discontinuous technology. The idea is that product language is employed to *de-emphasize the technological discontinuity*.

Conversely, Verganti (2011a, 2011b) considers the introduction of a discontinuous technology to trigger radically new language that disrupts the current product language and is not actually oriented toward the current user's needs. A "technology epiphany," which attempts to exploit a discontinuous technology with a radical language, is less centered on the launch of a new technology and more oriented toward dressing the technology with novel language and meanings to explore untapped market potential. The basic questions at the basis of this approach change accordingly. The author states:

When exposed to new or emerging technologies, most companies focus on a narrow innovation strategy: technology substitution. The question they ask is, "Can we substitute this for an old technology to better address customers' existing needs?" However, companies

> *that pursue technology epiphanies ask, "Will this new technology enable us to create products and services that people find more meaningful than current offerings? Will it transcend existing needs and give customers a completely new reason to buy a product?" (Verganti, 2011b, p. 116)*

This approach has been followed by companies in various industries, such as Apple, Nintendo, Alessi, Kartell, and Swatch, where it has opened new market and business opportunities based on new product categories and novel senses within the user-product relationship.

In this frame, a discontinuous technological innovation generates a sort of reframing in terms of product language and relative messages that amplify the technological change. The idea is that product language is employed to *mark the technological discontinuity*.

On the other hand, the literature on the relationship between continuous technological innovation and product language seems to implicitly provide similar approaches but, as for discontinuous technologies, without providing univocal statements.

Sanderson and Uzumeri (1995), for instance, analyze the new product development of the Sony Walkman. They codify a relationship where design entered after the launch of a new generational platform that was not intended as a real "*technological discontinuity*"; rather, "*materials, component technologies, features and performance were altered significantly*." Design, according to this framework, was mostly responsible for developing "*incremental and topological innovations*"—also labeled "*derivative projects*"—oriented to conceive products that were completely novel to consumers. Sony employed design to proliferate families of distinctive product language lines to better address specific emerging lifestyles and customer segments.

According to this perspective, the role of design during continuous technological change is to reinforce existing product languages and to consolidate the current meanings of the evolving technology. The idea is that product language is employed to *mark the technological continuity*.

More recently, Eisenman (2013) has pinpointed the evolutionary role of product design, and thus of product language, changes according to the development phase of the technology lifecycle. In the early stage, the author highlights a product language role that aims at communicating the product affordance. In the second development phase—when technology becomes more stable and technological incremental jumps are more focused on the process dimension—design "*enables firms to entice users to replace older product models with newer ones despite offering little technological justification for these new models and to address the issue of users taking for granted incremental technological progress*" (Eisenman, 2013, p. 347). During the maturity stage, the design seeks new languages to convey "*second-order meanings*" of the technology in an attempt to extend the useful life of the technology (Eisenman, 2013). From this perspective, continuous technological innovation triggers a discontinuity with past product languages in order to highlight the small technological improvements. The idea is that product language is employed to *de-emphasize the technological continuity* and promote the novel factors.

Thus, according to the existing literature, four different options can be identified and summarized as a 2 by 2 matrix whose x-axis indicates the magnitude of the technological change (continuous versus discontinuous) and y-axis indicates the magnitude of the product language change (continuity versus discontinuity with past product language) (see Figure 1).

The first quadrant identifies the choice to develop, in response to a discontinuous technological change, product languages that are far from the past ones, in order to mark the discontinuity and to leverage to the fullest potential the design opportunities provided by the new technology. The second quadrant identifies the choice to develop, in response to a discontinuous technological change, product languages that are in line with the past ones, in order to de-emphasize the discontinuity and to reduce the risk of rejection by the market of the new technology. The third quadrant identifies the choice to develop, in response to a continuous technological change, product languages that are in line with the past ones, in order to mark the continuity and to sustain a seamless transition from the previous to the new technology. The fourth quadrant identifies the choice to develop, in response to a continuous technological change, product languages that are far from the past ones, in order to de-emphasize the continuity and to create appeal for the new technology by highlighting its elements of innovativeness.

For all four possibilities, the literature provides a meaningful rationale without specifying, however, under which conditions each of them should prevail. In this paper, we argue, consistently with previous studies in other fields of management and innovation, that industry specificities are one relevant condition on the prevailing logic (Dosi, 1982; Teece, 1996).

In particular, the design innovation literature distinguishes between two broad types of industries: design-intensive industries and design-non-intensive industries, according to the role that product language innovation plays in the industry's market and competitive dynamics (Dell'Era & Verganti, 2007, 2011). In design-intensive industries, such dynamics are dominated by continuous change in product language. Indeed, customers are accustomed to products that are carefully designed and expect firms to continuously develop new product design solutions. Firms consequently engage in tough competition to develop a product language that is perceived as innovative and different (Ravasi & Lojacono, 2005). Competition is largely addressed by

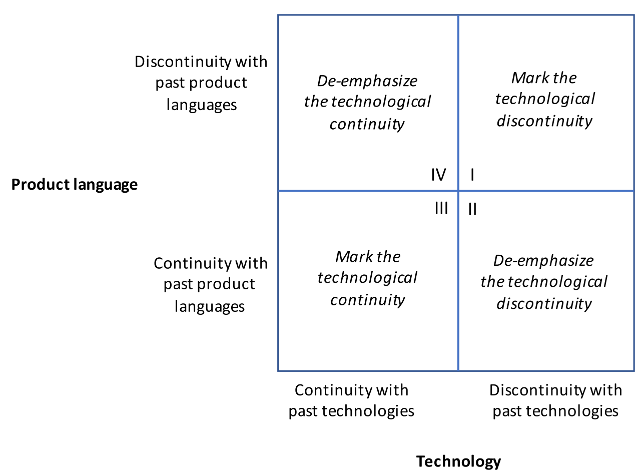

FIGURE 1 The product language–technology matrix [Colour figure can be viewed at wileyonlinelibrary.com]

outsourcing to external designers the development of design innovations in order to take advantage of any design innovation opportunity (Capaldo, 2007; Dell'Era & Verganti, 2010, 2011). Accordingly, it is expected that, in these industries, technological innovations create a strong trigger for designers to develop product design innovations.

Moreover, as previously noted, a discontinuous technological innovation largely departs from previous technologies, whereas a continuous technological innovation is contiguous with previous technologies in terms of performance, attributes, and the competences required to exploit the new technology. In fact, technological innovation discontinuity represents one of the reframing factors that foster new opportunity trajectories to redesign the creative problem related to the development of new product concepts. The template of the possible product design options is re-created with different borders and additional "problems to solve" in technological innovation discontinuity. As a result, a larger creativity space is available to design new product languages (Dorst & Cross, 2001).

Moreover, discontinuous technological innovation provides new components, a possible new architecture to join them, and possible new ways to mold the product structure. This induces a new "technological pliability" (intended as a set of product development cues and limits that each technology can implicitly suggest, given some intrinsic structural features) that expands the set of creative options related to the new product development (Cautela & Simoni, 2013). The new technological pliability thus offers new opportunities to foster product language innovation by leveraging the three main functions recognized in product design: the formal, aesthetic functions, the indicating functions, and the symbolic functions associated with the product (Steffen, 2009, 2010).

Finally, designers view a discontinuous technological change—from the industry itself or from other sectors—as an avenue to tap new market opportunities (Capaldo, 2007; Dell'Era & Verganti, 2010). From this perspective, the new technology is perceived as an opportunity to radically redefine the existing product languages in order to appeal to customers that, being in a design-intensive industry, are used to product design innovation and expect this type of innovation by firms (Cappetta et al., 2006).

Thus, in an industry whose market and competitive dynamics are driven by an ability to design new product language, it is expected that the great design innovation opportunities created by a discontinuous technological change will be fully exploited, and therefore the new product language will depart markedly from the past product language, even at the cost of exposing the new discontinuous technology to an eventual higher risk of rejection. Therefore, we present the following hypothesis:

> **Hypothesis 1a.** *In design-intensive industries, a discontinuous technological innovation is positively associated with a product language innovation that has a high degree of discontinuity with the past product language.*

It is also expected that the smaller design innovation opportunities created by continuous technological change will be exploited. However, the narrower creativity space enabled by the new technology, the lesser technology pliability and the fewer opportunities to address new market spaces will make past successful product languages an appealing option to seamlessly introduce the new continuous technological innovation. The new product languages are more likely to recall those developed for the previous technology than in the case of a discontinuous technological innovation. Therefore, we present the following hypothesis:

> **Hypothesis 1b.** *In design-intensive industries, a continuous technological innovation is positively associated with a product language innovation that has a high degree of continuity with the past product language.*

Based on the peculiarities of design-intensive industries, we thus hypothesize that in these industries, the approaches represented in the upper-right and lower-left quadrants of Figure 1 will prevail.

As attested by many studies in the design management field, materials are the main antecedent of the product language DNA (Ashby & Johnson, 2013; Karana et al., 2008, 2009) and of the resulting "materials experience", intended as the experience people have with and through materials (Karana et al., 2009, 2014). Indeed, in addition to their "general," "technical,"and "eco-attributes," materials are selected by designers for their "aesthetic attributes," that is for the attributes that unlock new opportunities of changing the main product language constituents, i.e., forms, joining elements, colors, textures, details (Ashby & Johnson, 2013; Doordan, 2003; Karana et al., 2009, 2014). This growing attention to materials in the innovation process has led to the concept of "material-driven design" to state that designing for new material experiences means to consider the material as the starting point of the design process (Karana, Barati, Rognoli, & Zeeuw van der Laan, 2015).

For instance, in the furniture industry, Kartell revitalized the concept of plastic, which was previously considered as a commodity (Verganti, 2009), using that material as a distinguishing and innovative tool to propose new forms and to redefine the relationship between the user and some furniture pieces. Moreover, Swiss watch manufacturer Swatch employed plastic and fabrics to renew the meaning of watches by proposing product languages closer to the world of fashion accessories than of traditional watches. Or even more, CP Company, an Italian garment manufacturer, pursued the application of new materials—as technical textiles, thermochromic materials—as a means to convey proper product personality by developing new product languages.

In design-intensive industries, the product language innovation is thus triggered not solely by the new features of the technology but also by the possibilities that the new technology offers of using materials in novel ways to design products. In particular, the constitutive features of the new technology can both enable the use of materials that were not useable with the previous technology or can allow existing materials to be used differently (e.g., the different use of paper for decorative lamps that are based on hot or cold lighting sources).

These possibilities to exploit existing materials to design new product languages may vary according to the magnitude of the technological innovation. For a discontinuous technological innovation, the significant increase in performance and the availability of new attributes and features of the technology will likely create large opportunities to employ materials in novel ways to develop new product languages. Conversely, for a continuous innovation, because of the contiguity with the previous technology, the new technology will likely face the same limitations of the old one in the use of materials for the development of new product languages. Accordingly, we present the following hypothesis:

> **Hypothesis 2.** *In design-intensive industries, the use of different materials positively moderates the relationship between technological innovation and product language innovation, with a stronger effect for a discontinuous technological innovation than for a continuous technological innovation.*

3 | METHODOLOGY

3.1 | Dataset

The empirical analysis was conducted in the decorative lighting industry, which is a specific branch of the general lighting sector. This sector can be divided into seven applications and relative markets: decorative (also defined as residential), office, shop, hospitality, industrial, outdoor, and architectural (McKinsey Report, 2011). Not surprisingly, in the industrial, hospitality, office and, partially, outdoor categories, product language innovation cannot be considered a competitive lever, and it minimally affects users or buyers' purchasing process. Here, factors such as investments, integration with complementary assets, durability, and resistance to atmospheric agents matter more than the stylistic and aesthetic solutions adopted by producers. By contrast, in the decorative lighting market, product language plays a dominant role because the final users buy lamps for a combination of reasons, including the primary function—lighting up a room or a space—and the creation of a specific sense, contextual atmosphere, and meaning.

Because of lamps' effect on the atmosphere and the sensations they create, users consider them an important component of home furniture. They are evaluated more for their symbolic and cultural aspects than for their basic function of providing light. Accordingly, different studies on product language innovation have classified decorative lighting as a design-intensive industry, i.e., an industry in which stylistic and aesthetic product innovation play a relevant role in competition among firms (Dell'Era & Verganti, 2007, 2011; Verganti, 2009), customer value is generated by the aesthetic experience conveyed by the product language (Bloch, 1995; Bloch, Brunel, & Arnold, 2003; Chitturi et al., 2008; Solomon, 1988), and innovation is primarily driven by the capability to leverage technological innovation to develop continuous alterations of the product's style and language (Verganti, 2011a, 2011b). In addition, players primarily engage professional designers in the new product development process (Bruce & Docherty, 1993; Bruce & Morris, 1994; Capaldo, 2007; Cautela & Zurlo, 2012; Dell'Era & Verganti, 2010).

The lighting sector has been characterized by different technologies over time. Starting with the incandescent bulb and its first applications at the end of the 19th century, technological evolution was subsequently marked by fluorescent (1938, primarily used in commercial and office contexts), metal halide (1961), and halogen (1959) lighting and CFLs (1981). The shift in technology was essentially led by incremental improvements in product performance and did not require any major adjustments of producers' design skills. The common foundation of these technologies consisted of competencies based primarily on electrical-mechanical knowledge. Technological shifts, up to the introduction of LED-based lamps, can thus be considered to have been continuous.

LED technology was first considered by decorative lighting firms as a possible lighting source in the late 1990s. It represents a discontinuous technology for at least four reasons: (i) the dramatic improvement in product performance measured by the lumen/watt ratio jointly with the efficiency and the operating lifetime gained in a very reduced time (with respect to the slight improvements that other lighting sources gained over several decades); (ii) the reduced size of the lighting sources, which steered new radical possibilities in terms of commercial applications (primarily in architectural design and furniture); (iii) the range and the amplitude of the "spectral power distribution," which is the different spectral blend permitted with LED and not attainable with alternative lighting sources; and (iv) the transition from an analogic set of competences to a digital and electronics-based set of competences in designing new products (Menanteau & Lefebvre, 2000; Steigerwald et al., 2002; US Department of Energy, 2012). Moreover, LED modified many dimensions of the previous user experience with regard to lamps. The ability to vary the intensity, the temperature, and the color of the light has augmented the perception of a lamp as a tool to shape the atmosphere of living spaces rather than as a tool to simply dispel darkness (in this respect, see, for example, the mobile apps that have been developed to remotely configure multiple lamps in an apartment). This perception has been strengthened by the enormous range of possibilities to mold light by arranging multiple micronized lighting sources on a surface. The need for users to develop lighting expertise in order to furnish the environment with light has consequently increased. Furthermore, the full integration, in some cases, of LED lamps in furniture is deleting the concept of a lamp as a separate object from the user experience. Finally, the traditional habit of bulb replacement has been progressively supplanted for many products by the idea of a very long-lasting disposable lamp.

After the first applications, which were limited to indicator lights, traffic lights, and video screens (in TVs and computers), LEDs began infiltrating decorative, commercial and architectural lighting applications (Collis & Furey, 2011). Because of their superior performance, energy efficiency, and cost-effectiveness compared with earlier technologies, LEDs are expected to grow significantly in the lighting sector (Collis & Furey, 2011; McKinsey Report, 2011). The 2007 Energy-using Products (EuP) European Directive mandated the phasing out of incandescent sources for lamps and lighting products by 2012. Today, the prevailing technologies worldwide are halogen and CFL sources and, to a lesser extent, LED (Table 1).

As noted previously, because of its effect on performance, competence systems, and competitive dynamics, the LED can reasonably be

TABLE 1 Performance comparison of different technologies for residential lighting (Collis & Furey, 2011)

Source	Cost ($)	Power (W)	Lifetime (hrs)	Cost of light (50 k/h)
Incandescent	1.12	60	1,500	$487.33
CFL	9.97	14	7,500	$171.40
LED	49.99	7	25,000	$152.48

considered a discontinuous technology compared with previous technologies. By contrast, halogen and CFL appear to share the same technological trajectory, with the latter being a continuous improvement of the former. Therefore, assuming the oldest halogen technology as a baseline, CFL products have been characterized as continuous technological innovation, whereas LED products have been characterized as discontinuous technological innovation.

Our dataset was built during a two-year explorative research activity centered on the interplay between technological innovation and product language change. Product sampling was based on the product portfolios of 12 companies belonging to the "Made in Italy" decorative lamps sector. These firms represent the set of LED early adopters (i.e., the first companies in the Italian market that adopted LED as a lighting source for their lamps). These firms embrace manufacturers awarded with numerous design awards—such as the Italian Compasso d'Oro, the most prestigious design-related award—and companies that may not have won such awards but have shown a high propensity for product language innovation. Because, in 2007, very few companies in the Italian market had started to commercialize LED-based decorative lamps, the set of LED products considered in the sample can be assumed to approximate the universe of LED products in the marketplace at that time. A total of 678 products from 2007 to 2011 were considered. Of these products, 215 were equipped with halogen technology, 269 with LED and 194 with CFL (Table 2).

For each product, the following data were collected: the product model ID, the name of the manufacturer, the type of product, the name of the product designer, the materials used to manufacture the product, the price of the product and the lighting technology used in the product. Information was obtained from companies' official catalogs. In some cases, additional secondary sources (primarily international design magazines, such as Abitare, INTERNI and the furniture web database Webmobili/designbest) were consulted to obtain missing information. According to convention, product types were classified as "table lamp," "wall lamp," "floor lamp," and "suspension lamp." The three main materials used for each lamp were classified using seven main possibilities: "metal," "wood," "plastic and composite," "glass," "rubber and resin," "stone," and "paper."

TABLE 2 Product sample

Manufacturer	Halogen	Technology LED	CFL	Total
Artemide	51	44	57	152
Catellani & Smith	0	94	1	95
Cini & Nils	10	9	2	21
Danese	13	51	36	100
Flos	29	19	10	58
Fontana Arte	21	0	11	32
Foscarini	35	5	34	74
Ingo Maurer	23	12	0	35
Luceplan	12	12	3	27
Martinelli	7	14	16	37
Nemo	8	4	7	19
Kundalini	6	5	17	28
Total	215	269	194	678

A computer-assisted disambiguation procedure was performed on the designers' names to avoid errors based on spelling differences. For example, the designer Michele De Lucchi appeared in one case as "Studio Michele De Lucchi" and in another as "Michele De Lucchi–Alberto Nason." After disambiguation, the same designer code was assigned to both cases.

A database including product pictures and technical datasheets was created for the analysis of the style profiles of the products in the sample. Product-style profiles were assessed, building on Chen and Owen's (1997) idea that stylistic features are psychological qualities perceived by an individual who can be captured through a semantic differential analysis based on an appropriate set of polar adjective pairs (Osgood, Suci, & Tannenbaum, 1957). The authors propose a tool that basically reproduces, in the form of semantic differentials (attributes referred to different categories), "basic elements of a product including the solids constituting the product's body, any graphics on the surface, materials used in construction, colors and textures" (Chen & Owen, 1997, p. 257). The tool was then adapted to fit the peculiarities of decorative lighting products following the approach described above.[1]

In the original formulation of Chen and Owen's (1997) tool, the attributes adopted for describing styles are assigned to six categories: (i) form elements, (ii) joining relationships, (iii) detail treatments, (iv) materials, (v) color treatments, and (vi) textures.

Following the previous literature, the tool was refined through a multi-step validation process. The first phase aimed to evaluate the consistency of the tool for the specific features of the analyzed products, that is, lamps. Four design scholars[2] were asked to assess the styles of ten lamps using the tool originally proposed by Chen and Owen. After the evaluation, the scholars were asked to identify the attributes that were more suited for lighting products, those that were ambiguous or unclear, and those that were inconsistent. The scholars suggested minor changes to the tool. These changes consisted of detecting materials directly, avoiding semantic differences in this product style-profile category, and modifying some ambiguous attributes in other categories.

After the first phase, the tool comprised five categories with a total of 17 attributes describing the product-style profile. Following Chen and Owen (1997), the items were operationalized using a six-point scale between two bipolar adjectives (Table 3).

The second phase aimed to identify the attributes that could have been a clear source of subjective bias. Thus, two experts in product design were trained on the tool and then asked to independently assess the style profile of a random sample of 50 common lamp models. Their judgments were then compared using Cohen's kappa analysis (Cohen, 1960). A weighted procedure was adopted, as the literature suggests for ordinal data, by which the degree of disagreement is taken into account (Cohen, 1968) (for further details, see the Appendix). The kappa coefficient allows one to measure the level of agreement between two raters against the possibility that the agreement is due to chance. Accordingly, kappa statistical significance indicates whether the null hypothesis of inter-rater agreement due to chance can be rejected.

Three items were identified whose kappas were not statistically significant (i.e., $p > 0.05$; for further details, see Table A1 in the Appendix):

TABLE 3 Style-profile assessment tool (Chen & Owen, 1997) to evaluate style profile distances among decorative lighting products

Category of product style-profile	Polar adjective pairs of style profile distance sematic differentials	
	1 2 3 4 5 6	
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

Texture #2, Texture #3 and Color Treatment #4. Moreover, the kappa values for these three attributes were below the threshold of 0.2 (i.e., κ = 0.1025, κ = 0.1383, and κ = 0.1754, respectively) that the literature considers to be "unfair" agreement (Landis & Koch, 1977). Following previous studies, these three attributes were thus removed from the tool to be further evaluated (Banerjee, Capozzoli, McSweeney, & Sinha, 1999; Durand, 2003; Jakobsson & Westergren, 2005).

In the next phase, the four design scholars who were initially involved were asked to analyze the nature of the reliability problems of the three items encountered by the raters in the previous phase. They noted that these attributes require physical contact with products to be correctly assessed, and evaluations based solely on pictures of the product were inappropriate. Indeed, simply looking at the picture of a product could easily skew bipolar adjectives such as "single-multiple" and "regular-irregular" in the Textures category and "hard-soft" in the Color Treatments category. The remaining attributes were instead considered to be easier to evaluate based only on product pictures. Based on this comment, the three attributes were definitively removed from the tool to avoid any ambiguity that would have been very difficult to overcome even with further training of the two raters. Nonetheless, these missing pairs were not expected to affect the analysis because the data could easily be replaced with information on the product's material that was recorded in the product details.

After removing the three items, the tool used to assess the style profiles of the 678 products in the sample comprised five categories, as articulated in the following bipolar attribute adjectives:

(i). Form Elements: harmonious-contrasting, homogeneous-heterogeneous, geometric-biomorphic, simple-complex, balanced-unstable;

(ii). Joining Relationships: monolithic-fragmentary, self-evident-hidden, static-dynamic;

(iii). Detail Treatments: uniform-multiform, angular-rounded;

(iv). Textures: harmonious-contrasting;

(v). Color Treatments: harmonious-contrasting, single-multiple, cool-warm.

The last phase aimed to improve the two raters' common understanding of the tool through a further training session (Bernardin & Buckley, 1981). In particular, the two raters were asked to evaluate the style profile of a set of randomly selected products and to discuss their respective evaluations in order to remove any misalignment. The process was repeated until convergence on all of the tool's items was reached.

The product sample was then randomly split into two sub-samples, and both raters were asked to assess the style profile of all of the products in one of the two sub-samples.

3.2 | Analytical model and variables

To analyze the changes in product language across the different technologies that characterize the decorative lighting industry, a model was adopted that considers the "style-profile distance" (Chen & Owen, 1997) between products as a function of the differences among the product characteristics.

The base model has the following form:

$$STdist_{x,y} = \beta_1 Techdiff_{x,y} + \beta_2 Matdiff_{x,y} + \beta_3 Cvardiff_{x,y} + \beta_0 + e_{x,y}$$

where x and y indicate, respectively, products x and y; $STdist_{x,y}$ represents the distance between the style profiles of the two products; $Techdiff_{x,y}$ represents the difference between the products' lighting technologies; $Matdiff_{x,y}$ represents the difference between the products' materials; $Cvardiff_{x,y}$ represents the difference between the two products of certain control variables that may account for the style-profile distance; β_0 is the model intercept; and $e_{x,y}$ is the error term. As clearly shown, the model has the form of a linear regression.

To operationalize the analytical model, halogen was considered the baseline technology and was used as a common reference, whereas CFL and LED were the two alternative technologies used to calculate the style-profile distances. All possible pairs of products between halogen and CFL and between halogen and LED were generated, resulting in a total of 99,545 pairs (41,710 halogen-CFL pairs = 215 halogen products × 194 CFL products + 57,835 halogen-LED pairs = 215 halogen products × 269 LED products). In addition, we modified the model to account for H2 by introducing an interaction term between the technology differences and the materials differences. For each pair of products, a set of dependent and independent variables was measured as follows.

3.3 | Dependent variables

The main dependent variable is the distance between the style profiles of two different products. The operationalization of Chen and Owen (1997) was used, and each profile was assumed to be represented by a specific function in an "n-dimensional space in which each dimension is represented by attributes." Accordingly, the style distance between product x and product y, each characterized by a vector of n attributes, can be calculated as follows:

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

where $STdist_{x,y}$ represents the distance between the style profiles of products x and y, Ay_j and Ax_j represent the value of the jth attribute for products y and x, respectively, and n represents the total number of attributes.

To obtain an order of magnitude of the dependent variable that is similar to that of the other variables, the six values on the Likert scale were rescaled to a range of 0 to 1, i.e., the minimum of the scale was set to 0, the maximum was set to 1, and the remaining values were distributed proportionally in the interval from 0 to 1. The rescaled values were used to calculate the style-profile distance. Consequently, $STdist_{x,y}$ has a minimum value of 0 for two products that show identical product languages and a maximum value of √14 = 3.7416 for two products that show the maximum difference in all product language elements.

3.4 | Independent variable

Two independent variables are included in our model. The first independent variable is dichotomous and measures whether the style-profile distance is calculated between a halogen and a CFL product or between a halogen and an LED product. In the former case, a value of 0 is assigned to the variable; otherwise, a value of 1 is assigned. Thus:

$$Techdiff_{x,y} = \begin{cases} 0 \leftrightarrow Teach_x = ha\,\text{logen}, Tech_y = CFL\ and\ \ viceversa \\ 1 \leftrightarrow Teach_x = ha\,\text{logen}, Tech_y = LED\ and\ \ viceversa \end{cases}$$

where x and y denote products x and y, respectively; $Tech_x$ and $Tech_y$ are the technologies of products x and y, respectively; and $Techdiff_{x,y}$ represents the type of technological discontinuity occurring between the two products.

The second independent variable measures the differences in products' materials. For each product, the three main materials were detected between seven possible alternative materials. Therefore, a binary vector with a length of seven was used to characterize each product. For each pair of products, the Hamming distance between their materials' vectors was calculated (Hamming, 1950). This distance, for the two binary vectors *Matx* and *Maty*, is equal to the number of vectors in *Matx* or *Maty*. Therefore, the value of this variable ranges from 0, for two products that share all materials, to 6, for two products that differ in every main material. Products with considerable differences in their materials should have a higher style-profile distance between them than products made of identical materials.

3.5 | Control variables

Several control variables were introduced in the model to account for different factors that may have affected the differences in the products' style profiles.

The first control variable is dichotomous and accounts for differences between lamp producers. This variable takes the value of 0 if the same firm markets the two compared products (i.e., the product based on halogen technology and the product based on either CFL or LED technology), and it takes the value of 1 if different firms market them. It is reasonable to expect that products from the same firm will have a lower style distance than products from different firms because each firm tends to impose its own characteristic design traits (Karjalainen, 2003).

The second variable controls for the differences among designers. It takes the value of 0 if the two products were designed by the same person and the value of 1 if they were designed by different individuals. It is assumed that products designed by the same person will share more style-profile elements than those designed by different individuals. Consequently, the distance between products' style profiles will be lower for the former products than for the latter products.

The third control variable considers the types of products, and it is also dichotomous. This variable takes the value of 0 if the two compared products are of the same type and the value of 1 otherwise. Indeed, products belonging to the same type should be more similar in terms of style than products of different types.

The last control variable is the product's price. Indeed, the price level of a product is a reasonable proxy for the intended target of the product, which in turn may affect the stylistic and aesthetic traits of the product. Products with similar prices addressing the same market segments may be more likely to show common traits in their product languages than products with very different price levels. Therefore, we calculated the difference between the prices of the two compared products, expecting that as the difference between their prices became higher, their style-profile distance would become greater. The measure was normalized by dividing the values by the range of the variable (i.e., the maximum minus the minimum price in the whole sample of products).

TABLE 4 Main statistics of analytical model variables

Variable	Obs.	Mean	Std. Dev.	Min	Max
Dependent variable					
1. Style-Profile distance	98,900	1.138	0.345	0.000	3.098
Independent variable					
2. Technological difference	99,545	0.581	0.493	0.000	1.000
3. Materials difference	99,545	1.257	0.947	0.000	5.000
Control variables					
4. Producer difference	99,545	0.902	0.297	0.000	1.000
5. Designer difference	99,545	0.982	0.134	0.000	1.000
6. Product Type difference	99,545	0.720	0.449	0.000	1.000
7. Price difference	63,050	0.080	0.125	0.000	1.000

Differences in the number of observations are due to missing values that vary across variables. The largest number of missing values can be observed for price difference because of the lack of data about the price of some products in the sample.

The main descriptive statistics of the dependent and independent variables are shown in Table 4.

4 | RESULTS

For the first analysis, a correlation test using Spearman's rho statistic was conducted (Table 5). This test is particularly suitable for ranked variables, and it allows for the evaluation of whether two variables are linked by a monotonic function (Spearman, 1904). Similarly to Pearson's coefficient, it ranges from −1 in the case of a perfect negative correlation to +1 in the case of a perfect positive correlation.

The independent and control variables are poorly correlated with each other, with the rho values mostly close to 0. The highest value of 0.32 can be observed for the variable pair producer difference-designer difference. This is no surprise because it can be assumed that different firms will tend to use different designers to design their products. Nevertheless, the statistical significance of the correlation coefficients among some of the independent and control variables, though they have low values, requires an investigation of the eventual problems of collinearity in our model.

Data were collected first by selecting the firms that acted as early adopters of LED technology in the Italian decorative lighting industry and then by analyzing their product-portfolio characteristics. This research design created a clustered structure of data that may require particular attention to avoid possible systematic biases (Bickel, 2007; Bryk & Raudenbush, 2002). Indeed, products that belong to the same firm could share some product language features because of the peculiar characteristics of the firm to which they belong (within-cluster variance) and could differ from products that belong to other firms because of the differences between firms (between-cluster variance). Therefore, the style-profile distance between products could, at least partially, depend on the heterogeneity of firms that were selected and whose product portfolios were analyzed instead of on the covariates considered in the study as independent and control variables. To account for this possibility, we performed a hierarchical analysis based on a random intercept model in which product pairs represented the first level of data and the firms that developed those products represented the second level (i.e., the clustering variable). In addition, we tested this hierarchical model against a pooled model (i.e., a model that did not distinguish products according to firms) to confirm the need to consider the clustered nature derived by our data-sampling approach (Rabe-Hesketh & Skrondal, 2012). Table 6 shows the results of the hierarchical analysis.

For each model, we report the coefficient of the analyzed variables and their statistical significance. In addition, we report the standard error of the random intercept based on the differences among firms that developed the products (i.e., between-cluster standard error) and the residual standard error (i.e., within-cluster standard error). As noted above, we also performed a test to verify the need to consider data as nested within firms instead of simply considering the data as pooled. Therefore, for each model, we report likelihood-ratio test statistics to verify the null hypothesis that there is no random intercept in the model and, therefore, that a hierarchical model is not required.

Model 1 is the baseline, and it analyzes the effect of the control variables on the style-profile distance between products. As expected, all coefficients of the control variables are positive and statistically significant at $p < 0.001$, with the exception of the product-type difference, which is statistically significant at $p < 0.05$. Therefore, control variables all positively affect the style-profile distance of products. That is, given a pair of products, one halogen product and one CFL- or LED-based product, the differences between the producers, the designers, the product types, and the prices of the two products increase the difference between their product languages.

Model 2 addresses H1a and H1b by introducing to Model 1 an independent variable that accounts for technological change. On the one hand, we expect that the coefficient of this variable is not 0 and is statistically significant, thereby showing that a change in the technology produces a change in the product language and, on the other hand, that the sign of the coefficient is positive, thereby indicating that the product language change is larger for a discontinuous technological innovation than for a continuous technological innovation.

As noted, the coefficient of the variable related to the technological difference is not 0 and is statistically significant at $p < 0.001$. In addition, the variable's coefficient is positive, highlighting that when moving from CFL-based products (i.e., a continuous technology with respect to halogen) to LED-based products (i.e., a discontinuous technology with respect to halogen), the style-profile distance from halogen-based products increases. Therefore, a discontinuous technological change produces a product language distance with a higher magnitude than a continuous technological change.

Model 2 was also used to verify the eventual problems of collinearity that emerged from the previous correlation analysis. Indeed, we calculated the variance inflation factor (VIF) of the model to

TABLE 5 Spearman's Rho analysis results

	1	2	3	4	5	6	7
1. Style-Profile distance	1						
2. Producer distance	0.065*	1					
3. Designer difference	0.057*	0.323*	1				
4. Product Type difference	0.001	0.015*	0.032*	1			
5. Price difference	0.062*	0.035*	0.006	0.010*	1		
6. Technology difference	0.043	0.076*	0.012	0.057*	−0.001	1	
7. Materials difference	0.050*	0.048*	0.043*	−0.020*	−0.011*	−0.127*	1

*$p < 0.05$

TABLE 6 Hierarchical regression analysis results

	Model 1	Model 2	Model 3
Producer difference	0.057***	0.052***	0.052***
Designer difference	0.163***	0.159***	0.159***
Product Type difference	0.006*	0.007*	0.007*
Price difference	0.056***	0.055***	0.055***
Technological difference		0.014***	0.008
Materials difference		0.028***	0.026***
Technological difference x Material difference			0.005*
Constant	0.886***	0.852***	0.855***
Between-clusters std	0.072 (0.015)	0.072 (0.015)	0.072 (0.015)
Within-clusters std	0.334 (0.001)	0.334 (0.001)	0.334 (0.001)
LR test against pooled linear regression	chibar(01) = 3294.08+++	chibar(01) = 3284.84+++	chibar(01) = 3280.57+++

For models coefficients +p < 0.1 *p < 0.05, **p < 0.01, ***p < 0.001; for likelihood ratio test (LR) +++Prob> = chibar(01) = 0.000

exclude the possibility that the variables' correlation may affect the reliability of the results.

The results of the test are reported in Table 7. As shown, the VIF variables' values are well below the threshold of 5, which the literature indicates is the value at which problems of correlation among predictors severely affect the model's error estimations (O'brien, 2007).

Model 2 highlights the main effect of the variable related to difference in materials among products. The coefficient of this variable is positive and statistically significant at p < 0.001, showing that material differences among products increase the product language distance. In other words, products using different materials, as expected, also tend to be characterized by different product languages.

Model 3 addresses H2 by introducing to Model 2 an interaction term between technological differences and material differences among products. The interaction term is positive and statistically significant at p < 0.05, showing that the two variables mutually reinforce each other. That is, in a discontinuous technological change, the use of different materials produces a higher product language distance than that in a continuous technological change. The interaction effect is clearly highlighted in Figure 2.

5 | DISCUSSION

The results support all our hypotheses. In the decorative lighting industry, discontinuous technological innovation triggers the development of new product language that has a high level of discontinuity with that developed for older technologies (H1a). Conversely, continuous technological innovation triggers product language with a high level of continuity with that developed for previous technologies (H1b).

Moreover, the use of different materials positively moderates the effect of the technological change on the product language change (H2). Namely, the use of different materials amplifies the change in the product language more for discontinuous innovation than for continuous innovation.

These results are largely related to the nature of the design-intensive decorative lighting sector. Indeed, as observed above, in design-intensive industries, any opportunity to innovate in product design tends to be fully exploited by firms for market and competitive reasons. This is particularly true in the Italian lighting industry, which has a long tradition of product design innovation and includes many firms nationally and internationally recognized for their design innovation capabilities (Verganti, 2006). The market has accordingly developed high expectations over time that lighting firms operating in the Italian market will lead, through their products, product language innovation. Moreover, firms in this industry face tough challenges that are mostly addressed by recruiting the best professional

TABLE 7 Test for collinearity of variables

	VIF	1/VIF
Producer difference	1.02	0.981
Designer difference	1.2	0.836
Product Type difference	1.12	0.891
Price difference	1.04	0.959
Technological difference	1.48	0.677
Materials difference	1.01	0.989
Mean VIF	1.26	

To account for the hierarchical structure of the analysis dummy for firms were included. Values are omitted in the table.

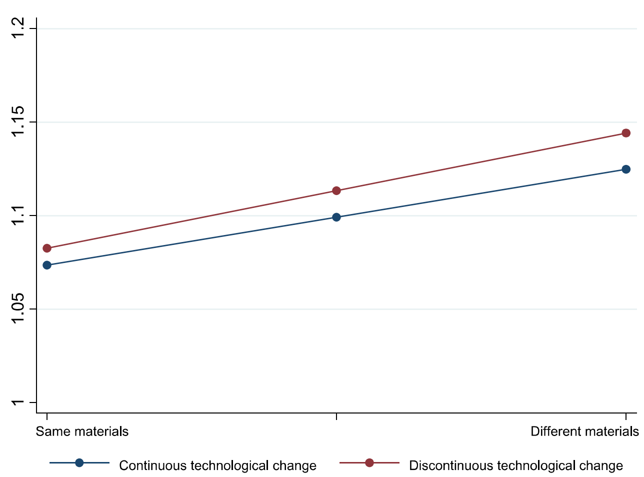

FIGURE 2 The interaction between technological changes and material changes [Colour figure can be viewed at wileyonlinelibrary.com]

designers to innovate in product design. These professionals operate as external partners whose primary aim is the development of an innovative and unique product language (Capaldo, 2007). Therefore, decorative lighting is largely dominated by product design innovation-based competition in which it is reasonable to expect that the opportunities to innovate created by a new technology will be fully exploited.

The introduction of LED technology has offered opportunities to create innovative product language that are clearly greater than those offered by the introduction of CFL technology. In fact, whereas CFL technology creates more design innovation opportunities than did halogen technology because of its naturally colder light, LED creates even more opportunities. LED is not only cold but also miniaturized and electronically controlled. These features, coupled with higher lighting performance, allow designers to rethink the main product language elements more radically than was possible for CFL technology. In an industry dominated by design innovation dynamics, it is not surprising that the technological discontinuity related to LED technology induced a product language "epiphany" (Verganti, 2011a), whereas the continuity related to CFL technology generated a more "robust" product language approach (Hargadon & Douglas, 2001).

In addition, our results show that this tendency of product language change is reinvigorated by the use of different product materials, which allow, in a discontinuous technological change, the development of product language that is even more radically different (Ashby & Johnson, 2013; Doordan, 2003; Karana et al., 2009, 2014). On the one hand, the new features of the discontinuous technology allow the use of existing materials that were not useable with the previous technology. For example, the fact that LED is a cold, high-performance light allowed the use of inflammable materials (such as paper) in the proximity of the lighting source, which was not possible with hot lighting sources, such as halogen technology. On the other hand, materials used with previous technologies may be molded in completely new, different ways leveraging the new technology characteristics. For example, the miniaturization of the lighting source made possible by LED technology allowed the positioning of mini-lamps on the surface of materials that were used with past technologies but in a different way.

Being clearly driven by the characteristics of the decorative lighting industry, these results can be extended to other industries that share the same characteristics: a design-addicted market, strong competitive dynamics led by product language innovation, a key role played by professional designers, and exposure to new technology discontinuities. This is probably the case in other design-intensive industries that are proximate to decorative lighting, such as furniture, interiors, and kitchenware. In design-intensive industries where exposure to technological innovation is slower and product language innovation is largely driven by cultural changes, such as the fashion industry, a different relationship between the extent of technological innovation (discontinuous versus continuous) and product language innovation may be observed. Similarly, in design-non-intensive industries, where factors other than product language innovation drive competitive dynamics, a different relationship may be observed. Both the generalizability of our results to other design-intensive industries and their validity in non-design-intensive industries require future empirical testing.

The paper's findings contribute to the literature on technological and innovation management in several ways. First, our results clarify that the contrasting explanations provided by the literature on the relationship between technological innovation and product language innovation depends on some relevant boundary conditions. We show that, among other factors, the role played by design innovation in the industry is one such relevant condition (at least for design-intensive industries) that explains the prevalence of certain innovation approaches relative to others. Second, our results extend the existing literature by highlighting that in these industries, a product language epiphany (Verganti, 2011a, 2011b) is likely to happen, when the technological innovation is discontinuous. Conversely, when the change is continuous, the tendency is toward new product language that consolidates that successfully developed in the past. Third, our results support the idea that in design-intensive industries, technological innovation is a factor used to unlock new design opportunities related to other product language-related technologies. In particular, in our study, we show that the use of product materials (which are key to the design of new lamps) is a factor that amplifies the possibilities to leverage a discontinuous technological change to design radically new product language.

These findings also have managerial implications. In particular, our results show that in industries where product design is a relevant competitive weapon (such as the decorative lighting industry), product language innovation is a means, for discontinuous technological innovations, to amplify the discontinuity and, for continuous technological innovations, to sustain a seamless transition from the previous to the new technology. Managers should thus be alerted that, in facing a new technology that radically departs from previous existing technologies, firms must expand the repertoire of their product languages beyond the current settings to embrace radically new solutions. This implies that firms must be equipped not solely with the technological skills required to use the new technology in their products but also with designers that are able to creatively exploit in new ways all the design innovation opportunities provided by the new technology. Conversely, in facing a technology that only slightly departs from previous technologies, managers should be alerted that firms must rather focus on the existing most widespread product languages. This implies that firms must be equipped with designers that are used to current product languages and are able to reproduce and adapt these languages to the new technology.

Our results also suggest that managers must pay clear attention to products' materials as a means to boost product language innovation. In particular, the possibility to use in novel ways existing materials can represent a powerful option for firms to further emphasize a technology discontinuity though the development of new product languages. This implies that in design-intensive industries, when the magnitude of technological change is high, research on materials should be strictly coupled with technological development in order to find radically new product design solutions. Conversely, when the magnitude of technological change is low, the use of materials that are most widely diffused should be extended also to the new technology.

6 | CONCLUSION

This study helps to clarify which of the alternative product language innovation approaches is induced in an industry by technological innovation and which approaches prevail in a design-intensive industry. The findings show that the magnitude of a technological innovation (i.e., continuous versus discontinuous) is a predictor of the magnitude of product language innovation and that the use of different materials positively moderates the relationship more for discontinuous than for continuous innovation.

This paper suffers from some limitations that reveal opportunities for future research. First, the rationale used to explain the prevalence of certain product language innovation approaches is largely based on the peculiarities of Italian decorative lighting, which is assumed to be a typical design-intensive industry. However, as noted above, the generalizability of the results from this industry to others (both design-intensive and non-design-intensive industries) requires future empirical investigation.

One line of inquiry could investigate, in design-intensive industries other than the decorative lighting industry and/or countries other than Italy, the effect of continuous and discontinuous technological changes on product language innovation. The analytical tools and the overall methodology provided in this paper could simplify the effort and ensure a high degree of comparability of the results. Another line of inquiry could be to investigate the same phenomenon in non-design-intensive industries or in industries in which design is starting to play a relevant role.

A second limitation of the paper stems from the data setting. Indeed, in the study, we focused on the language distance among products based on different technologies comprised in the catalogs of Italian producers of decorative lamps that first adopted LED as lighting source technology in the period 2007–2011. It may be that some of the products based on previous technologies (i.e., CFL and halogen) have a design that predates 2007. We assumed that firms that confirmed in their catalogs products with an older design made the precise choice to persist with that product language. This assumption may not always be true because some firms may retain products in their catalog without particularly considering the product languages of these products. Future research could consider a different approach by studying product language innovation in continuous and discontinuous technological changes when these changes first occur (eventually over a period of decades) and not in a given common time frame (as in our study). In this way the possible bias created by the comparison of product languages that originated in different periods could be overcome.

A third limitation of the paper is related to the choice of using the halogen technology as a benchmark to compare the product language innovation related to the introduction of CFL and of LED. A different approach could consider the LED product language as an evolution of the CFL product language. Therefore, future research could compare the product language distance between halogen and CFL and between CFL and LED, taking into account the temporal sequence of the three technologies.

ENDNOTES

[1] For further details on the style profile assessment tool and the style profile distance measure used in the paper, please consult the following works based on the same dataset and employing the same tool and measure: Cautela and Simoni (2013); Simoni, Cautela, and Zurlo (2014).

[2] The experts involved in the tool assessment were Matteo Ingaramo, Professor of Product Design at Politecnico di Milano; Lucia Rampino, Professor of Product Design at Politecnico di Milano; Professor Alberto Bassi, Professor of History of Design at International University of Venice; and Professor Fabrizio Pierandrei, Professor of Product Design at Politecnico di Milano.

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APPENDIX A

Following Cohen (1968), for ordinal variables, the importance of disagreements can be weighted to avoid similar but not exactly equal judgments from being considered as disagreeing judgments. The formula used to weight disagreement is (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.

Table A1 shows the Kappa values and their statistical significance after the first round of raters' training.

TABLE A1 Cohen's Kappa results based on two experts' evaluation assessments

Attributes	Kappa
Form Element #1	0.5043*** (0.1204)
Form Element #2	0.4973*** (0.1164)
Form Element #3	0.7130*** (0.1380)
Form Element #4	0.5275*** (0.1355)
Form Element #5	0.3754** (0.1267)
Joining Relationship #1	0.3450** (0.1247)
Joining Relationship #2	0.3807*** (0.1121)
Joining Relationship #3	0.4337** (0.1405)
Detail Treatment #1	0.2996** (0.1117)
Detail Treatment #2	0.4402*** (0.1131)
Texture #1	0.5631*** (0.1352)
Texture #2	*0.1025* (0.1363)
Texture #3	*0.1383* (0.1410)
Color Treatment #1	0.2168** (0.0866)
Color Treatment #2	0.386*** (0.1067)
Color Treatments#3	0.2365* (0.1150)
Color Treatment #4	0.1754 (0.1140)

Kappa statistical significance * = 0.05; ** = 0.01; *** = 0.001; standard errors in parentheses