Artefacts as boundary objects for concept development: a configurational approach

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Abstract

Purpose – This study aims to investigate how configurations of boundary objects (BOs) support innovation teams in developing innovative product concepts. Specifically, it explores the effectiveness of different artefact configurations in facilitating collaboration and bridging knowledge boundaries during the concept development process.

Design/methodology/approach – The research is based on data from ten undergraduate innovation teams working with an industry partner in a creative industry. Six categories of BOs are identified, which serve as tools for collaboration. The study applies fsQCA (fuzzy-set qualitative comparative analysis) to analyse the configurations employed by the teams to bridge knowledge boundaries and support the development of innovative product concepts.

Findings – The findings of the study reveal two distinct groups of configurations: product envisioning and product design. The configurations within the "product envisioning" group support the activities of visioning and pivoting, enabling teams to innovate the product concept by altering the product vision. On the other hand, the configurations within the "product design" group facilitate experimenting, modelling and prototyping, allowing teams to design the attributes of the innovative product concept while maintaining the product vision.

Originality/value – This research contributes to the field of innovation by providing insights into the role of BOs and their configurations in supporting innovation teams during concept development. The results suggest that configurations of "product envisioning" support bridging semantic knowledge boundaries, while configurations within "product design" bridge pragmatic knowledge boundaries. This understanding contributes to the broader field of knowledge integration and innovation in design contexts.

Keywords Product concept, Knowledge boundaries, Boundary objects, Front end innovation, Innovation teams

Paper type Research paper

1. Introduction

The front-end stages of innovation play a crucial role as product concepts developed during this phase serve as a foundation for decision-making in subsequent development stages (de Oliveira *et al.*, 2022). Generating innovative product concepts requires diverse teams to work together and integrate their knowledge, ideas and perspectives (Aggarwal and Woolley, 2019). Yet, diversity introduces boundaries which can hamper innovation (Gilson and Litchfield, 2017). Indeed, knowledge transfer across boundaries represents one of the most relevant problems in innovation research (Paraponaris and Sigal, 2015). To overcome these boundaries, innovation teams utilize artefacts to enable fruitful collaboration (Perry and Sanderson, 1998; Bucciarelli, 2002; Bogers and Horst, 2014).

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In collaborative settings, artefacts used by multiple individuals assume the role of boundary objects (BOs) (Bechky, 2003; Cooney *et al.*, 2018). BOs possess a shared nature that transcends knowledge boundaries, accommodating the simultaneous engagement of diverse actors (Carlile, 2002; Nosek, 2004). Carlile (2002) proposes a typology of boundaries which includes syntactic, semantic, and pragmatic boundaries. Depending on their nature and how they are employed, BOs can effectively help overcome each boundary. Syntactic BOs (e.g. repositories) provide a shared syntax; semantic BOs (e.g. problem-solving templates) translate knowledge across boundaries to create shared meanings; and pragmatic BOs (e.g. prototypes) transform knowledge across boundaries to create new knowledge (Carlile, 2004). Within innovation teams, an assortment of BOs is employed, encompassing drawings, physical models, technical schemes and project plans (Self, 2019).

Previous studies have categorized research on BOs into two main perspectives: the first perspective is object-centric and focuses on understanding the inner workings of individual BOs (Lauff *et al.*, 2020), whereas the second perspective is process-centric and explores how BOs contribute to the design process (Pei *et al.*, 2011). The former perspective offers an in-depth analysis of singular objects, while the latter takes a more comprehensive view of various objects at a given stage. However, it is important to note that the actual usage of BOs by teams is often more intricate, as teams frequently employ a combination of diverse objects that vary depending on the project stage and specific communication requirements. Over the course of the project, teams employ diverse BOs to engage in discussions pertaining to the various aspects of their work. These objects undergo gradual refinement depending on their intended purpose (Ogundipe *et al.*, 2022).

Consequently, it becomes evident that BOs serve multiple functions, and teams employ various combinations of them to attain specific objectives in different stages of product development. Nevertheless, no prior research has investigated the manner in which these BOs are integrated. Ogundipe posits that several redesigns may be imperative (Ogundipe *et al.*, 2022); however, it remains unclear whether all previous objects are reworked, or whether certain reworks necessitate the involvement of others as well.

This article presents a novel viewpoint on the combined functioning of BOs in facilitating the concept development process at the early stages of innovation. We address this gap, specifically answering the following research question: *What configurations of BOs effectively support innovation teams during concept development?*

Configurational approaches are helpful to uncover how different causes are linked to an outcome. By adopting a configurational approach to investigate the utilization of BOs, we could gain insights into how teams collectively employ these objects to advance the development of new product concepts.

Results of our analysis show five distinct configurations through which innovation teams use different BOs together. Two of these configurations encompass the development of a product vision, that is, a high-level description of the expected outcome developed at the beginning of a project (Benassi *et al.*, 2016). The other three configurations are related to the refinement of the concept to develop the final product design, without changing the underlying vision. Our findings also suggest that teams combine pragmatic and semantic BOs in the same configuration (Carlile, 2002). These findings support recent trends of flexible product development practices, according to which teams iteratively define and implement changes in the product concept.

In the following sections, we will first provide a theoretical background on BOs in innovation literature. Then, we outline the methodology of our inquiry, to finally shed light on the role of BOs throughout the creative process and discuss the implications of our work.

2. Theoretical background

2.1 Concept development during innovation

Innovation, the act of developing new products, consists in an initial phase of creative idea generation and a subsequent phase of implementation (Khurana and Rosenthal, 1998; Perry-Smith and Mannucci, 2017). The first, or front-end part of the innovation process, is a phase of concept development which requires the integration of different ideas (Koen *et al.*, 2001; Zhang and Doll, 2001; Gilson and Litchfield, 2017). Concept development comprises "the practices of product design, including creativity [. . .] and design using images and tangible models" (Keinonen, 2006, p. 16).

The product concept offers a broad idea of the solution which will guide the successive development stages. To be successful, a product must provide value to the user with both its tangible and intangible attributes (Clark and Fujimoto, 1990). Hence, the development of the product concept requires both bridging semantic knowledge boundaries (the meaning of a product) and pragmatic knowledge boundaries (its structure).

For this reason, a product concept is often abstract and equivocal. The product concept represents the set of attributes which will be translated into design specifications (Seidel, 2007). While it is well-known how product concepts can be expressed, the process of concept development is less clear. The fuzzy front-end is largely unstructured (Zhang and Doll, 2001; De Brentani and Reid, 2012) and requires knowledge integration from various sources.

Individuals must translate their knowledge from one domain to another, so it becomes usable for all team members. In such conditions, knowledge must bridge a set of boundaries from one individual to another (Gilson and Litchfield, 2017). Design scholars suggest that artefacts can help bridge these boundaries (Lauff *et al.*, 2020).

2.2 Boundary objects (BOs)

When individuals collaborate in teams, they often use artefacts to share their work with each other and other stakeholders (Bucciarelli, 2002). These artefacts are not simply means of visualization. Rather, they impact the product development process supporting communication among individuals across knowledge boundaries (Paraponaris and Sigal, 2015; Lauff *et al.*, 2020). Ungureanu *et al.* (2020) identify a variety of boundaries that affect knowledge exchange and integration; although these boundaries are more acute in inter-organizational settings (Ogundipe *et al.*, 2022), even within a single organization, teams need to cope with impediments if they wish to develop novelty.

When artefacts support the transfer of knowledge and meaning across boundaries, they work as BOs (Star and Griesemer, 1989; Carlile, 2004; Holzer, 2012). BOs include PowerPoint presentations, drawings or notes, blueprints, prototypes, among others (Bechky, 2003). Using these BOs, teams can integrate their understanding and develop new knowledge (Caccamo *et al.*, 2023).

Star and Griesemer (1989) originally introduced the concept as a bridge among different visions of actors working on a project of cultural innovation. BOs are shared representations and result in being both "*concrete and abstract, specific and general, conventionalized and customized*" (Star and Griesemer, 1989, p. 408). This twofold nature led scholars to employ them in multiple areas, among which is innovation (Carlile, 2002; Holzer *et al.*, 2011).

In a recent literature review, Caccamo and colleagues highlight the evolution of the BO literature over time, that is becoming increasingly more complex. Different actors and stages of new product development interact in temporary organizations to solve problems, and BOs gradually evolve as they support the envisioning of future solutions (Caccamo *et al.*, 2023).

Studies about BOs can broadly be divided into two perspectives. The first, object-centric perspective, delves into the in-depth analysis of a specific artefact within its application context. This approach aims to understand the working principles and functionalities of an individual artefact and its impact on team collaboration. On the other hand, the second, process-centric perspective, takes a broader view by exploring how a variety of artefacts collectively support and enhance specific collaborative processes within a team. This perspective recognizes that multiple artefacts can play complementary roles and contribute to different aspects of collaboration.

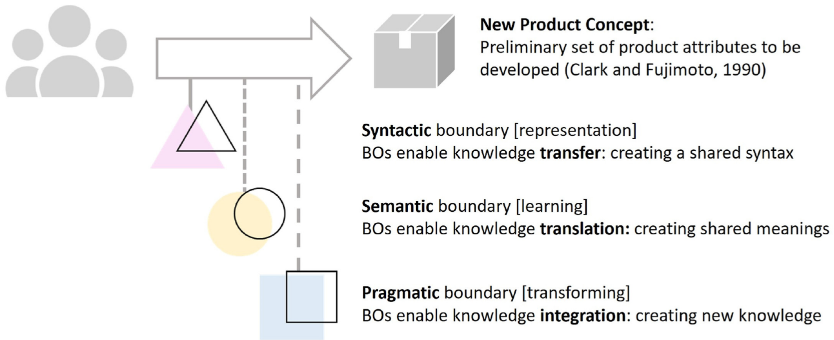
(A) The object-centric perspective

Following the object-centric perspective, the authors analyse individual artefacts and study their effect on knowledge transfer and integration. This perspective suggests that each BO has a specific role to play in bridging boundaries, depending on their context of application. This literature stream builds on Carlile's (2002) seminal work, which identifies a list of BOs which can help overcoming syntactic, semantic and pragmatic knowledge boundaries (Figure 1). Thereafter, scholars in different fields tried to apply this line of thought to specific categories of artefacts to highlight their role in bridging boundaries.

Prototypes are among the most researched BO (Lauff *et al.*, 2020). Despite their extensive usage in innovation, prototypes represent an under-appreciated artefact in terms of their potential for collaboration (Bogers and Horst, 2014). Depending on the stage during which prototypes are used, and on how teams make use of them, prototypes bring a more validative or exploratory contribution (BenMahmoud-Jouini and Midler, 2020). The authors highlight three archetypes of the prototype construct, which can function as stimulators, demonstrators and validators. Teams spend extensive time on prototyping to perfection the final design (Yang, 2005). Lauff *et al.* (2020) find that prototypes are effective not only for solving engineering problems but also for bridging communication boundaries.

Another much studied artefact is the product sketch, which can support creative work visualizing abstract thought (Purcell and Gero, 1998; Self, 2019). Again, the power of sketches lies not so much in the creation of a detailed representation but in supporting the communication within a group, making the work visible (Römer *et al.*, 2001). In general, there appears to be an increasing visual turn in BOs in design and innovation management (Ewenstein and Whyte, 2009; Meyer *et al.*, 2013).

In innovation, Koskinen (2005) focuses on metaphorical BOs such as a product idea, which can be represented in various forms, and help keeping a team aligned. In an extensive analysis of six front-end innovation projects, Zasa *et al.* (2022) find the importance of visually representing a single moment of the customer experience. The visualization of a single moment (the *moment of meaning*) helps to align the innovation team internally, as well as ensuring that the key values of the product are passed on in the next stages. In general, the



Source(s): Authors' own work

Figure 1.
Role of boundary objects during concept development

object-centred perspective sees knowledge integration and generation as the primary reason for employing BOs (Caccamo *et al.*, 2023). Yet, this is not the only benefit of BOs; focusing on the development process, it is possible to see how BOs contribute to alignment and collaboration at large.

(B) Process-centred perspective

The process-centred perspective consists in studies that explore specific processes and explore the role that BOs have in enhancing certain dynamics during that process. Literature in this area focuses on a specific type of process and uses the lens of BOs to explore how artefacts facilitate interaction in that realm.

This stream builds on the seminal work by Star and Griesemer (1989), who study the role of artefacts in the context of the development of a museum. In this context, both heterogeneity and cooperation are central to the success of the endeavour – and the materiality of BOs could support this.

In the field of organizational management, Bechky (2003) explores the role that workplace artefacts have in supporting interaction dynamics within occupational communities. Inside organizations, knowledge and competences are typically stored in silo form in functional units – and knowledge exchange among these units is knowingly tedious (Caccamo *et al.*, 2023). Bechky studies the role of two artefacts in supporting problem-solving across these boundaries, connecting engineers, technicians and assemblers. The progressive editing process on the artefacts helps to integrate knowledge and build shared understanding (Nosek, 2004).

Stigliani and Ravasi (2012) focus on the specific work of innovation at the organizational level, studying the sensemaking process underlying concept creation. The visual artefacts studied by the authors help to collect one's thoughts, sharing them with others and progressively elaborating the emerging ideas. Similar studies have been performed previously by Seidel (2007) and Seidel and O'Mahony (2014) to explore how a set of BOs supports product development and keeps the concept up to date throughout the process. The authors discuss how stories, metaphors and prototypes are used throughout the innovation process to help keep teams aligned. Discussing the idea of concept shifting, the authors suggest that BOs have both the flexibility in supporting integration throughout concept development, as well as sufficient stability to maintain coherence (Star and Griesemer, 1989).

Also, organizational innovation and transformation processes are not exempt from boundaries that prevent successful implementation. Press *et al.* (2021) perform action research in a variety of organizational settings and define a *design-driven dialogue* model that describes the diversity-cooperation dynamic as a continuous oscillation among individual and collective reflections and shaping efforts. The boundary object at the centre becomes the pivotal element that not only represents and transfers knowledge but represents the embodiment of the progressively created new meaning. Moreover, in such organizational processes, other mechanisms support artefacts in spanning a boundary – namely a discourse, a practice or an individual (Hawkins and Rezazade, 2012).

Eppler and Hoffmann (2012) study the idea generation process of generating new business models leveraging various artefacts. The authors hypothesize that sketches or a digital template enhances perceived group collaboration and creativity. While the authors try to combine different artefacts, their laboratory setting prevents from finding significant results.

Boundaries are stronger and more challenging if the collaborative environment is open, as during the co-creation process of solving social problems. Cooney *et al.* (2018) suggest that BOs support multi-individual sensemaking processes in complex environments, as they allow to visualize abstract ideas. The authors study the process of social problem solving, which requires a variety of stakeholders to interact and create shared meaning. The usage of

BOs facilitated the sensemaking process, helping the diverse community to create a shared understanding of the problem (Nosek, 2004). Singh (2011) explores visual artefacts more broadly, highlighting their role in fostering collaborative research. Again, the challenges of multi-stakeholder interactions are mitigated by using a set of visual artefacts to simplify the exchange of knowledge.

Despite research is increasingly confirming the theoretical and practical value of artefacts as boundary objects, no unique view exists as to how they exert their power (Caccamo *et al.*, 2023). Both studies that focus on the objects and those focusing on knowledge creation agree that BOs are crucial to supporting teams in working together; yet, a single perspective that connects various objects to different benefits throughout the process is still missing.

2.3 Research objective

During the front-end of innovation, product concepts are often equivocal and make the job of innovation teams difficult (Andriopoulos *et al.*, 2018). While BOs can help, extant studies are myopic. To understand how teams can overcome the variety of boundaries which hamper innovation, it is necessary to focus on more than one artefact (Majchrzak *et al.*, 2012). However, the usage of multiple artefacts has primarily been examined from a process-oriented standpoint, neglecting a deeper exploration of the objects themselves. This is surprising, given that evidence suggests that the combined use of multiple artefacts significantly influences collaboration.

With our study, we aimed to fill this gap and shed light on whether teams adopt specific configurations that combine various boundary objects, which prove to be more effective together during the development of concepts.

3. Method

To explore which BOs are used together and how they benefit collaboration, we adopted a configurational approach based on observations from a laboratory setting. Over two months, we observed ten innovation teams charged with the development of a new product concept. We collected reports in which the teams presented their work on the concept.

3.1 Research context

We chose a creative industry setting, where concept development is an iterative process of inspiration, framing, developing prototypes and validating initial hypotheses (Paris and Mahmoud-Jouini, 2019). This creative process is accompanied by a variety of BOs, ranging from images and drawings to physical or digital prototypes.

We adopted a laboratory setting, which allowed to analyse several BOs simultaneously; teams were self-formed. Subjects for the observations were recruited from an upper-level undergraduate course in fashion design held in a controlled physical environment. The course was designed to familiarize students with the setting of product design in the fashion industry. Student teams can provide useful insights in teamwork and creativity and are often used in laboratory studies (Aggarwal and Woolley, 2019).

The challenge: To increase the external validity of our findings, a design brief was presented by an external industry partner. Participants were asked to ideate a new product concept for the sportswear industry, with a particular focus on environmental sustainability. Instructions were given to the teams that the product concepts would be evaluated by the industry partner and eventually developed. There appears to be no significant difference among the usage of BOs in different industries (Seidel and O'Mahony, 2014); our choice to focus on a single industry aimed to increase the comparability across groups. The challenge was framed by the industry partner as an opportunity to develop an innovative product concept.

The teams: Creative development of ideas is favoured by social exchange (Hennessey and Amabile, 2010); thus, innovation team members were left free to form self-designing teams, with full autonomy on team organization and task execution. Participants worked in 10 self-created teams of up to 3 members with 64% female participants, of which 30% came from Italy, 20% from other European countries, 43% from Asia and the remaining 7% from South America. Most participants had a background in fashion design (53%) or in other design-related disciplines (11%, e.g. product design), while 36% had a background non-design discipline (e.g. economics). Table 1 provides an overview of the distribution of various categories across the teams with respect to the main descriptive variables, thereby reflecting the composite measure of diversity within each team. Teams received support from three distinct sources. First, methodological training was given at the beginning of the course concerning specific digital modelling tools. Second, throughout the course, the teams had interactions with the course instructor in the form of design reviews, which helped to spur critical reflection (Schön, 1983). Last, the course had three interactions with the industry partner at the start of the project, as a mid-way validation review and a final Go/No Go Gate (Khurana and Rosenthal, 1998).

3.2 Data collection

The concept development process was articulated in four iterations, delimited by an intermediate design review with the mentors or with the industry partner. One researcher participated at all the intermediate review sessions and interactions with the industry partner, taking notes on the usage of BOs during the interaction, covering in total 20 h of field work. Each iteration lasted between one and two weeks: at the end of each iteration, the teams were asked to share their progress with the research team. The data collected consisted in PowerPoint presentations and images of all material used, including 3D models created using the software Rhino and physical prototypes (349 pages total). The presentations were examined and coded as explained in the following.

3.3 Data analysis

To identify configurations of BOs adopted by the innovation teams, we proceeded in two steps. First, we performed a qualitative analysis of the BOs used. Second, we used the second-order themes to perform an fsQCA (Ragin, 2008; Sukhov *et al.*, 2021) to identify configurations of BOs which lead to a product change.

The coding process was carried out in multiple iterations, at the end of each collection period and at the end of the project. Two researchers coded each BO independently, while a

ID	Members	Nationalities	Background	Skills
1	3	2	2	3
2	3	3	2	2
3	3	3	2	2
4	3	1	1	2
5	2	2	2	1
6	3	1	1	2
7	3	3	2	2
8	2	2	2	1
9	3	2	1	2

Source(s): Authors' own work

Table 1. Distribution of categories and diversity levels among teams based on main descriptive variables

third researcher who was present in all laboratory activities contributed to sort out any differences. We applied a coding process in four steps, leading from the identification of the BOs to the definition of theory-based aggregate dimensions following the Gioia methodology (Gioia *et al.*, 2013; Caccamo, 2020).

The first step consisted in gathering all artefacts the teams had used during the projects. The second step involved a first round of coding and involved descriptive coding of their usage (Saldaña, 2015). Here, we aggregated artefacts which absolved the same function – for example, case studies used to share inspiration from other industries, or physical prototypes used to validate the assumptions made on a digital interface. This step was supported by interacting with the company representatives who had launched the design brief, as well as experts on the digital modelling software used. The third step involved organizing the descriptive accounts into categories of BOs. The BOs joined artefacts of a similar form and function – for example, digitalized hand drawings and computerized sketches were all classified as "sketches". In the last step, we linked these BOs to prior theoretical knowledge to highlight aggregate dimensions. These aggregate dimensions connect the BOs to the theoretical ontology.

3.4 Configuration analysis

Next, we performed a configurational analysis on the categories. To do this, fuzzy-set Qualitative Comparative Analysis (fsQCA) was adopted (Ragin, 2008; Fiss, 2011). The fsQCA is a methodology grounded in Boolean algebra, which allows to highlight conditions of co-occurrence among input conditions to determine the presence (or absence) of an outcome (Ragin, 2008). Through fsQCA, we highlight how different BOs are used together to develop a new or revised product concept. The analysis was carried out using the software fsQCA 3.0 (Ragin and Davey, 2017).

The first step in fsQCA analysis consists in calibrating the input conditions and the outcomes, incorporating both practical and theoretical knowledge (Ragin, 2008). Therefore, our calibration built on the analysis of the BOs used by the teams. All second-order categories were translated into a fuzzy-set representing the relative usage of each BO in the four iterations.

To do this, we first computed the relative usage of each BO for each iteration. Teams could work on any BO and report their work in the final document for each iteration. Pages displaying new material were considered in the analysis. The relative usage of each BO was computed as the number of pages reserved to that BO in a specific iteration over the total number of pages of that BO across the four iterations.

The relative usage was then calibrated using a fuzzy set membership score, which required the specification of three thresholds: Full membership (0.95) corresponded to a relative usage of at least 0.25, the situation in which the BO would be developed by at least 25% in that specific iteration. Full non-membership (0.05) corresponded to a relative usage below 0.01, and a crossover point (0.10) which represented the midpoint on the calibration scale (Ragin, 2008; Sukhov *et al.*, 2021).

The change in the product concept represented our outcome variable, coded as a crisp set indicating whether the concept had changed. Katila and Ahuja (2002) define a new product as any change in the product's core technical and user service features (Saviotti and Metcalfe, 1984; Katila and Ahuja, 2002). We considered any change in terms of *aesthetics* (e.g. color, materials) or *structure* (e.g. shape, features or parts) a change to the concept. Also, 1.00 represented full membership, and 0.00 represented full non-membership (no change in either).

The fsQCA determines *necessary* and *sufficient* conditions. Necessary conditions indicate that the outcome cannot be achieved without the presence of that specific condition. In fsQCA 3.0, a consistency score is associated to each condition; if the consistency score exceeds 0.90, the condition is considered necessary. Our analysis revealed that neither the presence nor absence of any condition would lead to the presence (or absence) of the outcome; thus, the usage of no single BO alone was associated to the development of a revised version of the product concept.

Sufficient conditions highlight the configurations which determine the presence (or absence) of the outcome. We applied a frequency threshold of at least one case and a consistency threshold of 0.80 to highlight configurations of BOs. The result showed a five-configuration solution; the solution *consistency* was very high (0.94), while the solution *coverage* was equal to 0.54. The measures of consistency and coverage are in trade-off in fsQCA analysis and represent the empirical relevance and frequency of occurrence, respectively (Sukhov *et al.*, 2021; Ragin, 2008). In the following, we discuss the configurations of the parsimonious solution, as qualitative interpretation suggests no further reduction (Ragin, 2008).

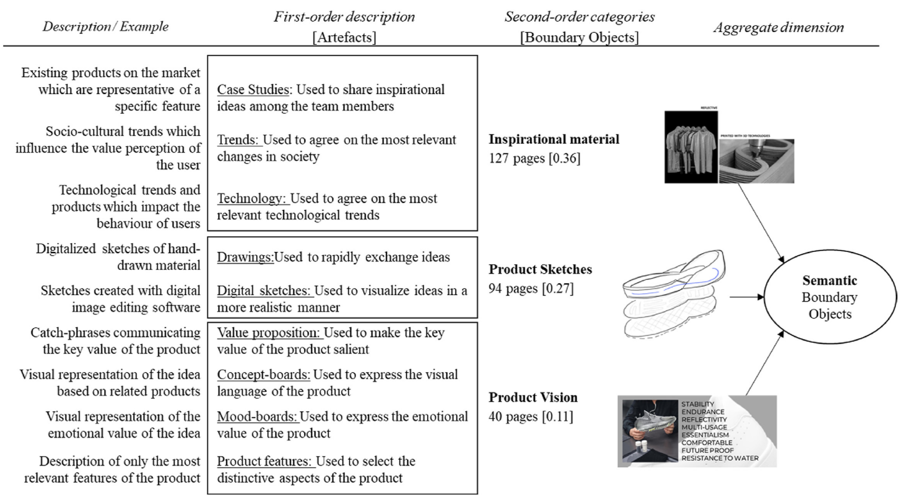
4. Findings

The findings of our study illustrate the BOs used by ten product innovation teams, and how these were used together in five configurations. First, we present the results of the coding process, where we highlight the BOs used and create aggregate dimensions (Gioia *et al.*, 2013). The aggregate dimensions reflect the theoretical classification by Carlile (2002). Second, we present the results of our configuration analysis, highlighting five configurations through which teams used groups of BOs together.

4.1 Qualitative analysis of boundary objects

Syntactic boundary objects: Teams used the same graphical instruments and visualization tools for representing their project. These artefacts are known as *syntactic* BOs: they help establishing a common language or syntax and are often technical in nature. Syntactic BOs were invariant among groups and phases; hence, we did not consider them in the further analysis.

Semantic boundary objects: We identified three categories of artefacts that teams used to learn across boundaries and develop shared meaning (Carlile, 2004): inspirational material, product sketches and the product vision. These are known as *semantic* BOs, standardized forms and methods that translate knowledge across boundaries. Figure 2 shows the results of our analysis, adapted from field material.



Source(s): Authors' own work, adapted from workshop material

Figure 2.
Data structure representing the first-order descriptions and second-order categories of the aggregate dimension semantic BOs

Inspirational material helped team members to share how they formed their understanding. Highlighting case studies and referencing social processes external to the project itself, each member could make certain meanings salient. Inspirational material allowed the communication of values and meanings: the BO helped make these abstract elements concrete.

Sketches are drawings created by hand or with the aid of specific software, which helped teams to visualize their preliminary ideas. Through sketches, team members could experiment with different combinations, in a creative attempt to integrate their preliminary ideas.

Last, the product vision summarizes the perspectives of the team in a single proposal. This could take the form of written descriptions of the product features, or more inspirational concept- or mood-boards. Through this textual or visual representation of the vision, teams could develop common ground on the product to implement before diving into the details of product design (Benassi *et al.*, 2016).

Pragmatic boundary objects: We identified three categories of artefacts that teams used to integrate existing and develop new knowledge across boundaries (Carlile, 2004): technical drawings, digital prototypes and physical prototypes. These are known as *pragmatic* BOs, objects, models or maps that transform knowledge across boundaries. Figure 3 shows the results of our analysis, adapted from field material.

Through technical drawings, teams could translate the inspirational material into concrete product features. Some teams added measurements to the preliminary sketches, adding details concerning the size or measures of the element. In other cases, technical drawings represented cross-sections of the product. Furthermore, teams used digital and physical prototypes to implement their ideas (Bogers and Horst, 2014). Digital prototypes were 3D renders of the garment. In line with previous literature, digital 3D renders helped the teams to integrate their knowledge in a single version of the product (BenMahmoud-Jouini and Midler, 2020). Since the first iterations, the teams simultaneously developed the product concept and the digital model of the same. The digital prototype evolved throughout the project, reflecting the changes which the teams did to the concept.

Last, teams also used physical prototypes to test their assumptions. Physical prototypes consisted in pieces of various materials, ranging from polystyrene to plain fabric, sewn or glued together. Despite being very rudimental in nature, these prototypes took hours to produce. Physical prototypes were used in review moments to gather early feedback from the industry partner.

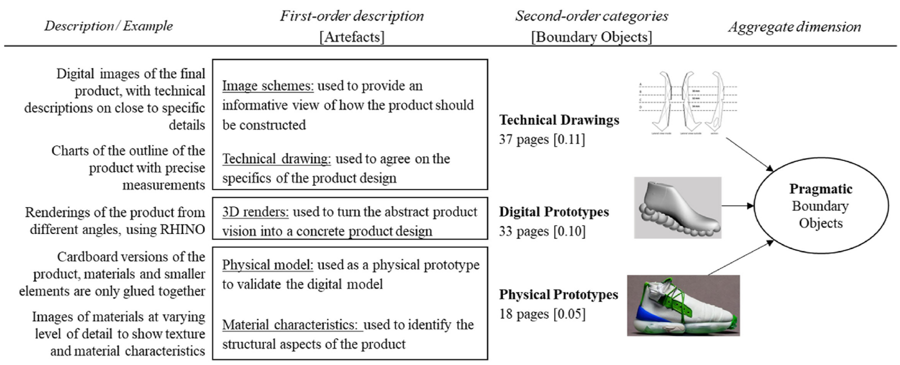


Figure 3.
Data structure representing the first-order descriptions and second-order categories of the aggregate dimension pragmatic BOs

Source(s): Authors' own work, adapted from workshop material

4.2 Configuration analysis

Building on these categories of boundary objects, we analysed configurations of BOs which lead to the development of a new product concept. First, a necessary analysis was performed that indicated that no single BO is always adopted in all configurations. Next, a sufficiency analysis highlighted five different configurations of BOs to support the concept development activity in *visioning, pivoting, experimenting, modelling* and *prototyping* (Table 2). In the table, each configuration is represented in a column. Individual BOs are presented on the rows: black circles (" ● ") highlight the presence of a condition, meaning the BO is used in that configuration. Crossed-out circles (" ⊗ ") represent the absence of a condition, meaning the BO is not used in that configuration. Blank space indicates the BO may either be used or not. Therefore, each configuration consists of one or more mandatory BOs, one or more supporting BOs whose usage is optional and one or more BOs which are not used.

The only BO which is never optional is the product vision. This BO acts like a discriminant variable: either the team changes the vision or the vision is frozen, and the team works on defining the final design. This allows to further cluster the configurations in two main families: product envisioning (where the product vision BOs are always adopted) and product design (where product vision BOs are never adopted).

Our findings suggest that BOs support teams in developing a new product concept in two ways: revising the vision or developing the product design. In the following, we discuss each set of configurations in depth. The configurations are not linked to any specific phase or order *per se*. Some teams used one configuration multiple times, while the same team never used some others. Yet, the configurations reflect existing actions necessary for successful concept design. Therefore, we highlight when these configurations may be used during concept development according to literature (Khurana and Rosenthal, 1998) (see Table 2).

4.2.1 Product Envisioning. Configurations grouped under the term product envisioning represent the activities where the team changes the product vision of their concept. The product vision represents an abstraction of the product in textual or visual form and is crucial to successful product development (Benassi *et al.*, 2016). Two configurations led to the development of a new version of the product concept with a change in the product vision. The first configuration, which supports *visioning*, is related to a change in the product vision alone; the second configuration supports *pivoting,* and the change in the vision reflects on many other objects (see Table 3).

4.2.1.1 Visioning. During early stages of concept development, one of the first challenges which innovation teams face is to develop a vision for their product (Benassi *et al.*, 2016). This vision should include the perspectives of all team members, integrating the meaning which they find in the new product. The configuration supporting *visioning* represents situations in which teams change their product concept without relying on either inspirational material or the development of technical details. Teams that adopt this configuration work on refining their product vision with details and descriptions.

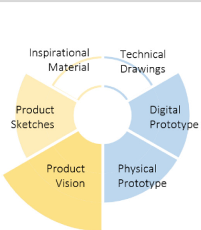
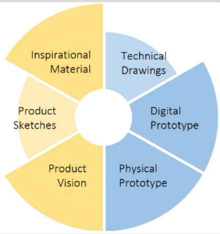
The usage of the product vision as the main BO in this configuration suggests that the teams rely on the information gathered previously to develop their ideas. Thus, this configuration supports *visioning*, as the team engages in developing a new vision on their project.

4.2.1.2 Pivoting. The configuration supporting *pivoting* refers to a situation in which the team leverages multiple BOs to develop a radically revised version of the product concept. When a team realizes that its current trajectory is unsustainable, they may decide to pivot and test a new hypothesis. This configuration refers to situations in which teams develop or change most of their product concept: they not only work on their vision, sourcing external inspirational material; these changes also affect the model of their product both in its physical and digital form.

Table 2. Configurations leading to the development of a new version of the product concept

Knowledge boundary		Product envisioning* Configuration supporting visioning	Configuration supporting pivoting	Product design* Configuration supporting experimenting	Configuration supporting modelling	Configuration supporting prototyping
Semantic	Inspirational material	⊗	●			⊗
	Product sketches				●	
	Product vision	●	●	⊗	⊗	⊗
Pragmatic	Technical drawings	⊗		●		
	Digital prototypes		●	⊗	●	
	Physical prototypes		●		⊗	●
	Interpretation of the configuration	The team changes the vision without considering external elements or technical details	The team changes the vison, drawing on new inspiring elements and modifies the concept accordingly	The team develops technical details without implementing them on the digital model	The team uses sketches and apports changes to the 3d model	The team uses a physical prototype to visualize the current version of the product concept
	Raw coverage	0.11	0.23	0.12	0.09	0.06
	Unique coverage	0.09	0.20	0.11	0.08	0.04
	Consistency	0.95	0.92	0.86	0.88	0.88
	Solution coverage	0.55				
	Solution consistency	0.95				

Note(s): * Configurations are grouped based on the presence or absence of the discriminant boundary object product vision
Source(s): Authors' own work

The configuration supports..	Visioning	Pivoting
Visual representation		
Main Boundary Object	*Product Vision* to define the meaning of the product.	*Inspirational material* and *Product Vision* to define the meaning of the product, combined to a *digital* and *physical prototype* to turn the vision into a concrete outcome.
Supporting Boundary Objects	*Product sketches* to visualize how the vision changes the product; *Digital prototype* to simulate the most promising sketches; *Physical prototype* to create a first tangible representation.	*Product sketches* to quickly visualize alternative product designs; *Technical drawings* to evaluate the technical requirements of the product.
Role of prototypes (Mahmoud-Jouini and Midler, 2020)	*Stimulator* – gather inspiration and generating ideas.	*Demonstrator* – weave the new product vision into a tangible outcome.
Use during concept development	Pre-concept phases of idea generation and visioning (Khurana and Rosenthal, 1998)	

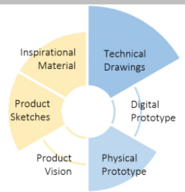
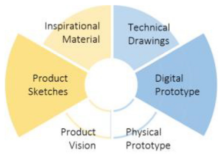
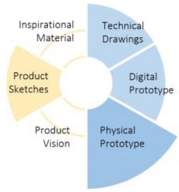
Note(s): Yellow represents Semantic and blue pragmatic BOs
Source(s): Authors' own work

Table 3. Synthetic representation of the configurations for *product envisioning*

While it would be expected that this configuration is used predominantly at the beginning of the project, our findings suggest that teams adopt it also in later stages. Thus, this configuration supports *pivoting*, as it indicates that team work on different BOs to provide a new or radically revised product concept.

4.2.2 Product design. With *product design* we refer to the configurations which lead to the definition of technical details of the product. We highlight three configurations through which teams work on their product without changing the product vision. When technical drawings are used, the configuration supports *experimenting*; the configuration supporting *modelling* refers to a situation where sketches inform the development of the digital model; the last configuration supports *prototyping* through a predominant usage of the physical model (see Table 4).

4.2.2.1 Experimenting. A key principle of successful product development is represented by flexibility since the early stages: exploring the implications of decisions at the concept level on the detailed technical design choices, to prevent mismatches in the downstream product development process (MacCormack *et al.*, 2001). Such a practice of experimentation

The configuration supports…	Experimenting	Modelling	Prototyping
Visual representation			
Main Boundary Object	*Technical Drawings* to develop the structural details of the product.	*Product Sketches* to quickly visualize alternative versions and a *Digital prototype* to design the final product.	*Physical prototype* to quickly model a real-life version of the product concept on which to interact.
Supporting Boundary Objects	*Inspirational Material* is gathered as an external reference for the new concept; *Sketches* help to visualize the modified product; a *physical prototypes* allows the team to interact with the new product.	*Inspirational Material* is gathered as an external reference for aesthetic details; *Technical drawings* are adapted to the new product concept and evaluate its' technical feasibility.	*Product Sketches* help the team to align on how the prototype should be designed; *Technical drawings* are used to keep track of the measures which are approximated on the physical prototype; *Digital prototype* is used as a replica of the physical product.
Role of prototypes (Mahmoud-Jouini and Midler, 2020)	*Demonstrator* – add details to the solution to increase specificity.	*Demonstrator* – weave the frozen product vision into a tangible outcome.	*Validator* – create a preliminary solution for validation and approval.
Use during concept development	Concept shifts during specification and design, once the vision is frozen (Khurana and Rosenthal, 1998)		

Note(s): Yellow represents semantic and blue pragmatic BOs
Source(s): Authors' own work

Table 4.
Synthetic representation of the configurations for product design

allows teams to change their product concept, while still maintaining a technically feasible design.

The configuration supporting *experimenting* is used when teams develop technical drawings without changing the product vision. Following this configuration, teams do not develop any additional inspirational material. Teams adopt this configuration once they have frozen the product vision and take a next step in defining the technical aspects. Thus, the product concept changes because of the new technical details added. This configuration supports *experimenting* because it represents a situation in which individuals take the conceptual work developed previously and turn it into a concrete product design with technical specifications.

4.2.2.2 Modelling. With the final two configurations, teams focus on the development of prototypes to demonstrate the features of a concept (Lauff *et al.*, 2020). Our findings show that teams use two types of prototypes: digital prototypes are used in a configuration which we term *modelling,* where they allow the team to visualize the product they are aiming for; physical prototypes occur in a configuration we term *prototyping*, where teams work almost exclusively with pragmatic BOs to implement their concept.

The configuration supporting *modelling* is used to take the knowledge shared previously and turn it into a product design. The teams thus develop new sketches and turn these into a digital model. This configuration refers to situations where the concept is frozen, but not yet turned into a concrete product design. The product changes because of new hypotheses expressed in the product vision. Thus, this configuration supports *modelling* as it describes the development of a new design.

4.2.2.3 Prototyping. Contrary to the previous case, the last configuration does make almost no use of semantic BOs. The configuration supporting *prototyping* is adopted when teams use a physical prototype to test their assumptions. The product vision is frozen, and the team avoids further inspirational material, instead working on their product by developing a preliminary, physical version of the same. The physical prototypes were taken to the review moments and helped the teams discuss their ideas more in depth with the customer. This configuration supports *prototyping*, as it indicates the construction of a preliminary version of the product to demonstrate current assumptions (BenMahmoud-Jouini and Midler, 2020).

5. Discussion

The goal of this research was to identify configurations of BOs through which teams develop new product concept. We explored how ten innovation teams developed a product vision and 3D model based on a brief by an external company.

BO literature suggests that artefacts are helpful in collaboration because they allow teams to integrate their knowledge across boundaries (Carlile, 2002; Stigliani and Ravasi, 2012).

Surprisingly, we find that no BO alone is indispensable for developing a new concept. The absence of a single necessary BO confirms finding from previous studies, which controversially found that some BOs – for example sketches – alone do not improve the design process performance. Indeed, our findings suggest that teams rely on multiple BOs throughout the concept development process. This creates a challenge to maintain coherence with a single overarching concept, as teams iterate through different ideas (Seidel and O'Mahony, 2014). The pivotal role of the product vision to discern among different combinations suggests that this BO may act as an "anchor" to provide orientation to the teams (Benassi *et al.*, 2016). This finding echoes the recent results by Ogundipe and colleagues, who identify interfirm problem representation (IFPR) as a socio-historical artefact, fundamental to the development process and consistently shared among stakeholders. Similarly, we assert that the product vision plays a critical role in this context. It is crucial to further investigate the extent to which the product vision influences the emergence, evolution and elimination of other business objectives to gain a comprehensive understanding (Ogundipe *et al.*, 2022).

Second, the configurations bear an interesting finding in their structure. Except for one configuration, all others are centred around maximal two dominant BOs. This provides support for previous studies which addressed the role of one dominant BO (Spee and Jarzabkowski, 2009; Singh, 2011). Our findings also suggest, however, that the dominant BO(s) may be supported by others. Only in the configuration supporting *pivoting* are many BOs used simultaneously, which suggests the team is undertaking a major change in the product.

The incremental change brought forward through the usage of a restricted number of BOs supports the idea of "concept shifting" (Seidel, 2007). The product concept gradually evolves throughout the development process. Different from previous research though, our findings suggest that also the BOs used to work on the concept change, depending on the specific needs of the team at that time. Hence, the configurations include BOs which allow bridging both semantic and pragmatic knowledge boundaries. Holzer and colleagues (Holzer, 2012; Holzer *et al.*, 2011) see knowledge integration as an iterative act, which requires to bridge both semantic and pragmatic boundaries, repeatedly. Such an iterative process would be difficult to grasp when the focus of a study lies predominantly on a single – semantic or pragmatic – BO. Our study highlights that each configuration also includes supporting BOs which some teams use to complement their primary work. For example, adopting a configuration supporting *experimenting*, a team may repeatedly re-define the technical drawings of their product (Bechky, 2003) – but to make these drawings meaningful, it would be necessary to observe why they are created the way they are, that is, their expected impact on the final product.

6. Conclusions

When designers collaborate to develop something new, they need to overcome a series of boundaries. Building on a growing line of research on the role of artefacts as BOs (Carlile, 2002; Stigliani and Ravasi, 2012), we discuss which elements can help teams to develop an innovative idea. Our contributions highlight that innovation teams adopt configurations combining different BOs, in which a dominant BO is supported by others.

We contribute to literature on artefacts, highlighting configurations of BOs adopted throughout concept development. Our study brings together the domains of semantic and pragmatic knowledge boundaries (Carlile, 2002), suggesting two main contributions: first, we extend the focus on the semantic side of BOs. While previous innovation literature has largely focused on the pragmatic role of BOs as knowledge integrators (e.g. Bogers and Horst, 2014), we find that teams use also semantic BOs in the front-end of innovation. Pragmatic BOs facilitate the integration of knowledge across knowledge boundaries caused by organizational diversity (Bechky, 2003).

Second, our findings connect to literature on concept development with a flexible approach. Though most studies on the front-end consider the concept as an unchangeable outcome, product innovation teams undergo a variety of concept shifts during their work (Seidel, 2007). These changes take place when the team elaborates the ideas they had conceived earlier, facing new requirements from the customer, or developing a more thorough understanding of the problem or solution. Today, firms are increasingly adopting flexible practices and agile product development approaches (Cooper and Sommer, 2016). In flexible approaches, changes in the product concepts are welcome when they increase alignment towards the market. Our findings suggest that changes to the concept can take place at two levels: a change using the configuration which supports *pivoting* changes most characteristics of the concept. The other configurations build on a more restricted number of BOs to introduce changes to the concept and are more aligned with the idea of a concept shift (Seidel, 2007). According to the configurations supporting *visioning, experimenting, modelling* or *prototyping*, teams implement changes in a restricted area of the concept – both at the semantic and the pragmatic levels.

Our study also holds various contributions for innovation teams and innovation managers. First, our findings highlight five configurations through which such changes can be incorporated: when a radical change to the foundations of the concept, that is the product vision should change, our findings suggest that teams should work on redefining the functional and semantic characteristics of a product. The configurations supporting *visioning* and *pivoting* provide an overview on the BOs which should be adopted here. On the other hand, when a more incremental change is required, different configurations should be adopted: these revolve around one dominant BO on which the main changes are implemented, and the supporting role of additional BOs. Our contribution lies in highlighting which additional BOs may provide valuable material for discussion to the teams.

Second, our findings help leaders to discern among the different configurations. Our study highlights the pivotal role of the product vision (Clark and Fujimoto, 1990) and contributes to better defining this concept, making it practical for use during concept development. Despite frequent mention of the product vision concept, its definition and key elements still remain blurred (Benassi *et al.*, 2016). Our findings suggest that the product vision comprises a value proposition for the product, and its description through key features, as well as more visual-oriented communication elements, that is, concept-boards and mood-boards. Our findings connect these ideas to the notion of BOs, highlighting how such a vision should be expressed to help team members defining it first, and keeping it stable thereafter.

Our study has also some limitations, which open opportunities for future research. First, we specifically concentrate on the positive aspects of BOs, limiting our findings to the various combinations that teams develop during their collaborative efforts. We intentionally exclude the interpersonal dynamics within teams. Research suggests that BOs can also serve to assert one's own viewpoint and wield power, instead of facilitating creative collaboration (Harrison *et al.*, 2018). Future research may explore these alternative perspectives, delving into the potential for certain configurations of BOs to instigate transformations in relationships (including power dynamics and overall team climate) within the utilizing group.

Second, we rely on a student sample; whilst being used in managerial literature for the purpose of studying cognitive processes as well as teamwork and creativity and that the outcome of such lab experiments closely relate to field studies (van Dijk *et al.*, 2012), the same dynamics should be investigated in an organizational setting for further analysis. Future researchers may therefore want to investigate how organizational dimensions influence the innovation process through BOs. Third, the categorization of BOs as semantic or pragmatic was based on observations and the judgement of researchers. Thus, our study is intended as a complement to previous research: various objects together can bring substantial benefit to the development of a product concept. We encourage future studies to enlarge their scope of observation, exploring the effect of different configurations when used by organizational teams.

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