Leveraging Transdisciplinary Engineering in a Changing and Connected World
P. Koomsap et al. (Eds.)

doi:10.3233/ATDE230599

Aspects Affecting Boundary Objects in Product Realization – A Systematic Literature Review

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Abstract. Product realization is inherently transdisciplinary, resulting in the need for different functions to collaborate. However, collaboration can be hindered by boundaries, arising from differences and dependencies in knowledge. One way to integrate knowledge across these boundaries is through the use of so-called boundary objects. However, boundary objects are situational, meaning that different aspects can affect whether an object functions as a boundary object or not. Based on a systematic literature review, this paper presents a comprehensive overview of different aspects that need to be considered for an object to function as a boundary object in the context of product realization. The aspects were divided into properties relating to the object, and situational aspects connecting to the situation in which the object is used. The paper further shows the role that interplay between aspects plays, and how it can be accounted for.

Keywords. Knowledge management, boundary crossing, boundary objects, systematic literature review, product realization, transdisciplinary engineering

Introduction

The development of new products is an inherently transdisciplinary endeavor that involves several different functions [1]. A consequence is that the success of a product is not solely dependent on the outcome from one function, but rather the interaction between several functions. Even though transdisciplinary alignment [2] and the integration between different functions [3] is of high importance, it has proven to be difficult [4]. One reason for this is that specialization in knowledge between different functions which results in knowledge asymmetry between functions [5]. Because of this, there is a need for integrating knowledge across different forms of knowledge boundaries [6,7]. To address the challenge of knowledge integration across boundaries, the literature has discussed different potential solutions such as brokers [8,9], arenas [9,10], and boundary objects [4], which can be used separately, or together as means of crossing boundaries. In this paper, we focus on boundary objects, that is objects that different social worlds can relate to and use to understand each other [11]. Looking further into the concept of boundary objects, we can see that they have been discussed in different areas such as in education [12] and innovation studies [13]. Work has also been done in the context of product realization [4,14,15], which still is highlighted as an area of interest in relation to boundary objects [13]. Using boundary objects is challenging since they are situational, meaning that an object that in one situation functioned as a boundary

object might not do so in another situation [4]. This situational dependence can be one reason why research on boundary objects often is carried out as case studies [13]. From previous studies, we can see that the function of a boundary object is connected to different aspects. Most obviously, the object itself plays a role through aspects referred to as properties of the object [16], which can be related to for instance the object's visualization [14,17], interpretive flexibility [11], and malleability [4]. The object is also used in a specific situation [18], which can entail aspects such as the place it is used [10], and in which phase of the product realization [15]. Aspects are also dependent on each other, affecting each other through an interplay between properties and situation in which it is used. Examples of such interplay can for instance be seen in Carlile's seminal work on the connection between objects and boundaries [19]. Previous work has led us forward in our understanding of boundary objects, but since the evidence from previous studies is scattered, generalizations of results become difficult. Previous literature reviews concerning the use of boundary objects have been performed in different areas such as knowledge management [20], innovation management [13], pedagogics [12], virtual collaboration [21]. There are also studies with focus on properties or characteristics of boundary objects [16]. However, a comprehensive overview of the literature and aspects that we need to consider for an object to function as a boundary object when working transdisciplinary [2] in the context of product realization is still lacking. Thus, the aim of this paper is to provide a comprehensive overview of the literature in relation to aspects that affect boundary objects, as well as their interplay, in the context of product realization.

1. Method

To get a comprehensive overview of the existing literature on boundary objects in product realisation a systematic literature review was conducted collaboratively among the authors of this paper [22]. The search was done in Scopus, Web of Science Core Collection, and Proquest, and included publications through 2022. The search string used in Scopus was: "(TITLE-ABS-KEY ("boundary object*" OR"boundary cross*"OR"boundary spann*"OR"boundary management" OR"epistemic object*"))AND (TITLE-ABS-KEY("product* reali?ation" OR "product* development" OR"product* introduction"OR"product* innovation"OR"product* platform*" OR"innovation process*"OR"construction project*"OR"construction industry*" OR "manufacturing industr*"))". For the other databases, the same search string was used, but tailored depending on the Boolean operators used for each database. The search string was designed purposefully broad, to ensure that as many relevant articles as possible would be included.

After the initial search, 1222 articles were found, of which 1057 were unique articles. The first screening was done on title-abstract-keywords using Rayyan. Selection criteria were that the article had to be in a product realization context and be related to boundary objects in some way. Not all articles in the first round mentioned boundary object explicitly, but could be related to boundary spanning, a context in which boundary objects can be present or be used. As such, those articles were included in this step. The screening resulted in a selection of 229 articles, which were read in full. For an article to be included in the full paper screening, it had to focus on boundary objects explicitly and be in the context of product realization. After the screenings, 123 articles remained, which were then, for the sake of this paper, filtered on journal publications to focus on

higher quality publications. Articles that solely mentioned that something was, or functioned as, a boundary object, but did not elaborate on properties, the effect of the situation, or interplay, did not qualify for the final selection, which comprised 55 articles. The final selection of articles was analyzed and compiled through an inductive thematic analysis [23]. Through the inductive thematic analysis, aspects, meaning something that has an effect on if something functions as a boundary object or not were identified. These aspects were first grouped based on if they were related to the object, which are called properties, or the situation in which the object is used, which are called situational aspects. Properties refers to a quality, or characteristic, that the object has which enables the function as a boundary object (adapted from Oxford Dictionary). The situation in which the object functions as a boundary object entails the circumstances and things that are happening at a particular time and place, which affects if the object functions as a boundary object (adapted from Oxford Dictionary).

2. Results

This section presents the results from the thematic analysis explained in the previous section.

2.1. Properties

Several aspects related to the object related to the visualization of the object in terms of different modalities [15,24–30], which can imply inclusion of text and visuals. The visual aspects can further pertain to the medium, such as if it is analog or digital [31,32], or the number of dimensions it contains [31]. Objects containing several dimensions can further portray that the intended design is solidly elaborated on from their iconicity [33]. Combining different visuals can further help in the object functioning as a boundary object [14]. Visualization can also relate to the inclusion of visual timelines [26], which can sometimes be misleading through their iconicity, restricting possible interpretations [33].

Other aspects were pertaining to the materiality of the object, such as the scale and exactness of the object, meaning that they should be usable for different users and not leave room for own interpretations could be seen [34]. Objects can also be more or less tangible [35], further connected to the materiality [35] of the object. Objects can be modular, entailing that it is built up of different smaller components [10] which can provide interactive elements for different individuals [36].

Pertaining to the object's recognizability, its name can be seen to play a role if individuals understand and recognize the object since it can provide a connection to the intended function [26]. The further articulation of the object can be defined in loose terms or in a specific manner [37], leaving the object open for interpretation [38]. The perception of the object, if it is seen as solely a form of software of a mean of work coordination, can further affect its function as a boundary object [39].

As objects can evolve over time [13], tracking the rationale behind changes, similarly to a change log, of the object plays a role [25]. Pertaining to this is how up to date the object is [5]. This can for instance be communicated through change notifications [25].

Different expressions were used to denote dyadic properties, pertaining to the rigidity of the object. A highly rigid object could be seen as standardized [35,40,41],

frozen [28], concrete [42], robust [42], and stable [25,43,44]. How stable the object is over time, meaning that it retains the same structure, can provide it with a recognizable structure [25]. On the other end of the spectrum, flexibility [19] of the object, in other words how plastic [42,45], fluid [28], abstract [46], and flexible [15,17,27,30,35] it is. Thus, we can identify two properties of importance, being the rigidity and flexibility of the object.

Shared syntax, or a shared language related to the object can be seen as a property [4,38,47]. Having a shared syntax can be seen as pertaining to a shared understanding of the meaning of words and features of the object [4]. Through a shared syntax, there is a mutually understood structure which can be used to communicate differences and dependencies [4]. The syntax should be balanced between groups so that it sits in the middle and is not directed more towards one group than the other [47].

The identified properties are summarized in **Table 1**.

Table 1. Properties of objects.

Property	Explanation	References
Visualization	Pertaining to a visual object's analog or digital state, dimensionality, and modality	[15,24–30,33]
Materiality	Scale and precision of an object and its structure	[10,34–36]
Recognizability	Object name, articulation, and perception	[26,37–39]
Up to datedness	Whether the object is up-to-date and how this fact is communicated	[5,13,25]
Rigidity	Levels of object standardization, concreteness, and stability	[25,28,35,40–44]
Flexibility	Levels of object plasticity and flexibility	[15,17,19,27,28,30,35,42,45,46]
Shared Syntax	Sharing a common language and understanding of the object	[4,38,47]

2.2. Situation

Temporal aspects were highlighted in several of the articles [15,24,28,34,45,48]. Different artefacts are used throughout different phases of the product realization project [24] such as early or late phases of the product realization [15]. The different phases involve different amounts of novelty and require different types of boundary objects [13,45], and the roles of the boundary object can evolve over time [10,13,48,49]. In earlier phases, there is more focus on cognition, used to envision the product, whereas later stages focus more on learning [13]. Object can also affect not only in the time they are used, but also future activities [15,49]. Further time pressure involved in different phases can cause the boundary object to become secondary [29]. Thus, boundary objects perform differently dependent on when they are used [28].

The space where the object is used is discussed by several authors [10,14,26,28,29,43,50–52]. The accessibility of the object and inclusion of individuals can be limited depending on where it is used [26,53]. Different spaces can have different types of intensity, referring to for instance the difference in talking over phone or meeting physically as well as the quality of boundary objects present [10]. Similarly, co-location could be seen to nurture experimentation rather than solely focusing on task completion [43], whereas physical dispersion can hinder collaboration [29] and result in the need of asynchronous communication [14]. Co-location can affect since actions from the individuals such as pointing, and movements are supported [28]. Dispersion can further

cause project management tools and visual aid to become less impactful, thus affecting their function as boundary objects [29]. Subsequently, different objects are used in different ways dependent on if the individuals are co located or not [54]. This can be summarized related to novelty, where higher amounts of novelty require co-location, whereas lower amounts of novelty do not require co-location.

Ownership of the tool could be seen as something that both enables as well as hinders the function of boundary objects. For instance, it can result in a not invented here mentality [35]. The further management of objects through for instance how objects are selected, created [5], and communicated has also been seen to enable them to function as boundary objects [25]. The creation and development of boundary objects was further seen as being supported by face-to-face interactions [50] and could be affected by communication processes within companies [49].

The use case of the object was discussed by several authors, seeing that the way the object is used can bring out different properties [42]. Examples of this related to visual representations can be through sketching on drawings, zooming in on details while having the drawings on a big table or on a wall [28]. It should also be clearly communicated how the object ought to be used, and expectations pertaining to it [54]. Objects can further play different roles, such as being stimulators, demonstrators, or validators, which in return affects if it can function as a boundary or not [38]. In [42], it was shown that not only the object, but also how it was used affected if it could be used to cross syntactic, semantic, or pragmatic boundaries.

The role of the individuals using the object was seen in several articles, relating to intrinsic and extrinsic factors. Intrinsic factors were related to the amount of shared experience in relation to both the object [10,24], affecting their competencies and skills, as well and working together [14,49], such as cultural and linguistic awareness between individuals [14,36]. Individuals can further have their own intrinsic goals and priorities which can affect their willingness to take in other's perspectives [40,43,49], and can adopt boundary objects differently mindfully [13]. The individuals can also choose to withhold their knowledge either intentionally or unintentionally [54]. Extrinsic factors can relate to the individual's engagement in the identification of relevant objects to use [25] and if the individuals trust the object or not [15]. Different terms of authority can further affect if individuals have unbalanced decisional powers [47] or use the authority to implement strict deadlines or use the boundary object as a means of control [36]. Intentionally or unintentionally, individuals can be excluded from the use of the object [44] which can limit the possibility for direct feedback, subsequently influencing the object's function as a boundary object [55]. It further seen that higher levels of novelty and complexity of boundaries may require the involvement of individuals as brokers together with the object [8,48]. The broker can further help in bridging contextual gaps between actors [56].

Boundaries are a prominent aspect in relation to boundary objects. Not all articles discussed boundaries, but the most used was Carlile´s typology of syntactic, semantic, and pragmatic boundaries [19], which was used in a plethora of the articles [5,8,28,36,38,42,45,50,56–58]. Other denominations of boundaries were organizational [14,34,51,52,55,58,59], geographical [14,29,52], between different domains [30,32,44,52,60,61], and cultural differences between individuals [36]. Connected to the boundary, the object's properties must match the boundary being crossed. Different properties were argued in the literature as more or less important relating to increasing novelty [50]. For instance, if there are low levels of novelty and need for creativity, having an object which is more standardized [35,40,41], frozen, concrete [42], robust

[42], and stable [25,43,44], which portrays higher level of elaboration through for instance its visualization [33], could be seen as preferrable. Reasons for this being those similar interpretations of the object [10] and a higher level of structure can support sharing of explicit knowledge [50]. On the other hand, situations with higher levels of novelty and need for creativity required more fluid, abstract [10,35,42], plastic [42,45] and flexible [15,17,27,30,35] objects. Reasons for this being that weakly structured objects can support in tacit knowledge being expressed [30,50], whereas structured objects work better for coordination and sharing of explicit knowledge [50].

The identified aspects pertaining to the situation is summarized in **Table 2**.

Table 2. Situational aspects.

Aspect of Situation	Explanation	References
Time	The phase of product realization when the object is used and evolution of the object over time	[15,24,28,34,45,48]
Space	Where the object is used, its physical dispersion among individuals, and varying intensities	[10,14,26,29,43,50–52,62]
Ownership	Pertaining to the creation, management, and ownership of the object	[5,25,35,49,50]
Use case	How the object is used and the role it plays	[28,38,42,54]
The individuals	Effects of intrinsic and extrinsic factors on users	[8,10,13–15,24,25,36,40,43,44,48,49,54–56]
The boundary	Boundaries can be of different types (e.g., syntactic, semantic, pragmatic, organizational, geographical, domain-specific, or cultural)	[5,8,28,36,38,42,45,50,56–58]

3. Discussion and conclusion

In this paper we have identified aspects that affect if something functions as a boundary object or not. The findings were divided based on if the aspect pertains to the object, which was referred to as a property, or if it pertains to the situation in which it is used. These aspects were summarized in table one and two and present a basis for understanding of aspects to consider for something to function as a boundary object during product realization.

Through our analysis it also becomes clear that the identified aspects cannot be addressed in isolation but need to be accounted for through a perspective on interplay. As was seen in several instances, higher degrees of novelty and the connection to the boundary being crossed. This was pertinent in relation to the space which required higher intensity and co-location. Properties of the object where more fluidness, abstraction and flexibility were needed for more complex boundaries, such as pragmatic boundaries. The use case was seen to play a supporting role connected to the boundary being crossed. The further inclusion of brokers could help when crossing boundaries of higher complexity. Thus, several forms of interplay pertaining to the boundary being crossed could be seen.

Further forms of interplay could be seen related to how objects can play complementing roles and affect each other, further bringing out different properties. Objects can also not only affect the time when they are used, but also over time, showing an interplay between object and time. Whether the object was used in a co-located

situation could further affect its accessibility between individuals and whether it was used for task completion or experimentation.

From this discussion, we can see that different forms of interplay need to be considered for an object to function as a boundary object, where the interplay between aspects supports or inhibits how an object functions as a boundary object. Considering the situational nature of boundary objects, it is not certain that all the identified aspects and forms of interplay will always play a role in the object functioning as a boundary object or not. However, these aspects can be seen as variables that can be used to design objects, situations, and interplay which lead to common understanding, thus supporting transdisciplinary work between functions with asymmetric knowledge. From our analysis and discussion, some insights related to what aspects play a bigger role related to boundaries can be achieved.

To conclude, this paper has summarized contributions of previous literature on aspects that affect if something functions as a boundary object or not when working transdisciplinary in the context of product realization. The contributions were divided between properties, the situation in which it is used, followed up with a discussion on interplay between aspects. The articles included in this review were mainly retroactive, describing in hindsight why something functioned as a boundary object or not. Thus, the instance where the object has been proactively chosen based on its properties, in a specific situation, regarding the interplay between aspects, is yet to be addressed. Future research could therefore entail using the identified aspects and interplay in a proactive manner, delving into how to proactively design boundary objects to support transdisciplinary work.

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