BOUNDARY OBJECTS: SUPPORTING BETTER COLLABORATIVE PRACTICE AND RESEARCH

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The purpose of this paper is to look for boundary objects that can develop and facilitate a "knowledge base", which can facilitate collaboration between faculty and industry. The paper investigates the meaning of boundary objects. It is a conceptual paper with an empirical example. The empirical example is from a Danish (global) supplier engaged in a development project with technical aid (tools) in mounting and assembling gypsum walls. The example demonstrates how the use of boundary objects help the supplier to gain an understanding of different professional practices and aid the transformation to utilise smarter tools. The concept of boundary objects enables an understanding of the epistemological difference inherent in the process of collaboration and research between the university and the wider construction industry. Boundary objects can be used to improve present technical understanding and further its implementation, which is a valuable function for applied research institutions depending on collaboration from a broad range of stakeholder groups. A three-step phase model is suggested for the use of boundary objects to develop and improve present and new practices and technologies.

Keywords: Applied research, automation, boundary objects, collaboration, knowledge

INTRODUCTION

The research in this paper is about applied research and collaboration with industry facilitated by a university of applied research. Vocational university colleges offer educational programmes at bachelor level and lower as well as continuing development programmes for professionals. In the Danish educational sector, the emphasis is on the connection between research, education and industry, complying with methods and standards from the "Frascati Manual 2015" (OECD 2015). The educational activities are built upon a knowledge base about practice, which is created in collaboration with practice.

The Danish Accreditation Council secures high quality and relevance in this type of higher education programme. The council will only accredit an educational programme if it lives up to certain quality criteria. One of these relates to the knowledge base of the education. The educational institution must have *"a practice which ensures that education and teaching is constantly based upon a knowledge base…[the] knowledge base includes the institution's strategic and practical work*

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which must ensure that relevant end updated knowledge forms the basis for the programs and that this knowledge is part of the ongoing teaching" (The Danish Accreditation Council 2019). Accordingly, the knowledge base is characterised as being close to professional practice, so the teaching becomes based on the latest knowledge created in close interaction with the industry, research environments and the labour market that the programmes target. This means that the continued development of the knowledge base must consider different practices.

The paper investigates how this knowledge base can be developed through collaborative arrangements that are empathetic to each community's characteristics, and how it becomes possible to produce high-quality scholarship for the researcher as well as actionable knowledge for the industry (Sexton and Lu 2009). The initial idea was that the knowledge base consists of boundary objects between the Applied Research University and practice/industry. However, during scrutiny of the knowledge base it became clear that although the knowledge base had many different representations, none of these where used by practice to translate their knowledge to the institutions. After some consideration the paper will instead deal with how different boundary object and the understanding of boundary objects can support the work with developing the knowledge base as a space for knowledge sharing and/or innovation in collaborative projects.

The work presented puts emphasis on new technology and practitioners from an industry working with digitalisation and automation in construction. Technologies are complex artefacts which on the one hand are constituted of multiple, interrelated physical and virtual materialities and on the other hand are inherently tied to social practices. In that context, artefacts do not have stable boundaries that one can point to and rely on. They develop through their continued use, organisation and placement. This view treats design and technology less as a stable outcome, and more as a continually emergent phenomenon.

By using the concept of boundary objects, this paper sheds light on epistemological differences among disparate parties. Boundary objects can be seen as a 'tool' to create a shared syntax or language, which enables participants from different communities to represent their knowledge and communicate across boundaries about their concerns or questions about a practice or idea and transform their own knowledge into innovative solutions (Carlile 2002). A boundary object can establish a working relationship around a particular issue, idea or innovative practice about which communities of practice or knowledge are normally separated.

The paper pursues two research questions: - How can boundary objects mediate knowledge sharing between applied research universities and industry practices? - What other objects or artefacts can mediate knowledge sharing between participants in the transformation of construction processes?

The paper is conceptual with an empirical example. In the following section, the paper examines the meaning of Boundary Objects, contributions and perspectives. The next section presents and analyses the paper's empirical example: A research and development project between an applied research institution and a global supply company. The purpose of the applied research project is automation and how to generate new materials, procedures and processes, with new technology (digital tools and robots), looking into a case on drywall installation. In the conclusion a three-step phase model is suggested for the use of boundary objects to develop and improve present and new practices and technologies.

Theoretical Perspectives

Knowledge boundaries have been closely studied over the past decades. A boundary can be seen as a sociocultural difference leading to discontinuity in action or interaction. The more specialized a practice becomes, the more explicit the boundaries towards other practices become. Boundary objects are used by individuals to overcome these knowledge barriers. Boundary objects are entities that enhance the capacity of an idea, theory or practice, in order to translate across culturally defined boundaries - for example between communities of knowledge or practice. This concept thus has the potential to explain, predict, mediate, and facilitate collaboration about technology implementation (Fox 2011).

Four relatively stable objects (repositories, ideal types, coincident boundaries and standardized forms) have been introduced by Star and Griesemer (1989), who emphasizes that boundary objects are both plastic enough to adapt to local needs and the constraints of parties employing them, yet robust enough to maintain a common identity across sites (Star and Griesemer 1989, 393). The dynamics of boundary objects is threefold, explains Star (2010, 604): *"[1.] The object (remember, to read this as a set of work arrangements that are at once material and processual) resides between social worlds (or communities of practice) where it is ill structured, [2.] When necessary, the object is worked on by local groups who maintain its vaguer identity as a common object, while making it more specific, more tailored to local use within a social world, and therefore useful for work that is NOT interdisciplinary and [3.] Groups that are cooperating without consensus tack back-and-forth between both forms of the object."* Boundary objects are thus useful for the communities both due to their function which enable communication between practices but also in situations, where no communication across the boundary is necessary.

Objects are not born as boundary objects. They become boundary objects within situated practices, when*: 1) they establish a shared language with which individuals can represent their knowledge; 2) they provide concrete means for individuals to specify and learn about their differences; and 3) they facilitate a process whereby individuals can transform the knowledge being used* (Gherardi 2012 91). Boundary objects will therefore only become boundary objects when the communicating practices transform them into boundary objects.

As not all objects become boundary objects, objects have been under close scrutiny. Some objects can be artefacts. Whyte and Harty (2010) study collaboration in *"shifting ecologies of hybrid practice"* in the design and construction of a large European building project. They characterize the role of the artefacts as follows: *"Objects had a dual epistemic and boundary-spanning role, allowing participants in the project to maintain connections and legibility of objects, across different locations and ties, while allowing flexibility and partiality to enable the development of new ideas and innovation",* (Whyte and Harty 2012, 201). The artefacts were continuously iterated. Consequently, they were plastic enough to hold the information stable at the same time as they allowed it to be changed. The artefacts took a role as partisans when conflicts around their coordination emerged. For instance, conflicts and debates between expert groups arose requiring negotiation about the central or peripheral status of information given by the expert groups in the project. The production (or transformation of objects into boundary objects) of boundary objects (objects are developed, evolved and discarded) is an ongoing socio-material practice. (Whyte and Harty 2012, 205).

BIM challenges the basic conceptions of design collaborations argues Paavola and Miettinen (2018), who finds that Ewenstein and Whyte (2009, p.10) misses a concrete thing-like artefacts or objects, which are at the same time modifiable and editable, or concrete and dynamic. They call them (co-developed) intermediary objects, which refers to all kinds of artefacts in a design process (Table 1). The use of the artefacts can have a mediating function and help the process of double stimulation (Haapasaari and Kerosuo 2014). The process of double stimulation is a complex process of development, which opens for personal agency to be expressed through the use of external resources (Sannino 2015).

To wrap up the above theoretical perspectives on boundary objects, objects and artefacts, Paavola and Miettinen's (2018) table is presented below. They have added an "Intermediary object" to Ewenstein and Whyte's (2009, 10) understanding of evolving objects and made a distinction between 'boundary objects', 'epistemic objects', and 'technical objects' (Table 1).

Technical objects do not always function as boundary objects. They are defined by Ewenstein and Whyte (2009) as able to "provide a frame for the objects of inquiry and involve the taken-for-granted equipment and tools." If practices view an object from this perspective, they will be concerned with what the tool can do (its specifications) rather than using the objects to translate meaning across boundaries.

Table 1: A comparison of characteristics of concepts 'boundary object', 'epistemic object' 'technical object' and '(co-developed) intermediary object'; the first three adapted from Ewenstein and Whyte, 2009, 10. (Paavola and Miettinen, 2018)

	Boundary object	Epistemic object	Technical object	(Co-developed) Intermediary object
Nature of the object	Concrete (e.g. a timeline of a project)	Abstract (e.g. a working hypothesis of a research project)	Concrete (e.g. an equipment used in a project)	Concrete, and reworkable (e.g. a versioned BIM-model)
Role over time	(Relatively) stable	In flux	Static	Modifiable and versioned
Function in activity	Allow interoperability and communication	Generates new open questions and issues for going further in the research	A means or an instrument for accomplishing something	Gives tangible intermediate means for working towards an end result

The following example presents a project about automation in the construction industry. Table 1 has become the paper's conceptual understanding and tool for questioning (knowledge), facilitation (mediation) and analysis. This helps to find and analyse boundary objects and share a knowledge base about automation within build environments and construction processes.

Empirical Example: Project on Automation

This example is from a research project on 'Automation and Robots in Construction'. The project is initiated and funded by a global supplier of construction materials and University College Northern Denmark (UCN). The example is based on several

meetings and interviews between two researchers from UCN and three employees from the supply company's R&D department in Scandinavia. Through interviews with these employees and access to their empirical materials and data (reports and presentations, as well as videos and transcribed interviews made by an Industrial Designer), researchers from UCN were able to study the value chain as well as mapping the global supplier's internal development process in retrospect. The supplier's investigations of the mounting and assembly process performed by practices on site is based on an inherent assumption that the mounting and assembly of gypsum walls includes challenges related to automation (technical aids).

The industrial designer's work consisted of two methods: Participant observations in the field and interviews with employees of the gypsum installers, with the developer of the technical aid (product development consultancy company), and with internal employees of the supplier.

The drywall installation is part of a construction contract of a huge new extension building to a large hospital in Denmark. The contract comprises several thousand square meters of plaster walls and ceilings. The supplier delivers a wide variety of plaster systems, i.e. different products composed in different ways depending on the use, such as x-ray rooms, bedrooms, depots, etc. The products come from different production factories across Europe and are not necessarily packaged in the same way.

The installation of gypsum walls involves many challenges and disturbances for the craftsmen. Including getting an understanding of where the many systems/products must be installed, finding space enough for materials, as well as room to manoeuvre around with the technical aids (a tool for lifting plasterboards and a "vehicle" to transport the plasterboards). Despite the use of technical aids, the gypsum board installation process involves manual handling of boards. An example is working in limited space with technical aids or when working in height, where boards or pieces of boards have to be carried and lifted into the right position on a scaffold by hand.

FINDINGS AND DISCUSSION

In this case, the participants' boundaries are defined as sociocultural differences that give rise to discontinuities in interaction and action. The case looks at three different groups of participants that encounter discontinuities in their action and interactions around a gypsum board installation process on the construction site. The experiences of these participants illustrate the ambiguity of boundaries (Akkerman and Bakker 2011, 133).

Materials and Process - Different Meanings as Boundary Objects

In the first and second example, the paper looks at the craftsmen's challenges and disturbances with the drywall installation process and the materials. They experience too many systems/products and a vehicle for moving things around which is difficult to use. This analysis is based on interviews with the Industrial Designer and transcribed interviews between her and the contract manager and a drywall installation craftsman from the company contracted to do the work.

In the first example, the participants created a mental model of different types of gypsum boards during the project. The model was not concrete, yet still stable enough for the individual craftsmen to have a kind of understanding of such a model. This became a boundary object operating at a pragmatic knowledge barrier as it "depicts or demonstrate current or possible form, fit, and function of the differences and dependencies identified at the boundary" (Carlile 2002). All three practices discussed

the boundary object from their practices. The contract manager is concerned with the logistics of the different types of boards and wishes to minimise the variety of materials on site; the drywall installer is worried about the heavy lifts of the boards while the global supplier's perspective is the sale of plasterboards. The global supplier transforms her knowledge. She presumed that a high complexity of boards would exclude competing suppliers, but her knowledge is transformed into also considering the customer's (site manager) and the user's (drywall installer) practice.

In the second example, the practices transform the vehicle (considered a tool for moving boards) as a boundary object, as they are discussing it as a model rather than a 'taken for granted' tool. The contract manager is concerned with the logistics of storing and moving plasterboards on site while the drywall installers focus on the availability of the tool. The industrial designer (supplier) transforms her knowledge and sees the tool as a means to increase sales. Had the practices viewed the tool as a technical tool, the discussion would have focused on what the individual tool could do (or not do). In the same episode, the use of a technical tool (the drawings) is used as a mediating artefact to solve the problem of explaining how the drywall installers work. The tool (a camera) used to take the picture is being used as a technical piece of equipment. This action does not interact with the practices' knowledge base

Both examples show, despite a common interaction on the construction site, that the participants have different approaches in their view of challenges associated with the mounting gypsum walls. Carlile (2002, 444) describes this situation as "a semantic knowledge barrier" which recognises that even if a common syntax or language is present, communication and collaboration becomes difficult due to interpretations. In this situation, the technical objects, such as materials, work processes and the vehicle tool, cannot be designed as boundary objects, since their social meanings have not been transformed to a common importance among the participants. In this case, the objects have negative meanings for a community of practice, with consequences for the transformation of knowledge within that community (Fox 2011, 81) and can be considered as inhibitory in promoting the further development of processes and materials.

Development of a Technical Aid - the Technology as a Boundary Object

The third example analyses the technical aid for lifting plasterboards. The paper employs knowledge from interviews from the industrial designer, and her observations of craftsmen's practices, processes, collaboration and artefacts, which she has documented on video.

The analysis focuses on the social meanings related to the object (the technical aid for lifting plasterboards) performing a function as a boundary object in relation to knowledge transfer between different communities (Fox 2011, 80), in this case between the developer of the technical aid, the gypsum installer and the supplier. Focus was to discover whether a technical object (the technical aid for lifting plasterboards) can be transformed into a boundary object which can transfer knowledge between different communities, in this case between the developer of the technical aid, the drywall installer and the supplier.

The paper found that the prototype technical aid version 1 was not used on site but had its place in the corner, where it is obstructed movement on site. At the request of the supplier, a new development process began as an experiment. The process was organised so it would become possible to understand and interact with the existing technical aid version 1. Subsequently, the development process became an interactive

development process where the developer was alternating between developing his technical aid at the workshop and then testing it in practice in interaction with the gypsum installer and the supplier, and then returning to his workshop to improve and optimize the aid.

By moving a part of the development process to the construction site, the boundary object was established. This is 'a pragmatic approach' which refers to transforming a knowledge process from altering current knowledge to creating new knowledge. The participants are validating the knowledge within each function and collectively across functions at the prototype (Carlile 2002, 445) - the technical aid version 1. For instance, in a situation on the construction site, the developer, the drywall installers and the supplier are discussing the working process while they are testing the technical aid. During the conversation between them, the drywall installers point at the transverse arm which holds the plasterboard and say; "Look, it's more stable than the previous one. It makes the plasterboard much easier to mount". This example shows that by providing situations where the participants can communicate their questions and ideas across boundaries, the participants allow their different knowledge communities to transform their knowledge in the light of the innovation or idea (Carlile 2002, 452). As the process moves through development, the technical aid becomes a boundary object as a result of negotiations as a part of the learning-by-doing process. It is the start of a change in the participants' common approach, reflecting the new knowledge and practices used to produce them.

Concluding Reflections

Research institutions need to consider new ways to mediate knowledge sharing between applied research universities and industry practices/practitioners. The use of boundary objects has been demonstrated as useful for overcoming knowledge barriers between practices. The purpose of this paper is to establish and enable knowledge sharing and growth between educational and applied research and industry practice and innovation, which are two very different practices with different perspectives.

A socio-technically informed vocabulary using terms like: 'social-technical systems', 'sociomaterial designer', 'user participation', 'user-driven design', 'robotics', 'technical aid', 'automation' and 'reflective practitioner' can aid this collaboration. We have found concepts that have the capacity to be transformed into boundary objects.

The case discussed in the paper focus on a technical tool as a boundary object. By the nature of the case, the facilitative boundary object became a user-driven design and a technical aid. These boundary objects were on the project level, but in the concrete case "Drywall installation - a product development process" we have focused on the "technical aid", a technical tool that makes it possible to share knowledge. A technical tool can, therefore, be used as a boundary object by discussing it as a model rather than a piece of equipment. This allows for a stable object, which can overcome the barrier between practices, so it becomes possible to represent, learn and transform knowledge bases via the object. This is a starting point for discussions between different practices in co-production projects.

The understanding of objects and the use of boundary objects is useful for overcoming knowledge barriers between practices. Different types of boundary objects exist, some of them can be of a technical nature. However, it is the participants' ability to consider the technical tool, not as a technical object but as a boundary object, which allows the practices to jointly transform their knowledge.

In the work on this paper, it has become clear that when applied research universities works on a common knowledge base with companies from practice, it can be thought of as three entangled phases where boundary objects can advantageously be used:

Phase 1: "Explore practice" - companies and institutions collaborating together to gain an understanding of practice. The characteristics of different issues can thus be determined. Data and material should be gathered through documents, interviews, observations, meetings, workshops etc.

Phase 2:" Research practice" (epistemic processes) - The companies and institutions can together and individually research with the possible theoretical and technological perspectives and will thus discover issues for further research. The academic theoretical perspective will challenge the company in these development projects and its understanding of technology. The researchers can develop epistemic objects based on data collection. The research knowledge will then be communicated to the industry at large.

Phase 3:" Develop practice" - The companies and institutions can appreciate the new applications of technology and organizational forms. Intermediary objects can be used to further improve co-created processes with the emphasis on interorganizational collaboration.

In further work, the researcher should aid the participants to create these boundary objects, so the transformation of knowledge can take place. This will also allow the researcher to gain knowledge of the involved practices, beliefs, values and significances. New ideas or innovations introduced by the researcher in co-productions will then be easier to implement. In this way, boundary objects become key in a joint-practice research project between different practices, also when it is between the research community and industry.

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