# *Epistemological differences and new technology in construction*

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# EPISTEMOLOGICAL DIFFERENCES AND NEW TECHNOLOGY IN CONSTRUCTION

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New technology within the construction industry originates from appeals to replicate the efficiencies seen in other sectors such as automation and manufacturing and construction firms are increasingly engaging in collaborative research and development (R&D) projects with sector specialists. These R&D projects create new communities of practice with a shared collection of knowledge, experience, and problem-solving approaches representing the disparate expertise of each member contributing to the development of new and innovative technological solutions. However, fundamental epistemological differences between the collaborating firms can hinder this process. Shared knowledge and experience to develop ideas is not easily communicated across a project team within which each member possesses a differing approach to understanding the common problem. This paper presents early research engagement in an R&D project investigating the potential of utilising Flexible Robotic Assembly Modules in the Built Environment (FRAMBE). Challenges observed to date during the process of developing FRAMBE as a technological solution are described. This paper aims to exemplify communication issues within cross-sector R&D projects to argue that boundary objects offer a means to consider the epistemological differences within communities of practice, establish a common understanding of the problem, and therefore ways in which to resolve issues surrounding technology development.

Keywords: robotics, technology development, epistemological differences

## INTRODUCTION

Cross-sector collaboration is seen as an important contributor to the increase in rate and efficacy of technology development within the construction industry (Fairclough 2002). Organisations are increasingly engaging in R&D projects that explore and test new methods of construction using concepts widely used in the manufacturing and automation industries - for example, robotics and prefabrication. But more specifically to this study, Flexible Robotic Assembly Modules in the Built Environment (FRAMBE).

These R&D projects bring practitioners from disparate fields of expertise - defined by the project objectives - together within a group to develop a solution to a problem. Problem-solving in this context necessarily requires the communication of knowledge and experience but in contrast to R&D projects carried out within single-industries, R&D projects in developing fields involving cross-sector collaboration - in this instance robotics in construction - 'much of the knowledge is yet to be codified' (Cardinal *et al*., 2001). Project members draw on knowledge, experience, and problem-solving approaches specific to their field in order to engage in an iterative 'learning-by-doing'

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process however, this is particularly difficult the greater the epistemological distant there is between collaborating participants.

Using the concept of boundary objects this paper begins to unpack the epistemological differences among disparate firms within a construction R&D project at the early stages of the problem-solving process. It is argued that epistemological differences can be better understood - particularly in an early stage R&D project - by placing more focus on the materiality of artefacts mobilised within group interactions. The production and transformation of boundary objects are suggested as a useful method to examine the epistemological differences within a cross-sector R&D.

This paper is structured as follows: firstly, the concepts of communities of practice and boundary objects are used to discuss the ways in which they can be used to frame knowledge development within cross-sector R&D projects; secondly, using these concepts the case study project is described, introducing the situated activities of each community and illustrating the localised contexts of their knowledge, experience and practice; finally, the utility of focussing future research activities on the examination of boundary objects in the development with R&D to support the process of technology development in the construction industry is discussed.

## KNOWLEDGE PRODUCTION ACROSS COMMUNITIES

A community of practice is a group of individuals 'who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis' (Wenger 1998). Within this context practice is defined as the work done by the group, and as a social learning theory communities of practice focusses on the way in which individuals 'establish themselves and function as a group by engaging in practices that are unique to or characteristic of that group.' (Cook and Brown 1999). Each member has knowledge derived from theories, rules and concepts that constitute the epistemology of the community of practice in which they are situated. The focus of learning is placed on how the group interacts and the way in which the tacit body of knowledge held by the group is exchanged to support, enrich and direct practice. Within a community of practice meaning and consensus of understanding is negotiated through participation and engagement with practice that is fundamentally social in nature.

However, this implies interconnectedness between individual knowledge and group knowledge to interpret meaning. Yet in some cases the epistemological differences within a group are too broad to be considered as a single community of practice - Wenger (1998) describes these configurations as 'constellations of practice' - and lack the connectedness between individual knowledge and group knowledge. Knowledge is 'localized, embedded and invested' in each community of practice and the greater the distant each community has from another makes the task of working 'across' practice boundaries and accommodating knowledge created in another more difficult (Carlile 2002).

In this instance, the concepts of reification and boundary objects are significant in bridging these epistemic boundaries. Wenger defines reification as "the process of giving form to our experiences by producing objects that congeal this experience into 'thingness'" - understanding is given form which then becomes the focus for the negotiation of meaning. These objects represent the tacit knowledge inherent within the group - the abstractions of epistemological perspectives - that the group interacts with.

Cook and Brown (1999) conceptualise the interaction between knowledge and ways of using knowledge ('knowing' as practice) as a 'generative dance' whereby knowledge is not simply transacted. Knowledge is acquired, reshaped by existing knowledge and practice to produce new knowledge and new practice, and it is through this 'generative dance' that epistemologies are 'bridged'. This interplay between knowledge and ways of using knowledge in the process of learning-by-doing brings to light the ways in which each community carries out their work. Reification within this context produces material artefacts that are a representation of the generative dance taking place and reflect the practices used to develop them. Both Cook and Brown (1999) and Wenger (1998) position these objects as products of human agency and secondary to the understanding of the social. However, a number of scholars provide an alternative to this perspective placing more emphasis on the role objects have to play in the bridging of epistemologies (Whyte and Harty 2012; Leonardi and Barley 2010).

In this way, the products of reification in the context of a cross-sector R&D project become boundary objects with attributed materiality. As the project moves through development these boundary objects - going through various 'generative dances', negotiations, and reifications as part of the learning-by-doing process - change in their content reflecting the new knowledge and practices used to produce them.

However, R&D projects have development programmes that define the types of activities that need to be completed and who are required to complete them. The types of knowledge boundaries faced will vary as will the type of objects that are useful to intersect them and transform knowledge (Carlile, 2002). Star and Griesemer (1989) define boundary objects as "both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites" maintaining that the methods used to generate boundary objects should "maximise the autonomy and communication between worlds". Based on their empirical analysis Star and Griesemer (1989) developed four types of boundary objects mobilised as analytical categories: **Repositories** - ordered piles of objects indexed in a standardised fashion provide a common reference point for shared definitions and values for problem solving. **Ideal type** - diagrams, atlases or other descriptions that are abstracted from all domains but are adaptable to a local site because of their vagueness serving as a 'good enough' roadmap for all parties. **Co-incident boundaries** - common objects which have the same boundaries but different internal contents that can be used across different sites demonstrating the current differences or possible resolution of different goals. **Standardised forms** - boundary objects devised as methods of common communication across dispersed work groups in the form of structured standardised indexes that convey unchanging information.

Carlile (2002) discusses the effectiveness of each boundary object category at different types of knowledge boundaries (syntactic, semantic, pragmatic) to characterise the most effective type of boundary object in new product development. Recognising that knowledge is 'localised, embedded, and invested' in practice that needs to be transformed - to create new knowledge, old knowledge has to change (Teece *et al*., 1997) - Carlile found that objects, models, and maps (co-incident boundaries and ideal type combined) were the most useful in dealing with pragmatic boundaries. But more significantly, boundary objects "have a portfolio effect; repositories and standardised forms support the use of objects, models, and maps as well as support processes to manage knowledge at a pragmatic knowledge boundary".

The context of new product development and R&D are similar - cross-cultural boundaries, different ways of presenting and interpreting meaning etc. - but more specifically in developing industries the production of repositories and 'codified knowledge' are somewhat necessary in establishing them as developed.

However, a key consideration in the development of knowledge and practice is the effect of power (Oswick and Robertson 2009) - communities of practice are defined as self-organising, however one member of the group make take precedence over another dominating the type of knowledge deemed useful and legitimating the ways in which that knowledge is used. As is illustrated in the vignette described in the case section this has had an influencing effect on the type and effectiveness of boundary objects in use.

# METHOD

The University of Reading are engaged within the consortium in a research capacity to examine the skills needs and cultural change required to facilitate the implementation of FRAMBE at an industrial scale. This is an ongoing project in the early research stages and this paper presents an emerging case study that focuses on a preliminary examination of the problems associated with trying to communicate tacit knowledge that resides in practice across epistemologically distinct boundaries.

**Data collection techniques**

Empirical work has involved observations of early factory visits and consortium meetings, and formal and informal discussions with Skanska's project manager and industrialisation manager. Each of the data collection techniques are discussed in more detail below:

- Observations

Field notes were used as a record of key events that happened throughout researcher engagement in consortium activities; including factory visits and consortium meetings. The primary purpose of these visits was to form an initial understanding and conceptualisation of the problem bringing to light the difficulty of these types of collaboration. Field notes were not standardised and not used explicitly for data analysis but used as points of discussion within informal interviews with the consortium members to corroborate researcher understanding of the problems faced by the R&D team.

- Consortium technical meeting - process map meeting

The R&D team have technical meetings whereby they discuss specific work packages related to the delivery of FRAMBE. On this occasion, the focus of the meeting was to discuss the development of process maps to support the design and development of the pilot project. The researcher attended this meeting as a non-participant observer with the aim of capturing how the R&D team interact and exchange knowledge with one another to meet FRAMBE deliverables. The meeting was videotaped and preliminary observations were made - framed through the literature - to identify instances of differing conceptualisations of the problem discussed and the way in which they were overcome.

- Informal interviews/discussions

An informal interview was held with Skanska's project manager and industrialisation manager to discuss the current progress of FRAMBE. Workflow diagrams, created by the Lean Consultancy firm (Figures 1 and 2) but based on consortium activities, were used as a visual point of reference to talk about project progression and future consortium activities. Within the context of this paper, these workflows are taken to represent emerging boundary objects that bridge the epistemological differences between consortium members and form early codified knowledge from which to collectively problem-solve. Talking around these workflows with Skanska's project manager and industrialisation manager focussed discussion on how the project had got to the point it was currently at and why decisions were made as they were. This interview was recorded but at the time of writing, was not fully transcribed.

## THE CASE: FRAMBE

The Flexible Robotic Assembly Modules in the Built Environment (FRAMBE) concept is a scalable, automated and modularised Flying Factory solution that will integrate advanced robotics to manufacture a wide range of building components that are appropriate to the needs of a specific project. Using robotics in a Flying Factory setting to automate a range of construction processes brings a broad set of benefits to both the project and the operatives involved, such as improvements to health and safety and productivity by using machines to carry out physically demanding and repetitive tasks in dangerous environments. This task-general approach to robot design also has a number of potential benefits including: reduced threshold and personnel training costs; provides a better economic justification by distributing initial capital costs across multiple projects; and also provides the opportunity to lease the robotic system.

The FRAMBE pilot project forms the early stages of a larger innovation project aiming to expand the concept of mobile ‘flying’ factories (Young *et al*., 2015) to include robotic automation. Prior to industrialisation Skanska are testing the feasibility of introducing robots and investigating the process change and technological requirements through a pilot project.

The consortium, led by Skanska UK, consists of: a major robotics manufacturer designing and developing the robotics technology; a lean consultancy firm mapping existing workflow processes and the higher level feasibility processes that a company will need to go through to identify tasks for automation; and a CAD/BIM consultancy firm developing a means to extract programmable data from 3D models for robot task execution.

Each of these project team members represents a distinct and localised context of knowledge, experience and practice. The epistemological differences between Skanska, the robotics manufacturer, and Skanska fabrications begin to emerge in the following vignette that describes the development of boundary objects necessary for the practical aspects of developing the pilot project.

### Selecting an appropriate pilot project

In the early stages of the R&D project, the team conducted a number of workshops to identify a suitable project to focus design and development activities. A simulation of the Flying Factory concept was used to stimulate discussion of various options to focus the pilot project on.

However, one of the primary goals of the FRAMBE project is to be able to export the required data from 3D models to automate the process of creating a tool path that the robot understands. In order to design a tool path for the robot to pick up a component, angle it against another, and begin to carry out a defined function it needs to have physical dimensions, diameters, vertices, edges and surfaces to trace around.

In light of this prerequisite the consortium have chosen to focus the pilot project research activities on the introduction of welding robots at Skanska's factory in Slough UK to improve the efficiency of manufacturing pipe modules for plant/boiler rooms. The purpose of selecting this case is that the prefabrication division of Skanska UK already have relatively consistent and well-defined workflows in place. These provide an ideal scenario within which to test and prove the information management solutions developed by the consortium that are necessary for the introduction of robotics into one of the factory's welding bays.

**Emerging epistemological differences - defining the problem**

Whilst the pilot project had been selected, further problems emerged that exposed competing epistemologies as to the scope of the problem and what kind of solutions should be investigated.

For example, in a technical meeting - that took place at the robotic company's head office - where the team first discussed the viability of focussing the pilot project on the manufacture of pipe modules, various automatable tasks were identified: painting, welding, manipulation, assembly etc. These were discussed by both Skanska and the Lean Consultancy representatives in terms of the wider process change requirements necessary to implement them, posing the question *"Can we automate all these things?"* - signifying their approach to the problem was coming from an industrialisation perspective. The Robotics representative responded to this question with a categorical *"the answer is yes to all of those things"* going on to imply that the wider considerations of how to implement robotics in construction was not the focus of inquiry at this juncture of the project, saying

> …let's get the automation in there first and then the construction industry is going to have to look at how it optimises its materials to take advantage of that.

Recognising the difficulty the team were having in deciding what to automate and how this could potentially stall the progress of FRAMBE the robotics project manager went on to describe the process by which they normally design and develop robotic systems with manufacturing based clients:

> …what our customers would normally do is to give our engineers or our applications guys these drawings and basically say 'go do' and the applications guys will look at it and say yeah do it that way. [Robotics Project Manager]

In effect presenting an abstraction of the process of robotic system design to which Skanska and the Lean Consultancy firm could focus the inquiry that followed. The problem was reframed toward the process of designing and developing a robotic system - that of requiring well-defined processes - and project activities turned towards capturing the factory's existing information and welding bay workflow processes. The development of these and the project decisions this resulted in are described in the following section.

**Existing factory processes - an 'ideal type' boundary object**

Developed from discussions between the factory manager and members from each consortium partner, Figure 1 shows the current information management processes of the factory. This provided a 'good enough' scope of the context for Skanska to understand how to approach the industrialisation aspects of FRAMBE and the robotics and CAD consultants to understand how to begin the design of the robotics system.

Currently the factory receives client drawings and 3D models that are insufficient to use as-is for the way that the factory manufactures - components may be in the wrong place, incorrectly specified, or misaligned. The factory then redrafts these 3D models solely for the purpose of rationalising the original into the design for manufacture standard the factory processes are attuned to - the models do not contain any useful data within them for the CAD consultants and robotic designers to easily proceed with the design of the robotic system. After the model has been rationalised the factory engineers draft cut-sheets independently from the 3D model handwriting orientation, vector, diameter and wall thickness information for the welder's to use on the shop floor. The reason for this two-stage information production process is primarily related to well-established practices on the shop floor that centre on the use of cut-sheets - as illustrated in the Welding Bay Process shown in Figure 1.

Through the production of this workflow diagram - as a boundary object to articulate the problem - decisions were made regarding the approach to both the development of the pilot project and the industrialisation of FRAMBE. Firstly, that the requisite data contained within the cut sheets would have to be manually translated into 3D objects by the CAD consultants to meet the primary objective of BIM integration.

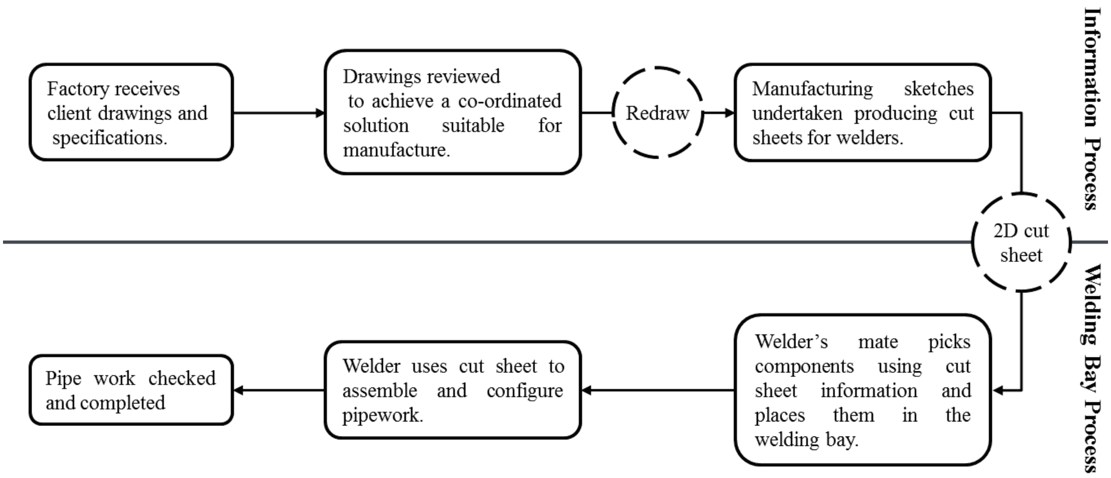


*Figure 1: Skanksa fabrications factory processes*

Secondly, that in order to industrialise FRAMBE the consortium need to develop better defined processes that can be used to bridge the knowledge boundaries between the FRAMBE team and Skanska fabrications, as the Lean Consultant alludes to:

> …once FRAMBE has proven the concept they can then go back to Skanska fabrications and say look this is how you should be producing drawings if we want to industrialise it as a method of construction

Furthermore, in understanding the existing process by which the factory operates, the team were able to circumnavigate issues relating to the practices of factory workers bringing coherency to the problem and focussing efforts on the technical activities that could be completed to move the project forward. In the following comment, this boundary is acknowledged by the FRAMBE project manager whilst also alluding to the ineffectiveness of the cut sheets as an object to bridge the boundaries between all the practices within the R&D group. Currently, the cut sheets are only useful as a boundary object between the CAD and robotics company to develop the technical aspects of FRAMBE:

> …we need to change knowledge and learning I suppose and the way things are done in order to make an automated robotics solution work. We can create something for the pilot to get by in which we need and at that point we need somebody to say we are going to change our procedures.

Figure 2 represents the synthesis of these decisions and shows how the robotic system fits into the existing factory context, in some ways forming an early example of codified knowledge within the R&D team. The development and transformation of the workflow - that centred around the cut sheets - represents an example of a 'generative dance' that occurred within the R&D team to move the project from a vague concept of FRAMBE through to a pragmatic set of solutions as to how to actually go about delivering the pilot project within Skanska Fabrications.

## DISCUSSION AND CONCLUSIONS

Using the concepts of communities of practice and boundary objects this paper has begun to unpack the epistemological difference inherent in the process of knowledge development within a cross-sector R&D project. The project investigates the potential of incorporating robotics into a 'flying factory' situation as a method of construction to reduce waste, transport costs, improve productivity, and to bring improvements to the health and safety of operatives carrying out dangerous and repetitive work.

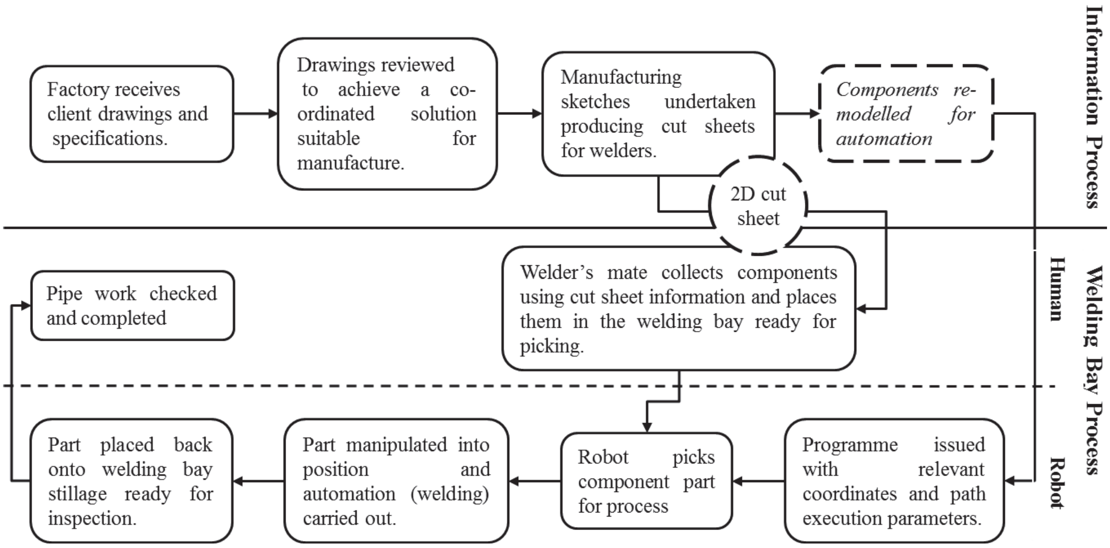


*Figure 2: Pilot project factory processes*

However, this requires cross-sector collaboration between communities of practice that necessarily bring challenges to the design, development and ultimately deployment of FRAMBE. Each community - Skanska, the robotics company, lean consultancy, CAD consultancy - possess specific knowledge and ways of using knowledge that when brought together in a collective problem-solving scenario meet barriers and difficulties to the exchange of knowledge within the community.

The concepts of communities of practice and boundary objects were used within this paper to frame this problem-solving scenario and begin to unpack the epistemological differences between each community. However, whilst useful in framing the work contexts of each community we argue that the use of communities of practice and the conception of boundary objects that it defines is insufficient in explaining these differences.

Groups of different communities often collaborate but it is our contention that the organic production of boundary objects implied by Wenger (1998) and Cook and Brown (1999) provides inadequate understanding of how groups interact. In the previous section we described how the issue of producing programmable data was addressed - the team identified a potential object to develop into a boundary object rather than going through an iterative 'learning-by-doing' process - illustrating both the significance of material artefacts in shaping knowledge exchange but also the epistemological challenges of creating effective boundary objects.

Epistemological difference causes imperfect knowledge exchange especially if one community presides with epistemological dominance over another. In the case of FRAMBE, core competencies required to produce a robotic system in construction resided with the robotics company and dictated the type of knowledge required. In the acquisition of this new knowledge, the processes of Skanska, the lean consultants, and the CAD consultants were directed towards the identification of an object that could usefully serve as a boundary object. Whilst this dominance over legitimate and illegitimate knowledge may also have been a result of the time constraints associated with a R&D project it still serves to illustrate how epistemological differences can be identify using the boundary objects - whether effective or ineffective.

For robotics to become a mainstream construction method that continues to improve and develop - rather than a one-off proof of concept - the relevant parties involved in the process of design and development need to be able to understand the problem. By capturing the process of knowledge development - focussing on boundary objects and their production - the epistemological differences between the FRAMBE team may be further unpacked to focus efforts on activities that produce effective boundary objects that bridge these.

As such, future research activities will be directed toward expanding on the vignette described within this paper, examining in further detail project participants' accounts of boundary object creation within FRAMBE. In this paper we have focussed on the creation of 'ideal type' objects - in the form of workflows and how these were used to solve the problem of how to approach the primary objective of BIM integration - but as the FRAMBE project progresses the transformation of knowledge into the different categories of boundary objects will be expanded on and documented. In doing so we can begin to highlight those that were effective as epistemological bridges, those that exposed epistemological differences, and how to use this deeper understanding of the knowledge development process of a cross-sector R&D team in the wider construction industry.

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