INTERFIRM PROBLEM REPRESENTATION: DEVELOPING SHARED UNDERSTANDING WITHIN INTER-ORGANIZATIONAL NETWORKS

Abstract

Actors in business networks often struggle to integrate their resources and bridge knowledge boundaries, which makes shared understanding difficult to establish and sustain. We develop the concept of interfirm problem representation (IFPR) to illustrate how networks of multidisciplinary teams create shared understanding and establish collective decisions in their day-to-day negotiations and joint problem-solving. IFPR is defined as an arrangement of localized artefacts or boundary objects that are jointly created by team members, and continuously adapted to facilitate mutual agreement and shared understanding in their daily conversations. We draw evidence from the UK construction industry to illustrate how team members from different organizations and knowledge domains manage their resource dependencies by creating IFPR as a common frame of reference to guide the implementation of their shared goals. Our data collection activities involve the observation of 3 different construction project teams over a period of 11 months. During the period, a total of 43 project team meetings were attended and 32 face-to-face interviews conducted across the 3 project teams. Findings from this study advance the discussion on subjective cognition and inter-subjective representations in networks by illustrating how diverse cognitive views and knowledge boundaries of network actors are synergized through an objectified system of representation. This enables us to offer important theoretical implications related to prior research on knowledge sharing and shared cognition. Our discussion highlights how actors, engaging in a shared activity that is extended over a period of time, collectively navigate different social contingencies while utilizing IFPR as a socio-historical artefact. IFPR enables network actors to critically review past mistakes to achieve improved collaborative outcomes.

Keywords: Boundary Spanning, boundary objects, networks, problem representation, sense-making

1. Introduction

Researchers have invested considerable research effort in developing an understanding of cognition and sensemaking in inter- and intra-organisational business networks (Corsaro and Snehota, 2012; Mattsson, Corsaro and Ramos, 2015). While this work is key to understanding relationship management and interactions between interdependent actors (Hauser, Tellis and Griffin, 2006), its conceptual evolution has been mainly focused on individual subjective cognition (e.g. a manager's network insights and network pictures: Mouzas, Henneberg and Naudé, 2008). Consequently, research attention has mainly been concentrated on individuals and dyads, with limited attention to the overall collective perspectives of the network (Araujo and Easton, 2012; Corsaro and Snehota, 2012; Mouzas and Henneberg, 2015). Put differently, research effort has been directed towards the psychological (or *soft)* element of interfirm interactions (e.g. how perception shapes the actions and commitment of actors towards shared goals; cf. Lenney and Easton, 2009; Corsaro and Snehota, 2012). The use of more *concrete* social artefacts (i.e., boundary objects and representations) and their impact on team interactions remains underexplored.

The paucity of studies in this area demands research attention, particularly because of the importance of social artefacts as templates for improving communication and coordinating actions (Carlile, 2002; Hauser, Tellis and Griffin, 2006) and as regulatory frameworks for generating common experiences between network actors (Araujo and Kjellberg, 2015). In addition, there is a scarcity of knowledge on how the socio-material space of interactions (i.e.

the entanglement of human interactions with non-human objects or organization artefacts) shapes network actors' understanding of their everyday work (Tyre and von Hippel, 1997; Carlile, 2002, 2004; Orlikowski, 2007). Scholars have highlighted the need to understand how network actors create shared understanding, and how individual perceptions are amalgamated into inter-cognitive representations to facilitate collective decision making (Mattsson, Corsaro and Ramos, 2015; Mouzas and Henneberg, 2015). Specifically, we respond to the suggestion that "… future research could move on from the study of subjective cognitive views (e.g. network pictures) to an investigation of objectified outcomes shared by other actors (e.g. the creation or change of boundary objects) in business relationships" (Mouzas and Henneberg, 2015:65).

Our study therefore contributes to the ongoing debate on the interplay between individual subjective cognition and inter-cognitive representations by introducing the concept of interfirm problem representation (IFPR) and illustrating the concept in the context of the work of inter-disciplinary project teams in the construction industry. IFPR provides a theoretical foundation for understanding how such teams collectively navigate difficult situations and coordinate each other's actions when there are unexpected changes affecting their joint activities and processes. The concept of IFPR addresses the call by Amabile and Pratt (2016) for a better understanding of feedback loops and the mechanisms by which subsequent iterations of the creative process change and develop. We propose IFPR as one possible way to investigate how boundary objects are created, arranged, modified, communicated, or even destroyed to facilitate joint problem-solving and shared understanding in business networks. The IFPR concept is empirically illustrated by examining the interplay between network actors and their social-material environment as they attempt to synchronize their different and, on several occasions, conflicting perspectives. With this conceptual development we contribute to the literature on change in business networks, as the creation of

IFPR is heavily characterized by managing and adjusting to unplanned contingencies that shape network relationships.

The paper is structured as follows. In the next section, we provide a more detailed discussion on the theoretical foundations of IFPR and present practical examples. We then explore data from three construction project teams to illustrate how network actors in business relationships create and change IFPR. We conclude the paper with a discussion of how IFPR provides a more nuanced explanation of the development of shared understanding in business networks. Specifically, we highlight how the material objects in the network environment mediate the interplay between individual and collective cognition in order to sustain a shared understanding of network activities and processes.

2. The concept of Interfirm problem representation (IFPR)

Fundamentally, IFPR has two conceptual origins. First, that of inter-cognitive representations based on the work of Mouzas and Henneberg (2015) and second the concept of problem representation based on the work of Simon (1991). *Inter-cognitive representations* are the organizational artefacts that inscribe shared understandings and function as a foundation for collective decision making. They guide interactions in business networks through establishing shared rules (Mouzas and Henneberg, 2015). As a unifying symbol that promotes self-learning and shared understanding between members of an organisation (Simon, 1991), we regard *problem representations* as (inter)organisational artefacts or heuristic systems upon which shared understandings develop (Okhuysen and Bechky, 2009; Mouzas and Henneberg, 2015). According to Simon, multiple cultural perspectives within an organization typically leads to multiple interpretations of roles which then complicates the establishment of a shared view of organizational goals or the resolution of problems (March, Sproull and Tamuz, 1991; Simon, 1991). Simon maintained that organisation members create a new set of representations and continuously change these representations to respond to problems they have not previously encountered (Simon, 1991, p. 132).

Both concepts rely on two assumptions that characterize how network actors establish and maintain a shared understanding across space and time. The first assumption is that rules, both tacit and explicit, dynamically shape and reconstitute micro-level interactions between network actors. Rules operate as higher-order representations that are contextualized and adapted into more localized boundary objects by social actors (i.e., individuals and organizations within the same network working together to achieve a shared goal) in different decision-making episodes. There are two types of rules: default rules and mandatory rules. *Default rules* (e.g., industry standards) are based on shared conventions or gentleman's agreement and are, therefore, non-legally binding. Examples in the construction industry of default rules are the industry standards (typically regarded as best practices), which may or may not be strictly adhered to by project teams. Some rules, on the other hand, are explicit and legally enforceable. Where these legally binding agreements are the result of dyadic interactions between business partners, they are termed *mandatory rules*. Where they are the accumulated effect of network interactions among multiple actors and affect all actors in a business network, and may be imposed upon them, they are termed *explicit regulations* (Mouzas and Henneberg, 2015). Explicit regulations in the construction industry (e.g., wiring regulations and safety regulations) are non-negotiable and must be strictly followed by project teams. Non-compliance could cause accidents beyond the boundary of the project teams and could potentially lead to serious legal and material consequences.

Mouzas and Henneberg imply that what shapes collective actions (and hence, cognition) is not the rule per se but how it is inter-subjectively perceived and interpreted. Thus, they did not regard rules as distinct mechanisms of change. We, however, argue that this assumption provides only a partial explanation for network processes as it overlooks different network contexts. In the construction industry explicit regulations are consequential and do not depend on the team's shared interpretations or understanding of them (Easton, 2010; Sayer, 2011). Instead, such rules themselves are used to facilitate a shared understanding, avoid ambiguity, and to coordinate the teams' interdependent activities (Kogut and Zander, 1996).

The second assumption is the need for feedback tools that capture and structure network actors' interactions and help align their different interests. We argue that IFPR is central to the structuring and aligning needed to accommodate the ephemeral nature of social agreements. IFPR provides temporal clarity in ongoing situations while also sensitizing the network actors to new social cues that have implications for their shared goals (Weick, 2011). Since the current study focuses on interfirm relationships, the problem of representation is not limited to cultural multiplicity alone because firms in business relationships are also influenced by diverse environmental and social conditions that transcend the boundary of any given firm (Carlile, 2002, 2004; Araujo and Kjellberg, 2015). Therefore, in interfirm relationships IFPR must also account for the diverse environmental and social-material objects of the interacting firms and must be continuously matched with the changes in the structure of the social environment (Todd and Gigerenzer, 2003; Orlikowski, 2007).

By integrating cues from human-to-human interaction with the heuristic resources in their environment (vis-à-vis shared representations and memories), social actors will make more sense of their world and reduce complexity in their social interactions (Wilson, 2004; O'Malley et al., 2009; Mouzas and Henneberg, 2015; Heylighen and Beigi, 2016). Moreover, because shared artefacts shape the mental representation of tasks between social actors, accommodating socio-material diversity between interacting firms through IFPR will facilitate complex problem solving and joint decision making (Tsoukas, 1996; Carlile, 2002, 2004; Orlikowski, 2007; Bardone and Secchi, 2009; Araujo and Easton, 2012).

By keeping the shared representation current and shared between actors, network teams can avoid misunderstandings and potential disruption to their workflow (Puranam, Raveendran and Knudsen, 2012; Kotha, George and Srikanth, 2013; Srikanth and Puranam, 2014). Shared representation motivates team members by offering a unified vision which supports the fulfilment of their collective goals (Sivasubramaniam, Liebowitz and Lackman, 2012). In the next section, we illustrate how interactive processes shape the execution of project activities through IFPR.

3. An empirical illustration of the concept of IFPR

To understand the evolving role of IFPR during everyday communications between network actors, three case studies were examined each consisting of a construction project design team. Each of these design teams were a network of actors (e.g., architect, electrical, mechanical, and civil engineers) from diverse knowledge domains and multiple companies that were temporally connected by shared activities and goals. Thus, they were embedded in an inter-organisational and cross-functional network, which we define as "a site of continuously evolving interactions performed by individuals on behalf of companies" (Halinen, Medlin and Törnroos, 2012, p. 217). We have chosen construction projects as our case context because such teams represent a business network where cross-boundary differences and challenges often impose unwanted tension on knowledge-sharing, shared understanding, and collaborative practices. In addition, construction project teams are particularly interesting in the formation of IFPR because the core activities of construction design involve the creation, arrangement, and coordination of boundary objects.

Case studies can be adopted not only as empirical data but also as illustrations of conceptual contributions to assist readers' understanding by helping them to see how the proposed concepts apply to practical settings (Siggelkow, 2007). We have adopted an abductive approach for our data analysis which enables the conceptual framework to develop simultaneously and interactively with empirical observations (Nenonen *et al.*, 2017, p. 1140). Hence, the role of the data is not only to illustrate but also to illuminate and extend our initial theoretical assumptions. See Table 1 for more details of the project teams.

Insert Table 1 here

Two main project milestones were covered during the observation of the project teams. The pre-contract stage (involving Case A) where the main design and specifications of the build are established, and the post-contract stage (Cases B and C) where the contractor has been appointed and construction work begins.

Insert Table 2 here

As shown in Table 2, there are different layers of complexities in the interaction processes and communication structure at the pre-contract and post-contract stages. Fundamentally, project teams tend to manage a more advanced form of knowledge boundaries at the later stages of the projects, which affect how they set-up their communication pathways, make decisions and achieve shared understanding. Therefore, to identify the nuances in the main project milestones and produce holistic insights regarding the effects of boundary objects in varying conditions and social situations of network actors, it becomes necessary to observe the pre-contract and post-contract stages. We have differentiated the pre-contract and post-contract stages in our discussion in order to highlight the temporal and dynamic nature of IFPR and its effects on the activities and change management processes of the projects over time. This allows the comparison of IFPR through the creation and use of boundary objects focused on two very different team activities.

First, that of pre-contract setting and agreeing goals, and second that of post-contract implementation of these goals (Peters, Pressey and Johnston, 2017). We were thus able to compare and contrast the pattern of events in pre- and post-contract team activities. More importantly, we were able to identify how the boundary objects that were created at one time period might shape project activities and processes at later phases in the project life cycle. Cases A and B were involved in the design and construction of buildings in the UK training and education sector. Case C involved the construction of a commercial building for a private property developer in the UK.

The data collection process takes place over a period of 11 months, and it involves face-to-face interviews, direct observation of team meetings, and project reports. Overall, we observed a total of forty-three meetings and conducted thirty-two face-to-face interviews across the three teams. The interviews started in the seventh month of observations after a sufficient knowledge of the teams' processes and technical languages had been acquired. The purpose of the interviews was to understand how each member of the teams perceived the design process. The outcome of the interviews was therefore instrumental in reflecting upon, clarifying, and analysing the data that were initially obtained during direct observation of meetings (Yin, 1994; Harrison and Easton, 1998; Araujo and Easton, 2012). Altogether, we compiled 646 pages of interview transcriptions, 201 pages of field notes from the observation of meetings, and more than one hundred pages of project reports. We stored all our data on NVivo12 to create a centralised database for a systematic coding process and data analysis.

Our coding and data analysis occurred simultaneously and involved two different stages. First, in line with recent research on boundary objects (e.g., Harrison et al., 2018), we explored our data through several rounds of intensive reading to obtain an in-depth background knowledge about the project and also gain familiarity with the core activities triggering interaction and collective decision making between the project partners. At the end of this process, we identified three main themes which form the foundation for our coding categories namely, creating and communicating boundary objects, changing, and arranging boundary objects, and destroying or discarding boundary objects. While being sensitive to new evidence from data, we have also interpreted the findings in the light of previous research with the aim of elaborating existing theories on boundary objects in networks (Mouzas and Henneberg, 2015).

Second, we systematically scrutinized the NVivo database by using search queries and keywords to identify raw data or relevant text passages that respondents associated with the three themes above (Ben-menahem *et al.*, 2016). The process enabled us to identify patterns and subthemes that were useful in explaining the role of boundary objects in network interaction processes. Relating to the use of boundary objects in establishing shared understanding between project partners, we identified two coding subthemes: information sharing, and communication protocol. Depending on the situation, each subtheme could correspond to any of the three main coding themes. As an example, the following texts from the Architect (Case C), which was coded under information sharing coding subtheme, corresponds with creating and communicating boundary objects. "*So, we assembled a set of documents [i.e., boundary objects], which is effectively taking the planning consent and developing it to the next stage of information. So, layering it with technical details which would give tendering contractors a clear understanding of what our design intent was*". Hence, linking the different text passages to the main coding themes offered key insights in developing a theoretical explanation and framework (see Figure 2) that demonstrate the centrality of IFPR in network interactions processes.

3.1. *Creating and communicating boundary objects*

3.1.1. Pre-contract stage (Case A)

The pre-contract stage culminates in specifying all the design needs and service requirements of the client. This development of the *client requirements documentation* is an example of IFPR as it utilizes various boundary objects such as building plans, office furniture layouts, floor plans, and mechanical and electrical services designs to inform the contractual obligations of the building contractor to the client. There were five different sub-teams (design team, project management team, client and cost-consultant team, user team, and stakeholder team) whose activities were influential in the creation and communication of these boundary objects. Each of the sub-teams had their own agenda, which created tension when making decisions. For example, the primary interest of the user team was to have a bespoke design that was customized to the specific needs of each user. Alternatively, the goal of the design team was to ensure compliance with regulations, to design a building that is functional and aesthetically pleasing, and to ensure that different design elements are properly aligned and well-coordinated. The project manager's goal was to liaise between all the different sub-teams in order to ensure that their *interests were aligned*. One contract manager explained why it is important for the design elements to align with the requirements of the users by saying:

> "… *it is pointless to build something that does not suit their [users] needs. It would be like shooting ourselves in the foot*" (Case A).

For this project, the design and building plans were based on a template from an existing building owned by the client. This indicated a shared history between some of the sub-team members and implies that boundary objects are not always created from a blank slate but are influenced by the *a priori knowledge* that exists between the project team actors. One immediate benefit of using this template was that it saved time and cost as well as facilitated communication between different sub-teams right from the start of the project. The lead electrical engineer on the project summed up how this influenced the design process:

> "*Yes, because you've got a good knowledge of what the architect is about, you've worked together in the past, you have a history of delivering projects together and you have a relationship with them. So, picking up the phone and speaking to them, contacting them, having their issues in terms of what we have with services and architecture and making sure the two are coordinated and would work. It makes that process a lot easier*". (Case A)

Another method of facilitating shared understanding was the use of explicit industry regulations in the form of building codes of practice (i.e., the top-down macro factors in Figure 2) that dictate and regulate features of any building design. However, this also posed a problem where (often frequent) changes in the design made to accommodate the client then necessitated a realignment of the design with regulatory requirements. For Case A, incompatible design elements remained unnoticed until the later stages of contract negotiation. Although they were able to resolve the technical queries amicably, it was noted that such errors could trigger a costly revision to building design. For example, one user vented his dissatisfaction with one specific change:

> "*… we had a layout that would work for us. I don't care what anybody else thinks. But you [design team] changed it to the layout that will not work. And that's the problem … the current layout could cost the [client] over a million pounds ... it is an issue we need to sort out*".

Thus the creation of boundary objects is not a linear but an iterative process involving both creation and modification through contestation between network actors (Carlile, 2002, 2004; Faraj and Xiao, 2006; Ben-menahem et al., 2016). This may then lead to confusion if requirements are constantly changing and there are gaps in communication which then require team members to revisit and change boundary objects. This indicates how organisational artefacts and boundary objects are at the heart of social interactions between network actors. Depending on the effectiveness of information flow and communication strategies between network actors, boundary objects may function as a tool for the collective rationalization of a joint task, and/or as an audit trail to establish consistent linkages between past, present, and future events. More importantly, through a process of *retrospective modification*, boundary objects can expose underlying weaknesses in the team's interrelation processes while also functioning as a heuristic tool for managing and potentially overcoming the knowledge boundaries between the team members (Ojansivu, Kettunen and Alajoutsijärvi, 2021).

3.1.2. **Post-contract stage (Case B and Case C)**

The post-contract stage involves the process of translating the agreed design into detailed and construction-ready technical drawings and implementing construction. We identified three main factors shaping this process. First, there were occasional ambiguities in the contractual agreement, as noted by the quantity surveyor (Case C):

> "*In terms of client-contractor conflict … we believe we've been clear and outlined what the changes were, but the client believed they had never been informed … the misunderstanding on ours and the client's side, which I guess, in some part is related to their inexperience*".

The relationship between the main contractor and the client is instrumental in how such disputes are resolved. In both Cases B and C, the primary mechanism used in such disputes was *mutual compromise*. Mutual compromise then becomes an intangible boundary object (Bechky, 2006) upon which new sets of agreements and shared understanding are established.

Second, unknown risks (such as changes in mandatory rules and explicit industry regulations) could have a significant effect on both IFPR and the creation and communication of boundary objects. For example, the contractor in Case B was required to accommodate a change in industry legislation and this led to changes in the client requirements (i.e., their IFPR). This change in legislation led to a redesign of the drawings, and the contractor had to seek a new manufacturer that could supply the required material, which then led to additional costs (i.e., a top-down effect of macro factors in Figure 2). Mutual compromise played a key role in the resolution of this problem, as normally the costs of unexpected changes would be expected to be paid by the contractor. However, in Case B the client split these additional costs with the contractor as a good will gesture, as noted in Case B by the client's cost-consultant:

"*And that shows just the sort of relationship there is because that won't happen in every project, certainly. And likewise, the contractor has tried to help out the client with issues particularly over site logistics and the likes which is obviously very important to the client".*

Third, we identified that the establishment of shared understanding is shaped by the structure of communication between team members. Each of the two cases had a distinct structure of communication. For ease of comparison, we refer to them as Type 1 and Type 2 communication protocols. For Type 1 communication protocol (adopted by Case B), the client retains control of the members of the design team (i.e., architect, structural engineers, mechanical and electrical engineers, etc.) who worked on the pre-contract stage. This ensures that the contractor deals with the original design team and helps continuity of design intent. For Type 2 communication protocol (adopted by Case C), members of the design team were not retained by the client, who then engaged in direct negotiations with the contractor. With the Type 1 communication protocol, the responsibility of translating the boundary objects (i.e., technical drawings) into a language that the client understands is borne by the retained members of the design team. This has the advantage that they are the same people who have established a communicative relationship with the client during the pre-contract stage. Moreover, according to the client (Case B):

"*… the team (i.e., the architect, mechanical, and electrical engineers) there just gives us that surety, that sort of say, they (i.e., the contractor) are building it how we designed it, they are not cutting any corners, they are fitting the right sort of equipment, they are doing the right fittings*".

Because the retained design team are experts in their respective fields and have had a history in the design process, their role as brokers improves communication outcomes across the project network. First, it facilitates cross-boundary knowledge sharing and the coordination of activities between the project stakeholders (Shepherd, Seyb and George, 2021). Second, it influences the attainment of shared understanding between the contractor and the client. . However, for the Type 2 communication protocol the client has limited experience in the technical details of the design, and therefore this tends to be a recurrent tension between the client and the contractor, resulting in complex boundaries between them (Carlile, 2002, 2004). The project manager (Case C) alluded to this saying:

> "*… so, the client facing* [role] *is a big challenge on this one, with it being a demanding client. Uneducated in this kind of level of construction*".

Unlike a Type 1 communication protocol, in a Type 2 communication protocol translating the meaning of a boundary object into the client's language is the responsibility of a (usually) different design team, one that works for the contractor directly.

We noted that neither of the two communication typologies were necessarily superior, and indeed there was a paradox in each approach. On the one hand, Type 1 communication protocols tend to rely on the specialist knowledgeability of the parties but at the same time reduce the direct involvement of the client. This is because the design team act as gatekeepers between the contractor and the client. Here the paradox is that sustaining a shared understanding can be hampered by the need to share information between multiple parties. The client in Case B summed this paradox up as that of Chinese Whispers (a game in which information can lose its context or meaning when passed through multiple channels or people):

> "*…so, if the end user says I want an extra cupboard in that room, I could hear it as 2 cupboards, by the time it gets to the project manager it's three cupboards, gets to the contractor it's half a cupboard, and then with architect it's no cupboard and they don't know about it. It's Chinese whispers really, it all changes*".

On the other hand, the Type 2 communication protocols focus communications on fewer parties (i.e., client and contractor). The paradox here is that while it favours spontaneity in decision making due to the direct engagement between the client and the contractor, it may also lack the detailed experience and knowledgeability held by the original design team specialists.

3.2. *Changing and arranging boundary objects*

3.2.1 Pre-contract stage

Arrangement or *arranging* is the bundling together of different boundary objects to create what Cacciatori (2012) refers to as "systems of artefacts" which facilitate the patterning of actions in both intra- and inter-organization settings (Harrison et al., 2018). However, on construction projects, arranging does not only involve the bundling together of different boundary objects but also the identification of misalignments or unintentional differences between the boundary objects, as well as an ongoing redefinition of project partners' responsibilities. As an iterative process, team members were aware that the creation of boundary objects was a work in progress (Mouzas and Henneberg, 2015) that could potentially change the boundary object itself and/or offer alternative arrangements as to who, what, and how such boundary objects are shared. For example, it was anticipated that changes would be needed once specific equipment requirements were known from the user group. Therefore, the initial problem of positioning the equipment into the building space was addressed by *trial-and-error* vis-à-vis educated guesses that were used for negotiating tentative agreements and shared understanding (Carlile, 2004). Four months into the pre-contract design process the lighting requirements from the user group for the laboratory rooms was double that normally required by building industry lighting regulations. According to the lead electrical engineer:

> "*… there's a lighting guide 5 which is for education which is written by CIBSE, so, for their (the users') type of spaces 500 lux is what that guidance recommends. So, for them to then turn around and go, we need 1000 lux, that's double what it should be.*

I appreciate they might need that but what they were trying to say to me is that they need that everywhere. And that's not the case. They need that in specific locations".

By changing the arrangement of boundary object access (i.e., presenting the explicit industry regulation to the users), the electrical engineer was able to convince the users to change their requirements accordingly. An important observation here is that despite not understanding the industry lighting regulation, the users were able to better understand their needs once they became aware of the regulation, which then helped to resolve the tension between them and the design team. The strategy proposed by the design team was for the client to have 500 lux in the laboratory rooms and to limit the 1000 lux to laboratory desks only where it was needed for experiments.

This illustrates how the amalgamation of user's perceptions of their needs (i.e., individual cognition) may then translate into a final agreement between the project sub-teams and users (i.e., collective cognition) yet does not necessarily require a shared understanding of rules (Mouzas and Henneberg, 2015). Rather, the duty of the design consultants was to call attention to the relevant explicit regulations required by the industry to facilitate a better understanding of their collective problems and needs to the end users. The level of knowledge asymmetry between the design team and the user group required a change in the arranging of boundary objects (i.e., making them known to the user group) and could be regarded as an opportunity to close the knowledge gap. Sharing these explicit industry regulations functioned as an objectified means of justifying the decision making of the design team, and being aware of the regulations was sufficient to alleviate the tensions associated with conflict resolutions in joint negotiation between multidisciplinary teams (Faems, Van Looy and Debackere, 2005). In other words, as a standardized social artefact, the explicit regulation functioned as a reservoir of power or a source of formalized authority because it reinforced and legitimized the design teams' position - which then enabled them to convince the client to change their initial aspiration (Chow and Leiringer, 2021).

For signoffs at major points in the pre-contract stage, each design specialist translated their element of the overall design into a simplified report. The translation of the original boundary objects into simplified reports (i.e. the creation of new boundary objects) and then their rearrangement (i.e. sharing them with the wider project stakeholders such as the client and the user groups) was necessary to facilitate shared meaning and shared understanding with the project stakeholders (Carlile, 2002, 2004; Ojansivu, Kettunen and Alajoutsijärvi, 2021). The project manager put this in context when advising the design team members during one of the review meetings

> "*XXX [i.e., the stakeholder team] members are not engineers, don't do it [the report] more than half page ... they are more interested in the progress from stage 2 to 3 and implications on cost plan ... and we seek endorsement*".

This arranging process reflects the reality that boundary objects have different layers of complexity which then necessitates a *simplification process of the boundary objects* (e.g., through simplified reports) to promote shared understanding. However, inconsistencies or clashes between overlapping design elements often only became apparent during this arranging process. For example, 3 months into the project the architect called attention to the need for a specialized workshop for comparing his drawings with the one from the mechanical, electrical, and structural engineers (i.e., further arranging activities). As he asserted:

> *"... we need another meeting ... we've drawn stuffs, they've drawn stuffs ... so we need to go through the drawings line by line*".

3.2.2 Post-contract stage

This stage involves the *creation of a new problem representation* (Simon, 1991) that captures all the client's and users' requirements as well as any post-contract changes. In essence, it involves the creation of a new IFPR that the contractor then uses to negotiate a set of contracts with subcontractors. In this way, the main contractor spreads the contract risks to all the different subcontractors.

For both Case B and Case C, the IFPR was created using a shared electronic platform where designs are simultaneously submitted, commented on, reviewed, and transformed into construction-ready outputs. The electronic platform shaped interactions between project participants considerably. Primarily, it allows team members to monitor each other's progress in real-time and facilitates the coordination of activities between all the project members. As noted by engineers on Case B:

> "*… we've set up a tracker, so, every time we get reviewable design data through, I'll put it on a tracker give it a date and when we need to respond by. We didn't have that at the start, but I think it was a bit messy. It was like, ah, we've got something due tomorrow. But now that we've got this, it's very manageable".*
>
> "*I think the common portal is more effective because all the documents are in one place and everyone has access to them*".

After the drawings go through the internal review process on the electronic platforms, they are then sent out to external specialist consultants, for example the local council's building control officers, to ensure that they comply with both building and fire regulations. This intentional and proactive managerial practice confirms scholars' recommendation that "managers need to be aware that the process of developing inter-cognitive representations does not occur automatically but can, and arguably needs to be guided carefully to develop a shared understanding" (Mouzas and Henneberg, 2015, p. 65). In the context of this project, the practice provides extra confidence in ensuring that the project teams meet the expectation of the regulatory agencies and the city council that will approve their planning applications. This additional step in the process ensures that the creation of the IFPR is more robust and hasslefree and thereby helps the project team to better understand and plan for the requirements and expectation of the regulatory agencies. Besides, by constantly updating their boundary objects, the project team facilitates coherence or avoids misalignment between their design aspirations and the dynamic regulatory requirements in the network environment (Shepherd, Seyb and George, 2021).

3.3. *Destroying or discarding boundary objects*

As a result of the changes in client/users' circumstances and aspirations or needs (i.e., the bottom-up micro factors in Figure 2), not only are boundary objects modified or changed, but they are also sometimes discarded. When boundary objects are discarded it may affect the bonds between actors, ties between resources and links between activities considerably (Halinen, Salmi and Havila, 1999; Ford et al., 2003; Lenney and Easton, 2009). For example, on Case A it was initially planned to use generators as alternative sources of energy to ensure flexibility of energy distribution once the building was in operation. As a result, there was a debate regarding generator choices (diesel or gas or both) as well as capacity and output frequencies (50 Hz and/or 60 Hz). An external consultant (i.e., the generator manufacturer) was also invited during the pre-contract stage, and they were to be specified to the contractor as the one to supply and operate the generators during post-contract and post-commissioning phases, respectively. The debate went on for almost six months. In the end, power distribution and earthen schematics were designed (i.e., boundary object created) with a generator as the power source.

However, weeks before going for tender (which is the start of contract negotiation) the client and the users completely discarded the generator idea which then resulted in the design team discarding the schematics (i.e., discarded boundary objects). This led to the end of the relationship with the generator manufacturer for this particular project, and a new relationship with another power supply company was initiated. Thus, there was a radical change in the network structure (Halinen, Salmi and Havila, 1999). The design team were also required to create an entirely new set of power distribution schematics within weeks to incorporate them into the employer's requirement before inviting potential contractors.

This last-minute change had two main implications for team coordination. First, the limited time available for the electrical engineer to redesign the schematics created *time pressure* – and this led to errors that were highlighted later by the contractors during contract negotiation. As the lead electrical engineer on Case A lamented:

> "*… it was very close to the deadline of when we were trying to issue our information from, I think it was like a week. So, as you can see it can be frustrating because you've had a long period of time from the beginning of February right through till now and the client [snaps his finger] can just decide, that's what I want. And you're like, what!*"

Second, the initiation of contract negotiation and the invitation for tender submissions was also *delayed* which then reduced the contract negotiation time by one week. Our interviews confirmed that an employer's requirement that is incomplete or contains ambiguous information tends to aggravate the already tedious contract negotiation process. It may also eventually lead to serious *tension* between the client and the contractor during the post-contract stage as well as cause a significant cost to the client due to the changes that would potentially be made to the contractual agreement (Okada, Simons and Sattineni, 2017).

Interestingly, on Case A the last-minute change also had a positive outcome for the project because the removal of the generator option substantially reduced the project price. This means that changes do not always attract negative consequences on a project if detected and implemented at the right time (Ibbs, Wong and Kwak, 2001). By identifying and addressing these changes in the pre-contract phase (i.e., before finalizing the employer's requirement or agreeing the contract negotiation) these changes could be agreed prior to signing the project contract and thus avoiding later costs and consequences.

Insert Figure 1 here

Figure 1 summarizes the key events and activities associated with creating, communicating, changing, discarding, and arranging of boundary objects. The Figure illustrates how social processes are characterized by the entanglements of humans and organisational artefacts. It also highlights the key roles of artefacts in enabling IFPR and facilitating the establishment of shared understanding or shared memory during the implementation of tasks that span over a long period. The iterative and interactive nature of the three highlighted practices in Figure 1 functions as (in)tangible resources which both enables and empowers project actors to evaluate their past, present, and future circumstances at any given point in the project.

Insert Table 3 here

Tables 3 outlines the main activity drivers that differentiate the implementation processes (*i.e.,* creating and communicating, changing and arranging, and destroying or discarding boundary objects) at the pre-contract and post-contract stages of construction projects. By capturing and contrasting the challenges that project actors deal with, the table offers invaluable insights that could sensitize project partners to the nuances of the two stages that they must carefully consider in order to achieve improved efficiency in their negotiation, planning and execution practices. Moreover, insights from the table are foundational in developing our final framework (Figure 2), which we present in the discussion below.

4. A conceptual framework of IFPR

There is a need to examine how individual perceptions are amalgamated into collective cognition in order to facilitate shared understanding and collective decision making in networks (Mattsson, Corsaro and Ramos, 2015; Mouzas and Henneberg, 2015). We propose IFPR as one mechanism that teams within a network use to tackle the challenges of disparate and differentiated knowledge backgrounds and other team diversities. Our cases indicate that networked actors create IFPR as a unified frame of reference for clarifying differences and resolving conflicts during everyday decision making. IFPR exemplifies the dynamic nature of artefacts in systematically and productively managing interest alignment or integrating divergent interests to facilitate and stabilize social interaction and network communication processes (Chow and Leiringer, 2021).

One specific practice identified in our cases was the creation of a centralized electronic platform that was tailored to the project and which served as an information database for reviewing, monitoring, commenting on, and managing project drawings and other technical packages as well as tracking changes in project activities. This shared platform facilitated IFPR by arranging and organising a variety of localized boundary objects, such as building sketches. By collating and integrating inputs from team members, the system facilitates shared understanding and ensures access to overall network resources (Möller and Svahn, 2006). It also facilitates simultaneous assessments and timely evaluation of progress during the periods between review meetings (Faraj and Sproull, 2000; Puranam, Alexy and Reitzig, 2014). The electronic platform is therefore not a replacement for, but a complementary mechanism to face-to-face interactions such as a formal review meeting (Rico et al., 2008).

We found that during review meetings, email exchanges, and/or phone calls it is not uncommon for team members to reach an impasse. In such situations, we found that the role of boundary spanners and knowledge or resource brokers (Mortensen and Haas, 2018; Shepherd, Seyb and George, 2021) such as the project architect was to call attention to the relevant explicit industry regulations which specify how the issue must be resolved. In this way, such rules function as tiebreakers or boundary objects which helped teams better understand their problems and offered a basis for decision making. Therefore, the main goal of an adaptive coordination system or representation, such as an IFPR, is to establish a shared understanding of problems rather than a shared understanding of rules, as initially assumed by Mouzas and Henneberg (2015). Rules in fact tend to influence *how* the IFPR is to be implemented. For instance, project clients do not necessarily have to understand safety regulations or wiring regulations. However, during negotiation with design teams, such regulations help the clients understand why their design requests or specifications may not be feasible or appropriate.

Our cases also revealed situations in which there are contradictions between two sets of rules. Particularly, situations where a network level explicit industry regulation overrides a dyadic level mandatory rule (i.e., a contractual agreement). For instance, in our cases changes in industry regulation led to the need for the contractor to deviate from the agreed contractual terms, which then led the design team to redesign the localized boundary objects that were approved at an earlier stage of the project.

As visualised in Figure 2, this finding extends bottom-up explanations that imply change in networks as primarily generated by social actors (Halinen, Salmi and Havila, 1999; Fonfara, Ratajczak-Mrozek and Leszczyński, 2018) to recognize the role of top-down structural change. What we observed in our construction project teams was a dynamic interplay between top-down and bottom-up processes (Taillard et al., 2016); where changes are triggered or influenced in both directions, and where actors make sense of the social complexities that come with this interplay by engaging in activities such as relational support and mutual compromise.

Insert Figure 2 here

While Figure 1 focusses on the specific ways in which team members create, communicate, interact with, and discard boundary objects, Figure 2 is a visual representation of how inputs and feedback mechanisms characterize the entire process of IFPR creation and use. As an overarching concept, IFPR incorporates the multiple views, needs and contributions of network actors. Hence, it creates a 'big picture' effect during joint negotiations and decision making. Moreover, it is a useful tool for managing expectations. Fundamentally, IFPR functions as a medium and outcome of joint interrelations between the project team. For instance, as indicated in the examples in Figure 2, the employer's requirement is the outcome of the pre-contract stage which is then used as a medium to negotiate contractual terms. Once the contract is signed, this becomes the framework used by the contractors for further negotiations with the subcontractors. In our construction industry context, the employer's requirement is the IFPR for the pre-contract stage and the legally binding contract is the IFPR for the post-contract stages of the construction projects. During the back-and-forth interplay between network actors using boundary objects and the IFPR, the intentions and aspirations of actors are continuously adapted to accommodate the unfolding realities of the project and ensure coherence with the external network requirements (Shepherd, Seyb and George, 2021).

In summary, we have been able to demonstrate how socially created and localized boundary objects (i.e., those that are created and utilized during everyday conversations) are at the heart of social relations and network processes. We emphasize in Figure 2 the interconnections that exist between forming the IFPR (e.g., an employer's requirements), explicit industry regulations, mandatory rules (e.g., binding contracts), default rules (e.g., industry standards), localized boundary objects (e.g., design drawings) and the aspiration of social actors (e.g., client's or users' change requests). These interconnected loops conform to five key assumptions.

First, from a top-down perspective, our findings extend earlier propositions advanced by Mouzas and Henneberg (2015). Specifically, it emphasizes the mutability of explicit industry regulations and their role as a mechanism of change. We, therefore, propose that changes in explicit industry regulations would override mandatory rules (i.e., binding contracts) and trigger a continuous change in the arrangement of boundary objects and micro-level agreements (i.e., the manifestation of consent such as employer requirement).

P1a: Explicit industry regulations are superordinate to mandatory rules in the creation and re-creation of boundary objects.

P1b: Changes in explicit industry regulations trigger changes in mandatory rules (i.e., binding contracts) that then facilitate necessary changes in the arrangement of boundary objects (i.e., design layouts).

Second, from a top-down perspective the creation and change of boundary objects by social actors is *conditioned* by mandatory rules, which stipulate the conditions for permissible and non-permissible actions.

P2: The creation and re-creation of boundary objects is subject to mandatory rules which are superordinate to default rules.

Third, from a bottom-up perspective, when connected by a shared activity the aspirations of social actors are jointly negotiated and constantly being refined through the creation and change of boundary objects, which then becomes the shared frame of reference that guides the actors' successive interrelations.

P3a: Social actors negotiate and refine their aspirations through the creation and re-creation of boundary objects.

P3b: The creation and re-creation of boundary objects creates a shared frame of reference, creating dyadic level default rules which then guide future interrelations.

Fourthly, from the interaction and process perspective, the systematic arrangement of the boundary objects and the contextualization of default rules leads to the creation of the IFPR, which then become the foundation for new social aspirations by actors.

P4: IFPR is created through processes of boundary object arrangement and the contextualization of the default rules that enable and constrain its creation.

Lastly, from a dynamic interplay perspective, the joint negotiation and refinement of IFPR leads to the creation of mandatory rules (i.e., contractual agreements) that enable the creation and further development of boundary objects and defines project team actions. However, when a client's circumstances or industry regulations change, the project team has the agency to redefine the contractual terms. Thus, we see a dynamic interplay between structure (the contract) and actors' agency. That is, despite conditioning their actions, the contract is also constantly being redefined as new realities unfold.

P5: While mandatory rules (i.e., binding contracts) are superordinate to default rules (i.e., industry standards and best practice guidelines), they are nevertheless subject to joint negotiation and refinement through IFPR.

5. Conclusion

By introducing the concept of IFPR we have been able to shed light on the role of boundary objects in establishing a shared understanding and convergence of views between network actors. Our context was that of construction projects where knowledge boundary issues typically create social tensions and complicate mutual understanding of shared activities between project members. Drawing on prior research related to boundary objects as a means to achieve shared understanding and coordination of activities (Carlile, 2002, 2004; Araujo and Kjellberg, 2015; Mouzas and Henneberg, 2015), we have contributed to this body of work by explicating the processes related to creating and using boundary objects. We highlight how actors, engaging in a shared activity that is extended over a period of time, collectively navigate different social contingencies while utilizing IFPR as a socio-historical artefact. The IFPR process enables network actors to retrospectively modify their decisions to take account of past mistakes and overlooked events. The process of retrospective modification sheds new light on our understanding of change in networks. Facilitated by IFPR, it is characterized by the shared ability of network actors to revisit prior decisions to jointly reinterpret, better understand, and redefine the past.

Our cases exemplify how retrospective modification of network processes typically leads to important and sometimes radical changes. For instance, in construction projects post-contract identification of undefined or ambiguous elements in the employer's requirement (IFPR) usually triggers a chain of events, such as: 1) a redefinition of roles and responsibilities between project members; 2) a redefinition of activities that may also result in changes in project members; 3) changes in inter-cognitive representations (e.g. industry rules) and these may result in radical changes to the network structure (Halinen, Salmi and Havila, 1999). Therefore, while it is undeniable that network change could be generated at the level of individual or dyads (e.g., through client's change request), our analysis of the process of creating IFPR also sheds light on why industry rules and regulations deserve to be treated as distinct mechanisms of change.

5.1 Theoretical contributions

The findings presented in this study have important theoretical implications which relate to knowledge sharing (Carlile, 2002; 2004) and the shared cognition literature (Mouzas and Henneberg, 2015). Both literatures have already spelt out the importance of using boundary objects and inter-cognitive representations to facilitate collective decision making in networks. In particular, the knowledge sharing literature has identified the different types of boundaries that could potentially exist between interdependent actors and proposed relevant processes for managing each type of boundary. However, the literature lacks an explicit discussion of how the structure of communication between networked teams could shape knowledge sharing and hence, shared understanding at each boundary. For instance, issues relating to who should be responsible for transferring, translating, and transforming boundary objects appeared to be taken for granted or assumed to be easily taken care of by project partners (Carlile, 2004). It has been shown in this study how two different typologies of communication structure (i.e., Type 1 and Type 2 communication protocols) could generate different effects on boundary management, while also contributing to the sustenance of shared understanding between network partners.

Regarding the shared cognition literature, the current study moves beyond earlier work on creating boundary objects (Mouzas and Henneberg, 2015) by positing a more complex process of arranging boundary objects. This arranging tends to expose the latent communication and misalignment problems that typically remain unnoticed when an individual boundary object is created in isolation. Without utilizing the appropriate communication protocols in networked teams, the establishment of shared understanding may become unnecessarily tedious even if relevant boundary management processes are implemented. In addition, unnoticed misalignment between boundary objects (e.g., resulting from fragmented arrangement processes), could lead to unintended consequences beyond the project completion time. A case in point is the Grenfell Tower fire, which claimed the lives of 72 building residents in London in June 2017 (Schulz *et al.*, 2021). Prior to the fire, new cladding had been installed on the exterior of the building as part of a nine million pound refurbishment project (Gonzalez and Voutsadakis, 2018). While each of the individual cladding materials used in the retrofitting and refurbishment of the building fulfilled the minimum installation requirements in relation to explicit industry regulations for combustible claddings and fire barriers in themselves, there was an unforeseen problem when they were used in combination to form cladding panels (Gorse and Sturges, 2017). Rather than creating a barrier, together the combination of materials used in the new cladding system acted as a catalyst, allowing the fire to spread rapidly across the building and resulting in a potentially preventable tragedy (Gonzalez and Voutsadakis, 2018). We argue therefore that it is not sufficient to address the creation of each boundary object in isolation. Marketing scholars need a more all-encompassing system (e.g., IFPR) if they are to offer robust and relevant insights to managers (e.g., how to guard against compliance gaps and identify design misalignment as early as possible in the design process). We also emphasize the importance of communication in that the creation of IFPR and the arrangement of boundary objects would have resulted in more effective outcomes if it had been supported by a shared electronic platform. As we have shown in this study, a digital platform allows real-time identification of design and compliance clashes, while also enabling a holistic or "big picture" understanding of shared goals.

5.2 Managerial implications

One of the difficulties in construction projects is the management of unplanned changes which tends to disrupt the design process. The current study acknowledges boundary objects, particularly explicit industry regulations, as important drivers of change. This implies that treating rules and regulations as distinct mechanisms of change allows network actors to reduce post-contract disputes by actively addressing how to deal with potential changes in regulations during the development and/or contract negotiation processes of the employer's requirement (i.e., IFPR). Current practice in the construction industry has focused mainly on client's or users' change requests as the primary culprit when explaining why unexpected changes (and therefore, disputes) happen in projects (Okada, Simons and Sattineni, 2017).

On the contrary, we argue that such practices are a reflection of extant notions on social change which tends to regard social actors as the only mechanism of change, while reducing changes in network structure (such as rules and regulations) to critical events (Halinen, Salmi and Havila, 1999; Harré, 2002). We maintain that much can be learned by placing structural features such as explicit industry regulations at the center of changes in project activities. In doing so, project actors and managers can take a more proactive approach to addressing changes in regulations rather than the reactive approach that critical events proponents suggest. As an example, project contractors and clients can make a pre-emptive decision during contract negotiation to share responsibilities and costs in the events of an unexpected change in regulations.

5.3 Limitations and future research

This study developed a framework identifying several top-down and bottom-up factors shaping the interplay between network actors and the socio-material objects in their environment. We developed five propositions that we propose could guide future research. In relation to **Proposition 1a**, we propose that the following research questions might address the need for a better understanding of how explicit industry regulations influence the creation and re-creation of boundary objects:

- How do different communication structures enable or constrain how explicit industry regulations translate into industry practices?

- How do those practices affect the creation and re-creation of boundary objects?

Regarding **Proposition 1b**, future research could explore the different decision-making and feedback practices that enable network teams to dynamically capture and integrate changes in explicit industry regulations into their localized boundary objects to ensure internal-external coherence (Shepherd, Seyb and George, 2021). Future research could also investigate industries with different regulatory structures (e.g., technology-related and software manufacturing industries) to better understand the extent to which changes in explicit regulations shape and condition the negotiation processes and joint decision making of project teams.

To further explore and test **Proposition 2,** the following questions are worthy of research attention:

- How do project teams evoke mandatory rules to stimulate agreement when creating or re-creating boundary objects?
- What communication styles or approaches are most effective when using mandatory or default rules to justify boundary object design decisions?
- Could mandatory rules and default rules be overused or result in exploitative behaviours when negotiation boundary object creation?

Regarding **Proposition 3a**, researchers could explore the use of boundary objects to create alignment of interests. Possible research questions could include:

- How do social actors navigate and resolve conflicts in their aspirations?
- Under what conditions does the use of boundary objects lead to a broad consensus between social actors with shared objectives and goals?

Proposition 3b could direct future work exploring the extent to which teams rely on boundary objects as a frame of reference, including:

- To what extent do teams use boundary objects rather than intuition or practical judgement (e.g., see Flyvbjerg, 2004; Shotter and Tsoukas, 2014), to jointly make sense of their everyday decision-making?

More empirical verification is needed regarding how to reduce the challenges associated with arranging and assembling multiple boundary objects to contextualize default rules when creating IFPR (i.e., **Proposition 4**). The current study argues that the use of electronic platforms for collating boundary objects offers more advantages when compared to arranging boundary objects manually. However, there might be some hidden costs associated with using electronic platforms, which may negate its benefits. Therefore, further work could explore different network contexts to identify situations where manual arrangement might be more beneficial for creating IFPR.

To address **Proposition 5**, we need more empirical insights into the creation and use of IFPR. For instance:

- How do network actors adhere to the requirements of mandatory and default rules while also simultaneously utilizing their agency to respond to the social dynamics in the network environment?
- Under what conditions are network actors able or unable to modify the mandatory rules when new social realities emerge?

Relating to interaction processes, we identify two typologies of communication structure (i.e., Type 1 and Type 2 communication protocols) in networks that are instrumental in shaping shared understanding and addressing boundary tensions between network actors. However, our investigation does not explain the implication of each communication protocol on the level of heedful, or heedless interrelations within networks (i.e. the collective mind; Weick and Roberts, 1993). How might the type of communication protocol adopted influence the level of collective mind that is attainable within the network? This question is important because network actors may, despite establishing shared understanding on their collective course of actions, engage in actions that deviate from the initial agreements to fulfil their own objectives or to respond to an unexpected situation. We argue that the type of communication protocol that exists between network actors could shed light on how networks collectively deal with such potential deviation from agreements. This might also expand our knowledge of how individual aspirations are amalgamated into collective goals (Mouzas, Henneberg and Naudé, 2008; Mouzas and Henneberg, 2015). Investigating this could provide additional explanations on how to enhance both the individual and collective experience of network actors in their social engagements and uncover missing links in the interplay between cognition, action, and outcomes (Mattsson, Corsaro and Ramos, 2015). In addition, in relation to calls for a better understanding of the organisation and leadership of teams (Verona, 1999; Hauser, Tellis and Griffin, 2006), communication protocols could illustrate alternative ways of organising people and offer insights into how that affects processes or outcomes.

Finally, we suggest that future research could draw upon alternative methodological approaches such as necessary condition analysis (Dul, 2016) to consider the structure of communication vis-à-vis coordination of actions and shared understanding as potential necessary conditions for collective mind. Such analysis could potentially reveal two things. First, if the coordination of actions in relation to the structure of communication adopted by a network has implications for the degree of shared understanding that is attainable between the network actors during social negotiations. Second, if there is any difference in the extent to which collective mind is attainable when a Type 1 or a Type 2 communication protocol is adopted.

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Table 1. Background information of projects and project teams

	Case A	Case B	Case C
Type of project	Institutional building	Institutional building	Commercial building
Purpose of project	Offices, laboratories, workshop spaces, meeting rooms	Science laboratories, offices, and meeting rooms	Corporate offices, headquarters spaces and retail centers.
Project Budget	9 million pounds	23 million pounds	28 million pounds
Location of Project	United Kingdom	United Kingdom	United Kingdom
Duration of project	Autumn 2017 – summer 2019	January 2018 – October 2019	July 2015 – summer 2019
Stages of construction work observed	RIBA Stage 2 & 3 – Concept and advanced design stages. Activities include intensive discussion with clients to jointly develop proposals on building plans, structural, mechanical, and electrical designs as well as to develop preliminary cost plans. This also includes risk analysis by the design team, and ongoing negotiations with client on alternative design options.	RIBA Stage 4 – Technical design stage. Activities include consulting with third parties on how to address health and safety strategies, rounding off electrical and mechanical design, consulting with BREEAM to address sustainability issue, and negotiating design decisions with building control.	RIBA stage 5 – Preconstruction and construction stages. Activities include obtaining planning and building permissions, conducting specialists design works (e.g., finalizing tender documents), ground preparation works, procurements and other construction activities.
Project team	Design team, client team and end-user representatives	Design team, client team, clerk of work team, building managers, contractor team, sub-contractors, and design consultants.	Design team, design consultants, contractor team, sub-contractor, commercial team, project management team, and client team
Team composition	Project Manager, electrical engineers, mechanical engineers, Architect, cost manager, project PI, and engineering professors	Project managers, contract manager, mechanical & electrical engineers, architect, structural engineers, consultants, acoustics, surveyors, and building services manager	Project managers, contractor, operations director, project secretary, structural engineer, design engineer, Architect, client representatives and project developers
Number of interviews conducted	8	13	11
Companies represented	5 organizations	7 organizations	6 organizations

Table 2. Characteristics of the Pre-contract and Post-contract stages of construction projects

Pre-Contract	Characteristics	Post-contract
The client and the architect. It may also include **the** design team. The architect and the engineers are employed directly by the client	**Participating actors**	The client, the architect, the contractor, the client design team, the contractor design team, design consultants, and the subcontractors Mixed employment relations between the actors – i.e., some engineers may switch roles from being employed by the client to being employed by the contractor (i.e., novation).
Bi-directional, relatively simple, involving the design team, the client, and/or users	**Communication structure**	Multi-directional, relatively complex, involving two design teams, the client, contractors, consultants and multiple subcontractors
Information flow is mostly client-led and generally managed through face-to-face communication Characterised by bi-monthly design meetings and a limited use of electronic medium, mostly email communication Information filtering, communication restriction, and design misinterpretation is less likely	**Communication pathway**	Information flow could be client-led, intermediary-led (i.e., design teams), contractor-led, or multi-actor-led Characterised by multiple and overlapping face-to-face meetings, and multiple electronic communication media (e.g., emails and shared electronic platforms) Information filtering, communication restrictions, and design misinterpretation is highly likely.
The syntactic [1]and semantic[2] boundaries are activated when negotiating the client's design requirements and interpreting engineering concepts or regulatory requirements (boundary objects) to facilitate a shared understanding with the client	**Knowledge boundaries**	In addition to Syntactic and Semantic boundaries, the Pragmatic[3] (or political) boundary is also activated to manage the tension that typically arises when negotiating design and contractual changes. Multiple communication channels create multiple knowledge boundaries, and shared understanding becomes more difficult to attain (e.g., if the client does not retain the pre-contract engineers but instead novates them to the contractor).
Agreeing the employer's requirements (i.e. the contract), which is created by bundling together all the design elements of the different engineers working for the client The contract creates a big picture of the client's aspiration and facilitate contract negotiation	**Process output**	Unbundling of the design elements of the employer's requirements to create buildable design plans and layout for different construction specialists The "buildable" design plans and layouts are constantly modified as the client's aspiration changes or as a result of environmental, regulatory, or market factors

[1] **A syntactic boundary is the simplest form of information processing that relies on common knowledge or shared lexicon between interacting actors** (Carlile, 2004).
[2] **The semantic boundary is an interpretive boundary that requires the translation of complex knowledge into shared meaning between the interacting actors** (Carlile, 2004).
[3] **The pragmatic boundary requires interacting actors to identify and resolve any conflicting interests that could impede the implementation of their shared goals** (Carlile, 2004).

Figure 1: The entanglements of humans and organisational artefacts during social interactions

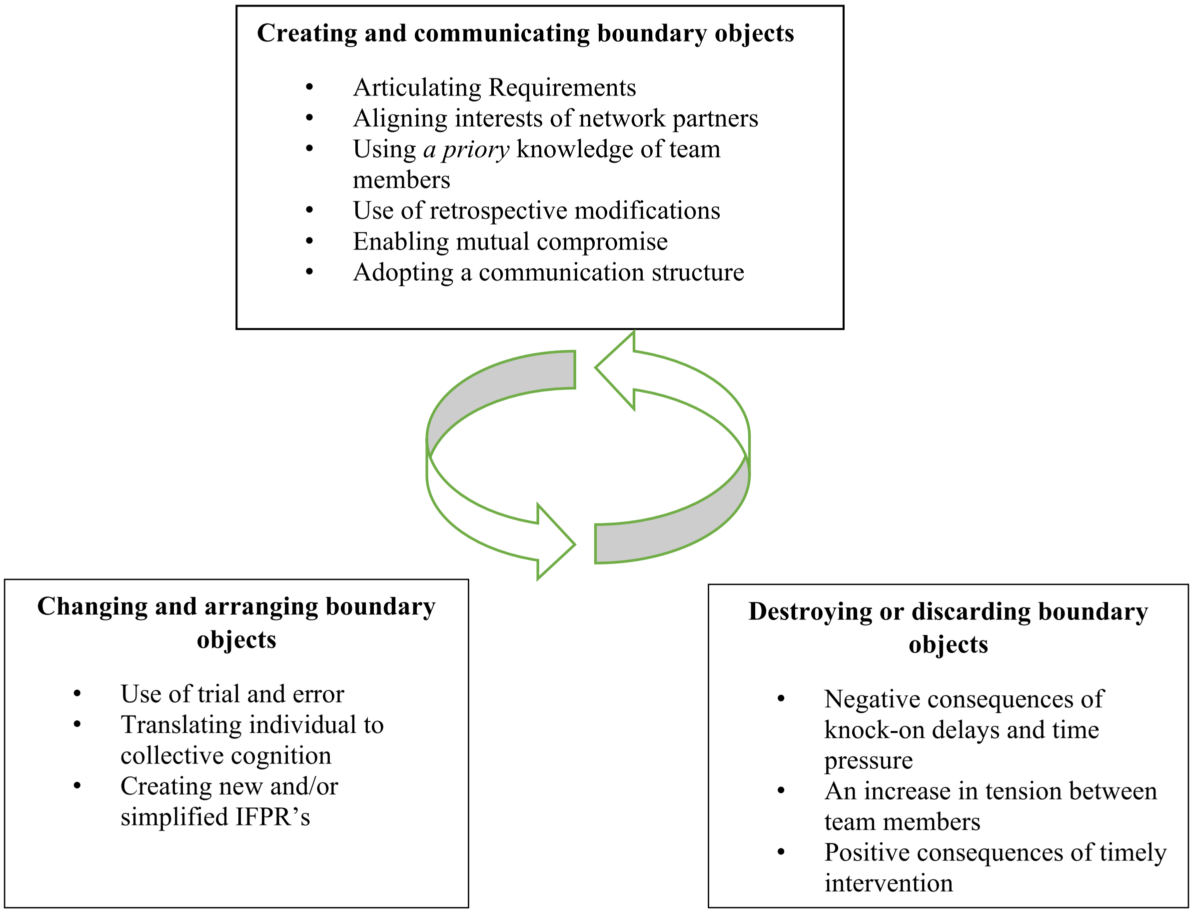

Table 3. Key process divers at the pre-contract and post contract stages

Processes	Pre-Contract activities	Post-Contract activities
Creating and Communicating Boundary Objects	• Speculations of design measurements are part of the process • One main communication driver is to ensure that the design aligns with industry regulations and standards • The client's design team are responsible for translating engineering drawings and concepts into a "layman" language	• Accurate design measurements are required to develop buildable layouts • The main communication driver is primarily to ensure that the design aligns with the pre-agreed client requirements • The responsibility of translating complex design drawings to the client is not always specified or clearly defined
Changing and Arranging Boundary Objects	• The client is responsible for the costs of design changes • As a relatively less rigorous process, arranging at this stage could be done manually or with limited use of technology • Changing the arrangement of design layouts is more controlled and less complicated as it requires input from a relatively smaller number of project actors	• It is sometimes unclear between the contractor and the client who should pay for design changes • Because of multiple actors' involvement and the ongoing changes to the design, arranging is mostly done with technology • Changing the arrangement of design layouts could trigger power tension and activate political boundaries because it requires inputs from more actors
Destroying or Discarding Boundary Objects	• Discarding of designs is mainly a result of changes in client request – hence, • The process is relatively more manageable and potentially less costly	• Discarding of designs could be triggered by multiple actors and factors – hence, • The process is relatively less manageable and potentially more costly

Figure 2:
Top-down and bottom-up factors shaping the interplay between network actors and the socio-material objects in their environment