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# An actor–network theory approach to developing an expanded conceptualization of collaboration in industrialized building housing construction

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## ABSTRACT

Our aim is to examine the value of selected actor–network theory (ANT) elements in contributing to the development of an expanded theoretical and empirical conceptualization of collaboration in industrialized building construction for the housing sector. A review of collaboration meta-analyses literature from different disciplines suggests that collaboration is still commonly portrayed in a limited way as a strategy of integration driven in a top-down manner by a “convenor” of human stakeholders in ways that privilege simplified notions of coherence. We use specific ANT concepts empirically grounded in five case studies of innovative housing construction projects to describe an expanded conceptualization of the infrastructure of actor-networks. We examined a range of issues with respect to collaboration in industrialized building particularly in relation to network formation and disintegration. As the collaboration networks formed they sought coherence but not conformity and aimed for the management of tensions between integration and separation as well as stabilization and destabilization. This expanded conceptualization of collaboration describes the material-semiotic characteristics arranged around industrialized building technologies that are simultaneously stabilizing yet disruptive and proposes new ways by which the ideal of integration can be pursued in a fundamentally fragmented industry.

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## Introduction

The aim of this paper is to analyse collaboration in industrialized building (IB) settings in the Australian housing sector, using concepts of actor–network theory (ANT) to extend existing theoretical understandings of the term particularly within the construction management field of research. In Australia, the uptake of IB has been low and much of the industry continues to operate in an inefficient, fragmented manner (Loosemore *et al.* 2003, Blismas *et al.* 2005). There has been significant research into the barriers to IB in other parts of the world and Blismas *et al.* (2005) synthesized the work of 10 authors. It has been suggested that these challenges have been overcome through a complex process requiring extraordinary collaborative efforts by influential entrepreneurs that led to industry-wide transformation (Miles and Whitehouse 2013). It has been previously noted that whilst construction innovation can be achieved by addressing fragmentation in the construction supply chain, it is difficult for any one single party in the sector acting alone to make such changes (London 2008). A significant challenge to IB is how to enact this extraordinary collaborative effort required of construction

chain actors, from developer to builder to trade contractors to suppliers, to initiate and drive change within new socio-technological network of actors and artefacts. IB has the capacity to improve efficiency but it will require extensive collaboration and supply chain integration. However, what does this industry-wide transformative collaborative effort look like in IB settings? What is the infrastructure that underpins the network of actors and how is it formed and reformed?

Our interest in collaboration in IB case settings arises from four major reasons: (1) fragmentation in the Australian IB housing sector, (2) collaboration's role as a key integration strategy, (3) the conceptual value of IB case settings as domains for theoretical development, given that they have distinct characteristics that push the boundaries of widely-held conceptualizations of collaboration and (4) the lack of Australian case studies that look closely at how successful collaboration is carried out.

Collaboration is a term that is frequently used in construction supply chain management research. As a concept it is often explicitly, albeit fleetingly, mentioned as an activity or practice (Ozorhon 2013, Mao *et al.* 2014),

implied in discussions that foreground supply chain integration (Kim *et al.* 2015, Tezel *et al.* 2015) or briefly defined (Isatto *et al.* 2013, Erdogan *et al.* 2014). Importantly, there is a small but growing volume of work that has begun to explore collaboration in systematic ways (Whipple and Russell 2007, Smyth and Pryke 2008, Xue *et al.* 2010, Meng *et al.* 2011, Walker and Walker 2015) and we seek to contribute to this currently limited body of research.

To expand systematic understandings of collaboration in construction, we drew from research studies from different fields that sought to define collaboration through meta-analyses (Wood and Gray 1991, Mattessich and Monsey 1992, Xue *et al.* 2010, Schöttle *et al.* 2014, Hughes *et al.* 2016). We found that disciplines such as construction, organization studies and the social sciences generally still portrayed collaboration narrowly, for example as a human activity driven by the ideal of complete integration. A review of these studies suggests that existing understandings of collaboration are underpinned by five limiting assumptions. We thus argue that understandings of collaboration can be expanded by interrogating each of these assumptions using concepts of ANT. ANT is a network approach that assumes that much of reality is the outcome of actants interacting in heterogeneous networks (Latour 1987, Law 1992, Callon 1999). ANT is a social science method that provides specific analytical devices such as prime mover, problematization, convergence, relational materiality, stability and multiplicity. These concepts assist researchers in describing and critiquing empirical settings and in developing theory. As a network approach, it is useful in understanding supply chain dynamics given that it departs from the limiting assumption that organizations are autonomous entities (Pryke 2012). Our research question is: How do the ANT concepts of prime mover, problematization, convergence, relational materiality, stability and multiplicity contribute to an expanded understanding and theoretical conceptualization of collaboration in industrialized building?

The paper is structured as follows. First we contextualize the research by explaining how industrialized building addresses serious concerns in the Australian housing construction sector. We then highlight that industrialized building is challenging to implement because it requires extraordinary levels of collaboration. We show that there is currently limited IB and construction research that has been carried out to systematically develop theoretical understandings of collaboration. We then present a review of collaboration across a range of disciplines that suggests that while definitions of collaboration are emerging, they are limited in at least five ways. We explain ANT concepts and key analytical devices for interrogating these assumptions. We present empirical findings through a comparative case study of five collaborative housing construction

networks using innovative IB technologies in Australia. We conduct an analysis of data from 29 in-depth semi-structured interviews using qualitative case study data coding techniques. We present detailed findings of two case studies, and a summary of the other three. Our findings suggest that the use of ANT concepts enriches the dominant conceptualization of collaboration in five ways. First, it moves away from a unitarist view of collaboration as “convening” and instead highlights ambiguity, complexity and plurality in collaborative work. Second, it views collaboration as the work of objects and artefacts and the physicality of the industrialized building setting and the housing sector as much as it is the work of people. Third, it interrogates the idealistic notion of total conformity and seamless integration and instead privileges the more tempered ideal of significant coherence. Fourth, it presents collaboration as a network effect that stabilizes, while also highlighting that collaboration can disrupt and destabilize during different phases of the innovation initiative. Fifth, it presents challenges to collaboration as misalignments between multiple overlapping networks and not as outside forces.

### **Collaboration as actor-network**

Our interest in collaboration arises in part from fundamental fragmentation-related challenges in the Australian housing construction sector. The sector is currently failing to meet demand. Houses in Sydney and Melbourne are now among the least affordable in the world (Demographia 2016), planning and approval processes have become increasingly cumbersome and costly (Hsieh *et al.* 2012) and more vulnerable sectors of society have become increasingly characterized as precariously housed (Beer *et al.* 2016). Many of these challenges have been tracked back to bottlenecks in housing supply, resulting from a housing sector that has long been criticized for remaining craft-based and which is fundamentally highly fragmented and inefficient (Loosemore *et al.* 2003). The emergence of these unfavourable housing trends has triggered increased interest in industrialized building as a solution.

Industrialized building has been used interchangeably with terms such as offsite construction, offsite manufacturing and preassembly, all referring to the manufacture of parts, components, systems or entire units in a controlled environment, for installation on site (Gibb 1999, p. 262). International research has linked IB adoption to a number of benefits, including reductions in construction time, defects, health and safety risks, environmental effects and whole-life cost, as well as increasing sustainability, productivity, whole-life performance and profitability (Blismas and Wakefield 2009, Pan and Goodier 2012). Despite these benefits, uptake in Australia continues to be low. Early research has sought to account for this limited

uptake by identifying a number of barriers to adoption and diffusion, among them resistance on the part of labour, lack of knowledge in manufacturing and the costliness of disjointed regulations across jurisdictions (Blismas *et al.* 2005). While these findings on barriers have been useful, they are not definitive as case studies on industrialized building in Australia remain sparse. Those that have been conducted appear to overlook an important consideration: that housing construction projects introducing industrialized building involve problematiques (Warfield and Perino 1999), which are complex issues that can only be addressed through highly coordinated efforts of multiple stakeholders working together. In such cases, high levels of interdependence are required and we proposed that the key enabler to successful industrialized building is collaboration.

### **Collaboration in industrialized building and construction supply chain management**

In the field of industrialized building, collaboration has been touted as a facilitator of the industrialized building processes (Yashiro 2014), as an aid to behavioural change within a sector seen to be problem-ridden (Sunding and Ekholm 2015) and as an important component of supplier-buyer relationships (Bildsten 2014). In broader construction supply chain management literature, our review of work over the last 10 years suggests that most of the research on collaboration can be categorized into four areas: studies that use the term without defining it (Ozorhon 2013, Mao *et al.* 2014); studies that make no explicit mention of the term, but imply its importance by highlighting some form of integration (Kim *et al.* 2015, Tezel *et al.* 2015); studies that define collaboration, but without any discussion on how such a definition emerged (Isatto *et al.* 2013, Erdogan *et al.* 2014) and finally a fourth group, again a very limited body of work, that analyses collaboration in methodical ways through a systematic review of literature (Xue *et al.* 2010, Meng *et al.* 2011, Poirier *et al.* 2016) or contributes to theoretical development through rigorous empirical work (Whipple and Russell 2007, Smyth and Pryke 2008, Walker and Walker 2015, Hughes *et al.* 2016). These studies have laid solid groundwork that we are building upon to continue a systematically developed understanding of collaboration. There is currently a plethora of meanings of the term (Simatupang and Sridharan 2002, Chen and Paulraj 2004, Meng *et al.* 2011), which continues to be loosely associated with various degrees of coupling (Chan *et al.* 2004) and a diverse array of alliances (Xue *et al.* 2010). Holti and Standing (1996, p. 5) have commented that collaboration is not “definable in its own right”. Collaboration, like its related concept “partnering”, is a term “so diffuse and malleable that it can be ascribed

to any form of non-adversarial relationship” (Bresnen and Marshall 2000, p. 232).

It can be argued that the elusiveness of a single definition of collaboration can have advantages. One of these is the argument that defining collaboration is an empirical matter, that a single definition can be limiting and that collaboration cannot be confined to narrow descriptions because it can be expected to emerge in different forms from case to case. That said, such a nebulous conception of collaboration in construction literature could account for researchers’ conclusions that contractors often do not know what the term means (Osipova 2014). The lack of understanding also limits the possibilities for transferring best practices of collaboration across different contexts, as knowledge transfer becomes an adhoc process (Bresnen and Marshall 2000). The challenge, therefore, is to work towards the development of a theoretically informed, empirically grounded conceptualization that is broad enough to capture a range of arrangements while still being endowed with enough specificity to distinguish collaboration from other types of relationships (Wood and Gray 1991). In the next section we explore key studies from different fields that have sought to develop conceptualizations of collaboration in a systematic manner.

### **Towards a definition of collaboration**

While the development of a meaningful theoretical definition of collaboration has been difficult, there are a number of researchers that have begun to systematize collaboration research by conducting meta-analyses, leading to proposed definitions of the term. As Schreiber *et al.* (1997, p. 314) propose, qualitative meta-analysis is characterized by “the aggregating of a group of studies for the purposes of discovering the essential elements and translating the results into an end product that transforms the original results into a new conceptualization”. In collaboration studies meta-analyses have emerged from different fields: construction, governance, information technology, organization studies and the general social sciences. We have chosen five papers of which four are meta-analyses. Three of these papers are from construction management and the other two are from mainstream management (organizational science and human services). The construction management studies provide the most relevant context of collaboration for our research and the other two papers are theoretically aligned to our study because they are framed within the social sciences tradition. These papers are to our knowledge the most comprehensive examples of meta-analysis on collaboration that synthesize key elements into a systematic definition. We are confident of our selection of papers; for example Mattessich and Monsey (1992) have been cited 1344 times. They have

**Table 1.** Assumptions underpinning mainstream collaboration theory.

Key assumptions	Wood and Gray (1991)	Mattessich and Monsey (1992)	Xue <i>et al.</i> (2010)	Schöttle <i>et al.</i> (2014)	Hughes <i>et al.</i> (2012)	Dominant conceptualization
Nature of study examined	Meta-analysis on collaboration based on nine papers in organization studies	Meta-analyses on collaboration based on 18 papers from multi-disciplinary fields	Meta-analysis on collaborative working based on 84 papers in engineering, construction and architecture	Meta-analysis on collaboration and cooperation based on 28 partners in lean construction	Empirical study involving surveys and interviews aimed at developing a definition of collaboration	–
Collaboration drivers: Who or what drives collaboration?	A single convener brings together stakeholders to establish, legitimize and guide the collaborative alliance (p.149)	A “skilled convener” with respect and legitimacy brings together the collaborative group that formulates a common vision, mission, objectives, strategy (p. 17)	A “common value viewpoint” is a critical success factor for collaborative working (p. 201)	A common vision is shared among the key participants who share responsibilities, risk, and rewards (p. 1275)	A team is formed where participants share a “common aim motivated by a fair method of pain share gain share to produce a win-win outcome” (p.365)	Collaboration involves a unified, stable goal, and is often led by a convener.
Collaborative participants: Who or what acts in collaborative activity?	Stakeholders are “groups and organizations with an interest in the problem domain” (p.147)	Collaborating partners are community representatives (p. 15) and usually involve “two or more organizations” (p.11)	Collaboration is shaped by human behaviours and attitudes (pp. 202–203)	Collaboration is an inter-organizational relationship (p. 1275)	Collaborating partners are team members with clear roles and responsibilities (p.365)	Collaboration is a human activity.
Collaborative ideals: What is the goal of collaboration?	Emphasis on integration as implied by “convene”; stakeholders are expected to agree on “shared rules and norms” (p. 148)	Emphasis on integration as implied by “mutual goals; a jointly developed structure and shared responsibility; mutual authority and accountability for success; and sharing of resources and rewards” (p. 11)	Emphasis on integration through the “reduction of adversarial conflicts” through relational contracting (p. 203), and by highlighting the importance of trust (p. 204)	Emphasis on integration through the development of “a new and jointly developed project culture, based on trust and transparency...[and by] solving problems mutually through interactive processes, which are planned together” (p. 1275)	Emphasis on integration and consensus as implied by the ideals of team spirit and mutual trust; also relationships are managed and problem solving is collective (p. 365)	The collaborative ideal is integration.
Temporality of collaboration: To what extent is collaboration persistent/stable?	Arrangements persist through “shared structures” which can take durable forms such as joint ventures and international associations (p. 148)	Arrangements persist through structures in the form of decision-making processes, communication systems, and policies and guidelines (pp. 25–29)	Little mention of structures but stability is implied through an emphasis on forging long-term relationships (p. 201)	Arrangements persist in the form of a “common project organization with a commonly defined structure” (p. 1275)	Stability is emphasized (p. 366); in addition arrangements can be understood to persist through formalization via contracts (p. 365)	Collaboration involves “structures” that make arrangements stable and persistent, rather than contingent.
Collaborative context: Is there a collaborative environment?	Collaboration is a response to complexity in the external environment, which should be controlled (pp. 155–156)	Collaboration takes place in the context of an environment with characteristics such as geographic location and social context (p. 19)	Collaboration takes place in an external environment described primarily as organizational culture (pp. 202–203)	Collaboration takes place in an external environment captured in the term “culture” (p. 1276)	Collaboration should take place in an ideal environment described as “non-adversarial” (p. 365)	Collaboration takes place in the context of an external environment that should be managed.

aggregated a group of 18 papers on collaboration from different social science fields and concluded that collaboration comprised six elements. Wood and Gray (1991) analysed seven papers in the field of organization studies and sought to develop a comprehensive theory of collaboration. Schöttle *et al.* (2014) examined 28 papers on collaboration based on studies in lean construction. Xue

*et al.* (2010) through a much larger meta-analysis consolidated findings from 84 papers in the fields of engineering, construction and architecture to explore more deeply the notion of collaborative working. The work of Hughes *et al.* (2012) is also noted. While not a meta-analysis, it is an empirical study that proposes a definition of collaboration based on findings from surveys and semi-structured

**Table 2.** Positioning the development of collaboration theory towards an expanded conceptualization for industrialized building settings.

Assumption of comprehensive theory of collaboration	Characteristics of ib/construction that signals a point for further exploration
Collaboration is led by a single convenor bringing together stakeholders to address a defined problem domain	There may be more than one convenor in construction settings (see Harty 2008). We suggest the possibilities of multiple convenors multiple problem domains should be considered given the fragmented industry landscape.
Collaboration is a human activity involving group and organizational stakeholders	IB settings are permeated not just by people and social groups but also by artefacts/material objects. We suggest the role of artefacts/material objects should be considered.
Collaboration is understood to seek integration and is unitarist, as implied by the terms “convene” and “shared rules and norms”	IB is situated in the construction industry which is fragmented; such unitarist views may not be feasible. We suggest a more tempered alternative to unitary ideals should be considered.
Collaboration, whether temporary or permanent, tends towards stabilization through shared norms of structures	IB networks which by definition use innovative technologies can at least initially be disruptive collaborative arrangements that bring together actants in new ways, for new purposes. We suggest the possibility of collaboration leading to stabilization should be considered alongside the possibility of collaboration leading to disruption.
An external environment shapes collaboration	Collaboration in IB takes place in ways that involve individuals, groups, organizations and supply chains. It is not clear where the environment begins and where it ends. We suggest an alternative to a clearly defined external environment should be considered.

interviews. In systematically examining these papers, our approach is in effect a meta-analysis of a meta-analysis which is very similar to the approach taken by Poirier *et al.* (2016).

Our review leads to a new conceptualization of collaboration in that it allowed us to identify the fundamental assumptions underpinning each meta-analysis. Our review of these studies reveals at least five recurring assumptions about the way collaboration is understood. These five assumptions, along with discussions on how each study maps to each one, are summarized in Table 1. The studies capture the key elements that shape what we would now term the dominant conceptualization of collaboration and we now discuss them in turn.

First, collaboration is driven by a unified, stable goal, often led by a “convenor”. It was common across all the studies in Table 1 to assume that collaborative participants were working towards a goal that was shared. “Goals” referred to missions, visions, objectives, strategies, aims or common value viewpoints. In two cases, the idea of a

“convenor” was also raised. Wood and Gray (1991) noted that the convenor’s task was to establish, legitimize and guide the collaborative alliance using strategies such as persuasion. Mattessich and Monsey (1992, p. 201) likewise noted the primacy of the role of this “skilled convenor”. These premises lay the groundwork for a unitary, top-down view of collaboration where a leader guides a network towards a shared objective.

Second, collaboration is considered a sociological phenomenon in that it assumes that collaborative activity is the work of people or social entities. Hughes *et al.* (2016) described participants as “team members” capable of reflecting and instilling mutual trust and team spirit, characteristics linked to people. Xue *et al.* (2010) echo this human-centric role by pointing to the significance of human behaviours in shaping collaboration. On another level, other researchers (Wood and Gray 1991, Mattessich and Monsey 1992, Schöttle *et al.* 2014) argue that collaboration is primarily a relationship between two or more organizations.

Third, collaborative interactions aim for increasing integration. Collaborating parties are expected to “convene” (Wood and Gray 1991) and adversarial conflicts will then be reduced (Xue *et al.* 2010). Collaboration is discussed primarily in the language of convergence: goals, rules and norms are “shared”, trust and problem-solving are “mutual” (Hughes *et al.* 2016), culture is “jointly developed” (Schöttle *et al.* 2014). Again, these are reflections of the idea that collaboration is unitarist and consensual.

Fourth, increasingly converged collaborative arrangements eventually stabilize through specific structures. Structures can take the form of decision-making processes, policies and guidelines (Wood and Gray 1991), a common project organization (Schöttle *et al.* 2014), or formalized contracts (Hughes *et al.*, 2016). This leads to long-term relationships (Xue *et al.* 2010) and durable, relatively permanent arrangements such as joint ventures (Wood and Gray 1991). This view thus privileges the increasingly reified nature of collaborative arrangements, instead of its contingency.

A final assumption is the idea of a collaborative environment. In general terms this refers to the notion that collaboration is “done” within a larger context. This context has been framed as organizational culture (Xue *et al.* 2010) or as culture in general (Schöttle *et al.* 2014). Mattessich and Monsey (1992) argue that this context comprises geographic location and social elements. Wood and Gray (1991) suggest that this environment is characterized by levels of complexity and stakeholders in collaborative arrangements seek to control this complexity. Collectively these discussions suggest that there is an internal collaborative environment that can be distinguished from the external collaborative environment.

The dominant conceptualization of collaboration, which we have summarized in Table 1, is robust insofar as it has been grounded on existing theoretical and empirical work. There are two points to note about this table. First, we have identified five assumptions that appear to underpin different meta-analyses of collaboration. We are pointing out that the studies share common assumptions but we do not imply that all studies define collaboration in identical ways. For example, each study ultimately chooses to break down collaboration into different aspects or elements. Second, we believe that it is most productive to treat this conceptualization as a platform for further development, not as a confining framework that is to be imposed unreflectively across all cases. Collaborative contexts can differ; for example, they can exhibit varying degrees of homogeneity and coherence. Some settings are more conflict-ridden and litigious than others and the assumption of collaboration as unitarist and consensual should, in such cases, be interrogated.

Industrialized building is one context where a nuanced conceptualization of collaboration has to be considered. This argument is not new; Harty (2008), for example, proposed an alternative conceptualization of innovation in construction settings because existing theories failed to consider construction's fragmented, diverse landscape. Construction settings in general and IB settings specifically have features that set it apart from integrated, consensual settings. First, research has found construction and IB settings involve multiple specialized entities, thus projects are driven not just by monolithic project goals but also by the potentially disparate organizational and personal objectives of project participants (Anvuur and Kumaraswamy 2008). Also, leadership may not be monolithic as multiple parties may play the role of convenors (Harty 2008). These research findings interrogate the idea that collaboration is always clearly centred on a single goal or a single point of leadership (assumption 1). Second, construction and IB settings are permeated by non-human entities such as equipment, structures and funding. Earlier research argues that these entities are active (Tryggestad *et al.* 2010) and this would suggest that non-human actors can play a role in collaborative work (assumption 2). Third, construction settings are known to be fragmented (Poirier *et al.* 2016) and therefore full integration as a collaborative ideal may be untenable as a goal in these contexts (assumption 3). Fourth, construction settings are permeated by supply chains with varying degrees of permanence. Some are durable while others are temporary. Bechky (2006, p. 3) describes temporary organizations as "flexible, discontinuous, and ephemeral; they require 'swift trust' on the part of their members to make up for the limitations of working in the organizational equivalent of a 'one-night stand'". The idea of what constitutes "stable" collaborative

arrangements in construction thus has to be probed (assumption 4). Finally, construction projects involve complex webs of supply chains, not clearly defined organizational entities with distinct boundaries. The notion of a vivid demarcation between the internal and external environment may thus have to be reconsidered (assumption 5).

In summary, we argue that a domain-specific conceptualization of collaboration in IB should take into account the realities of the context. We therefore use the five assumptions underpinning the dominant conceptualization of collaboration as a starting point for developing an expanded theoretical conceptualization of collaboration in IB in housing. These assumptions include collaboration driven by a single convener and a unifying problematique, collaboration as human work, collaboration as seeking convergence, collaboration as eventually stabilizing, and collaboration as taking place within a clearly demarcated external environment (see Table 2).

### ***Implications for selecting a network-based analytical approach***

We argue here that our objective of extending the dominant conceptualization of collaboration can be addressed by employing a network approach. Network studies of organizations are premised on the assumption that much of social reality can be explained by understanding the patterns of interaction and relation that arise between actants in a given context (Kilduff and Tsai 2003). They are distinct from other traditions in the social sciences in that they depart from "atomistic perspectives" wherein "individual actors are depicted as making choices and acting without regard to the behaviour of other actors" (Kilduff and Tsai 2003, p. 3). Network approaches have been described as well-suited to construction contexts, mainly because construction projects are complex undertakings that generally involve several organizational actants, leading researchers to argue that conceptual approaches that emphasize the firm as an autonomous unit of production tend to be incomplete and limiting (Pryke 2012). The fact that this study focuses on collaboration in construction strengthens this argument, given that collaboration is by definition a type of relationship.

While network approaches are diverse, we specifically mobilize concepts from an analytical approach called ANT. ANT is premised on the assumption that much of reality is the outcome of human and non-human actants interacting together in networks (Latour 1987, Law 1992, Callon 1999). There are four main reasons why we feel it is one of the most suitable approaches to address our research goal. First, ANT has a conceptual toolkit with components that allow us to explore the five limiting assumptions of mainstream conceptualizations of collaboration. As we

**Table 3.** An overview of the analytical approach.

Claims of dominant conceptualization (Wood and Gray 1991, Mattessich and Monsey 1992, Xue <i>et al.</i> 2010, Schöttle <i>et al.</i> 2014), Hughes <i>et al.</i> 2016)	Ant concept	Possible conceptual value for collaboration
Current theory assumes a single convener and a unified, stable goal	Prime mover; problematization; translation	Key ANT concepts can provide a frame for examining how collaboration is driven: the role of the convener can be examined as prime mover and the work of convening can be examined as the work of translation. Importantly, ANT's "ruthless empiricism" can potentially carve out space to identify complexities in this seemingly orderly effort
Current theory assumes that collaborative work is a human activity	Generalized symmetry	ANT can enrich the concept of collaboration by highlighting how it is the work of humans as well as non-humans
Current theory places and emphasis on achieving integration, for example through trust or relationship building	Interactions Relational materiality Convergence	ANT's definition of convergence provides a conceptual device for exploring the affordances and limitations of complete integration in collaborative settings
Current theory explores the role of "structures" in collaboration, implying that collaborative arrangements can become fixed and reified	Stabilization and contingency	ANT can allow researchers to explore how "immutable mobiles" can capture structures that make collaboration durable, but ANT researchers also argue that these arrangements are always contingent
Collaboration theory emphasizes the need to understand factors in the "external environment" that help or hinder collaboration.	Multiplicity	ANT reframes an understanding of the "collaborative context". With ANT, a collaborative network is not set in a monolithic setting called an "environment"; it is a network enmeshed in other existing networks.

will show later, the ANT concepts of prime movers and problematiques, general symmetry, convergence, stabilization and multiplicity can, in that order, be used as starting points for extending the limits of assumptions 1–5, discussed earlier. Second, ANT is a qualitative approach committed to detailed levels of empiricism that allow us to discern the nuances of collaboration as a little-explored phenomenon in IB. Hardy *et al.* (2003) note that the details and nuances of qualitative approaches can help develop a more comprehensive understanding of collaboration, in ways that quantitative approaches cannot. Third, ANT is a network approach that foregrounds inter-relationships rather than autonomous actors and therefore it captures the inter-organizational complexities associated with construction settings (Pryke 2008). Finally, ANT upholds a methodological commitment to "following the actors" (Latour 2005), which allows researchers to move away from the stance of predefining a collaborative network at early stages of a study and setting up a possibly arbitrary demarcation between who is and is not part of a collaborative alliance. This lays the groundwork for identifying collaborative actors which could otherwise be overlooked.

In this next section we discuss the key ANT concepts of prime mover and problematiques, general symmetry, convergence, stabilization and multiplicity and show how they accommodate the characteristics of IB contexts in ways that extend mainstream conceptualizations of collaboration. Two important points are noted. First, we employ the term "extend" to highlight that we are seeking to enrich, not debunk, the dominant conceptualization of collaboration. Second, ANT is an approach that is far from

monolithic and ANT scholars mobilize it in ways that sometimes raise internal contradictions within the theory. What we present here, then, is not "the" definitive way of mobilizing ANT in its pure form, as such a pure form does not exist. Our aim is much more modest: to show that specific ANT concepts can sensitize us to nuanced forms collaboration that emerge in IB settings. The term "collaboration", currently associated with coherence and integration, can thus be conceptualized more broadly than how it is currently portrayed. This process of extending the dominant conceptualization of collaboration requires identifying points of tension where enrichment can occur. These are summarized in Table 3 and are discussed more extensively in the following section as well as in the analysis section.

### Prime movers and translation

In ANT, much of the work of creating a network is attributed to a key actor known as the *primum movens* or prime mover. The idea of such a key actor has considerable overlaps with Wood and Gray's (1991) and Mattessich and Monsey's (1992) idea of a convener, but goes further by suggesting a logical sequence to this key actant's tasks. According to ANT scholars, a network emerges when a prime mover identifies a problem and frames it, along with a possible solution, in a particular way (problematization). The prime mover then begins attributing characteristics and interests to potential actors who can play a role in addressing the problem. The key actor demonstrates to these disparate players that their different goals can only be achieved through a commitment to a single programme

as defined by the prime mover (obligatory point of passage). This puts the potential enrolees in a dilemma where they must choose between identities as defined by the prime mover and other competing identities (*interessement*). A number of actors may consent to the prime mover's programme and are successfully enrolled into the network. A possible condition of such enrolment is that actors may take on narrow, simplified roles. Other actors, however, may resist enrolment. After enrolling actors, the prime mover then seeks (successfully or unsuccessfully) to stabilize and extend the network (Callon 1999). While networks may sometimes appear stable and converged to the point of being seen as a single black box, they are always provisional and contingent (Law 1992). This process of problematization and enrolment marks the beginning of a process known as "translation" (Callon 1999).

### Generalized symmetry

According to ANT scholars, networks are made up of human and non-human actors. This is an assumption known as generalized symmetry (Law 1992) and is radical in that it paves the way for examining how humans as well as objects in construction settings could have a role in collaborative activity. General symmetry interrogates the dominant assumption that participants in collaboration are "stakeholders" in the form of groups and organizations. To highlight this broader understanding of network participants, we begin at this point to refer to them as "actants". Past ANT studies in construction have taken this view by portraying objects as actively "behaving" in certain ways (see for example Tryggestad *et al.* 2010).

Human and non-human actants can form networks that are large or small. ANT scholars analyse these networks in the same way regardless of size. Defining a network's boundaries is an empirical matter and is achieved by "following the actors" (Latour 2005). Early in the research process, researchers identify an initial pool of possible network participants and begin gathering data. As findings from the study unfold, these are used to identify other actors who are also part of the network (Callon 1991). As mentioned earlier, "following the actors" means that network boundaries in ANT are thus not pre-determined at the start of the study.

### Relational materiality and convergence

In the work of Wood and Gray (1991), relationship is conceptualized as *autonomous stakeholders* who are convened and then begin to engage in *interactive processes*. ANT positions itself differently, as it assumes the essential characteristics of autonomous actants are irrelevant. Instead ANT scholars claim that important attributes

emerge only as actants interact with one another, thus "... [creating] convergences and homologues by relating things that were previously different" (Callon 1981, p. 211). Convergence is thus another key concept in ANT. A fully converged network is one that is understood to be a single, punctualized black box (Law 1992). What is interesting is that convergence does not seem to imply homogenizing different things; Callon's (1981) definition seems to suggest it involves *relating* different things into a network without forcing them to be the same.

### Network effects, stabilization and expansion

The interaction between actants eventually stabilizes, with stabilization first being achieved at a local level. When a network has stabilized, it settles around a programme of action geared towards achieving network goals. The *primum movens* can then seek to extend this ordering over time and over space to more locations (Callon 1999). The strategies for doing so are varied; our review of meta-analyses identifies some as shared norms, rules and structures. In this sense, the dominant conceptualization and ANT are significantly aligned. However, ANT also emphasizes the contingency of these stabilizing structures, as researchers argue that networks can fail at any time (Law 1991). In foregrounding destabilization alongside stabilization, ANT emphasizes the importance of exploring how stable collaborative networks can be also destabilized, not just as an unexpected outcome of actants resisting, but perhaps as a result of deliberate strategies mobilized by a revolutionary prime mover. Put another way, ANT provides the conceptual space to explore how new collaborative networks can deliberately be created to disrupt existing collaborative networks, an important consideration in IB settings where radical technologies and work arrangements are introduced.

### Multiplicity

Another important concept that accounts for the complexity of ANT networks is multiplicity, which can take a number of forms, for example actants having a range of attributes and identities, or actants having memberships in multiple networks. Singleton and Michael (1993), for example, examined how an actant could be part of several networks at once, leading to ambivalence as they sought to fulfil multiple conflicting roles. Thus realities do not always emerge from networks that are clear and a network outcome can be shaped by multiple networks. Furthermore, these networks may exhibit various degrees of (mis)alignment, with actants pursuing different or mixed goals. Multiplicity, then, calls into question the dominant assumption that a collaborative arrangement is a bounded

entity operating within a clearly defined external environment. ANT takes an alternative view as it portrays the collaborative arrangement as a network enmeshed in other networks and external “challenges” as possible issues of network misalignment.

## Methods

To address our research question, we have conducted in-depth qualitative case studies of Australian-based housing supply chains using large-scale collaboration to pursue innovative industrialized building techniques. These case studies are part of a three-year nationally funded research project.

### Case study design

Our research design involves multiple qualitative case studies. The use of qualitative case studies is useful in this case because it allows us to capture the complexities of collaboration in IB settings in ways that quantitative studies cannot (Hardy *et al.* 2003). Our case studies are therefore exploratory in that they are contexts for examining a phenomenon that is little understood and significantly social. Each case study presented here is a network of individuals, organizations and non-human entities. As discussed earlier, these networks were not predefined, but were allowed to emerge. This is consistent with ANT principles.

Our selection of multiple case networks was driven by two goals. First, we sought to achieve maximum variation to increase the generalizability of our findings (Flyvbjerg 2006). This decision was reinforced by our consultations with industry partners who are part of the project steering committee, who noted that maximum variation would make findings more relevant across a larger set of IB scenarios. Our five cases’ characteristics therefore reveal a mix of diverse features. For example, our mix of cases showed the focal organizations of each network as being at different life stages (two start-ups, two in growth stage, one mature), producing different housing types (detached, low-rise and medium rise) and mobilizing IB at different levels (manufacturing components, systems and modular housing). This type of case selection is consistent with what is referred to as a “loose design”, and it is appropriate in situations where a new field is being explored and where theoretical constructs and concepts are limited and underdeveloped (Flick 2004).

A second reason for exploring multiple case studies is due to the fact that our research goal involves examining collaboration along several dimensions. Flick (2004, p. 150) argues that “if [multiple] dimensions [of a phenomenon] have to be considered, then a number of cases have to be considered for each of the manifestations”. The breadth

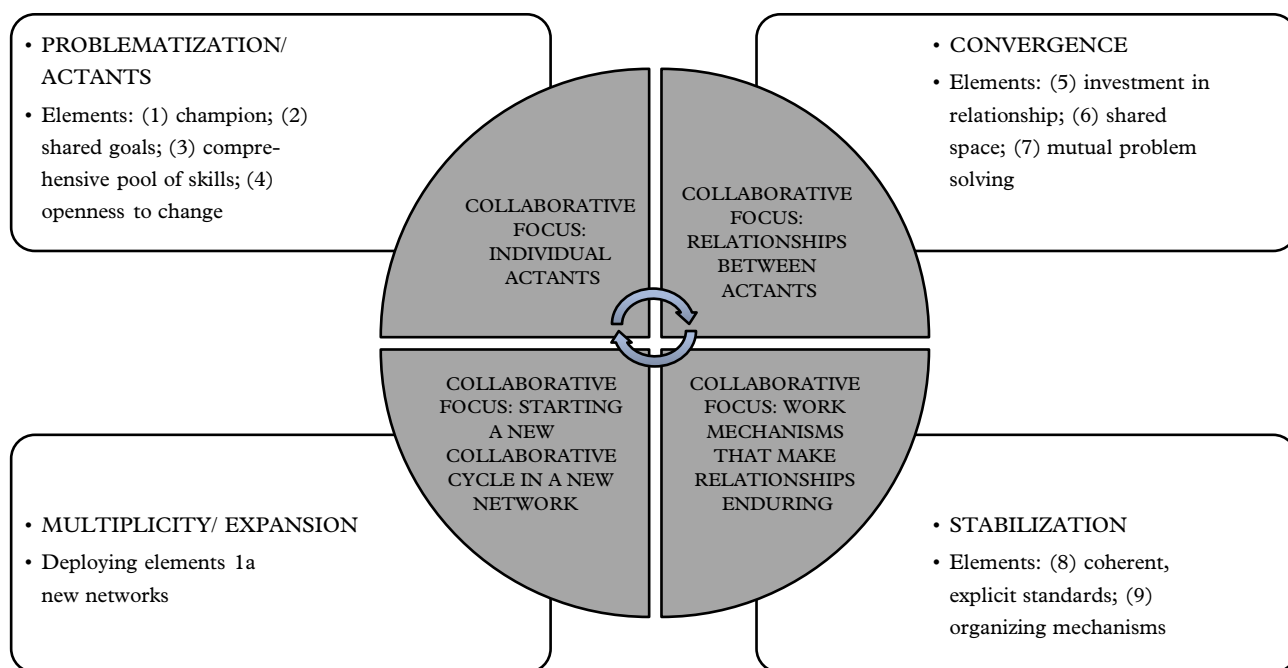
afforded by multiple case studies thus provides a more robust empirical basis for addressing our multifaceted research question.

A multi-case design, however, leads to the challenge of having to manage then subsequently meaningfully present large volumes of data in a succinct manner. We are therefore caught in a dilemma where we need the breadth of multiple cases to demonstrate some degree of generalizability, but we do not have the space to present in-depth findings for five cases. To address this dilemma, the strategy we take is two-fold. We limit our in-depth discussion to two case studies which, as we show in a later section, have been chosen because of key similarities and differences. However, following this discussion we also present summary findings of the other three case studies. When the summary findings are taken alongside detailed findings of the first two, we are able to show that there is a strong basis, grounded in five diverse cases, to support the overall goal of this paper: that there is a need to interrogate the prevailing dominant assumptions underpinning work on collaboration.

### Data collection

In examining each case network, we began by identifying a focal organization which was seen to lead an IB innovation. Actors were identified within these organizations through a coordinator, a “point person” who played a key role in a project and was able to identify other relevant participants. Our main criterion for participant selection was a human actant’s meaningful participation in the large-scale IB initiative under consideration. However, we did not limit ourselves to participants selected by the coordinator, or to participants within the focal organization, or even to human actants. As findings unfolded we were led to other actors of the network, oftentimes in other organizations.

For these 5 case studies, we conducted 29 detailed interviews, each 1–2 h in duration, with managers of companies in construction supply chains, as well as selected partners such as architects, structural engineers and fabricators.<sup>1</sup> Interviewees were provided with written information on the overall objectives of the project: to identify barriers and drivers to IB, to identify drivers and barriers to collaboration and to understand the link between collaboration and performance. This paper focuses primarily on the second objective. Given the qualitative stance, questions were broadly framed in line with these objectives (“Who did you collaborate with?” “What made that successful?” “What made that challenging?”). The broad line of questioning led to rich narratives that tackled a broad range of topics. In the course of conducting interviews, we were also able to visit yards and factories where IB innovations took place and we were given additional materials such as videos,



**Figure 1.** Categorization of themes into nine collaborative practices, linked to ANT concepts.

photos and company presentations, which allowed us to develop a more nuanced understanding of the context of operations. Importantly, these additional resources provided a preview of important non-human actors that were part of the network. The identification of non-human actors was thus based primarily on “a systematic reading of the empirical material to ... identify objects with a significant role in the chain of events” (Tryggestad *et al.* 2010, p. 698). For example, as interviews from Case Study 1 were transcribed and coded, we noted frequent references to objects such as “cassette floors” or face-to-face meetings “in a single room”. Such frequent references became the basis for noting which non-human entities could be classified as “active” in the collaborative process.

### Data analysis

Interviews were transcribed, then coded using NVivo. NVivo was used primarily as a data management tool for organizing and categorizing quotes into a hierarchy of themes. Based on our 29 interviews, a total of 102 different themes emerged. To give some very brief examples: questions on drivers of IB yielded themes such as increases in speed, customization and worker health and safety; barriers to IB included themes like technical challenges and regulatory hurdles; drivers of collaboration included themes such as positive attitudes towards change and the definition of clear roles for partners; barriers to collaboration included themes such as unclear positioning of the lead organization and the difficulties brought about by increased transparency. The 102 themes were deliberately

defined in a fine-grained manner to support significant interpretative flexibility.

This study focuses primarily on the 72 themes that were linked directly to the drivers and barriers of collaboration. These 72 themes were categorized into nine collaborative practices, which in turn were further classified under the specific ANT concepts of prime mover and problematization, general symmetry, convergence, stability and multiplicity. This is shown in Figure 1, which we discussed more extensively in other work (see Pablo and London *in press*).

In-depth case studies such as the ones we have conducted are useful in that they yield generalizable learnings which provide rich insights on little-explored phenomena (Flyvbjerg 2006) and are useful for theoretical development (Eisenhardt 1989). Findings from our case studies are generalizable in at least two ways. First, they can as discussed earlier be generalized to diverse IB settings, not just one type of IB setting. Our diverse cases, for example, interrogate the common assumption that collaborative IB networks are led by large firms with considerable capacity for investing in research and machinery. Our findings (discussed in narrative form and in Table 4) show that collaborative IB networks can in fact be led by firms of different sizes, at varying levels of maturity and with various levels of investment in equipment. Actants in firms that are small or have limited investment capacity and are contemplating a shift from traditional building to IB can thus still benefit from these findings. Second, findings can be generalized to collaborative networks outside of construction, possibly in domains that are less fragmented, conflict-ridden and litigious. In these cases, the lessons on collaboration we

**Table 4.** Justification for an expanded conceptualization of collaboration.

Ant concept	Case study 3 (Interviews = 6)	Case study 4 (Interviews = 6)	Case study 5 (Interviews = 5)
Background on focal organization	A small South Australia-based regional builder of transportable houses. Case study was conducted at a time when the focal organization was in major transition due to a change in CEO	A small Tasmania-based design/build company focused on component-based prefabrication targeting customized houses with very complex designs. Case study was conducted at a time when the company was transitioning from a single company with different functions (design, consulting, manufacturing, building) into four separate entities	New Victoria based organization also using German technology similar to that in Case Study 2. Equipment manufactures roof, floor, and wall systems. Significant investment made to bring in European partners for installation and training. Recently completed first project. Targets completion of 400 houses per year
Prime mover and translation	Prime mover position shifted from one actor to another	Moves from a single prime mover to multiple prime movers. Suggests collaboration can take place under more distributed leadership arrangements, instead of under a single convener	Surprisingly, no mention of a single individual seen to be responsible for establishing the new company. More research needed to examine under what circumstances a more nebulous conception of a convener is effective
Generalized symmetry	Houses were a key player in collaboration. Their simple designs dictated the emergence of straightforward collaboration processes	Much of the operations focused on the resourceful use of a single CNC machine that was stretched to fulfil diverse functions. An example of a single piece of equipment being core to collaborative operations	Another example of equipment and factory being significant collaborative players, as they defined significant aspects of collaborative work which was set up in a linear, sequential manner
Convergence	Repeated references made to too much emphasis being placed on community relationships, often at the expense of performance. Suggests that an overemphasis on relational convergence can be limiting	Found that “de-converging” through the uncoupling of functions (by splitting a single organization into four different ones) better supported collaborative organizations, as compared to full convergence under a single umbrella	Very high levels of operational convergence because of exceptional precision of processes and standards. Leads organization to internalize manufacturing rather than relying on external suppliers. Worth exploring if this is a case of internal convergence discouraging external convergence
Stabilization	New CEO seen as deliberately “destabilizing” existing relational collaborative arrangements in favour of more contractual ones	Former CEO deliberately “destabilizing” existing collaborative arrangements under a single organization, to support more organic collaborative arrangements across four separate entities	“Stable” technology soon to be mobilized as a potentially destabilizing force in the industry. Plans in place for the company to set up a unit that will capitalize on creating new knowledge/intellectual property on prefabrication, to be disseminated to other parts of the sector
Multiplicity	New CEO speaks of company being myopic and locked into small regional market. Indication of narrow definition of market as a single regional network, instead of acknowledging multiple overlapping networks for transportable housing	Increasing need to understand that what was previously a single network is now four overlapping networks. Considerable work being carried out to define interactions that define these overlaps. For example, many informal inter-unit transactions (between designer and builder) are now being formalized and billed	New organization depicted as being nested in overlapping networks: it is a network within a larger parent organization, within a web of European partners and as part of the industry

present here can be employed with a significant level of confidence. This is based on Flyvbjerg's (2006) argument: that if these collaborative lessons work in highly pluralistic environments, they could be expected to work in more monolithic and consensual ones. IB and construction contexts, therefore, are potent sites for the development of theories of collaboration as they can be acid tests for the robustness of collaboration models that can be deployed in more benign areas.

It is important to note our case studies, while detailed and nuanced, are qualitative in nature and thus findings are not meant to be deployed in formulaic ways. Researchers and practitioners are invited to examine our recommendations, but just as importantly they are also invited to

look into our case descriptions and analyses *in order to come up with their own interpretations and action plans*. As researchers undertaking a qualitative case study, our aim was to come up with *one* possible robust and systematic interpretation of the data. To do so we have done three things: we sought transparency in the way we moved from coding to analysis to detailed interpretations; we sought a form of validity in that we presented our interpretations in quarterly meetings to non-academic industry partners who are part of the research project's steering committee, to obtain their feedback; we have sought performativity in our interpretations through detailed themes, in-depth narratives and cross-case analyses, which collectively demonstrate “a plausible case that patterns in the meaning of the

text are constitutive of reality in some way" (Hardy *et al.* 2004, p. 21). But because it is not a quantitative study, we did not seek formal measures of intercoder reliability, nor do we put forth the claim that ours is the only single robust and systematic analysis that can emerge. Consistent with our interpretivist stance, we argue that other interpretations can emerge and that differences in multiple robust interpretations are not problematic. In fact, multiple interpretations can be enriching (Hardy *et al.* 2004).

### **Description – case study 1**

Case Study 1 is a supply chain led by a diversified property group, referred to here as Company 1. Company 1 is a national leader in housing development with an employee base of approximately 600 people. The company is well regarded for corporate social responsible goals. Company 1's housing projects in Australia typically include detached, low-rise and medium-rise timber-framed apartment buildings. The company recently led the development of an offsite innovation in the form of a floor cassette system. Floor cassettes were manufactured offsite out of timber floor joists constructed into panels with engineered floor sheeting. They could be manufactured on a large scale, then craned into place, resulting in faster construction times and improved worker safety. The development of the floor cassette innovation emerged in the midst of a five-stage housing project. In early stages, the project team had made use of concrete floor slabs, which posed among other things the risk of fall from heights. In 2012, increasing concerns over the flooring system led the construction director to carry out research on alternative flooring solutions in Europe. The construction director, referred to here under the pseudonym Francis, presented the concept of the floor cassette to the executive team, secured approval, then with the estimating manager Barry brought together a team of key suppliers, designers and consultants that developed a prototype for a timber floor cassette. After six months of frequent, face-to-face meetings, a prototype was developed and was eventually used in Stage 4 of the project, a five-storey timber building. Use of the floor cassette led to the building being completed one month early and to a 25% reduction in costs. Shortly after this, the floor cassette was also successfully used in the construction of 48 two-storey homes.

### **Description – case study 2**

Case Study 2 is a supply chain driven by a start-up in Victoria, Australia, referred to here as Company 2. Company 2 has yet to begin operations. The organization's stated mission is the manufacture of precision-engineered wall and roof elements for timber frame construction, in a fully

automated factory using German technology. Executives see the company as a catalyst for radical change in the timber construction industry, claiming their approach will usher in a revolutionary shift from building construction to building assembly based on "lean" manufacturing principles. Executives claim that once the factory is operational, its teams can assemble a bespoke two-storey house in two days with a workforce of five, a crane and a single truck delivering materials on a real-time basis to the building site.

The current CEO of Company 2, Eric, is a former executive of the car manufacturing industry; a number of key executives come from the same family. Company 2's major challenge at present is obtaining financing to this machine. While a 40% down payment has been made, there has been a long and protracted process in finding the remaining 60%, mainly because of restrictions in financial regulations. Skeleton operations were originally set for March 2016, but have yet to begin.

### **Similarities and differences**

We have chosen to discuss Case Studies 1 and 2 because they share common goals and some contextual similarities, but they also possess interesting contrasts. Our research design thus involved a within and cross-case comparative analysis, allowing "the analysis and synthesis of the similarities, differences and patterns across two or more cases that share a common focus or goal" (Goodrick 2014, p. 1).

In terms of similarities, both companies are in the state of Victoria, seeking to influence the housing industry to shift to industrialized building techniques. Both are pursuing the same business strategy of serving the broad national housing market. Importantly, both are in "start-up mode", albeit in different ways. Case Study 2 was, at the time of interview, literally setting up shop, furnishing its head office and working to import equipment. Case Study 1 showed Company 1 not as a literal start-up, but nevertheless at a critical point of discontinuity: the development of the floor cassette, an event that was decisive in ushering in a time of intense building of new networks, new processes and new systems during which a number of collaborative practices emerged.

There are also numerous differences between these two firms. Company 1's business strategy involves mass customization, whereas Company 2 claims its houses will be completely bespoke. Company 1's floor cassette emerged primarily from a concern over worker safety; Company 2's innovations stemmed initially from family business interests, then a desire to overhaul the industry and, to a limited extent, to take advantage of the environmental benefits of manufacturing with timber. Company 1 has limited itself to the floor cassette, while Company 2

is poised to manufacture wall and flooring systems. This mix of similarities and differences can potentially allow us to “obtain information about the significance of various circumstances for case process and outcome” (Flyvbjerg 2006, p. 230).

### Case studies 3–5

Space limits prevent us from discussing our other case studies in detail. Nevertheless, we have compiled sample findings from case networks 3–5 to highlight how their collaborative activities, analysed using ANT concepts, also support the need for an extended conceptualization of collaboration. We show these sample findings in Table 4.

## Analysis

### Case study 1

#### Prime mover and translation

ANT theorists argue that network building begins with a prime mover initiating the process of translation. Our initial analysis of Case Study 1 seemed to suggest the prime mover of the network was Company 1 itself. This is because interviewees made frequent reference to “Company 1” as an entity acting with agency: “Company 1” defined a problematique framed around unsafe and inefficient flooring system, developed the solution in the form of “... a system that can be built offsite and installed in modules and significantly reduce the risk of fall from height”, then carried out enrolment in a well-researched, calculative manner, doing “research on [each] company” and eventually recruiting selectively.

Interviews suggest invited actants who willingly enrolled in the network did so because of a desire to align with “Company 1”. They saw Company 1’s proposal as an intriguing but risky opportunity to fulfil their own objectives (ANT’s obligatory point of passage). The partner-architect we interviewed, for example, saw the proposal as an opportunity to capture a market niche: becoming “the” architectural firm that would specialize in designs incorporating floor cassettes. Another significant motivator for actants was that Company 1 holds a significant market share, a high degree of purchasing power and a reputation for being a “good corporate citizen”. At least one actant that agreed to be enrolled by Company 1 willingly took on a simplified role in relation to others. A timber solutions firm that was enrolled into Company 1’s network, for example, was capable of designing as well as manufacturing floor cassettes, but in this case it agreed to limit its involvement to design and initial fabrication. Firm representatives explained demanding a large and

ongoing manufacturing role would “challenge the supply chain” and therefore refrained from insisting on an enlarged role.

The initial analysis is useful insofar as it briefly shows how some key ANT concepts such as prime mover, translation and enrolment can aid analysis on how a collaborative network emerges. ANT concepts so far support the dominant conceptualization in that both point to the process of convening led by an organization. However Whittle and Spicer (2008, p. 619) caution against the use of ANT concepts as simple categories deployed unreflectively in ways that limit further critical analysis of data. They remind researchers that ANT’s commitment to deep empiricism compels researchers to explore if translation “could be ongoing, iterative, disorderly and disjunctive rather than a linear one-way process”. We have thus deepened our analysis using a number of strategies, one of them being Latour’s (2005) guideline of following the actors. In doing so we have begun to identify potential points of departure relative to the dominant conceptualization of collaboration.

ANT sensitizes us to the idea that our initial identification of an organization as prime mover may have been an oversimplified interpretation. The ANT concept of punctualization (Law 1992) points to the idea that organizations might be black boxes masking a complex set of actants. In probing more deeply during interviews, we found there were two prime movers in this case and both are influential human actants. One was the construction director, Francis, who headed the housing project where the floor cassette was first used. He was a high-level executive who was described as “the main guy” who “built all the bridges” in this network of actants and who initially proposed the cassette to the executive team. The second was the estimating manager, referred to here as Barry, who was described by interviewees as facilitating many of the intense round-table discussions with the multi-disciplinary team that was tasked to develop the prototype of the floor cassette. One interviewee recalled

... if you had to say which person said, “Let’s do it,” it’d be Francis and then which person did the hard yards in getting the numbers sorted and getting – talking to [partners] and working out that it was a possibility to do it, going to the meetings; that would be Barry, with Francis’ protection and mentorship, if you know what I mean? – Alex, Development manager, Company 1

A second finding was that problematization was not carried out in a unified manner across the entire network, but appeared to morph over time and across different sections. Francis and Barry were both very much involved in onsite work and spoke extensively about worker safety and the limitations of existing flooring solutions as drivers for the shift to industrialized building techniques. The general

manager of Victorian operations, who was relatively new and appeared to be more involved with strategic matters, described the problematique leading to the floor cassette as primarily aligning with corporate ideals of environmental and community sustainability, without discounting the fact that “we’re very focussed on obviously making money”. Meanwhile, former executives that had been involved with the project discussed the project with the media and highlighted efficiency gains from industrialized building techniques in the form of reduced construction time and cost savings (Jewell 2014).

A third area of complexity was the strategy used for framing the shift into IB. In describing the change to the media and to the general public, Company 1 interviewees and partners framed the initiative as “revolutionary”, with far-reaching repercussions on the structure of the labour market as well as on the manner which housing would be delivered in the future (Jewell 2014). In speaking with partners, however, it appears that the language used was highly restrained, conservative and linked to more cautious, incremental change:

I think a lot of people want to go from A to P immediately. I say let’s get to B, C, D, E and those are the baby steps that, I guess, generate because if you try and jump straight to P you’ll fail. – Barry, estimating manager, Company 1

The use of ANT and its methodological commitment to empirical detail thus provides potential theoretical insights into collaboration that are different from the prevailing dominant assumptions. The most significant insight is that successful collaboration can be “ongoing, iterative, disorderly and disjunctive” (Whittle and Spicer 2008, p. 619). Collaboration in this case was underpinned by layers of disjointedness instead of integration: multiple prime movers, fragmented and incoherent problematization and an inconsistent strategy in deploying language to frame the change associated with a disruptive industrialized building innovation according to the audience. Importantly, collaboration was successful even when it was pluralistic and not seamless. This is significant in industrialized building settings, where projects are supported by seemingly integrated manufacturing processes but still entrenched in a conflict-laden, adversarial domain (Phua and Rowlinson 2003, Chan *et al.* 2004). A second important insight is that individuals can be important stakeholders in collaboration. In this case, the role of prime mover was played by individuals. This questions the assumption in meta-analyses that stakeholders are primarily groups and organizations. The importance of individuals also interrogates common assumptions that supply chains are collaborative relationships that should be analysed primarily as a series of links between organizations such as manufacturers, their suppliers and their customers (Frohlich and Westbrook 2001).

In the next section, we use ANT to interrogate this limited definition of “stakeholders” in an even more radical way.

### Generalized symmetry

According to ANT, prime movers create networks composed of human as well as non-human actants. This departs from definitions of collaboration as interactions and relationships between “parties”, “stakeholders” or “actors” who embark on activities like negotiating shared goals or execute joint decisions. This human-centric assumption also underpins much of the research on supply chains, where it is largely assumed that any coordination and interaction that takes place involves “decision-makers (i.e. *human beings*) from economic institutions based on a division of labor” (Halldorsson *et al.* 2007, p. 286, emphasis ours).

Case Study 1 has carved out space to consider the role of non-humans in construction. A particularly vivid example involves the floor cassette. The floor cassette took on different forms. The artefact began as an idea on paper, developed into a sample prototype manufactured in a yard and is now a mass-produced commercial project. At each stage, it was a key actant that played a role in organizing the complex sets of collaborative arrangements surrounding it. In its drawing form at the design stage, for example, it “disciplined” groups of people, compelling them to design and fabricate in conformance with strict specifications:

So we had a drawing which had all the details of the fabrication of the floor cassette and a quality system on the side which the manufacturer had to check, so [too] the fabricator. And then there was [*sic*] two sections ... our team actually went out and measured and checked the floor cassette. – Partner engineer, Case Study 1

As a new prototype being used for the first time, it radically altered the way tasks were distributed. The floor cassette displaced multiple carpenters who had formerly laid joists and sheets, created new jobs around automated manufacturing and paved the way for a role for cranes, which now had to be enrolled as non-human actants. Finally, as a mass produced product, the floor cassette necessitated the enrolment of more non-human actants in the form of a full-scale factory and manufacturing equipment, opened up new markets in the form of customers shifting from traditional flooring, shifted recruitment standards in ways that privileged manufacturing skills over traditional carpentry and created a new information technology-based function that previously did not exist: interfacing with clients who require various degrees of customization. In short, it was “active” in the collaborative process in that it set the tone for many of the complex collaborative relationships that emerged between itself and other humans and non-humans. This has important implications for understanding collaboration in IB. When planning an IB

project, it is no longer sufficient to consider which humans, groups and organizations should be included. "Planning" a collaborative project would mean identifying individuals, groups, organizations, equipment, products, tools and a myriad of other actants. In short, both human and non-human actants are part of the equation; in certain cases, non-human actants might even be weightier in that they are treated as less flexible and less negotiable. Thus it is also inadequate to frame the management of collaborative activity to purely social dynamics. An understanding of collaboration in IB must take into account how non-human entities like objects and texts can "authorize, allow, afford, encourage, permit, suggest, influence, block, render possible, forbid, and so on" (Latour 2005, p. 72).

### **Relational materiality and convergence**

As human and non-human actants are enrolled in a network, they begin to interact and their attributes emerge. ANT scholars thus claim they have no *a priori* assumptions about essential attributes of actants. Neither social nor technical actants, in and of themselves, unilaterally shape the network; it is interactions between actants that are crucial. This was evident in Case Study 1. The construction manager, Francis and the estimating manager, Barry, had sought to systematically recruit engineers, architects and regulators into the network on the basis of their qualifications. However, these actants' so-called attributes – their qualifications, track records and expertise – were in one sense of diminished relevance since all actants were moving into an uncharted territory, thus one partner architect commented, "none of us knew anything about the cassette floor". The representative of the timber solutions company likewise recalled that he had jumped on board the network by saying "Yes of course we can do it", but then "had to go away and work out how to do it". It was unknown if and how actants would actually "rise to the challenge". In the language of ANT, it was not clear how these actants would interact with one another and what kind of attributes or outcomes would emerge.

One mechanism that facilitated the emergence of favourable attributes was team meetings. The estimating manager set up six months of frequent face-to-face meetings that would run until the prototype was deployed. Interview data clearly shows that Company 1 facilitated these face-to-face meetings but specialists actively participated. This was a strategy of convergence, defined by ANT scholars as comprising two elements: alignment (shared space and shared history) and coordination (Crawford 2005). In this case, team members who were recruited to work on the floor cassette prototype were all too aware of its novelty and their own collective lack of knowledge. But this did not mean that Barry or Francis dominated the

meetings as the only experts. They were very much the central "conduit" for information, but the environment was egalitarian in so far as discipline specialists were treated as authorities when a problem in their area arose and were thus allowed to take the lead as appropriate. There was also an emphasis on solving problems in a collective manner, as well as an emphasis on anticipating rather than reacting to issues. The meetings contributed to alignment through the use of a literal shared space that facilitated intense interaction:

By us having everyone there at the table once we hit an issue we can ask that discipline, how do we get around it, what are my options, bang. Decision is made right there and then, you move on. – Barry, estimating manager, Company 1

This intense interaction then led to actants in the meeting being transformed:

... it's a momentum. It just builds moment and momentum and people catch on ... Yeah, the positivity just really catches on. And people start becoming like-minded when you put that group together ... everyone was very narrow-minded but by the time you finished with the group after six months, everyone knew, okay, if I put this floor joist here it will do this to acoustic, it will do this to fire. Everyone becomes a little bit more understanding of how each other thinks. – Barry, estimating manager, Company 1

The reference to "like-mindedness" is interesting, as it seems to imply that ANT's foregrounding of convergence is equivalent to seamless integration as an ideal. Following this interpretation, ANT seems consistent with the dominant conceptualization in that collaboration involves entities that come to "share a negotiated order" (Wood and Gray 1991, p. 148). We argue, however, that ANT does not push for sameness in the simplified sense. While it was true in this case that specialists were described as becoming "a little but more understanding" of other disciplines, they did so while continuing to take charge of knowledge creation in their own specific domains. Like-mindedness and convergence did not mean the gradual creation of team members all thinking in exactly the same way. Members retained their own domains of knowledge, but had sufficient understanding of other domains that allowed for negotiation as well as debate. Thus an interviewee, when asked to recount what had happened at meetings, described them as powerful collaborative mechanisms:

... that's why we have people around the table because I know I don't know engineering to the nth degree but I've got a fairly good understanding of it from a frame and truss point of view. But to draw on knowledge from these guys has given me a bit more confidence in making decisions in big meetings to say, guys I think we can do this." – Barry, estimating manager, Company 1

This supports the view of Callon (1991, p. 148), who cogently argues that a network can be converged while remaining differentiated:

... a totally convergent network would thus be a kind of Tower of Babel. Everyone would speak their own language, but everyone else would understand them. Each one would have specific skills, but everyone would know how to use them.

### **Network stabilization, network effects**

Following six months of intense prototyping, actants felt they had “learned” how to pattern their work and became confident enough to try to move into mass production. The process of replicating the process was “not as intense, because the learning had already taken place”. The diminishment of intensity and its simplification of work into regular rhythms suggest the network was settling into a stable pattern of activity.

ANT scholars claim that one way for a converged network to achieve stability is to take a network’s programmes of action and to inscribe them into devices that in effect extend the reach of a network: texts, oral messages, technological artefacts like machines, social artefacts like institutions. Latour (1991, p. 129) points to these stabilizing devices as technology, defining the term as “the moment when social assemblages gain stability by aligning actors”. In Case Study 1, we can argue that there were two stabilizing technologies: the floor cassette itself and the equipment that eventually mass produced it. Both technologies allowed the product and the construction methodologies to be replicated in other settings. Early efforts at expansion were successful. Following the initial project, mass production of the floor cassette began and the floor cassette was successfully used in a project involving 48 two-storey detached homes. The project was completed in six and a half months, instead of the projected 12 months.

Following this initial success, however, efforts to replicate the network in another state of Australia did not prove to be effective. The inability to expand stable network programmes into another location can be explained in a number of ways. One explanation offered by ANT is that collaborative patterns that are seen as stable in some networks (networks in Victoria) have to be expanded to other networks, where they are seen as radical and disruptive (networks in New South Wales). The floor cassette, its surrounding work practices and the machinery had reached a state of significant punctualization at the location where the innovation had originated. The success of expanding it to New South Wales, however, depended on key actants’ collective ability to dismantle traditional, craft-based models of collaboration that were currently in place. This would suggest that understanding collaboration should not be limited to the mechanisms (norms, rules and structures)

that stabilize it (as discussed in Table 1). In innovative contexts like IB, there is a need to understand how to intentionally destabilize collaborative networks as well. This is an area for future work, as our data-gathering in Case Study 1 did not extend to examining Company 1’s attempt to expand to New South Wales. What did emerge from our findings was that there was a degree of frustration by the proponents in the Victorian network, since it was felt they had learned much but these lessons had limited impact on their colleagues in the NSW network. The idea of expansion is related to the idea of moving into other networks and is discussed in the next section.

### **Multiplicity**

The failure to expand to New South Wales could have been understood as a challenge in the external environment, had we been using the dominant conceptualization as a lens. In management literature, such external environmental factors are often seen as sets of causal conditions that facilitate or hinder collaborative initiatives. Hindrances in particular are understood as outside forces that must be controlled, eliminated or minimized (Wood and Gray 1991). In industrialized building settings, external “barriers” to collaboration include restrictive or fragmented regulations, unionized labour and procurement hurdles (Blismas and Wakefield 2009).

ANT deals with these contextual issues in a different way (Latour 2005). These environmental opportunities and threats are seen not as autonomous forces, but as the contingent outcomes of other networks of human and non-human players. In cases where transport, fire safety or acoustic standards appear to hamper industrialized building initiatives, a possible ANT analysis would say that the prime mover of one network (a developer) is seeking to enrol an actant (a fire safety expert) that is part of an existing network (the network that makes fire safety rules for buildings) which in turn is programmed to run according to entrenched processes (i.e. the rules are meant for buildings constructed using traditional materials and methodologies). The existing regulatory network with traditional rules might thus be misaligned with a network that is seeking to run on more innovative rules. The innovative network thus faces a number of possible outcomes and these can fall between two extremes. One is that this new network could potentially remake the rules of networks that it becomes enmeshed within, a case of a collaborative network being disruptive. Alternatively, it may find itself being forced to conform to pre-existing rules.

In this case, what happened was Company 1 sought to demonstrate that the traditional rules of the regulator and the innovative rules of the company were different but equivalent. That is, managers acknowledged that their innovations were “not something that is compliant with

the current building codes”, but they went about seeking to demonstrate that their products were nevertheless “equivalent to a concrete building from a fire perspective, from an acoustic perspective, from a longevity perspective”. This process began with Company 1’s first innovation, the use of timber, at a time when “it was pretty tough to try and get a building surveyor to sign off on a timber building”. Initial steps involved providing regulators with evidence that their timber structures were yielding the “equivalent to a concrete building from a fire perspective, from an acoustic perspective, from a longevity perspective”. The process was described as difficult and paper-intensive. Once regulator-actants were enrolled for early timber projects, they then had to be progressively re-enrolled in subsequent innovative projects, for example as Company 1 “progressed from building two storeys to three storeys, four to five”. Each time Company 1 made the same argument: “the fundamentals haven’t really changed”. At the completion of each cycle, it became “easier to get them through the journey”. Eventually the regulator-actants became a part of the stable network. By the time Company 1 began spearheading the development of the floor cassette prototype, it was routine to have acoustic and fire consultants as part of their regular face-to-face meetings. The face-to-face meetings, then, became mechanisms not just for convergence for specific local networks, but also strategies of alignment.

One of the affordances of ANT, then, is that its concept of multiplicity provides an alternative way of understanding what has often been referred to as the external collaborative environment. Multiplicity suggests that there is not a single external environment; there are instead networks overlapping with other networks; and “challenges” can be understood as failures in alignment across multiple networks. Solutions can thus be formulated in the form of alignment strategies.

## Case study 2

### Prime mover and translation

Case Study 2 involves a Victorian start-up that has initiated the acquisition process of German equipment capable of manufacturing floor, wall and roof elements. In this case, we also have a case of two prime movers, but they took on the role sequentially, not simultaneously. The first convenor of the network that would eventually become Company 2 was a man named John. From an ANT-oriented approach, John was the prime mover who found a new business opportunity, enrolled his finances as an initial investment, then sought to enroll the equipment, as well as his sons, into his network. His motivation for creating this network was not just the economic goal of investing in another profitable business; there was also the social

and perhaps more altruistic goal of leaving something for his sons. The tentative collaborative network at this time was a small group of family members linked by relational ties. However, John went on to recruit Eric, a former car manufacturing executive, who had different motivations and thus reframed the problematique. When Eric stepped in, he redefined the goal as “revolution[ing] the whole industry” through manufacturing engineering principles of the automotive industry. This drove the creation of a network on a much grander scale. Eric continues to drive the network today.

Case Study 2 points out three important things about collaboration. The first is a point similar to one made in Case Study 1. The choice of problematique is not fixed; we can see in this case that it started small and evolved into something that was much more ambitious. That said, we show later that it can also be stabilized. Second, the nature and form of collaboration in a specific construction setting is very much shaped by an overarching problematique. One might argue, for example, that John’s problematique can drive collaboration in the form of a small, relational network linked mainly by informal, familial ties, while Eric’s problematique of revolutionizing the industry calls for many actants linked in predominantly professional ways and formalized interactions. This raises an important point that the dominant conceptualization does not articulate: there is a possible link between the nature of a collaborative problem and the form and structure of collaborative alliance that emerges in response to this. A third point is that collaboration, portrayed by Wood and Gray (1991) and Mattessich and Monsey (1992) as an inclusionary process of “convening”, should be broadened given that it also involves processes of exclusion. In Case Study 2, we discerned that successful collaboration efforts were focused on bringing actants in, as well as on keeping certain actants out. For example, Eric’s overarching problematique of remaking the industry through manufacturing technology has led to a search for actants with specific qualifications and expertise. Actants’ roles in the factory were described in manufacturing rather than construction terms: warehousing, logistics, manufacturing and assembly. By defining the work in these terms, Eric is also, in effect, excluding trades such as; plumbing, electricity and welding. This is *interessement*, where one key prime mover task is “cutting” or “weakening [actants’] links” (Latour 1999, p. 72) with traditional construction identities and roles and proposing new identities for them as skilled technicians capable of operating manufacturing equipment. More profoundly, the case also shows attempts to weaken the entire industry’s attachment to an old identity (traditional and cottage based) in order to get it to embrace a new identity (modern and automated). Therefore the use of ANT in Case Study 2 highlights the need to explore how strategies related

to separation are as significant as strategies of integration. Both must also be considered in efforts to achieve collaboration.

### *Generalized symmetry*

One of the actants that John attempted to “integrate” into the network early on was a non-human actant, the German equipment. As an actant, it is particularly significant because it had elements that were “stabilized and oblige others to support it” (Harrison and Laberge, 2002, p. 505). The equipment was even more significant than the floor cassette in Case Study 1, as it was at the core of Company 2’s factory, operation strategy and business mission. The equipment in this case sets the tone for just about all collaborative work arrangements. The equipment is designed to support processes that mirror car manufacturing, with parts set up into workstations supporting different stages of production in a factory. All other collaborative elements that will make up the factory will have to dovetail around this actant. Recruitment standards, job descriptions, operational procedure manuals, factory layouts and strategic targets were all being defined bearing the capabilities of the equipment in mind. Working back further, financing is a key non-human actant as well, as it paves the way for the enrolment of the equipment. Eventually, it can be expected that other influential non-human actors like slabs, trucks, cranes and additional funds will be enrolled as well, depending on the shape of operations dictated by the German equipment. In cases such as this, attempts to define collaboration as a dynamic involving humans and groups would be severely limited. A non-human actant might actually shift to the role of prime mover in the future.

### *Relational materiality and convergence*

Case Study 2 is an evolving network. In its earliest form it was built around three highly influential actants: John the businessman, John’s financial assets that formed the 40% down payment for the equipment, and the equipment itself. Since then the network has evolved and is now arranged around two highly influential actants: the equipment discussed earlier and the current CEO of Company 2, Eric. Human-centred definitions of collaboration would automatically identify Eric as the single most important actant or convenor, as they do not consider non-humans as key players. An ANT-oriented approach renders this issue debatable. On one hand, Eric seems to be the convenor as he seems to exercise considerable agency in network-building. However, it is just as plausible that the equipment could be more powerful, given that Eric’s employment (a former car manufacturing executive) was dependent on the nature of the German technology.

One way that ANT resolves this dilemma is by drawing on relational materiality to argue in this manner: network

programmes are significantly shaped not by Eric alone or by the equipment alone, but by the relationship between Eric and the equipment. As a former auto industry executive, there were specific potential knowledge and skill sets that Eric has that were foregrounded when he was tasked to strategize for a business that was built around lean manufacturing equipment. Had Eric been contextualized in a setting where his key interactions were with another type of actant, it could very well be that a different skill set would be foregrounded. Assumptions about future interactions between Eric and the machine thus set the tone for the rest of the collaborative network. As a result of this interaction, network programmes were defined around the goals of house assembly rather than house building and around the ideals of revolutionizing the industry rather than preserving the status quo.

We point out here, however, that many aspects of the decisive relationship between Eric and the relationship have yet to be consummated. The equipment is at present ambiguously positioned as it is not yet “fully” enrolled in the network. The German technology is partly enrolled in the sense that a considerable financial investment has been paid, thus some definite network activities have been carried out and future network programmes have been planned on the assumption that it is on its way. For one, a factory suited to its specifications has been brought into the network. However, the equipment is not yet completely enrolled as ownership has not been transferred, the equipment has not been delivered and it has not yet been harnessed to operations. The equipment cannot be fully enrolled until another actant, the 60% financing, has also been enrolled. An ANT-oriented approach thus raises a number of interesting questions, among them when it is that an actant is actually enrolled and to what extent an ambiguously enrolled can actant shape collaborative activity.

The ambiguous status of the equipment has implications for convergence and stability. Specifically, its absence has prevented convergence and stability from taking place on a large scale. As a result, other actants appear to be looking for alternative mechanisms for converging and stabilizing and one actant that seems to play this role is Company 2’s head office. Our visit gave us the impression that it was not utilized on a full-time basis: it was mostly empty and the furniture and fixtures appeared new and largely unused. However, the office did appear to fulfil a valuable function as it provided a space where planning meetings could take place and where interviews and interactions with third parties could occur. The head office also allowed for an address to be published on calling cards and marketing materials, supported the display of sample wall and roof products and otherwise provided a hub that allowed Company 2 to be perceived by outsiders as a

“going concern”. The head office acted as a physical anchor for networking operations that could otherwise be transient and decontextualized.

### Network effects and stabilization

The ambiguity of the status of the equipment as part of the network has not completely prevented it from exercising a disciplinary, stabilizing force and from shaping a repeatable, durable pattern of collaborative work (Martin and Sommerville 2004). In Case Study 2, this repeatable pattern of work is envisioned to be a radical one that will start with Company 2 but will eventually “reshape the industry”.

In construction, such durable patterns take numerous forms and two are mentioned here: project-based work and production-based work. Project-based work is characterized by actants linked in reciprocal interdependencies shaped by mutual adjustment and is typical of traditional construction sites. Production-based work is characterized by sequential interdependencies where the output of one is the input of another (Bygballe *et al.* 2013) and is seen in assembly-line manufacturing. Company 2 is seeking, rightly or not, to drive the logic of production work patterns across the housing construction sector, thus shifting domain dynamics from project-based building to production-based assembly. Production-based patterns emerge in this case mainly because a core technology dictates sequential patterns of work which human actants are required to adapt (Harrisson and Laberge 2002). This is a case of technology making social patterns durable (Latour 1991).

While Company 2 could very well succeed in establishing production-based work patterns within its own company domain (the factory), expanding this logic of production to the site or to the rest of the supply chain remains to be seen. Some attempts have been successful, an example being timber suppliers recently agreeing to revised selling terms, reflective of manufacturing rather than building requirements. Eric recounted:

We’re going to purchase in timber. We’re going to purchase 950,000 mm of timber ... they’re actually excited. The reason is because they only have to deliver to one spot and they only have to do to one size and quality. And I said “but that will have its offsets as well.” Because if we’re asking for some timber that’s 2.7, we don’t want it 2.75. And we don’t want to twist it. So we’ve got constraints. But we’ll also have some other processes in place that puts them on a containment program if something does come in wrong. So the supply side of it have [sic] been absolutely over the top.

In such cases, Eric has succeeded in destabilizing traditional collaborative arrangements with suppliers, in ways that are innovative (Lawrence *et al.* 2002). However, there have also been initial attempts to extend a manufacturing

mentality from the factory to the job site, but this is proving difficult. For example, attempts are being made to train former car manufacturing executives to become project managers, but Eric noted “they have no idea what to do when they go to the site”.

### Multiplicity

The example on enrolling former car manufacturing executives highlights that Company 2 is seeking to recruit actants that are already part of an existing network. Recruiting these car manufacturing actants has been straightforward because both the automotive industry and Company 2 are, in ANT terms, “aligned”; they are running according to the principles of lean manufacturing. Former automotive workers can thus be unproblematically transplanted into the new factory network.

However it is not always the case that the Case Study 2 network is aligned with other important networks. The persistent problem of misalignment is particularly vivid when we take into consideration the financial network. In early 2016, interviewees shared that they had been seeking the remaining 60% funding needed to purchase the equipment over a long period. They had approached and been declined by “all of the banks”, in part due to the banks’ perception of uncertainty on the resale value of the equipment purchased. The entrenched rules of the financial network thus appear to be misaligned with Company 2’s rules:

... there were several conditions of which we met all of them except for one, the one we couldn’t meet was initially, well, the banks have always been, well, there’s probably two major things that prevents the banks from funding the equipment and one is that they don’t understand it and its specialised equipment, it’s new to the market, they don’t know what the resale value is. – Finance manager, Company 2

In short, the funding failure is not an “external challenge”, as the dominant conceptualization would portray. The difficulty stems from failure to align two networks, hence the solution must also be framed in network terms. More work could be done to explore specific alternatives available to Company 2 managers in this case. However, ANT sensitizes us to a few alternatives. One is to explore how the network sustaining this set of financial rules, seemingly durable, can be destabilized, resisted or reversed. In other fields like criminal justice, for example, ANT scholars have noted that “resistance [in the network] ... can provoke translations that can compete with the law, to the extent that they may even destabilize the network in place” (Renard 2015, p. 115). A second alternative might be to enroll an actor who straddles both networks, supports the goals of both, then seeks ways to align the larger goals of both networks.

**Table 5.** Summary of ANT concepts in reconceptualizing collaboration.

Ant concept	How it contributes to an expanded understanding of collaboration	Relevance to industrialized building settings
Prime mover and translation	Moves away from limited understandings of collaboration as unitarist; highlights how leadership, vision, strategies can be pluralist, ambiguous, complex	Provides a more relevant, perhaps realistic template for collaboration IB settings, which are contextualized in the construction industry, known to be fragmented and litigious
Generalized symmetry	Moves away from limited understandings of collaboration as human work	Provides deeper consideration of the active role of non-human actants in creating and stabilizing collaboration; non-human actants are prevalent in IB settings
Convergence	Moves away from oversimplified understandings of convergence as conformity, as seen in Callon's (1991) "Tower of Babel"	Provides guidance for actants in IB "supply chains" on how to achieve collaboration as "coherence" instead of conformity
Stabilization	Provides a processual explanation of how stabilized collaborative structures emerge through a process of translation, while highlighting that these structures are always contingent	Provides empirical understanding on how technologies, prevalent in IB settings, can be stabilizing. Corollary to this, it carves out space for speculating how disruptive technologies in IB can be used to destabilize existing collaborative arrangements in favour of new ones
Multiplicity	Moves away from the idea of the "external environment" as a source of opportunities for and threats to collaboration. Instead, it views collaborative challenges as misalignment among multiple networks	Provides insights on how IB networks involve actants that are enmeshed in other potentially misaligned networks and how the process of network alignment is crucial to achieving collaboration

## Discussion

We have so far mobilized specific ANT concepts as analytical devices for examining collaboration in industrialized house building settings, specifically to interrogate key assumptions underlying the dominant conceptualization of collaboration. We have identified specific directions to take in terms of developing a nuanced theoretical conceptualization of collaboration in IB settings, summarized in Table 5.

Table 5 identifies the five ways that an ANT concept can be used to interrogate the limitations of the dominant conceptualization of collaboration and how extending existing theory at these specific points are enriching for examining collaboration in IB settings. We now discuss each one.

### ***An ANT-oriented approach demonstrates that successful collaboration can be underpinned by plurality, disjointedness and complexity***

Collaboration has often been understood as the work of unification and integration: there is a single key mover known as the "convenor" (Wood and Gray 1991, Mattessich and Monsey 1992); there is a single issue that participants must collectively frame in a coherent way (Hardy *et al.* 2006); there is an emphasis on shared goals, norms and standards. However, ANT scholars argue that

actor-networks are not simply sustained through black boxing, simplification and the generation of unitary identities and discrete associations. Rather, ambivalence, ambiguity, problematization, marginality, and multiple identities can also play a part. (Singleton and Michael 1993, p. 257).

An ANT approach allows us to discern that collaboration, often understood as a process led by a single convenor to achieve coherence, can in fact be built around multiple prime movers. Collaboration can involve a process of problematization that varies across different overlapping networks and it can call for strategies of integration as well as separation.

### ***An ANT-oriented approach considers humans as well as non-humans as key actants in collaboration***

From an actor-network perspective, objects (for example pods, modules in construction, equipment) can be expected to perform specific dimensions of collaborative tasks. One way to understand this is by taking what Ribes *et al.* (2013) call a delegation perspective. Delegation is

a redistribution of human work and social ties rather than a complete supplanting of them, [including the] the reconfiguration of who or what does the organizational work, highlighting, for instance, the introduction of new (*human and non-human*) actors for purposes of sustaining collaboration (Ribes *et al.* 2013, p. 5, emphasis ours)

This is important in IB settings, as IB involves the introduction of new human actors (for example labour skilled in manufacturing and also with construction knowledge; labour skilled in on site fixing of components) and new non-human actors (for example factory equipment). Humans and non-humans can radically "reconfigure" the collaborative interactions that sustain the work of supplying housing through IB methodologies. Our findings show that analytical approaches limited to examining the role of humans would overlook the significant, often decisive manner that objects can profoundly shape collaboration.

### ***An ANT-oriented approach foregrounds the ideal of coherence, not conformity***

An important concept that emerged in our discussion of ANT is convergence, which is best exemplified when a heterogeneous network appears as a single punctualized black box (Law 1992). It is important to note that the emphasis on a converged network is not to be misconstrued as groupthink or conformity, which can have negative repercussions. Conformity implies seamlessness through a common language, but it is also associated with “the creativity associated with tension, diversity and difference” (Hardy *et al.* 2006, p. 106). Callon’s idea of convergence (1991, p. 148), based on his “Tower of Babel” reference noted earlier, makes it clear that such seamless communication is not the ideal of network convergence. In IB settings, then, the collaborative ideal is better captured by the term “coherence”. This is described as a situation where

understandings converge – but not to the extent that all differences are quashed or ignored – allowing participants to communicate in the collaboration but also to exploit the potential for innovation that derives from a wide range of contradictory ideas associated with the member’s different constituencies. (Hardy *et al.* 2006, p. 106)

### ***An ANT-oriented approach permits the examination of collaboration as both stabilized outcome and destabilizing force***

In Case Studies 1 and 2, we noted how patterns of collaboration could be rendered durable, primarily through equipment and fixed assets that compelled other actants to repeatedly execute the same work processes. It is important, though, not to limit the discussion to ideas of stability, as ANT theorists argue that network stability is always contingent (Law 1992). Actants can at any point choose to interrogate network goals and resist to the point of destabilizing the network. The idea of destabilization is important in IB, especially in light of the fact that it involves potentially disruptive technologies. In ANT literature, the work of destabilization has been explored, but it is often assumed to be work done in the context of resistance or creating controversies (Callon 1999). What is less explored is the extent to which a prime mover that stabilizes can also destabilize the very network it created. In the case of innovative IB supply chains, however, it is conceivable for disruptive technologies to be introduced by the prime mover that created a network in the first place. There is limited work on ANT that has sought to explore this. That said, ANT is as an approach well-suited to pursue this, as it has the analytical resources to explore

how “technology both creates systems which close off other options and generates novel, unpredictable and indeed previously unthinkable options” (Callon 1991, p. 132).

### ***An ANT-oriented approach reframes external challenges as failure to align networks***

Multiplicity is a helpful concept as it allows us to explore collaboration as the effect of many networks, each made up of actants that have “multiple memberships in many worlds at once”, thus one cannot “presume unity or simple membership” (Star, in Singleton and Michael 1993, p. 231). Multiplicity therefore highlights that collaborative networks are not unitary or clear, but are fraught with ambiguity and complexity (Singleton and Michael 1993). Again, this assumption of complexity could ultimately be more insightful for IB and construction settings. Housing construction contexts generally involve actants that are simultaneously members of projects as well as their own organizations. Thus projects inevitably involve actants with multiple constituencies and competing commitments, making situations of multiplicity prevalent and goal alignment an ongoing task. Enrolling an actant does not simply mean defining a compelling problematique for the new network; this problematique must also be framed in ways that align with other problematiques that actants are already seeking to address as part of other “older” networks. Once enrolled into multiple networks, actants are still in a constant state of tension, struggling to balance their commitments to many networks. This state of tension need not be a disadvantage; Hardy *et al.* (2006) point out that it is in the context of these struggles that change and innovation arise.

### ***Some limitations of an ANT-oriented approach***

While we have provided a lengthy discussion on the value of key ANT concepts, it is necessary to mention a few of its limitations. First, researchers have questioned the idea of general symmetry and have claimed that in equalizing humans and non-humans, ANT now tends to overlook the meaningful, purposeful nature of human action (Whittle and Spicer 2008). The objection raises the question of whether non-human actants actually are collaborating when they are not purposefully doing so. Other limitations of ANT include the ongoing question of whether it generates description or explanation (Cresswell *et al.* 2010), whether it attributes too much power to key actants (Latour 1999) and whether it fails into account critical elements like unexpected network effects (Whittle and Spicer 2008).

## Conclusion

### *Theoretical contributions*

To summarize, we have demonstrated that key ANT concepts such as prime mover, problematization, relational materiality, convergence, stabilization and multiplicity provide a robust set of theoretical concepts that extend the dominant conceptualization of collaboration as unitarist and consensual. ANT's commitment to empiricism also allows researchers to use these concepts in ways that surface nuances that enrich existing theoretical conceptualizations of collaboration. While current research understands collaboration as human stakeholders brought together by a single convenor to address a shared problematique, ANT concepts sensitize us to the idea that collaboration in IB can take more ambiguous, complex forms. Collaboration is the work of multiple prime movers that deploy shifting problematiques and incoherent strategies, in ways that nevertheless stabilize human and non-human actants into significantly coherent, not totally conformed, networks. Collaboration also compels prime movers and other actants to continuously manage tensions: tensions between integrating actants and separating them; tensions between stabilizing collaborative networks and destabilizing them with new innovations and tensions between addressing problematiques in one network while maintaining meaningful participation in another.

In terms of future work, these ANT concepts also carve out a space for future studies in diverse areas. Work can be done, for example, to examine whether non-human actants can be prime movers; whether actants' individual attributes are indeed irrelevant as assumptions in network-building; how prime movers can intentionally destabilize their own networks and what processes are involved as a technology shifts from disruptive force to stabilizing force.

### *Methodological contributions*

Our study makes three methodological contributions. First, in mobilizing the ANT concept of general symmetry, we have pointed out that future research on collaboration should be inclusive in the search for collaborative participants. The question of "who is collaborating" is misleading as it is human-centric. In using general symmetry we have foregrounded how non-human actants can be participants in collaboration. Second, the inclusiveness of the definition of collaborative participants, coupled with the ANT methodological guideline of "following the actors" (Latour 2005), emphasizes the need to move away from the supply chain was the predefined unit of analysis. Literature often portrays "chains" as entities arranged in a linear relationship of suppliers, then manufacturers,

then customers, with this progression sometimes refined by tiers (Frohlich and Westbrook 2001, Childerhouse and Towill 2011). In our network-centred study, we discerned a collaborative mesh that was much more intricate than a sequential chain. Traditional conceptualizations of focal organizations linked to tiers of suppliers should therefore be reconsidered. Third, we have used the process of translation as a frame for tracing how collaborative networks are created, converged, stabilized and perhaps disrupted. This should be taken into account by researchers who are seeking a single static understanding of collaboration. In our case studies, we have shown the processual nature of collaboration. Collaborative work begins even when the prime mover has not yet successfully recruited anyone. As a phenomenon, collaboration takes a different form when a network is being separated from another, when it is being stabilized and when it is deployed to be disruptive.

### *Implications for practice*

Our qualitative case studies, while not exhaustive, nevertheless provide a level of specificity and vividness given that they are captured in detailed narrative form and hence endowed with significant levels of interpretative flexibility (Czarniawska 1998, in Schreyogg and Koch 2006). The empirical findings in our five case studies can readily be translated into actionable knowledge, in ways that bridge the evidence-to-practice gap. There are four possible directions for knowledge translation that can be identified at this stage. First, the detailed themes that emerged and that were categorized into nine collaborative practice elements can be translated with ease into a competency framework that defines the knowledge, skills and behaviours that are needed to develop collaborative capacity in the IB industry. This helps address the persistent issue of practitioners not knowing what collaboration means. Second, this competency framework is envisioned to be the basis for developing training materials, specifically in the form of training scenarios that seek to develop collaborative capacity in the Australian IB context. Third, the themes and nine practices, currently presented as one "list" explicating one possible form of collaboration, can be customized to suit different IB settings. Cross-case analyses suggest that some elements are foregrounded in some cases, but not in others. This would suggest that collaboration can emerge as a flexible mix of different ingredients, possibly depending on the characteristics of the network or the goals of IB. We can therefore propose multiple models of collaboration for different IB contexts. Finally, analysis is ongoing to establish clearer links of sequentiality and causality between collaborative practice elements. This can become the basis for a process-based framework that shows the forms and

conditions of collaboration at different stages of network development.

## Note

1. Interviews for case studies (CS): CS1 = 8, CS2 = 4, CS3 = 6, CS4 = 6, CS5 = 5.

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