KNOWLEDGE TRANSFER AND APPLICATION IN INTEGRATED PROJECT DELIVERY TEAMS

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ABSTRACT

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Architectural, Engineering, and Construction (AEC) project teams gather experts from different disciplines and organizations to develop a common project. Promoting knowledge transfer among these experts is vital to effectively integrate their diverse knowledge and optimize project outcomes (i.e., time, cost, and quality). Therefore, AEC teams are progressively adopting project delivery methods creating knowledge transfer networks involving all key parties (owners, designers, contractors, and subcontractors) early on during the delivery process. However, application of transferred knowledge across disciplines and organizations within these networks is frequently deficient, thus negatively impacting project performance.

This dissertation examines the key factors driving knowledge transfer networks in AEC project teams to enable knowledge application and benefit project outcomes. To achieve this aim, this study focuses on AEC project teams contractually implementing the Integrated Project Delivery (IPD) method. This method allows free interactions among key parties since early on during the design phase under shared goals, risks, benefits, and decision-making power. Thus, IPD method allows detecting key factors shaping knowledge transfer networks other than imposed or constrained knowledge transfer structures.

Based on the literature in construction management, organizational science, communication, psychology, and social networks domains, a model is developed whereby individuals' knowledge

transfer interactions and knowledge application are influenced by their absorptive and articulating capacities, and common knowledge with other peers. To test this model longitudinal data was collected via cross-sectional surveys from an IPD by contract project team with more than 160 team members. The model was analyzed via structural equation modeling and linear regression.

Key findings suggest that in IPD teams: (1) Team members occupy network positions where their absorptive capacities enable application of received knowledge; (2) Team members' absorptive capacities can help to identify and understand valuable new knowledge without sharing large portions of common knowledge with senders; (3) Team members with high absorptive capacities can apply received knowledge regardless of senders' articulating capacities; (4) Team members preferably make the effort to properly articulate knowledge to those peers with low absorptive capacity struggling with knowledge application; (5) Knowledge transfer across disciplinary and organizational boundaries improves team members' articulating capacities; and (6) Team members form temporary ad hoc sub-teams gathering the adequate expertise to devise solutions adapted to changing project demands.

The study's main contribution to the body of knowledge states that individuals' absorptive capacities and free interactions constitute two key factors to shape knowledge transfer networks facilitating knowledge application in AEC project teams. This expands our understanding about AEC project team integration which is not a mere increase of knowledge transfer interactions across disciplinary and organizational boundaries. In addition, effective team integration involves the degree to which team members can freely move in the knowledge transfer network to take positions where their absorptive capacities enable knowledge application. Therefore, owners aiming to optimize AEC project outcomes should include early on during project delivery those key parties whose absorptive capacities in key network positions enable knowledge application.

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KEY TO ABBREVIATIONS

AEC	Architectural, Engineering, and Construction
CMR	Construction Management at Risk
DB	Design-Build
DBB	Design-Bid-Build
IPD	Integrated Project Delivery
MLR	Multi-Linear Regression
PDM	Project Delivery Method
PNC	Project Team Network Center
SEM	Structural Equation Modeling
SLR	Simple Linear Regression
SNC	Sub-Team Network Center
ST	Sub-Team

CHAPTER 1: INTRODUCTION

1.1. Background

This section offers an overview of current practices implemented by Architectural, Engineering and Construction (AEC) project teams to enhance knowledge transfer to improve projects' outcomes. Problems associated with these practices are identified and used as the foundation to build the problem statement in Section 1.2.

1.1.1. Knowledge Transfer in AEC Project Teams

Architectural, Engineering and Construction (AEC) project teams gather members from diverse organizations and disciplines to develop a common project. They are expected to collaborate to deliver a product meeting targeted cost, time, quality, and sustainability requirements. During project delivery, AEC project teams go through *action* and *transition phases* Marks et al. (2001). During action phases, they perform tasks directly increasing project completion (e.g., mechanical system design); whereas in transition phases they assess their performance and develop planning for next action phases (e.g., pull planning meetings to coordinate subcontractors' tasks, or meetings to update cost estimate). Frequently, AEC project teams' transition phases fail to effectively foster knowledge transfer among team members during action phases. Consequently, their tasks' outcomes fail to effectively merge (e.g., design incompatibilities between building systems). Team members end up pursuing their personal interests regardless of project success, rejecting taking responsibility for project inefficiencies. This is frequently referred to as team fragmentation in AEC project delivery, and produces deficient project outcomes (i.e., time, cost, and quality) (Korkmaz and Singh, 2012).

To overcome team fragmentation via enhanced knowledge transfer, the AEC industry recently started looking at project teams as social networks needing increased quantity and quality of interactions (e.g., degree of trust) between team members (Chinowsky, Diekman and Galotti, 2008; Chinowsky, Diekmann and O'Brien, 2010). Therefore, AEC project teams recently started implementing relational contracting approaches to project deliver to promote knowledge transfer interactions based on trust among team members. These approaches are described in the following section.

1.1.2. Relational Contracting Approaches to AEC Project Delivery

Relational contracting approaches refer to collaborative project delivery methods (PDMs) such as design-build, project alliancing, and integrated project delivery (IPD) (Kumaraswamy et al., 2005; Lahdenpera, 2012). They rely on the creation of trustful interactions raising AEC team members' commitment to jointly solve events not captured in contracts (Ghassemi and Becerik, 2011). However, AEC project teams' members frequently team up for the first time, thus lacking trust. Trustful relations can be developed via collaborative interactions, especially if they occur at initial phases of AEC project delivery, when their impact on projects' outcomes is stronger (Baiden et al., 2006; AIA, 2007; Chinowsky et al., 2008; Chiocchio et al., 2011). Therefore, AEC teams implementing relational contracting approaches bring all key parties (i.e., owners, designers, contractors, and subcontractors) early on in project delivery allowing them to freely interact (Lahdenpera, 2012). This strategy raises trust among team members and multiplies knowledge transfer interactions, especially across AEC project teams' disciplinary and organizational boundaries (AIA 2007; Ghassemi and Becerik, 2011). In doing so, AEC teams can achieve higher level of team integration (Baiden et al., 2006; Troy et al., 2008). Although higher team integration is presumed to improve AEC teams' performance it presents some challenges that may also weaken their performance (Baiden et al. 2006, 2011; Matthews and Howell, 2005; Mollaoglu et al., 2013, Franz et al., 2016). This is discussed in the following section.

1.1.3. AEC Project Team Integration

Integration in AEC project teams' increases knowledge transfer across disciplinary and organizational boundaries (Mollaoglu et al., 2013, Franz et al., 2016). This raises several challenges such as multi-disciplinary team members transferring divergent knowledge difficult to reconcile (Troy et la., 2008); team members lacking common knowledge to combine their diverse expertise (Reagans and McEvily, 2003); and/or multi-organizational team members lacking common procedures to collaborate (Tushman and Scanlan, 1981; Dyer and Nobeoka, 2000). Per Ghasemi and Becerik (2011), AEC project teams reveal high integration when multi-disciplinary designers can merge their systems into a single model regardless of transferring large amounts of knowledge. Integration is beneficious if the increment of knowledge transfer is accompanied with application of transferred knowledge. Otherwise, lowly integrated AEC project teams can outperform integrated ones (Baiden et al., 2006, 2011).

In summary, this section argued that AEC project teams often undergo fragmentation. Thus, the AEC industry recently started treating project teams as social network where the quantity and quality of interactions matter. Thus, AEC project teams are increasingly adopting relational contracting approaches to project delivery such as IPD. These approaches improve trust among team members while promoting higher levels of knowledge transfer interactions across AEC project teams' disciplinary and organizational boundaries. However, increased knowledge transfer might be problematic if transferred knowledge is not applied. All the above served to identify the problem statement described below.

1.2. Problem Statement

Architectural, Engineering, and Construction (AEC) project teams are formed by members from different disciplines and organizations combining their knowledge into a unique product. Recurrently, poor knowledge transfer between these team members results in team fragmentation and deficient project outcomes (i.e., time, cost, and quality) (Korkmaz and Singh, 2012). To reverse this situation, AEC project teams are increasingly implementing the integrated project delivery (IPD) to improve knowledge transfer among team members (Carrillo and Chinowsky, 2006; Chinowsky et al., 2008, 2010; Lahdenpera, 2012; Zhang and Zhou, 2013; Mollaoglu et al., 2013; Ibrahim et al., 2015; Franz et al., 2016).

IPD method imposes free knowledge transfer interactions among key parties (i.e., owners, designers, contractors, and multi-disciplinary subcontractors) since early on during project delivery (AIA, 2007; AGC, 2010). This method generates knowledge transfer networks notably augmenting the number of interactions within AEC project teams. Although this augment aims to strengthen inter-disciplinary and inter-organizational collaboration, it might negatively impact team performance (Haas and Hansen, 2007, Baiden et al., 2006, 2011). This negative impact might be caused due to: (1) Team members' lack of common knowledge to understand knowledge from disciplines or organizations other than their own (Alavi and Leidner, 2001; Reagans and McEvily, 2003); (2) Multi-organizational team members inability to collaborate because of following dissimilar procedures to manage knowledge transfer (Tushman and Scanlan, 1981; Dyer and Nobeoka, 2000); (3) Opportunity costs due to, e.g., resources allocated assimilating knowledge that is not finally used (Hansen, 1999; Hansen, Podolny, and Pfeffer, 2001);

and/or (4) Team member acquiring excessive knowledge surpassing the limit that they can handle based on their bounded rationality or learning capabilities (March, 1978; Cohen and Levinthal, 1990; Zander and Kogut, 1995; Szulanski, 1996).

The four problems above frequently impede that knowledge transferred within AEC project teams is applied to benefit project outcomes. Therefore, incrementing knowledge transfer within AEC project teams via IPD method implementation might be innocuous or counterproductive. Currently, it is not known how knowledge transfer networks in IPD teams are shaped so they favor effective application of multi-disciplinary and multi-organizational knowledge to deliver a product meeting targeted project outcomes.

1.3. Research Goal and Objectives

The research goal is to **examine the key factors shaping knowledge transfer networks facilitating knowledge application in IPD project teams.** The objectives to achieve this goal along embrace the following:

1. *To detect the key factors affecting knowledge management outcomes such as knowledge creation, transfer, retention, and application in diverse domains and units (e.g., individuals, teams, and organizations):* This objective is to be accomplished via a review of knowledge management literature. This will allow detecting key factors for effective knowledge management and, in addition, learning what research has been conducted regarding these key factors in AEC and other domains. In doing so, the author will be able to build this dissertation upon current research in AEC and domains, and clearly mark the dissertation's new contributions to the body of knowledge;

2. *To define and differentiate knowledge transfer and application phenomena, and to determine the key factors influencing them:* First, this study focuses on knowledge management outcomes including knowledge transfer and application. In the literature, their meanings frequently overlap. Defining and differentiating these concepts will help the author to develop unambiguous study hypotheses, measurements, and contributions to the body of knowledge. And second, determining the key factors affecting them will allow development of study hypotheses;

3. *Based on theory, to discuss knowledge transfer in AEC project teams under different project delivery methods (PDMs):* Some PDMs in the AEC industry impose constrained knowledge transfer interactions. Thus, the key factors pointed out in Objective 2 above might have a limited effect on shaping knowledge transfer interactions in AEC project teams. Thus, Objective 3 aims to assess the adequacy of focusing on AEC project teams implementing the IPD method to examine the key factors shaping knowledge transfer interactions;

4. *To develop a multi-level model of knowledge transfer and application in IPD project teams:* This will guide hypothesis development for this study. The literature about knowledge management points out that knowledge transfer and application phenomena at macro-levels of analysis (e.g., organizational, sub-team, and team levels) can only be well understood if they are previously examined at micro-levels of analysis (e.g., individual level) (Foss et al., 2010). Thus, the multi-level interconnects three levels of analysis (i.e., individual, sub-team, and team levels) to guide proper development of study hypotheses; and

5. *To empirically test study hypotheses, and develop practical and theoretical applications:* This research is based on the scientific method, therefore, data are to be collected to empirically test study hypotheses and, subsequently, develop practical and theoretical outcomes based on empirical evidence.

1.4. Research Design

The methods employed to accomplish the objectives above are as follows:

1. *Objective 1:* Collect and review relevant publications related to knowledge management in AEC project management, organization science, communication, psychology, and social networks domains; based on this literature, detect key factors for knowledge management; and classify the collected publications under the detected key factors for knowledge management.

2. *Objective 2:* Review literature within knowledge application, transfer, sharing, exchange, and diffusion domains to first create a definition for knowledge transfer and diffusion concepts, and, second, establish their differences.

3. *Objective 3:* Review literature related to project delivery methods in AEC projects, relational contracting approaches to AEC project delivery, AEC teams' integration, and theories of firm for knowledge management including transaction cost (Williamson, 1981), system-structural organizational (Astley and Van de Ven, 1983), and knowledge-based (Grant, 1996) theories.

4. *Objective 4:* Take as the point of departure to build the model the social network theory of influence and selection at the individual level (Frank and Farhbach, 1999), and using

the literature in the domains specified in Objectives 1, 2, and 3 above, develop the entire model along with study hypotheses.

5. *Objective 5:* Collect longitudinal data via cross-sectional surveys at two time points from an AEC project team contractually following the IPD method; using these data, test study hypotheses via structural equation modeling and linear regression; and, combining the results of study hypotheses' tests and literature mentioned in Objectives 1 to 3 above, propose theoretical and practical applications.

1.5. Scope and Limitations

The scope of this study is inter-organizational AEC project teams implementing IPD method by contract. These teams temporarily gather key parties (i.e., owners, designers, constructors, and multi-disciplinary subcontractors) which, by contract, transfer knowledge without imposed constraints since early stages of the design phase. Therefore, IPD project teams are suitable to examine what factors, other than imposed hierarchical structures, shape knowledge transfer networks. Generalizability of study findings to teams or organizations in industries is discussed in Sections 4.7.3 and 6.4.

Main limitations of this research include AEC projects teams' size, complexity, and adopted PDM. This research focused on a detailed examination of one IPD project team relatively large developing a complex design (i.e., more than 160 team members, and $60 million budget approximately). Therefore, comparisons with smaller teams, and project teams developing simpler designs or implementing non-IPD methods could not be empirically analyzed.

1.6. Deliverables/Research Contributions

The primary deliverable of this research is an assessment of the key factors developing knowledge transfer networks enhancing knowledge application in IPD project teams. In addition, this deliverable is accompanied by the following ones:

1) Review of relevant literature for knowledge management within AEC project teams, and theoretical discussion PDMs' influence on knowledge transfer in AEC project teams during design and construction phases of project delivery;

2) Description of how PDMs' differing practices to manage knowledge transfer result in different knowledge application outcomes during the design and construction stages of AEC project delivery;

3) Theoretical implications of knowledge transfer and application in inter-organizational and inter-disciplinary project teams (i.e., as opposed to permanent organizations with expertise in limited disciplines);

4) Practical applications of knowledge transfer and application for owners in the AEC industry to improve project outcomes (i.e., time, cost, and quality);

5) Multi-level model of knowledge transfer and application in IPD project teams, operationalization of study variables, collected data, and propositions for future research; and

6) Differential equations at the individual, sub-team, and project team levels, mathematically describing knowledge transfer and application phenomena within IPD project teams.

1.7. Reader's Guide

In the following sections, Chapter 2 conducts an extensive review of the literature in diverse domains (e.g., construction management, communication, psychology, organization science, and social networks) to determine the key factors affecting knowledge management, define knowledge transfer and application phenomena, and discuss the influence of PDMs on AEC project teams' knowledge transfer; Chapter 3 presents a multi-level model of knowledge transfer and application within AEC project teams to guide development of study hypotheses; Chapter 4 describes the methodology to collect data and test hypotheses; Chapter 5 includes the results of study hypotheses testing; Chapter 6 presents the key findings extracted from study hypotheses, discusses their theoretical and practical applications in AEC project teams, and offers some propositions or future research; finally, Chapter 7 offers a summary of this dissertation highlighting the most relevant points.

1.8. Summary

Currently, AEC project teams are increasingly adopting the integrated project delivery (IPD) method which gathers all key parties early on during project delivery under free knowledge transfer interactions. This method drastically increases knowledge transfer interactions within AEC project to avoid team fragmentation, and enhance collaboration across disciplinary and organizational boundaries to optimize project outcomes (i.e., time, cost, and quality). Nonetheless, the IPD method can create knowledge transfer networks that are counterproductive due a lack of common knowledge among team members; wasted resources to manage knowledge that is not later used; absence of common procedures to manage knowledge transfer; and/or team members' acquisition of knowledge that they cannot handle. Therefore, increased knowledge transfer within AEC project teams might not result in application of transferred knowledge. Accordingly, the study research goal is *to examine the key factors shaping knowledge transfer networks allowing application of transferred knowledge*. To achieve this aim, this chapter described a set of research objectives and the methods to accomplish them, Additionally, this chapter described the research scope, limitations, and deliverables.

CHAPTER 2: LITERATURE REVIEW

Based on the literature, this chapter first offers an overview of the key factors to be considered to manage knowledge within units (e.g., individuals, teams, and organizations). Then it describes and differentiates knowledge transfer and application phenomena. Finally, based on theories of the firm, this chapter discusses how different project delivery methods (PDMs) in the AEC industry affect knowledge transfer and application in project teams.

2.1. Knowledge Management

Webb (1998) defines knowledge management as “the identification, optimization, and active management of intellectual assets to create value, increase productivity and gain and sustain competitive advantage.” During the last two decades, knowledge management has attracted many researchers due to its drastic impact on organizational performance. This has resulted in a general shared perception that processes involving knowledge transfer, diffusion, creation, retention, and combination are critical to optimize organizational efficiency, and gain and sustain competitive advantage (Grant, 1996; Webb, 1998; Argote and Ingram, 2000; Earl, 2001; Argote et al., 2000, 2003; Frank et al., 2011; Foss et al., 2010).

Based on the work performed by Argote, McEvily, and Reagans (2003), Figure 2-1 displays a framework including the key factors to be considered to enhance knowledge management outcomes. These outcomes include, e.g., knowledge transfer, retention, and creation. They are affected by the features of (1) units involved in knowledge transfer, (2) relationships between these units, (3) knowledge, and (4) knowledge transfer networks. Units may refer to, e.g., individuals, teams, and organizations. The fourth factor (i.e., features of knowledge transfer networks) is added by this study based on the literature review compiled in Tables 2-1 and 2-2. Table 2-1 presents the main streams from the literature in diverse domains (e.g., organization science, communication, psychology, and social networks) with potential contributions to the AEC industry. Table 2-2 contains literature contributions on knowledge management from the AEC field. The main factors identified in literature affecting knowledge management are shown in Figure 2-1. Figure 2-2 shows knowledge management outcomes examined in this research (i.e., transfer and application) and the key factors considered (i.e., properties of units, relationships between units, and knowledge transfer networks).

The AEC literature embraces research under all key factors affecting knowledge management outcomes. AEC project teams' difficulties to integrate diverse knowledge, due to involving individuals with different backgrounds that typically do not know each other before project start, has strongly attracted researchers. Thus, recent research has greatly focused on knowledge transfer across disciplines (e.g., Iorio et al., 2012, 2014; Alin et al., 2011, 2013), motivations for knowledge sharing (e.g., Chinowsky et al., 2008; Javernick, 2012), adoption of collaborative project delivery methods (PDMs) as an innovation (e.g., Unsal and Taylor, 2011; Sun et al., 2015), or effects of PDMs on team integration and performance (e.g., Baiden et al. 2006, 2011; Mollaoglu et al., 2013, Franz et al., 2016).

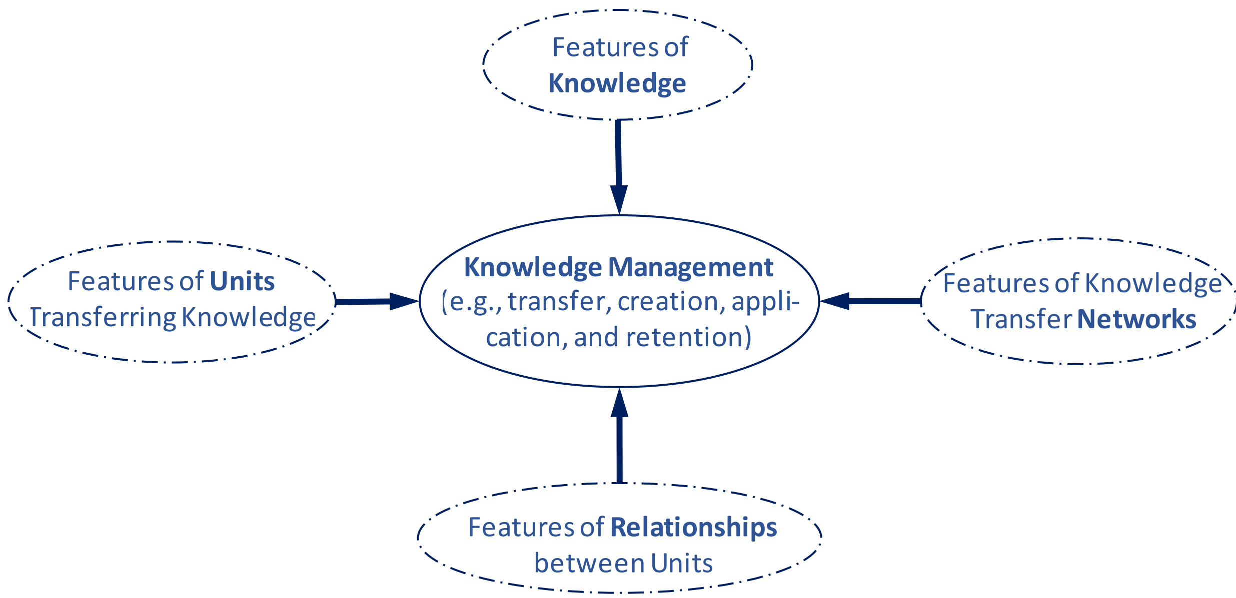


Figure 2-1. Key Factors Influencing Knowledge Management within Units
(Adopted from Argote et al. (2003); features of networks added by this study)

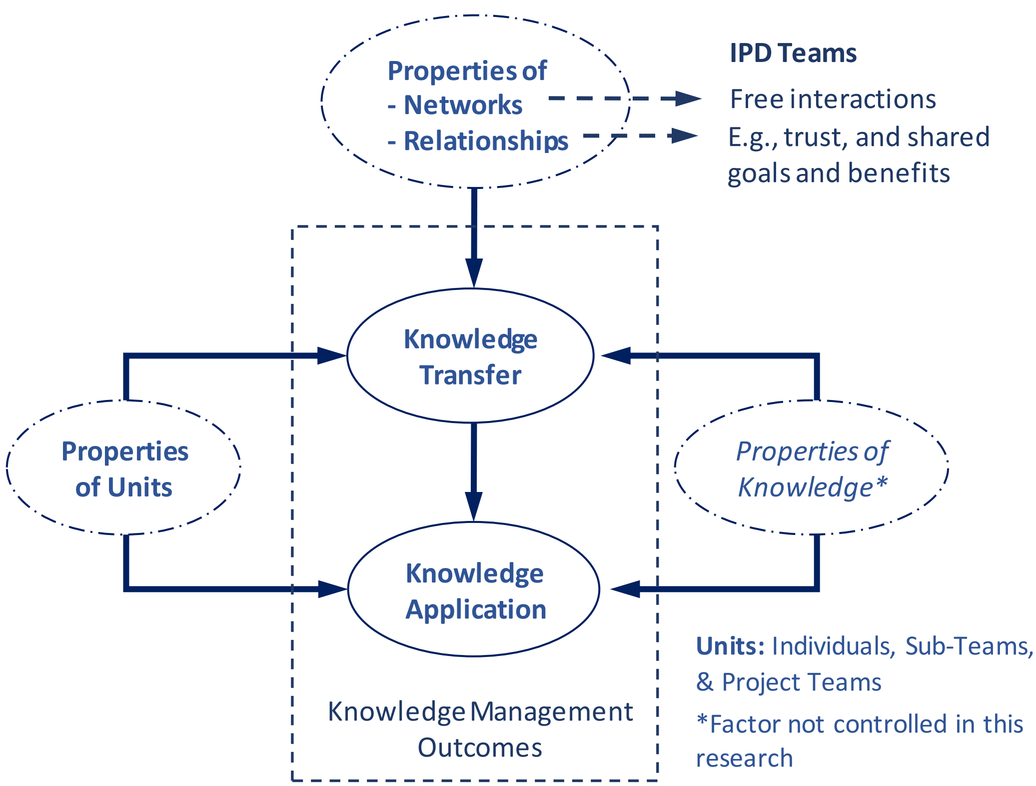


Figure 2-2. Knowledge Management Outcomes and Key Factors
Examined in This Research

Table 2-1. Knowledge Management Literature (Categories are based on Argote et al.'s (2003) work; fourth category added by this study)

Features of Units Transferring Knowledge (e.g., Individuals, Organizations, and Teams)	
Describing knowledge embedded in organizational units to create a transactive memory system indicating "who knows what" and "who needs to know what" within a network.	Wegner (1987); Moreland and Myaskovsky (2000); Oshri, Fenama, and Kotlarsky (2008).
Units' cognitive abilities effect on knowledge sharing and diffusion such as absorptive and articulating capacities, and common knowledge.	Cohen and Levinthal (1990); Szulanski (1996); Reagans and McEvily (2003).
Boundary spanners characteristics (e.g., diverse language) to effectively introduce external valuable knowledge into organizational subunits.	Tushman and Scanlan (1981).
Barriers for knowledge sharing such as lack of identity with network social values, or lack of common knowledge between units exchanging knowledge.	Reagans and McEvily (2003); Dyer and Nobeoka (2000).
Attributed knowledge to individuals based on their technical background and physical features.	Burdenson (2003).
Units' degree of freedom to experiment/modify innovative knowledge for its effective diffusion.	Dearing and Meyer (2011); Frank, Zhao, Penuel, Ellefson and Porter (2011).
Features of Relationships between Units Transferring Knowledge	
Frequency of interaction and closeness influence on effective knowledge diffusion.	Hansen (1999, 2002).
Effect of trust on knowledge sharing.	Coleman (1988), Levin and Cross (2004).
Informal talks influence on effective innovative knowledge diffusion.	Frank, Zhao and Borman (2004).

Table 2-1. (cont'd)

Features of Knowledge	
Influence on knowledge sharing and diffusion efficiency of knowledge properties such as tacitness (i.e. acquired through experience), explicitness (i.e. degree of codifiability), or complexity.	Nonaka, (1991); Grant (1996); Zander and Kogut (1995); Szulanski (1996); Smith (2001); Alavi and Leidner (2001); Hansen (2002).
Features of Knowledge Transfer Networks	
Structural holes, centrality of units with enhanced absorptive capacity, or number of innovation-related knowledge senders in knowledge flow networks for efficient innovation outcomes.	Ahuja (2000); Tsai (2001); Frank, Penuel and Krause (2015).
Direct/indirect connections, interactions across boundaries, and centrality degree of knowledge transfer networks effect on knowledge sharing and diffusion.	Hansen (2002); Reagans and McEvily (2003); Tsai (2002); Tortoriello, Reagans, and McEvily (2012).
Inter/intra organizational networks density, and average strength of connections influence on knowledge search.	Hansen, Mors and Løvås (2005).

Table 2-2. AEC Literature on Knowledge Management. (Categories are based on Argote et al.'s (2003) work; fourth category added by this study)

Features of Units Transferring Knowledge (i.e., Individuals, Organizations, or Teams)	
Characteristics of individuals creating systems of awareness about "who knows what" in virtual project team networks.	Comu, Iorio, Taylor and Dossick (2013).
Individuals' abilities to monitor, manage, challenge and negotiate knowledge influence on innovative knowledge implementation.	Mollaoglu, Miller and Sun (2014); Sun, Mollaoglu, Miller and Manata (2015).

Table 2-2. (cont'd)

Boundary spanners' characteristics to facilitate knowledge exchange interactions among team members in virtual project teams.	Iorio, Taylor and Dossick, (2012).
Construction companies' absorptive capacities influence on innovation performance.	Unsal and Taylor (2011); Wang, Xue and Wang (2013).
Individuals' motivations for knowledge sharing such as resources availability (e.g. time), effortless altruism, incentives from overall organization's performance, and social motivations.	Javernick-Will (2012); Zhang and Fai (2013).
Features of Relationships between Units Transferring Knowledge	
Informal and spontaneous conversations for tacit knowledge exchange across functional boundaries in ACE project teams implementing building information modeling.	Dossick and Neff (2011).
Effect of trust on knowledge transfer interactions and team performance.	Chinowsky, Diekman and Galotti (2008); Chiocchio, Forgues, Paradis, and Iordanova (2011).
Influence of shared goals, risks, benefits and power in decision making on knowledge transfer and diffusion.	AIA (2007); AGC (2010).
Interactions through electronic tools within virtual teams to guide and facilitate knowledge sharing and negotiation across functional boundaries for efficient conflict resolution.	Alin, Iorio and Taylor (2013); Iorio and Taylor (2014).
Frequency of interactions and utilization of a shared format to codify knowledge for effective innovation implementation.	Alin, Manula, Taylor and Smeds (2013).
Features of Knowledge	
Institutional knowledge (e.g. laws, social norms, and local cultural beliefs) for successful international projects.	Javernick-Will and Scott (2010).

Table 2-2. (cont'd)

Strategies to manage tacit and explicit knowledge.	Carrillo and Chinowsky (2006).
Features of Knowledge Transfer Networks	
Interactions across/within organizational and functional boundaries influence on knowledge creation, combination or alteration.	Alin, Taylor and Smeds (2011).
Characteristics of knowledge flow networks established by different project delivery methods and their influence on team integration, that is, extent to which knowledge flows across functions and disciplines (Fergusson and Teicholz, 1996).	Baiden, Price and Dainty (2006); Baiden and Price (2011); Mollaoglu, Swarup and Riley (2013); Franz et al. (2016)
Adjusting actual knowledge transfer network to required knowledge network.	Chinowsky, Taylor and Di Marco (2011).

2.2. Knowledge Transfer

After an extensive review of knowledge transfer investigations, Foss et al. (2010) observed that knowledge "sharing", "exchange" and "transfer" are often used interchangeably and with different meanings. Sometimes authors refer to them as the mere process of engaging in sending or receiving knowledge, whereas others present them as knowledge utilization or assimilation. This study considers that ***knowledge transfer, exchange or sharing refer to either sending or receiving knowledge*** without the need to understand or use it. There are many forms in which knowledge can be transferred such as direct conversations (Dossick and Neff, 2011), electronic or paper-based documents, rotation of employees (Almeida and Kogut, 1999), observation of knowledge application (Nonaka, 1991; Grant, 1996), training (Moreland and Myaskovsky, 2000), technology acquisition (Galbraith, 1990), or via information technologies (Alavi and Leidner, 2001; Alin, Iorio and Taylor, 2013).

There is not a unique form to optimize knowledge transfer within organizations. This depends on organizations' features and needs (Argote and Ingram, 2000). In AEC project teams, typical ways to transfer knowledge include information technologies (e.g., BIM software or email), electronic or paper-based documents (e.g., drawings either printed or in pdf), training (e.g., laborer training in construction methods), direct conversations (e.g., meetings), or observation of applied knowledge (e.g., field inspections to compare actual versus planned drawings).

Poor knowledge transfer within AEC project teams might result in team members holding asymmetric knowledge or inversely understanding the same knowledge, thus hindering effective collaboration across disciplinary and organizational boundaries (Adler, 1995; Poole, 2011). AEC teams can ensure an appropriate quantity and quality of knowledge transfer via engaging in key communication behaviors such as monitoring, managing, and negotiating (Paik, Miller, and Mollaoglu, 2017). They involve, respectively, detecting key knowledge impacting project performance, sharing key portions of knowledge across disciplinary and organizational boundaries, and devising combined solutions via open communication (Sun, Mollaoglu, Miller, and Manata, 2015). These behaviors might improve AEC teams' performance via enhanced team integration promoted by higher levels of knowledge transfer (Mollaoglu et al., 2014; Mihic et al., 2014). Nevertheless, increased knowledge transfer might be useless if it does not enable knowledge application, that is, exploitation of transferred knowledge as explained in the following section.

2.3. Knowledge Application

Knowledge application refers to individuals' exploitation of acquired knowledge (Alavi and Tiwana, 2002) due to replication (Zander and Kogut, 1995), or assimilation for later modification and adaptation to specific needs (Szulanski, 1996). Knowledge "application" and "diffusion" have a similar meaning in literature. Argote and Ingram (2000) define knowledge diffusion as "the process through which one unit (e.g., individual, group, department, and division) is affected by the experience of another." In such case, knowledge may be transferred and utilized/replicated but not assimilated as for knowledge application. Whereas assimilating knowledge refers to a cognitive process by which an individual understands the causes generating an effect, replicating refers to the ability to imitate certain knowledge which results in the desired effect without the need of understanding the causes (Szulanski, 1996).

Assimilation and replication have different advantages and handicaps when applying knowledge in AEC projects. For instance, a designer might learn that a wall system with specific layers and materials is energy efficient in a cold climate zone. If the engineer ignores why, then he/she might not be able to manipulate its layers and materials to make it energy efficient in hot climates. However, the designer might merely replicate the wall in other AEC projects in cold climate zones with satisfactory results.

Therefore, since replicating knowledge without fully understanding its details might still be a valid strategy to benefit AEC project outcomes, this dissertation considers ***knowledge application as the act of exploiting received knowledge without the need to fully comprehend it.***

2.4. Knowledge Management in AEC Project Teams Based on Project Delivery Methods

The most common project delivery methods (PDMs) in the AEC industry include Design-Bid-Build (DBB) (60%), Construction Management at Risk (CMAR) (25%), Design-Build (DB) (15%), and Integrated Project Delivery (IPD) (1%) (CMAA, 2012). These project delivery methods present two main differences affecting knowledge management in AEC project teams, especially regarding knowledge transfer outcomes. First, regarding *Features of Knowledge Transfer Networks* (Figures 2-1 and 2-2), they propose different timing of involvement of key parties (i.e., owners, designers, contractors, and multi-disciplinary subcontractors), and degree to which they can freely interact. And second, regarding *Features of Relationships between Units* (Figures 2-1 and 2-2), they implement distinct motivational factors to promote collaboration between key parties. The effect of PDMs on knowledge transfer dynamics based on these two differences is discussed in the following sections.

2.4.1. Effects of PDMs on Knowledge Transfer Networks

Team members in AEC projects are distributed across different tiers (Mollaoglu et al., 2014): A core tier with designers, contractors, and owners (Tier 1); an intermediate tier including Tier 1 members' organizational colleagues (Tier 2); and a peripheral tier with subcontractors, suppliers and consultants (Tier 3). These tiers are illustrated in Figure 2-3. They establish time, geographic, and interaction scope boundaries that might hinder knowledge transfer (Sun et al., 2015). Figure 2-4 illustrates the timing of involvement of members from Tiers 1, 2, and 3 depending on the PDM implemented. The most opposite cases are represented by DBB and IPD. The former brings into the project owners and designers (Tiers 1 and 2) during the design phase, and brings members from all tiers during the bidding and construction phases. Conversely, IPD gathers members from all tiers since the design phase.

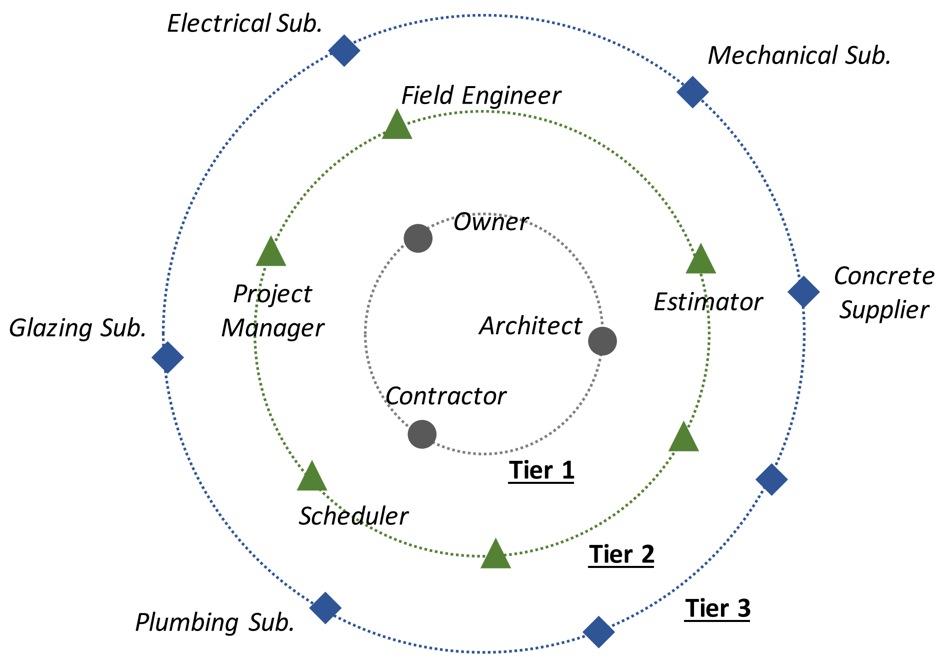


Figure 2-3. Tiers in AEC Project Teams

Knowledge management in DBB and, to a lesser extent, CMR and DB is mostly based on the transaction cost (Williamson, 1981) and system-structural organizational theories (Astley and Van de Ven, 1983). Per transaction cost theory, organizational efficiency excels if costs associated with knowledge transfer are minimized while producing profit. This perspective leads to the adoption of the system-structural theory to control knowledge transfer costs. By this theory, internal structures are created to determine and constrain knowledge transfer interactions among team members. Consequently, since it is determined the knowledge received by individuals, then hierarchies are established to govern who makes important decisions. For example, in DBB owners and designers (Tiers 1 and 2) develop project drawings which are delivered to subcontractors (Tier 3) at the beginning of the construction phase. Therefore, knowledge transfer interactions of

Tier 3 are suppressed during the design phase. In addition, Tier 3 must develop a set of specifications indicated in contracts to contribute to the project. The important design decisions have already been made and their interactions with designers are minimal.

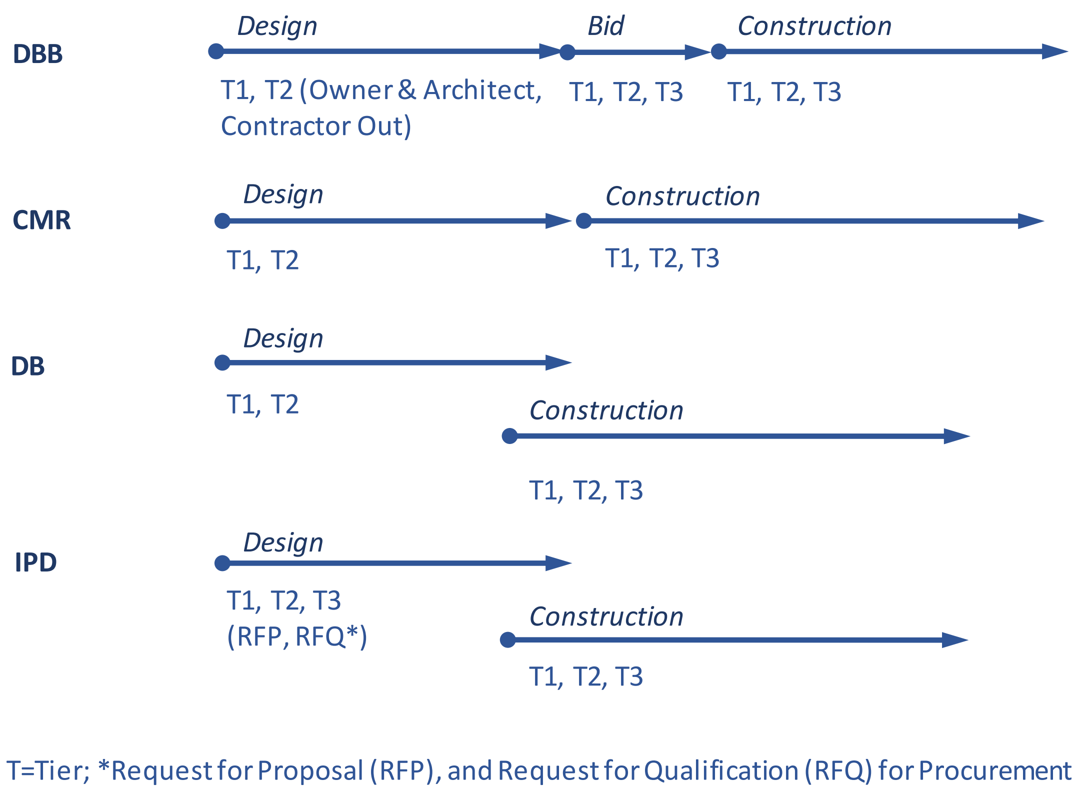


Figure 2-4. Project Delivery Methods in AEC Industry, Their Phases, and Tiers Involved

Thus, **DBB and, to a lesser degree, CMR and DB methods create knowledge transfer networks suppressing Tier 3's knowledge transfer interactions during design, and limiting them during construction to minimize knowledge transfer costs.**

Conversely, IPD method is guided by the knowledge-based theory (Grant, 1996). Per this theory, highest organizational efficiency is achieved if all key parties freely interact and contribute to decision-making processes without any imposed hierarchy or knowledge transfer structure. This facilitates identifying and exploiting all individuals' valuable knowledge. Therefore, although applying this theory might entail higher knowledge transfer costs, it might produce a greater payoff later due to involving key individuals into critical decision-making processes. Accordingly, the IPD method involves all key parties from Tiers 1, 2 and 3 since project design to freely transfer knowledge.

The purpose is to pull into design any key valuable knowledge early on during project delivery. In doing so, IPD project teams concentrate efforts in developing a thorough design with higher ability to control project outcomes (i.e., time, cost, and quality) as compared with DBB project teams. This can be observed in the in the MacLeamy curve depicted in Figure 2-5. Since DBB project teams discard Tier 3 input during design, then the design might be subject to important changes during construction. Per the MacLeamy curve, these changes are harder to implement than during design, and their impact on project outcomes is more limited. Consequently, although IPD project teams might incur in higher knowledge transfer costs during design, they might produce project outcomes with value deliver a greater payoff as illustrated in Figure 2-6.

In summary, **in IPD method involves team members from Tiers 1, 2, and 3 since project design to create a knowledge transfer networks with interactions across Tiers to identify and exploit any valuable knowledge.** To conclude, based on the discussion above, IPD allows key factors, other than imposed or constrained knowledge transfer structures, to shape team members' knowledge transfer interactions in AEC project teams.

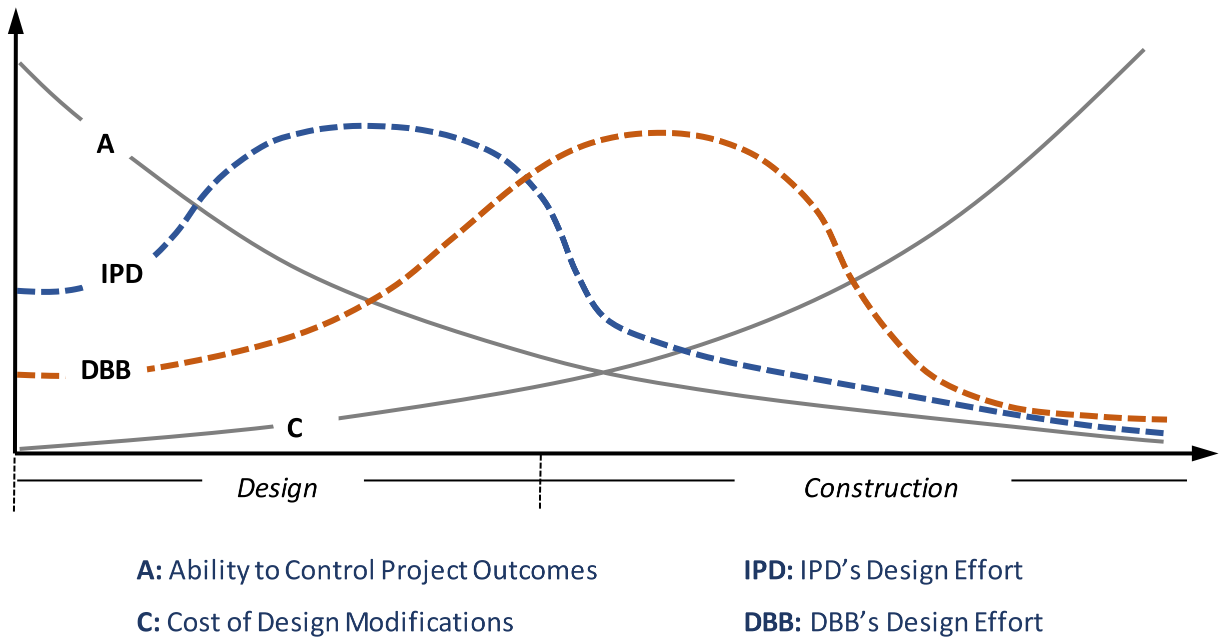


Figure 2-5. MacLeamy Curve (AIA, 2007; AGC, 2010)

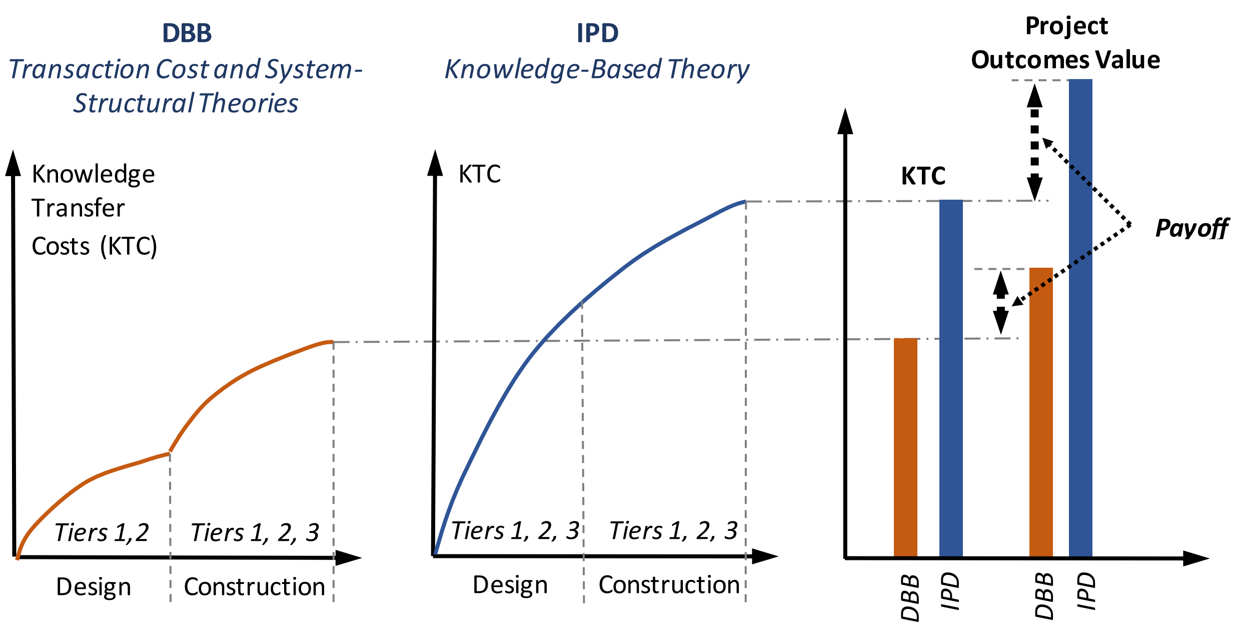


Figure 2-6. Cost and Value Generated by Different PDMs in AEC Projects

2.4.2. Motivational Factors in PDMs to Promote Knowledge Transfer

As discussed above, DBB, CMR, and DB methods limit Tier 3 team members' range of knowledge transfer interactions. These methods, based on transactional contracting, expect team members to realize a set of obligations indicated beforehand in AEC contracts in exchange of an economic transaction (Williamson, 1981). This might be the only formal mechanism to motivate them to transfer knowledge. In addition, this motivational mechanism might be complemented with other informal mechanisms such as social motivations (e.g., prestige) or effortless altruism (Javernick-Will, 2012).

On the other hand, IPD method, grounded on relational contracting, aims to motivate knowledge transfer based on the quality of team members' relations (Lahdenpera, 2012). IPD brings team members from all tiers to transfer knowledge under contractually shared risks, benefits, goals, and decision-making. These factors aim to create close relations based on trust and mutual respect across tiers that raise team members' commitment to cooperatively solve events not captured in contracts (Ghassemi and Becerik, 2011). As briefly described below, the effect of these factors on team members' motivation to collaborate transferring knowledge is notable (Chinowsky et al., 2008, 2010; Chioccio et al., 2011; Ghassemi and Becerik, 2011).

2.4.2.1. Shared Risks, Benefits, Goals, and Decision-Making

Sharing risks, benefits and goals fosters team oriented behavior, that is, team members move towards productive resolution of conflicts. They emphasize open-minded discussions favoring "win-win" collaboration (Tjosvold, 1999; Tjosvold et al., 2004). And shared decision-making rises team member' sense of ownership of and commitment to project outcomes, thus strengthening their willingness collaborate (Campion et al., 1993; Cohen and Bailey, 1997; Matthews and Howell, 2005).

2.4.2.2. *Trust and Mutual Respect*

Trust refers to the belief that taking the risk of exposing oneself to the actions of others is beneficial (Mayer et al., 1995). Respect, although it might involve trust, entails showing deference and consideration (Ferris et al., 2009). The combination of trust and mutual respect propitiate "team psychological safety" which mitigates team members' fear to peers' potential negative reactions when collaborating (e.g., embarrassment for asking a question with an obvious answer) (Edmondson, 1999). Psychological safety promotes the adoption of learning behavior, that is, "asking questions, seeking feedback, experimenting, reflecting on results, and discussing errors or unexpected outcomes" which ensures higher quality collaboration (Edmondson, 1999).

2.5. Summary

This chapter first posited that knowledge management outcomes (e.g., retention or creation of knowledge) depend on four key factors including features of knowledge, of units transferring knowledge, of knowledge transfer networks, and of relationships between units. A literature review including key publications under each factor in the AEC and knowledge management domains was developed. Second, since this dissertation focuses on knowledge management outcomes including knowledge transfer and application, knowledge transfer was defined as either sending or receiving knowledge, whereas knowledge application as exploiting knowledge regardless of fully comprehending it. Finally, this chapter discussed the influence on knowledge transfer of different project delivery methods (PDMs) in the AEC industry. Design-Bid-Build (DBB), Construction Management at Risk (CMR), and Design-Build (DB) methods create knowledge transfer networks constraining many team members' interactions to reduce costs associated with knowledge transfer. Conversely, Integrated Project Delivery (IPD) method creates knowledge transfer networks via free interactions involving all key parties to detect and exploit any key valuable knowledge. Despite increasing knowledge transfer costs, IPD might ultimately generate a greater payoff due to improved project outcomes.

CHAPTER 3: MULTI-LEVEL MODEL OF KNOWLEDGE TRANSFER & APPLICATION, & HYPOTHESES

Based on the review of knowledge transfer and application literature in the previous chapter and adding insights from a variety of domains including communication, psychology, social networks, construction management, and engineering and organizational efficiency, this chapter develops **the multi-level model of knowledge transfer and application** in inter-organizational and multi-disciplinary project teams illustrated in Figure 3-1. The model guides study hypotheses development and argues the following at each level:

1. At the **individual level**, the model argues first that a receiver's knowledge application in a network position is influenced by his/her absorptive capacity, the senders' articulating capacities, and receiver-senders' common knowledge. Second, if the receiver's knowledge application is high in such network position, then the receiver maintains his/her knowledge transfer interactions over time. And third, if the receiver applies transferred knowledge, then he/she improves his/her absorptive and articulating capacities, and common knowledge with other peers;

2. At the **sub-team level**, the model posits that individuals' absorptive capacities contribution to a sub-team's absorptive capacity is moderated by their centrality degree in the sub-team's network. In turn, sub-teams' absorptive capacities are correlated with their knowledge application; and

3. Finally, at the **team level**, following an analog reasoning as for sub-teams, sub-teams' absorptive capacities influence on a project team's absorptive capacity is moderated by their

centrality degree in the project team's network. In turn, the project team's absorptive capacity determines its knowledge application.

The developed multi-level model (Figure 3-1) follows Foss et al.'s (2010) claim that knowledge application at macro-level variables (i.e., sub-team, and team) can be only well understood by first examining knowledge application at micro-level variables (i.e., individuals). The model considers key factors displayed in Figure 2-2 to examine knowledge transfer and application, including individuals' features (e.g., absorptive capacity), features of relationships between units (e.g., team members' relations within IPD teams are based on trust and mutual respect), and features of knowledge transfer networks (e.g., IPD method allows free knowledge transfer interactions). Knowledge features (e.g., complexity) are not considered in this model.

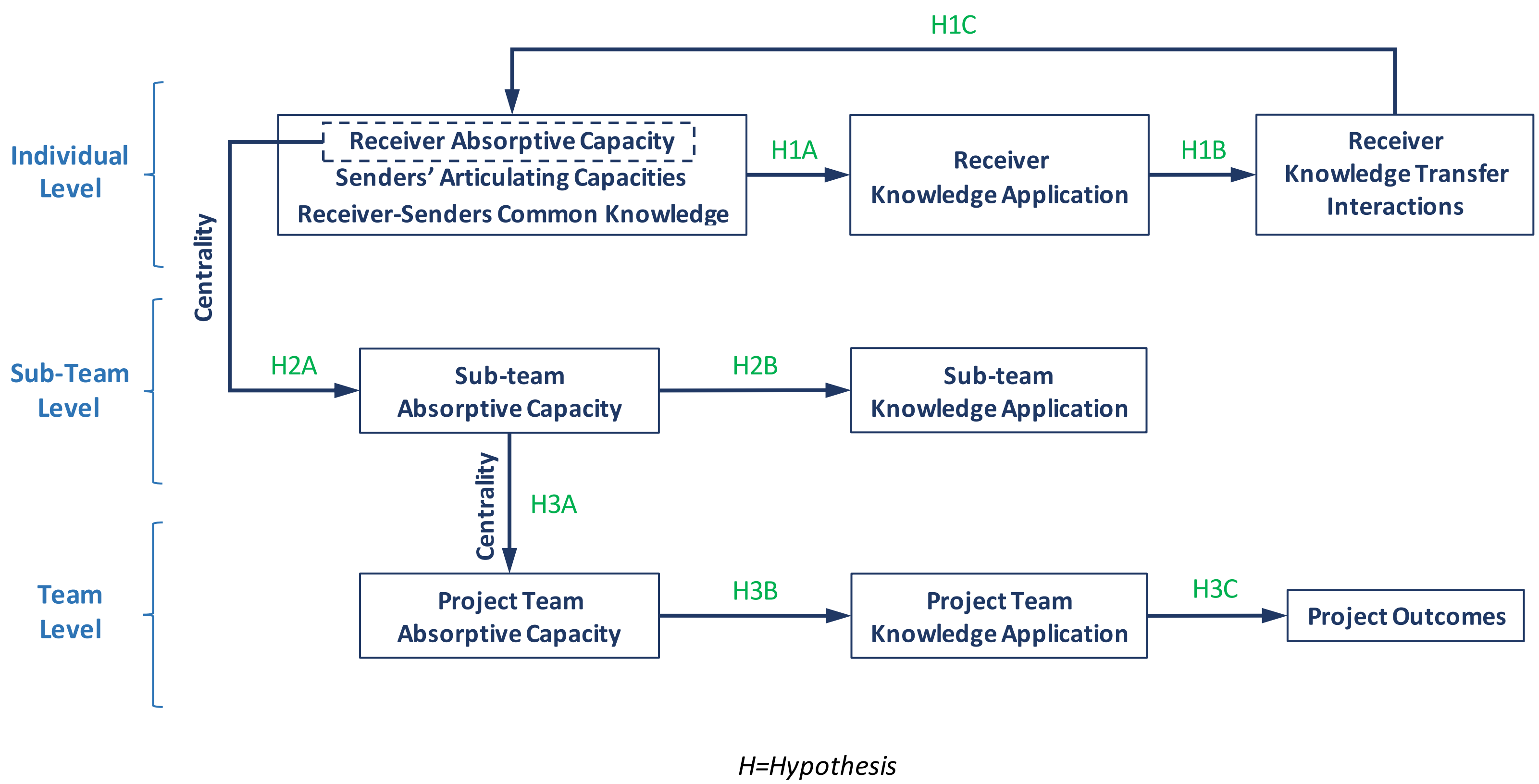


Figure 3-1. Multilevel Model of Knowledge Transfer and Application in IPD project teams

3.1. Point of Departure

The multi-level model in Figure 3-1 is built upon three main points:

1. The framework in Figure 2-2 in previous chapter which was developed based on the literature. Accordingly, the multi-level model examines the influence of units' absorptive and articulating capacities, and common knowledge (i.e., properties of units) on knowledge transfer and application (i.e., knowledge management outcomes) within IPD project teams (i.e., properties of networks and relationships established by IPD method);

2. Frank and Farhbach's (1999) social network theory of selection-influence. This theory argues that individuals' beliefs influence the interactions that they select; in turn, these interactions shape their beliefs. Parallelly, at the individual level, the multi-level model argues that at individuals' ability to apply knowledge influence their selection of knowledge transfer interactions; in turn, the selected interactions influence their ability to apply knowledge via shaping their characteristics (absorptive and articulating capacities, and common knowledge); and

3. Understanding knowledge application at the individual level is crucial to understand knowledge application at the project team level (Foss et al., 2010). Thus, the model interconnects knowledge application at the individual, sub-team, and team levels.

The next sections present the study hypotheses following the multi-level model in Figure 3-1.

3.2. Individual Level Model

IPD project teams are created temporarily gathering individuals from different organizations and disciplines to develop a common project. The IPD method imposes free knowledge transfer interactions among these individuals. This section examines the key factors influencing members' knowledge transfer and application in IPD project teams.

3.2.1. Hypothesis 1A: Receiver Knowledge Application

In the literature, individuals' characteristics affecting their knowledge transfer and application include their articulating and absorptive capacities, and common knowledge. They are explained in more detail below to present the first study hypothesis.

3.2.1.1. Absorptive Capacity

Individuals possess certain level of absorptive capacity, a concept including three dimensions: The ability to identify, assimilate, and apply valuable knowledge (Cohen and Levinthal, 1990; Mowery and Oxley, 1995; Da Silva and Davis, 2011). The third dimension coincides with the concept of knowledge application previously presented. Nonetheless, in this dissertation, absorptive capacity is defined as *the ability to only identify and understand knowledge*. The reason is the need to separately consider the concept of knowledge application which, unlike absorptive capacity, allows exploitation of valuable knowledge without the need to previously understand it.

A knowledge receiver's absorptive capacity depends on his/her network position, and stored knowledge in his/her brain related to transferred knowledge (Cohen and Levinthal, 1990). First, the network position determines a receiver's accessible knowledge and, therefore, what valuable knowledge he/she can identify. And second, a receiver assimilates new knowledge easier if he/she has some related knowledge (Grant, 1996; Alavi and Leidner, 2001). By "associative learning," he/she manipulates and combines portions of this related knowledge to understand transferred knowledge (Reagans and McEvily, 2003). For instance, someone describing a room may use the concepts of height, width, and length, and combine them to articulate a description. If the receiver of this description also commands the same geometric concepts, he/she will make associations with them to depict the room in his/her mind.

Therefore, despite possessing large amounts of knowledge, a receiver's absorptive capacity might be low if he/she occupies network positions supplying knowledge with which he/she lacks related knowledge (Lane and Lubatkin, 1998). In IPD project teams, a receiver might tend to avoid these network positions due to being unable to apply acquired knowledge, and his/her willingness to collaborate because of sharing goals, risks and benefits (Tjosvold, 1999).

Thus, in IPD teams, a receiver with high absorptive capacity indicates that he/she is placed in a network position capturing knowledge with which he/she shares some related knowledge, thus easing knowledge application.

3.2.1.2. Articulating Capacity

Individuals possess articulating capacity to codify knowledge and make it comprehensible to others (Reagans and McEvily, 2003). In IPD teams, knowledge senders with high articulating capacity possess common knowledge with receivers (Burt, 2002). This allows senders to codify knowledge considering a receiver's perspectives or assumptions to understand knowledge, thus facilitating the receiver's assimilation of transferred knowledge without being distorted (Thomas, DeScioli, Haque and Pinker, 2014). For example, an individual in an IPD team might send a project schedule to a peer. If the peer receiving the schedule possesses differing assumptions regarding resources' productivities to calculate durations of activities, then he/she will not be able to understand the schedule. Therefore, senders with high articulating capacity make it easier for a receiver to apply transferred knowledge.

3.2.1.3. <u>*Common Knowledge*</u>

As argued above, a key component constituting individuals' absorptive and articulating capacities is their stored common knowledge with transferred knowledge. Nevertheless, how much of this common knowledge do individuals' absorptive and articulating capacities need to favor application of transferred knowledge?

Common knowledge is necessary to ease assimilation of transferred knowledge via "associative learning" (Reagans and McEvily, 2003). A receiver may just need small portions of common knowledge with transferred knowledge to identify and understand the valuable pieces. Moreover, too much common knowledge might impede the receiver to test novel combinations of diverse knowledge and devise innovative solutions (Nooteboom et al., 2007). For instance, a mechanical engineer may know that key 10% of the electrical system that is important for him/her to develop and connect a compatible mechanical system. Thus, his/her absorptive capacity (i.e., ability to identify and understand valuable knowledge from the electrical system) might be high while sharing low common knowledge (i.e., 10%) with the engineer developing the electrical system.

Therefore, individuals' knowledge application might not be dependent on sharing large amounts of common knowledge but key pieces. Herein it is tested whether high common knowledge between a receiver and his/her senders enhances his/her knowledge application. If the test fails, it would suggest that key shared pieces of knowledge, even though small, might suffice to enhance knowledge application.

Considering all the above, the following hypothesis is examined:

- **Hypothesis 1A:** In IPD project teams, the higher a receiver's absorptive capacity, senders' articulating capacities, and common knowledge between the receiver and senders, then the higher the receiver's knowledge application.

3.2.2. Hypothesis 1B: Receiver Knowledge Transfer

If individuals' interactions result in high knowledge application, they might tend to maintain them over time. In IPD project teams, fruitful knowledge transfer interactions develop trust (Chinowsky et al., 2008; Chiocchio et al., 2011); in turn, trust raises a receiver's expectation that relying on previous successful interactions will keep leading to effective knowledge application, ensuring a beneficious return on the resources invested (Mayer et al., 1995). Searching for new interactions might be time consuming, while a receiver might be uncertain about whether they will be fecund (Hansen, 1999). In addition, productive interactions generate commitment, a persistent involvement due to expecting benefits in exchange (Eisenberger, Fasolo, and Davis, 1990). Moreover, prolific interactions might lead a receiver to become familiar with how senders articulate transferred knowledge, thus easing his/her knowledge application. In IPD teams, these interactions might endure due to a receiver's preference to select interactions easing application of transferred knowledge (Szulanski, 1996; Hansen, 1999; Zander and Kogut, 1995; Reagans and McEvily, 2003; Park, Suh and Yang, 2007). Hence, the hypothesis below is tested:

- **Hypothesis 1B:** In IPD project teams, the higher a receiver's knowledge application, the higher the number of knowledge transfer interactions he/she will maintain over time in the network.

3.2.3. Hypothesis 1C: Receiver Characteristics

Of all available knowledge within a team, knowledge transfer interactions determine what portions of knowledge are provided to a receiver. That is, knowledge transfer interactions might filter knowledge supplied to a receiver, limiting it to those portions that he/she can apply. Successful application of acquired portions of knowledge might result in receivers storing new knowledge in their brains, thus growing their (1) common knowledge with other peers; (2) their absorptive capacity due to expanding their related knowledge with the knowledge that they acquire (Cohen and Levinthal, 1990); and (3) their articulating capacity because of learning new perspectives and/or approaches taken by other peers for articulating knowledge, especially when interactions occur across disciplinary and organizational boundaries (Reagans and McEvily, 2003). Thus, the hypothesis below is tested:

- **Hypothesis 1C:** In IPD project teams, the higher a receiver's knowledge application, the higher will be the increment over time of his/her absorptive and articulating capacities, and common knowledge with other peers.

3.3. Sub-Team Level Model

IPD project teams break down into different inter-disciplinary sub-teams developing distinct parts of the project which are later integrated. This section first analyzes the relation between individuals' and sub-teams' absorptive capacities. Then the influence of sub-teams' absorptive capacities in their knowledge application.

3.3.1. Hypothesis 2A: Sub-Team Absorptive Capacity

In IPD teams, sub-teams are identifiable in the team network via maximizing the concentration of ties within versus across the sub-teams' boundaries (Comu, Iorio, Taylor, and Dossick, 2013).

They are highly cohesive sub-networks within the project team network. Their formation is crucial to bring together and blend multi-disciplinary expertise (Gibson and Vermeulen, 2003). They constitute a dynamic mechanism to place team members within the appropriate context to identify and understand valuable knowledge (Dyer and Nobeoka, 2000; Van den Bosch, 1999; Jansen et al., 2005). However, frequently their members lack common knowledge necessary to integrate each other's knowledge into a single solution (Tortoriello, Reagans, and McEvily, 2012).

Since free knowledge transfer interactions are allowed in IPD project teams, specific individuals emerge within the sub-teams as informal leaders facilitating sub-team members' valuable knowledge transfer and application (Iorio et al., 2012). These leaders can be effective if they occupy a central position in the sub-team network. In such position, they can access larger amounts of knowledge circulating within the team (Chinowsky et al., 2010). Thus, they can examine what valuable knowledge is embedded in the sub-team and to whom it should be transferred for assimilation. Therefore, their absorptive capacity can help other sub-team members to detect and understand valuable knowledge within the sub-team (Lenox and King, 2004).

Consequently, sub-team members' absorptive capacities might exert a greater influence on sub-teams' absorptive capacities (i.e., sub-team ability to identify and understand valuable knowledge) if they hold a central network position. Sub-team members in more peripherical positions, have less access to identify valuable knowledge, thus making a weaker impact on the sub-team absorptive capacity. Therefore, the following hypothesis is analyzed:

- **Hypothesis 2A:** In IPD project teams, the influence of a member's absorptive capacity on a sub-team's absorptive capacity is moderated by his/her centrality in the sub-team's network.

3.3.2. Hypothesis 2B: Sub-Team Knowledge Application

Members in cross-disciplinary sub-teams can apply transferred knowledge from different disciplines without understanding it, that is, merely replicate it partially or totally (Zander and Kogut, 1995). Nonetheless, in IPD projects, sub-teams must integrate multi-disciplinary knowledge to develop a unique solution. Replicating sub-team members' knowledge without understanding it might impede sub-teams implementing appropriate changes to optimally connect multi-disciplinary knowledge (see Section 2.3). Hence, sub-teams' knowledge application (i.e., ability to apply sub-team members' knowledge) might be defective without proper levels of absorptive capacity. Therefore, the hypothesis below is tested:

- **Hypothesis 2B:** In IPD project teams, the higher a sub-team's absorptive capacity, the higher the sub-team's knowledge application.

3.4. Team Level Model

As argued above, IPD project teams are comprised by sub-teams developing different tasks. The sub-teams do not work disconnectedly. They are embedded in a project team network where they transfer the adequate knowledge to make their tasks' outcomes compatible, and work towards a common goal. This section first explains the connection between sub-teams' and project teams' absorptive capacities. Then it examines the factors driving IPD project teams' knowledge application and outcomes (i.e., time, cost, and quality).

3.4.1. Hypothesis 3A: Project Team Absorptive Capacity

The emergence of the inter-disciplinary sub-teams above manage knowledge of a limited number of team members. These sub-teams generate the project team's absorptive capacity. Their relative contribution to the entire project team absorptive capacity (i.e., ability to identify and understand project team members' valuable knowledge) is different depending on their position in the team network (Van den Bosch et al., 1999; Tsai, 2001; Andersen and Foss, 2005). Sub-teams' in central positions within the team network receive larger amounts of knowledge from other sub-teams (Chinowsky et al., 2010). Therefore, they can identify and understand larger quantities of valuable knowledge that are later transferred to other sub-teams in the network. Thus, network position limits the extent to which a sub-team can influence the team's absorptive capacity. Accordingly, the hypothesis below is analyzed:

- **Hypothesis 3A:** IPD project teams, the influence of a sub-team's absorptive capacity on the project team's absorptive capacity is moderated by its centrality in the project team's network.

3.4.2. Hypothesis 3B: Project Team Knowledge Application

Following the same reasoning as for sub-teams' knowledge application in Section 3.3.2, project teams can apply its team members' knowledge by replicating it without understanding it (Zander and Kogut, 1995). However, this might hinder developing proper changes to multi-disciplinary knowledge to effectively integrate it. Hence, high project team absorptive capacity might be crucial to enable effective knowledge application (i.e., project team ability to apply its project team members' knowledge). Therefore, the following hypothesis is posited:

- **Hypothesis 3B:** The higher an IPD project team's absorptive capacity, the higher its knowledge application.

3.4.3. Hypothesis 3C: Project Performance

IPD project teams tie key parties' goals and success. Therefore, while transferring knowledge, they are willing to analyze diverse or opposing points of view to negotiate combined solutions (Sun et al., 2015). In doing so, they foster diverse knowledge application into a unique solution potentially improving project outcomes (i.e., time, cost, and quality). However, they frequently need to invest extra time learning about their peers' disciplinary backgrounds or organizational procedures. Thus, although IPD team members might ultimately improve project outcomes such as quality, they might damage others such as time for project completion. Hence IPD projects' outcomes might fail to meet targeted goals or outperform projects following other project delivery methods (Baiden et al., 2006, 2011). Hence, the hypothesis below is tested:

- **Hypothesis 3C:** The greater an IPD project team knowledge application, the better project outcomes (i.e., time, cost, and quality).

3.5. Summary

Chapter 3 presented a multi-level model of knowledge transfer and application at the individual, sub-team, and team levels. The model served as a framework to develop the study hypotheses which are compiled in Table 4-2 in next chapter.

CHAPTER 4: METHODOLOGY

4.1. Summary of Study Objectives and Methods

The research goal is to **examine the key factors shaping knowledge transfer networks facilitating knowledge application in IPD project teams.** The objectives to achieve this goal are listed in Table 4-1.

Table 4-1. Study Objectives and Methods

Study Objectives	Methods
1. To detect the key factors affecting knowledge management outcomes such as knowledge creation, transfer, retention, and application in diverse domains and units (e.g., individuals, teams, and organizations).	Review of literature regarding knowledge transfer and application processes of individuals, teams, and organizations (Section 2.1).
2. To define and differentiate knowledge transfer and application phenomena, and to determine the key factors influencing them	Review literature within knowledge application, transfer, sharing, exchange, and diffusion domains to first create a definition for knowledge transfer and diffusion concepts, and, second, establish their differences (Sections 2.2 and 2.3).
3. Based on theory, to discuss knowledge transfer in AEC project teams under different project delivery methods (PDMs)	Review literature related to project delivery methods in AEC projects, relational contracting approaches to AEC project delivery, AEC teams' integration, and theories of firm for knowledge management including transaction cost (Williamson, 1981), system-structural organizational (Astley and Van de Ven, 1983), and knowledge-based (Grant, 1996) theories (Section 2.4).

Table 4-1. (cont'd)

4. To develop a multi-level model of knowledge transfer and application in IPD project teams	Take as the point of departure to build the model the social network theory of influence and selection at the individual level (Frank and Farhbach, 1999) and key point (Section 3.1), and using the literature in the domains specified in Objectives 1, 2, and 3 above, develop the entire model along with study hypotheses (Sections 3.2, 3.3, and 3.4).
5. To empirically test study hypotheses, and develop practical and theoretical applications	Collect longitudinal data via cross-sectional surveys at two time points from an AEC project team contractually following the IPD method (Chapter 4); using these data, test study hypotheses via structural equation modeling and linear regression (Chapter 5); and, combining the results of study hypotheses' tests and literature mentioned in Objectives 1 to 3 above, propose theoretical and practical applications (Chapter 6).

4.2. Study Hypotheses

Study hypotheses are contained in Table 4-2 below and graphically displayed in Figure 3-1.

Table 4-2. Description of Study Hypotheses

Study Hypotheses		
H1	**A.**	The higher a receiver's absorptive capacity, senders' articulating capacities, and common knowledge between the receiver and senders, then the higher the receiver's knowledge application in IPD project teams.
	B.	The higher a receiver's knowledge application, the higher the number of knowledge transfer interactions he/she will maintain over time in the network in IPD project teams.

Table 4-2. (cont'd)

	C.	The higher a receiver's knowledge application, the higher will be the increment over time of his/her absorptive and articulating capacities, and common knowledge with other peers in IPD project teams.
H2	**A.**	The influence of a member's absorptive capacity on a sub-team's absorptive capacity is moderated by his/her centrality in the sub-team's network in IPD project teams.
	B.	The higher a sub-team's absorptive capacity, the higher the sub-team's knowledge application in IPD project teams.
H3	**A.**	The influence of a sub-team's absorptive capacity on the project team's absorptive capacity is moderated by its centrality in the project team's network in IPD project teams.
	B.	The higher an IPD project team's absorptive capacity, the higher its knowledge application.
	C.	The greater an IPD project team knowledge application, the better project outcomes (i.e., time, cost, and quality).

4.3. Study Site

The sections below offer a detailed description of the study site from which data was collected to later test empirically study hypotheses.

4.3.1. Case Study Project

The selected case study project was a higher education project developed in Michigan, and consisting of a new addition to an existing facility. The addition included four stories with a total size of 100,000 square feet. The initial project cost estimate was around $60 million. The design phase started in January 2016 and was completed after 13 months in February 2017. The construction phase did not start yet due to being in the process of obtaining permits. The design went through four main phases including validation, conceptual design, design development, and construction documents (Figure 4-1). The project required participants to follow an integrated approach to green planning and design. A main goal of the case study project was to deliver a design optimizing energy consumption and indoor environmental quality, while opting to achieve the silver level of Leadership in Energy and Environmental Design certification. This approach required designers to closely cooperate to merge different building systems (e.g.., mechanical, electrical, structural, plumbing, and architectural) into a single model via Building Information Modeling (BIM) utilizing Revit software. This allowed designers to develop building energy performance simulation and design clash detection before construction start.

4.3.2. Project Delivery Method

The followed project delivery method was IPD by contract. All key parties in the project including owners' representatives, designers, constructors, and mechanical, electrical, structural, glazing, and plumbing subcontractors signed a multi-party contract by which they shared goals, benefits, risks, and power in decision-making. To avoid team members to maximize their profit by proposing savings at the expense of project quality, savings were reinvested into the project.

Owners' representatives and designers kicked of the project with the validation phase; general constructors came on board at the beginning of the conceptual design; electrical and mechanical subcontractors got involved at the end of the conceptual design phase; steel, structural, and glazing subcontractors came into the project at the beginning of design development phase; and other subcontractors who did not necessarily sign the multi-party contract, were added later during design development when required (e.g., landscaping).

4.3.3. Adequacy of Selected Study Site

The selected study site is appropriate for this research for several reasons: First, the selected AEC project team follows IPD method by contract. This ensures that all key parties are involved early on during project delivery to freely transfer knowledge while contractually sharing risks, benefits, goals and decision-making power. Second, the study site gathers more than 160 team members. Therefore, it is impossible for team members to interact with everyone; they must select key interactions. And third, the case study project involves relatively complex AEC work requiring effective integration of multiple building system. Thus, team members are forced to interact across disciplinary and organizational boundaries to make their task outcomes compatible, and develop a single and unique product meeting project goals. In summary, based on these three reasons, the selected study site is suitable to achieve the research goal (i.e., *to examine the key factors shaping knowledge transfer networks facilitating knowledge application in IPD project teams*) since it brings AEC team members under a context where they must create valuable knowledge transfer interactions based on the key factors that this research aims to reveal.

4.4. Data Collection

Since this study involves human subjects, a data collection protocol was developed and submitted to the Institutional Review Board (IRB) at Michigan State University (MSU) (Appendix A). An application approval letter was obtained from the IRB to start data collection (Appendix B1). Data was collected via online surveys which begun with a consent form approved by the IRB (Appendix B2) informing participants about the research objectives, potential benefits and risks, privacy and confidentiality issues, and their rights to participate or withdraw. Finally, they were offered the contact information from the author, some dissertation committee members, IRB, and MSU for any concerns they could have.

Longitudinal data was collected from all study variables from one IPD by contract project team at two time points during the design phase (Figure 4-1). The main reason to focus on the design stage is that IPD method fosters intense knowledge transfer interactions early on during the design stage. The purpose is to maximize the impact of all key team members' knowledge on design outcomes (Figure 2-5), eliminating or minimizing design changes during construction. Therefore, most key knowledge transfer interactions tend to occur during the design stage of the project delivery process. The reasons to select Time points 1 and 2 as displayed in Figure 4-1 are: First, at Time point 1 most key parties were already involved; and second, Time Points 1 and 2 are placed in such a way that team members participating at both time points are approximately the same. This facilitates accomplishing the research goal (i.e., *to examine the key factors shaping knowledge transfer networks facilitating knowledge application in IPD project teams*) due to minimizing the variation of team composition across time.

The data was collected via three surveys, namely, Surveys #1, #2 and #3. These surveys are described in detail in Section 4.5. The process to collect data followed the following steps:

1. First, Survey #1 was sent to all team members. This survey captured individuals' top 5 most valuable knowledge transfer interactions; individuals' absorptive and articulating capacities, common knowledge, and knowledge application; and project team's absorptive capacity and knowledge application. Reminders via email were sent every two days during ten days to achieve the highest response rate.

2. Second, with data collected with Survey #1 regarding individuals' top 5 most valuable knowledge transfer interactions, sociograms were developed, and sub-teams identified via KliqueFinder software which maximizes the concentration within versus across sub-

teams' boundaries. Then Survey #2 was sent to team members with higher centrality in identified sub-teams to confirm their existence, and rate their absorptive capacities and knowledge application. Reminders via email were sent every two days during ten days to endure a high response rate.

3. And third, Survey #3 was sent to owner's representatives to rate project outcomes including time, cost, and quality. Reminders via email were sent every two days during ten days to endure a high response rate.

On average, Surveys #1, #2, and #3 took 15, 3, and 2 minutes to be completed respectively. The whole process to collect data with the three surveys took 20 days approximately at each of the two time points in which data were collected. A pilot survey was completed by all team members in the case study project in February 2016 to assess and improve Surveys #1, #2, and #3. First time point for data collection occurred in June 2016 after 50% of design was complete; and the second time point occurred between November and December 2016 after 80% of design completion. This process is depicted in Figure 4-1.

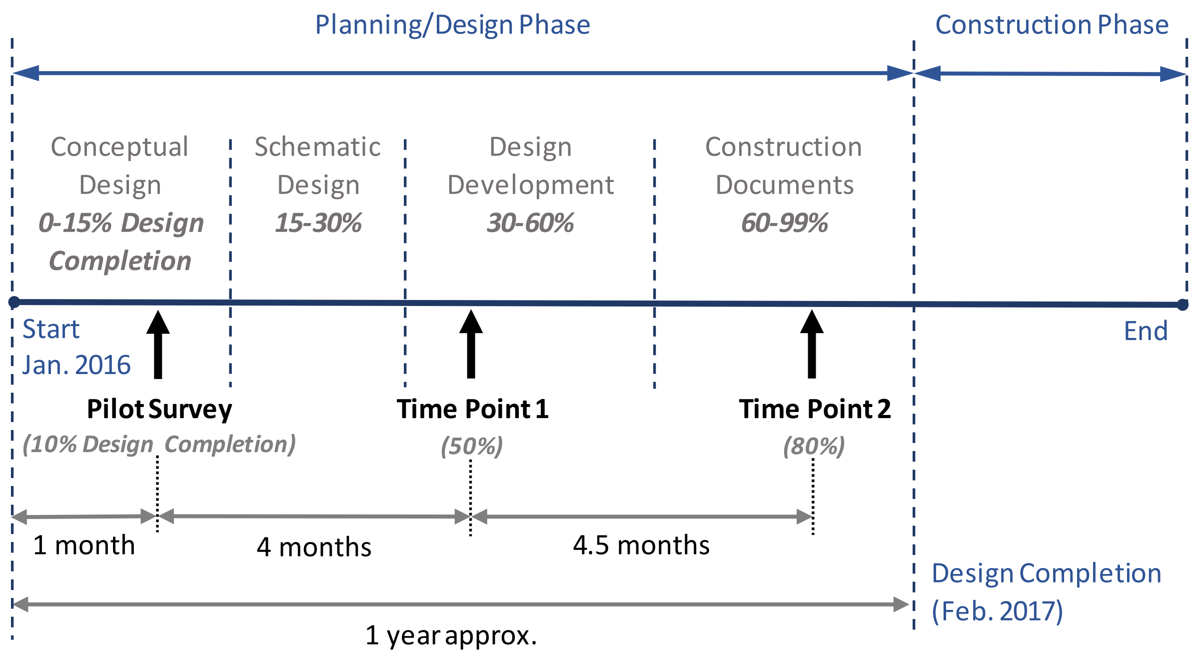


Figure 4-1. Timing of Data Collection

4.5. Study Variables: Description and Operationalization

All study variables, except for project outcomes, deal with the concept of knowledge. Generally, project teams have two types of knowledge available to achieve project goals, namely, explicit and tacit knowledge (Nonaka and Takeuchi, 1995; Smith, 2001). Explicit knowledge means "academic knowledge or *know-what*" which is easy to code and transfer, and gained through education, books, and/or training (Smith, 2001). Whereas tacit knowledge refers to "practical, action-oriented knowledge or *know-how* based on practice," is difficult to articulate and code, acquired through experience, and often similar to intuition (Smith, 2001). However, "whether tacit or explicit knowledge is the more valuable may indeed miss the point. The two are not dichotomous states of knowledge, but mutually dependent and reinforcing qualities of knowledge: tacit knowledge forms the background necessary for assigning the structure to develop and interpret explicit knowledge" (Polanyi 1975). Therefore, this study does not distinguish between tacit or explicit knowledge.

The study variables' description, operationalization, and respondents are shown in Table 4-3 below. The surveys utilized to measure the study variables are contained in Appendix C. The surveys included pictures representing knowledge transfer scenarios in IPD project teams to help respondent understand the questions. To ensure that all respondents interpreted the survey items in the same manner, Survey #1 included two definitions at the beginning: (1) ***knowledge transfer*** is providing theoretical or practical information, insights, or skills that have value to the project.; and (2) ***valuable knowledge*** is that knowledge that allows team members to effectively accomplish their tasks, contributing to improve project performance.

Except for the first variable (i.e., *Individual Knowledge Transfer Interactions* which intends to identify individuals' interactions), the rest are measured using a five-level Likert scale (i.e., 1 – strongly disagree, 2 – disagree, 3 – Neither agree nor disagree, 4 – agree, 5 – strongly agree).

Table 4-3. Study Variables' Description, Operationalization, Survey Number, and Respondents

Survey #1 Completed by all team members	
Variable	**Description and Operationalization**
Individual Knowledge Transfer Interactions	Act of receiving or sending knowledge (Chinowsky et al., 2008). Individuals report those team members who provided them with valuable knowledge (Chinowsky, Taylor, and DiMarco, 2011): ▪ *List in order of importance the **top 5 individuals** (within/outside your organization) who provided you with the most valuable knowledge during the last month*

Table 4-3. (cont'd)

Individual Articulating Capacity	Individuals' capacity to make knowledge comprehensible to others (Reagans and McEvily, 2003). Measured in a five-level Likert scale with items *Art1* and *Art2*: *For each of the 5 individuals listed above and during the last month…* ▪ *Art1: "This person articulated his/her knowledge in such a manner that it was easy to understand"* ▪ *Art2: "This person made complex knowledge look simple"*
Individual Absorptive Capacity	Individuals' capacity to identify and understand valuable knowledge (Cohen and Levinthal, 1990). Measured in a five-level Likert scale with items *Iden1, Iden2, Und1,* and *Und2* below: *For each of the 5 individuals listed above and during the last month…* (Ability to <u>identify</u> valuable knowledge) ▪ *Iden1: "This person was able to identify within the team the knowledge that would be most valuable to improve project performance"* ▪ *Iden2: "This person was able to determine what knowledge within the team was credible and trustworthy"* (Ability to <u>understand</u> valuable knowledge) ▪ *Und1: "This person's expertise in design-construction projects made it easy for him/her to understand the knowledge conveyed to him/her"* ▪ *Und2: "This person was able to easily connect to his/her knowledge in design-construction projects the knowledge conveyed to him/her"*
Individuals' Common Knowledge	Shared knowledge or overlapping areas of expertise between two individuals (Reagans and McEviliy, 2003). Each dyad common knowledge to be measured in a five-level Likert scale with items *Ck1* and *Ck2* below: *For each of the 5 individuals listed above and during the last month…* ▪ *Ck1: "This person's expertise in design-construction projects overlapped with mine"* ▪ *Ck2: "This person and I had similar knowledge that helped us communicate easier"*

Table 4-3. (cont'd)

Individual Knowledge Application	Individuals' ability to exploit received knowledge to develop her tasks (Alavi and Tiwana, 2002). Survey items are developed based on Gold, Malhotra, and Segars' (2001) scale and measured in a five-level Likert scale with items *Kapp1* and *Kapp2* below: *For each of the 5 individuals listed above and during the last month…* ▪ *Kapp1*: *"This person easily adapted his/her work to make use of the knowledge conveyed to him/her"* ▪ *Kapp2*: *"This person quickly applied the knowledge conveyed to him/her improving project performance"*
Project Team Absorptive Capacity	Project team's ability to identify and understand team members' key knowledge (Cohen and Levinthal, 1990). Scale from Cadiz et al. (2009) taken as a point of departure. Measured in a five-level Likert scale with the items below: *During the last month…* (Ability to <u>identify</u> valuable knowledge) ▪ *"People in this project team were able to identify the knowledge that would be most valuable to improve project performance"* ▪ *"Our knowledge in design-construction projects allowed us to determine what knowledge within the team was credible and trustworthy to meet our client's demands"* (Ability to <u>understand</u> valuable knowledge) ▪ *"The shared knowledge within this project team made it easy to understand new knowledge brought up by team members"* ▪ *"It was easy for my team to see the connections between different pieces of knowledge held jointly"*

Table 4-3. (cont'd)

Project Team Knowledge Application	Project teams' ability to exploit team members' knowledge improving project performance (Alavi and Tiwana, 2002). Gold, Malhotra, and Segars' (2001) scale taken as point of departure. Measured in a five-level Likert scale with the items below: *During the last month…* ▪ *"It was easy to adapt our work to make use of the knowledge shared by project team members in this project"* ▪ *"Knowledge shared by team members could be quickly applied to our work improving project performance"*
Survey #2 Completed by team members with higher centrality in sub-teams' networks	
Variable	**Description and Operationalization**
Sub-team Existence	After the sub-teams and boundary spanners are identified, a list including sub-team members is sent to the boundary spanners via email. They are requested to respond (Yes or Not) to the following question: ▪ *"During the last month, would you agree that the sub-group has closely worked together to develop common tasks (e.g., developing design, cost estimates, or project planning)?"*
Sub-team Absorptive Capacity	Sub-team's ability to identify and understand sub-team members' key knowledge (Cohen and Levinthal, 1990). Scale from Cadiz et al. (2009) taken as a point of departure. Measured in a five-level Likert scale with the items below:: *During the last month…* (Ability to identify valuable knowledge) ▪ *"The sub-team was able to identify the most valuable knowledge to improve project performance"* ▪ *"The sub-team's knowledge in design-construction projects was helpful to determine what knowledge was valuable"* (Ability to understand valuable knowledge) ▪ *"The shared knowledge within the sub-group made it easy to understand new knowledge brought up by sub-team members"*

Table 4-3. (cont'd)

	▪ *"It was easy for the sub-team to see the connections between different pieces of knowledge held jointly"*
Sub-team Knowledge Application	Sub-teams' ability to exploit sub-team members' knowledge improving project performance (Alavi and Tiwana, 2002). Gold, Malhotra, and Segars' (2001) scale taken as point of departure. Measured in a five-level Likert scale with the items below:: *During the last month…* ▪ *"It was easy for the sub-team to adapt its work to make use of the knowledge shared by the sub-group members"* ▪ *"Knowledge shared by sub-team members could be quickly applied to the sub-team work improving project performance"*
Survey #3 Completed by owners' representatives	
Variable	**Description and Operationalization**
Project Performance	Degree to which established objectives are accomplished or team outcomes surpass standard benchmarks (e.g. Gladstein, 1984). Most common metrics in AEC projects include schedule growth (actual vs initial), cost growth (actual vs initial), and quality (from owner's perspective). Measured in a five-level Likert scale with the items below: ▪ *"Project cost outcomes met targeted goals"* ▪ *"Project schedule outcomes met targeted goals"* ▪ *"Project quality met targeted goals"* ▪ *"You may add other performance metrics if you wish"*

Values of study variables above are to be calculated averaging team members' responses. Individuals' absorptive and articulating capacities are rated by other team members. Common knowledge between two peers is rated by both. Their numerical value would be calculated as follows:

- ***Articulating capacity.*** If (a_{ij}) is the articulating capacity of team member (i) as perceived by team member (j), then the articulating capacity of (i) which is rated by (N) peers, is calculated as $a_i = \Sigma\, a_{ij} / N$.

- ***Absorptive Capacity.*** Following an analog process as for articulating capacity above, the absorptive capacity of team member (i) is $b_i = \Sigma\, b_{ij} / N$.

- ***Common knowledge.*** If (K_{ij1}) is the common knowledge between team members (i) and (j) as perceived by (i), and (K_{ij2}) as perceived by (j), then the common knowledge between (i) and (j) yields $K_{ij} = (K_{ij1} + K_{ij2}) / 2$.

4.6. Data Analysis

This research used a quantitative approach via inferential statistics to analyze the associations among the study variables described in the study hypotheses. To achieve this aim, structural equation modeling (SEM) or linear regression analyses were conducted via RStudio software. SEM was used only for Hypothesis 1A. The other hypotheses were tested via simple or multi-linear regression methods since the sampling sizes were not sufficiently large to allow SEM produce accurate estimates. SEM is a general framework utilizing path analysis techniques and general linear models such as multiple linear regression while allowing to model latent variables. All study variables in this research are latent variables, that is, unobserved variables that must be inferred from observed variables (e.g., survey indicators). SEM is an adequate method to evaluate both the established correlations among the latent variables in the study hypotheses, and internal validity of latent variables' indicators, that is, whether the survey indicators are truly measuring the study variables (Rosseel, 2013).

This section develops below mathematical models capturing the relation of study variables as described in study hypotheses. They helped the researcher to (1) ensure that the hypotheses are properly interconnected according to the study multi-level model (Figure 3-1), and (2) develop statistical models to guide tests performed via structural equation modeling or linear regression. In addition, these mathematical models will be later offered for future research to simulate knowledge transfer networks' formation and evolution in AEC project teams.

4.6.1. Hypothesis 1A Model: Receiver Knowledge Application

The model below reflects Hypothesis 1A which states that *the higher a receiver's absorptive capacity, senders' articulating capacities, and common knowledge between the receiver* and *senders, then the higher the receiver's knowledge application in IPD project teams*. Factors' meanings are shown in Table 4.4.

$$A_{it} = \alpha_0 + \theta_1\, b_{it} + \theta_2\, (\Sigma\, a_{i't}/N) + \theta_3\, (\Sigma\, K_{ii't}/N) + e_t$$

Table 4-4. Factors of Hypothesis 1A Model

Factor	**Meaning**
A_{it}	Ability of receiver (i) to apply transferred knowledge at time (t).
α_0	Intercept.
Θ_1	Effect of factor.
b_{it}	Absorptive capacity of receiver (i) at time (t).
$\Sigma\, a_{i't}/N$	Average articulating capacity of (N) senders (i') transferring knowledge to receiver (i) at time (t).
$\Sigma\, K_{ii't}/N$	Average common knowledge between receiver (i) and (N) senders (i') transferring knowledge to receiver (i) at time (t).
e_t	Errors are assumed iid normal, with mean zero and variance (σ^2).

4.6.2. Hypothesis 1B Model: Receiver Knowledge Transfer

The bold portion of the model below reflects Hypothesis 1B which claims that *the higher a receiver's knowledge application, the higher the number of knowledge transfer interactions he/she will maintain over time in the network in IPD project teams*. Factors' meanings are shown in Table 4-5.

$$\log\left(\frac{w_{it}}{1-w_{it}}\right) = \alpha_0 + \theta_1 A_{i(t-1)} + e_t; \text{ where } w_{it} = \Sigma\, u_{ii't} / \Sigma\, u_{ii'(t-1)}$$

With (i') being all the team members that sent knowledge to (i) at time (t-1)

Table 4-5. Factors of Hypothesis 1B Model

Factor	Meaning
w_{it}	Proportion of knowledge transfer interactions of receiver (i) at time (t-1) that also occurred at time (t).
$u_{ii't}$	Knowledge transfer between receiver (i) and sender (i') at time (t). $u_{ii't}$=1 if yes; $u_{ii't}$=0 if not.
α_0	Intercept.
Θ_j	Effect of factor, or of difference in attribute.
$A_{i(t-1)}$	Ability of (i) to apply knowledge at time (t-1).
e_t	Errors are assumed iid normal, with mean zero and variance (σ^2).

4.6.3. Hypothesis 1C Model: Receiver Characteristics

The models below represent Hypothesis 1C which claims that *the higher a receiver's knowledge application, the higher will be the increment over time of his/her absorptive and articulating capacities, and common knowledge with other peers in IPD project teams*. Factors' meanings are compiled in Table 4-6.

$$a_{it} = a_{i(t-1)} + \theta_1 A_{i(t-1)} + e_t$$

$$b_{it} = b_{i(t-1)} + \theta_2 A_{i(t-1)} + e_t$$

$$\Sigma K_{ii't}/N = \Sigma K_{ii'(t-1)}/N + \theta_3 A_{i(t-1)} + e_t$$

Table 4-6. Factors of Hypothesis 1C Model

Factor	Meaning
a_{it}	Articulating capacity of (i) at time (t).
b_{it}	Absorptive capacity of (i) at time (t).
$\Sigma K_{ii't}/N$	Average common knowledge of (i) with other team members (i') at time (t).
$A_{i(t-1)}$	Ability of (i) to apply knowledge at previous time (t-1).
Θ_j	Effect of factor, or of difference in attribute.
e_t	Errors are assumed iid normal, with mean zero and variance (σ^2).

4.6.4. Hypothesis 2A Model: Sub-Team Absorptive Capacity

The model below represents Hypothesis 2A which states that *the influence of a member's absorptive capacity on a sub-team's absorptive capacity is moderated by his/her centrality in the sub-team's network in IPD project teams.* Factors' meanings are contained in Table 4-7. The reason to utilize a logarithm in the equation below is that the distribution of team members' distance to the sub-team network center tends to be left-skewed (Figure 5-18 in Chapter 5). Sub-teams are to be identified via KliqueFinder software which maximizes the concentration of knowledge transfer interactions within versus across sub-teams' boundaries. Sociograms displaying sub-teams are to be drawn via Netdraw. The data to be used to identify sub-teams include individuals' top 5 most valuable knowledge transfer interactions reported in Survey #1. Finally, sub-teams are to be validated by members with higher centrality in the sub-teams' networks.

$$b_{STt} = \alpha_0 + \theta_1 \Sigma \log (b_{it,ST}/R_{it,ST}) + e_t$$

Table 4-7. Factors of Hypothesis 2A Model

Factor	Meaning
b_{STt}	Absorptive capacity of sub-team (ST) at time (t).
$b_{it,ST}$	Absorptive capacity of individual (i) within sub-team (ST) at time (t).
$R_{it,ST}$	Distance of individual (i) to sub-team's (ST) network center at time (t).
α_0	Intercept.
Θ_1	Effect of factor.
e_t	Errors are assumed iid normal, with mean zero and variance (σ^2).

4.6.5. Hypothesis 2B Model: Sub-Team Knowledge Application

The model below reflects Hypothesis 2B which indicates that *the higher a sub-team's absorptive capacity, the higher the sub-team's knowledge application in IPD project teams*. Factors' meanings are contained in Table 4-8.

$$A_{STt} = \alpha_0 + \theta_1 b_{STt} + e_t$$

Table 4-8. Factors of Hypothesis 2B Model

Factor	Meaning
A_{STt}	Ability of subteam (ST) to apply knowledge from its members at time (t).
b_{STt}	Absorptive capacity of sub-team (ST) at time (t).
α_0	Intercept.
θ_1	Effect of factor.
e_t	Errors are assumed iid normal, with mean zero and variance (σ^2).

4.6.6. Hypothesis 3A Model: Project Team Absorptive Capacity

The model below represents Hypothesis 3A which says that *the influence of a sub-team's absorptive capacity on the project team's absorptive capacity is moderated by its centrality in the project team's network in IPD project teams.* Factors' meanings are contained in Table 4-9.

$$b_{PTt} = \alpha_0 + \theta_1 \Sigma \log (b_{STjt, PT}/R_{STj, PT}) + e_t$$

Table 4-9. Factors of Hypothesis 3A Model

Factor	Meaning
b_{PTt}	Absorptive capacity of project team (PT) at time (t).
$b_{STjt,\ PT}$	Absorptive capacity of sub-team (ST_j) within project team (PT) at time (t).
$R_{STj,\ PT}$	Distance of sub-team (ST_j) to the project team's (PT) network center at time (t).
α_0	Intercept.
θ_1	Effect of factor.
e_t	Errors are assumed iid normal, with mean zero and variance (σ^2).

4.6.7. Hypothesis 3B Model: Project Team Knowledge Application

The model reflects Hypothesis 3B which asserts that *the higher an IPD project team's absorptive capacity, the higher its knowledge application.* Factors' meanings are contained in Table 4-10.

$$A_{PTt} = \alpha_0 + \theta_1 b_{PTt} + e_t$$

Table 4-10. Factors of Hypothesis 3B Model

Factor	Meaning
A_{PTt}	Ability of the project team (PT) to apply knowledge from its members at time (t).
b_{PTt}	Absorptive capacity of project team (PT) at time (t).
α_0	Intercept.
θ_1	Effect of factor.
e_t	Errors are assumed iid normal, with mean zero and variance (σ^2).

4.6.8. Hypothesis 3C Model: Project Performance

The model reflects Hypothesis 3C which asserts that *the greater an IPD project team knowledge application, the better project outcomes (i.e., time, cost, and quality).* Factors' meanings are contained in Table 4-11.

$$\Sigma\,(C_{PTt} + T_{PTt} + Q_{PTt})/3 = \alpha_0 + \theta_1 A_{PTt} + e_t$$

Table 4-11. Factors of Hypothesis 3C Model

Factor	Meaning
$\Sigma(C_{PTt}+T_{PTt}+Q_{PTt})/3$	Average project outcomes including cost, time, and quality respectively of project team (PT) at time (t).
A_{PTt}	Ability of project team (PT) to apply knowledge from its members at time (t).
α_0	Intercept.
θ_1	Effect of factor.
e_t	Errors are assumed iid normal, with mean zero and variance (σ^2).

4.7. Research Quality

Research quality of this study was ensured via construct and internal validity, external validity, and reliability (Groat and Wang, 2002; Yin 2003) as explained in the following sections.

4.7.1. Construct and Internal Validity

Construct and internal validities are concerned with first the degree to which definitions of variables are accurate, and second, the extent to which survey indicators truly measure the study variables and nothing else (Singleton and Straits, 1999; Groat and Wang, 2002). Construct validity takes place during the data collection phase, whereas internal validity during the data analysis. Below it is explained how they were addressed in this research.

Construct validity was addressed by developing definitions and measurements for study variables based on the literature (Table 4-3). In addition, a pilot survey was sent out to team members in the study site to get their feedback and implement modifications if necessary (Figure 4-1). The study variables were measured with IPD team members' responses to an online survey. Thus, measurements of study variables were potentially subject to bias due to respondents under- or over-estimating the true score. This effect was mitigated due to utilizing the input of multiple respondents to measure the same variables. For example, a team member's absorptive or articulating capacity was rated by between one to thirty individuals; and study variables at the team level variables were rated by more than fifty team members. The study variable *Individual Knowledge Transfer Interactions* which was used to develop a team knowledge transfer network. To avoid individuals wrongly estimating their influence in the network and weakening construct validity, the survey asked *"List the top 5 individuals that provided you with the most valuable knowledge"* rather than *"List the top 5 individuals to whom you provided knowledge."* Construct validity was threatened by non-response bias caused by some team members not completing the survey. This problem was alleviated by closely following up with team members to have them complete the survey and maximize the response rate.

Finally, during data analysis, internal validity was ensured for study variables in Hypothesis 1A (e.g., individuals' absorptive and articulating capacities, common knowledge, and knowledge application) via structural equation modeling. SEM uses Confirmatory Factor Analysis (CFA) to quantitatively assess what indicators in the survey are valid (Hunter and Gerbing, 1982).

4.7.2. Reliability

Reliability refers to the consistency of measurements, that is, the extent to which survey indicators provide the same scores when repeatedly measured under similar conditions (Groat and Wang, 2002; Zeisel, 2006). Reliability can be increased by adding more survey indicators of the same quality as the existing ones (Spearman, 1910; Brown, 1910). Reliability in this research was assessed via Cronbach's alpha (Cronbach, 1951). It is generally considered that reliability is good if the Cronbach's alpha is equal or greater than 0.7 (Nunnally, 1978). To improve reliability, a pilot survey was utilized to examine whether respondents with similar or distinct roles in the IPD project team interpreted the survey questions in the same manner (Singleton and Straits, 1999).

4.7.3. External Validity

External validity addresses the generalizability of research findings (Groat and Wang, 2002). Although the hypotheses proposed herein focus on IPD project team in the AEC industry, they are grounded on research findings and/or theories from diverse bodies of knowledge such as construction management, social networks, psychology, communication, knowledge management, or organizational science (Yin, 2003). For example, the literature utilized to support study hypotheses development comes from journals such as Administrative Science Quarterly, Organization Science, Project Management Journal, Management Science, Social Psychology Quarterly or Communication Theory among others. Thus, it is expected that the study findings will be applicable to industries other than the AEC one where inter-organizational project teams similar to IPD teams are temporarily formed to achieve specific goals.

4.8. Summary

This chapter described the methods to accomplish the research objectives. To empirically test the study hypotheses, longitudinal data were collected from a case study project including an IPD project team formed by more than 160 team members. These data were collected via cross-sectional survey during the design phase of project delivery. Study variables' definitions and operationalization were developed based on the literature. Methods utilized to test study hypotheses embrace structural equation modeling, and linear regression techniques. In addition, this chapter addressed described the research quality. Measurements' internal validity was addressed via first using literature for study variables' definition and operationalization, and second mitigating response and no-response bias of survey participants. Reliability of study variables was addressed via Cronbach's alpha. Finally, since study hypotheses were developed based on literature in diverse domains such as social networks, psychology, communication, it was argued study findings are expected to be applicable to industries other than the AEC one.

CHAPTER 5: RESULTS

In this chapter first describes the characteristics of the sample from which data was collected; second, presents an outline displaying how study hypothesis were tested; and finally, describes in detail the results of the tests of study hypotheses.

5.1. Sample Characteristics

The case study project used in the analyses included 164 and 162 team members at time points 1 and 2 respectively. All of them were invited to complete Survey#1, and 53 (32.3%) and 62 (38.3%) responded. Team members were classified as those being strongly involved in the project (i.e., those exerting a notable impact on project outcomes such as owners' representatives, designers, subcontractors, and general constructor), and those with a tangential participation (i.e., those having a low impact on project outcomes such as some owner's representatives). After differentiating these two types of participants, 68.5% (37 out of 54) and 72.2% (39 out of 54) of participants strongly involved in the project completed Survey#1 at time points 1 and 2 respectively. Survey#2 was sent to 8 and 12 members with higher centrality within the sub-teams at time points 1 and 2 respectively. All of them completed it, one of them partially. Each member filled out the survey for only the sub-team to which he/she belonged. Finally, Survey#3 was sent to and completed by 4 and 5 owner's representatives at time points 1 and 2. Demographics of team members and knowledge transfer patterns within the case study project are described below.

Project Team Members: The project team during the design phase involved more than 160 team members. As explained in Section 4.4, data was collected at two time points. Hence, when describing team members' characteristics below, two percentages are offered (i.e., x% / y%) referring to percentages of characteristics at time points 1 and 2 respectively. The sample included male (75% / 72%) and white (98% / 96%), few were American Indian or Alaskan Native (2% / 0%), or of another race (0% / 4%). Team members belonged to more than 10 different organizations. Their roles included owner's representatives (21% / 25%); architects (11% / 6%); contractors (11% / 4%); mechanical subcontractors (11% / 8%); electrical subcontractors (4% / 4%); structural subcontractors (2% / 2%); and others (40% / 51%, no more than 1-2% each) including steel fabricators, data communication and information technology engineers, LEED consultants, glazing contractors, plumbing and fire protection engineers, mechanical and electrical consultants, project managers, lightning and controls engineers, BIM/CAD coordinators, landscape architects, archeology experts, soil erosion engineers, interns, and advisor on needs. Most of team members involved had an experience working in the AEC industry between 20 and 35 years. Most of them had participated in less than 5 AEC projects implementing IPD by contract before getting involved in the case study project.

Knowledge Transfer Patterns: Frequent methods that the IPD project team utilized to transfer knowledge across disciplines and/or organizations included core team meetings to evaluate work performed and plan future work, pull planning meetings to coordinate team members' tasks, cluster groups using Revit software for BIM to simultaneously design multiple building systems, and reconciliation meetings to adjust design according to cost estimate. Most of the knowledge transfer interactions between team members occurred weekly (45%) or monthly (37%). Daily interactions were the least frequent (18%). Team members primarily transfer knowledge via face-to-face conversations (63%), video-conferences (15%), phone calls (13%), and shared software (e.g., Revit) (6%).

5.2. Outline for Testing Study Hypotheses

Tables 5-1 below shows how the study hypotheses were tested including dependent and independent variables, the time points in which they were measured, and the statistical methods utilized. Table 5-2 includes complementary analyses developed to further assess Hypothesis 1A which, as opposed to analyses in Table 5-1, utilize longitudinal data.

Table 5-1. Dependent and Independent Variables of Study Hypotheses, and Methods for Testing Study Hypotheses

Hyp.[1]	Dependent Variables	Independent Variables	Method
1A	▪ Receiver Knowledge Application ***(Time 1)***	▪ Receiver Absorptive Capacity ***(Time 1)*** ▪ Senders' Articulating Capacities ***(Time 1)*** ▪ Receiver-Senders Common Knowledge ***(Time 1)***	Structural Equation Modeling with ***Cross-Sectional Data*** (Section 5.3.1)
1A	▪ Receiver Knowledge Application ***(Time 2)***	▪ Receiver Knowledge Application ***(Time 2)*** ▪ Senders' Articulating Capacities ***(Time 2)*** ▪ Receiver-Senders Common Knowledge ***(Time 2)***	Multi-Linear Regression with ***Cross-Sectional Data*** (Section 5.3.2)
1B	▪ Receiver Knowledge Transfer Interactions ***(Increment between Time 1 and 2)***	▪ Receiver Knowledge Application ***(Time 1)***	Simple Linear Regression with ***Longitudinal Data*** (Section 5.4)

Table 5-1. (cont'd)

1C	▪ Receiver Absorptive Capacity ***(Increment between Time 1 & 2)*** ▪ Senders' Articulating Capacities ***(Increment between Time 1 & 2)*** ▪ Receiver-Senders Common Knowledge ***(Increment between Time 1 & 2)***	▪ Receiver Knowledge Application ***(Time 1)***	Simple Linear Regression with ***Longitudinal Data*** (Section 5.5)
2A	▪ Sub-Team Absorptive Capacity ***(Time 1 & 2)*** [2]	▪ Receiver Absorptive Capacity (Moderator: Receiver centrality in the sub-team's network) ***(Time 1 & 2)*** [2]	Simple Linear Regression with ***Cross-Sectional Data*** (Section 5.6)
2B	▪ Sub-Team Knowledge Application ***(Time 1 & 2)*** [2]	▪ Sub-Team Absorptive Capacity ***(Time 1 & 2)*** [2]	Simple Linear Regression with ***Cross-Sectional Data*** (Section 5.7)
3A	▪ Project Team Absorptive Capacity ***(Increment between Time 1 & 2)***	▪ Sub-Team Absorptive Capacity (Moderator: Sub-team centrality in the project team's network) ***(Time 1)***	No method used due to extremely low sample size (Section 5.8)
3B	▪ Project Team Knowledge Application ***(Increment between Time 1 & 2)***	▪ Project Team Absorptive Capacity ***(Time 1)***	No method used due to extremely low sample size (Section 5.8)

Table 5-1. (cont'd)

3C	▪ Project Outcomes ***(Increment between Time 1 & 2)***	▪ Project Team Knowledge Application ***(Time 1)***	No method used due to extremely low sample size (Section 5.8)

[1]Hyp. = Hypothesis; [2]Data at time points 1 and 2 were merged since sub-teams were different at each time point.

Table 5-2. Complementary Analyses for Testing Hypothesis 1A with Longitudinal Data

Hyp.[1]	**Dependent Variables**	**Independent Variables**	**Method**
1A	▪ Receiver Knowledge Application ***(Time 2)***	▪ Receiver Absorptive Capacity ***(Time 2)*** ▪ Senders' Articulating Capacities ***(Time 2)*** ▪ Receiver-Senders Common Knowledge ***(Time 2)*** ▪ Receiver Knowledge Application ***(Time 1, Control Variable)***	Multi-Linear Regression with ***Longitudinal Data*** (Section 5.1.3)
1A	▪ Receiver Knowledge Application ***(Increment between Time 1 and 2)***	▪ Receiver Absorptive Capacity ***(Time 1)*** ▪ Senders' Articulating Capacities ***(Time 1)*** ▪ Receiver-Senders Common Knowledge ***(Time 1)***	Multi-Linear Regression with ***Longitudinal Data*** (Section 5.1.3)

[1]Hyp. = Hypothesis.

5.3. Hypothesis 1A: Receiver Knowledge Application

This section tests Hypothesis 1A illustrated in Figure 5-1. This Since data was collected at two time points, Hypothesis 1A was tested twice. The first test was performed via structural equation modeling (SEM) since the number of observations was ample. In the second test, due to a low number of both observations and indicators to measure latent variables, SEM could not be performed. Instead, multi-linear regression (MLR) was used. Although this method cannot assess the internal validity of latent variables' indicators, it can help to evaluate relations between them.

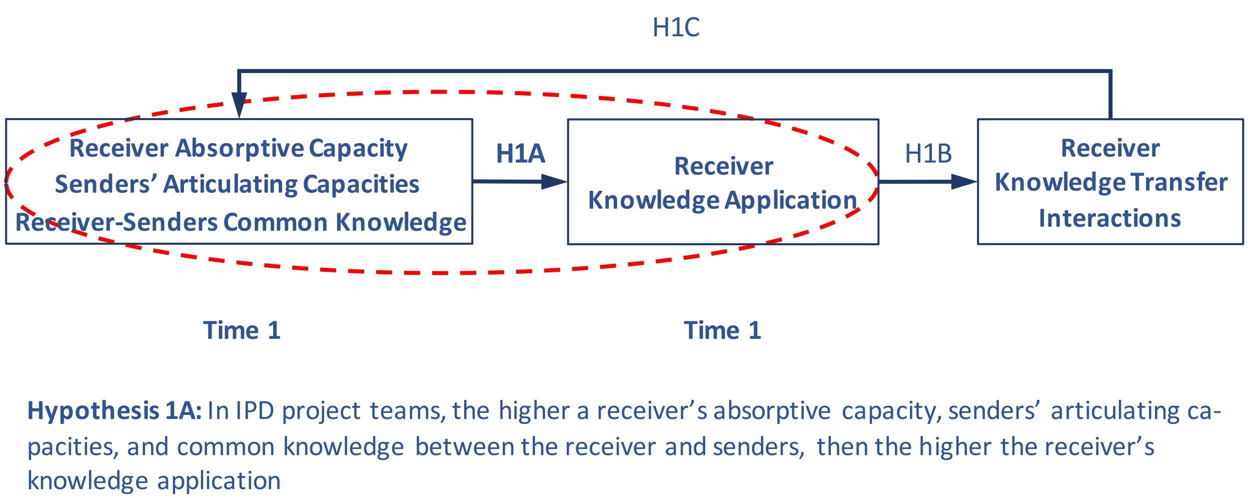


Figure 5-1. Hypothesis 1A (Dash Line)

5.3.1. Structural Equation Modeling (SEM) at Time Point 1

This section examines Hypothesis 1A at time point 1 via structural equation modeling (SEM) of the model illustrated in Figure 5-2. SEM was performed via RStudio software with the Lavaan package. Since the dependent variable's sampling data was left-skewed, the function testing the model's fit used the MLR estimator (i.e., maximum likelihood estimation with Huber-White standard errors). This estimator ensures robustness when dependent variables' sampling data is not normally distributed (Rosseel, 2013). Descriptive statistics of the data collected at time point 1 are shown in Tables 5-3, 5-4, and 5-5. These tables indicate that the sample size equals 48. This sample size contains individuals for which values for all latent variables could be collected. There were 53 additional individuals for which there were missing values for one or two latent variables. When performing SEM, the missing values were estimated via full information maximum likelihood (FIML) which calculates "unbiased parameter estimates and standard errors" (Newsom, 2017). Therefore, SEM was performed over 101 (i.e., 48 + 53) observations.

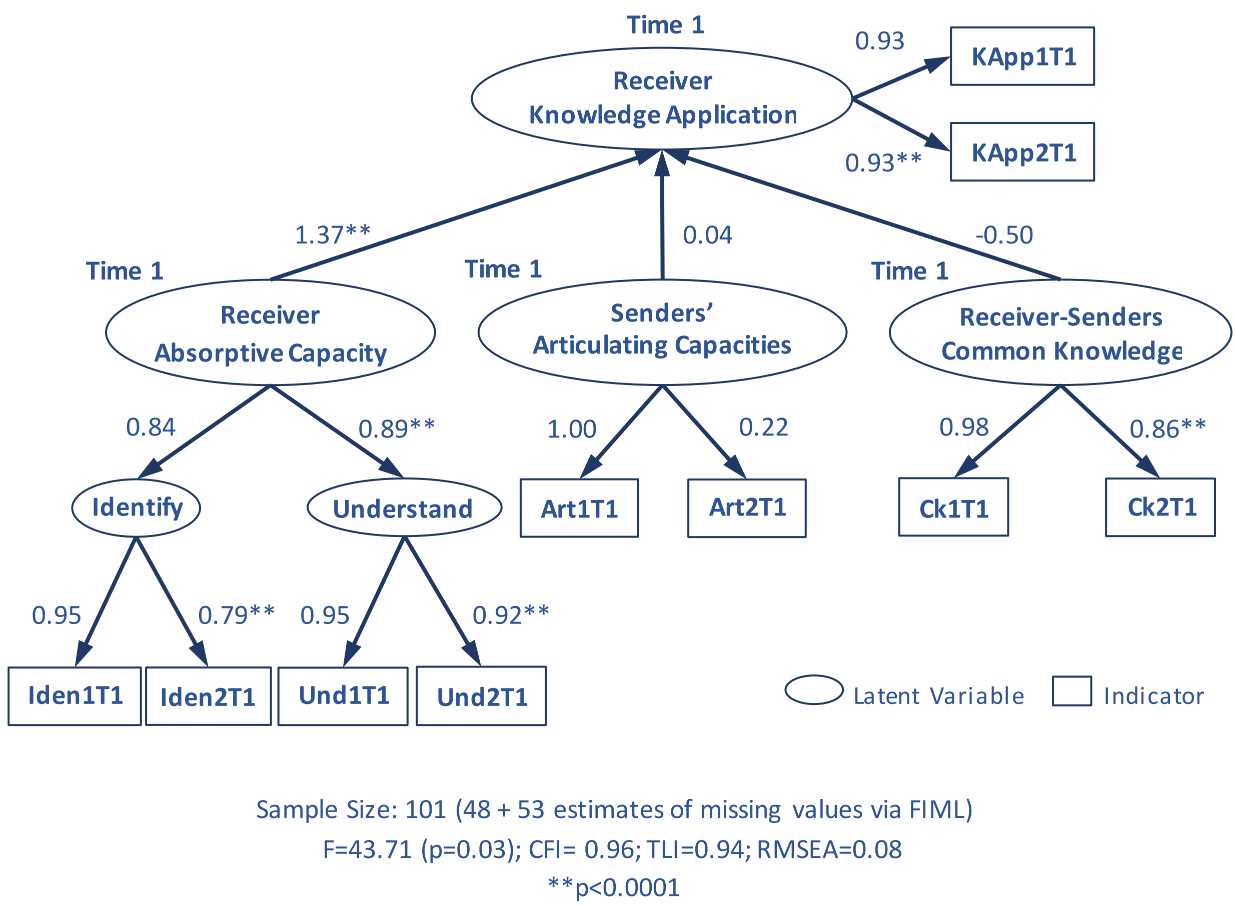


Figure 5-2. Model to test Hypothesis 1A at Time Point 1 Including Path Coefficients, and Model Fit Indices

Table 5-3. Sampling Data Distribution and Correlations of Latent Variables in Hypothesis 1A at Time Point 1

Lat. Var.	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	KappT1	AbsT1	ArtT1	CkT1
KappT1	2.00	4.00	4.43	4.25	4.77	5.00	-	-	-	-
AbsT1	2.50	4.00	4.38	4.27	4.69	5.00	0.79	-	-	-
ArtT1	3.70	4.14	4.29	4.31	4.43	5.00	-0.36	-0.32	-	-
CkT1	2.17	3.75	4.24	4.04	4.50	5.00	0.34	0.50	-0.18	-

Sample Size: 48
KappT1: *Receiver Knowledge Application* at Time 1
AbsT1: *Receiver Absorptive Capacity* at Time 1
ArtT1: *Senders' Articulating Capacities* at Time 1
CkT1: *Receiver-Senders Common Knowledge* at Time 1

Table 5-4. Sampling Data Distribution of Indicators of Latent Variables in Hypothesis 1A at Time Point 1

Value	Kapp1T1	Kapp2T1	Iden1T1	Iden2T1	Und1T1	Und2T1	Art1T1	Art2T1	Ck1T1	Ck2T1
Min.	2.00	2.00	2.00	2.00	2.80	3.00	3.82	3.00	1.0	1.00
1st Qu.	4.00	4.00	4.00	4.00	4.03	4.00	4.32	4.05	3.87	4.00
Median	4.50	4.67	4.39	4.71	4.71	4.50	4.53	4.22	4.25	4.25
Mean	4.44	4.42	4.24	4.42	4.49	4.44	4.50	4.19	4.15	4.19
3rd Qu.	5.00	5.00	5.00	5.00	5.00	5.00	4.66	4.36	5.00	5.00
Max.	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00

Sample Size: 48
Kapp(i)T1: Survey item no. (i) to measure *Receiver Knowledge Application* at Time 1
Iden(i)T1: Survey item no. (i) to measure *Identify* (1st dimension of *Receiver Absorptive Capacity*) at Time 1
Und(i)T1: Survey item no. (i) to measure *Understand* (2nd dimension of *Receiver Absorptive Capacity*) at Time 1
Art(i)T1: Survey item no. (i) to measure *Senders' Articulating Capacities* at Time 1
Ck(i)T1: Survey item no. (i) to measure *Receiver-Senders Common Knowledge* at Time 1
Survey items can be found in Table 4-3 (Section 4.5)

Table 5-5. Correlations of Indicators of Latent Variables in Hypothesis 1A at Time Point 1

Indicator	Kapp1T1	Kapp2T1	Iden1T1	Iden2T1	Und1T1	Und2T1	Art1T1	Art2T1	Ck1T1	Ck2T1
Kapp1T1	-	-	-	-	-	-	-	-	-	-
Kapp2T1	0.85	-	-	-	-	-	-	-	-	-
Iden1T1	0.73	0.72	-	-	-	-	-	-	-	-
Iden2T1	0.48	0.43	0.69	-	-	-	-	-	-	-
Und1T1	0.69	0.66	0.57	0.35	-	-	-	-	-	-
Und2T1	0.68	0.59	0.46	0.34	0.88	-	-	-	-	-
Art1T1	-0.36	-0.39	-0.36	-0.21	-0.29	-0.15	-	-	-	-
Art2T1	-0.16	-0.23	-0.05	0.20	-0.52	-0.38	0.20	-	-	-
Ck1T1	0.50	0.39	0.34	0.29	0.66	0.64	-0.03	-0.30	-	-
Ck2T1	0.37	0.30	0.29	0.40	0.48	0.42	-0.09	-0.05	0.75	-

Sample Size: 48; Meaning of abbreviations are displayed in Table 5-4

Model Structural Changes: After a first attempt running SEM, several actions were performed to improve the model fit (Figure 5-2). The variances of *Receiver Knowledge Application* (at Time 1) and *Art1T1* were constrained to equal zero due to delivering negative values. In addition, based on variables' modification indices, a new path was added in the model between indicators *Und1T1* and *Art2T1*. Modification indices can be used to select key additional links in the model to improve the fit (Rosseel, 2013).

Model Fit: SEM results are built upon 101 observations, including estimated missing values. The model's Minimum Function Test Statistic (Chi-Square) is 43.71 ($p = 0.03$), indicating that we do not reject the null hypothesis of perfect model fit. The Comparative Fit Index (CFI=0.96) is greater than 0.95 and close to 1.00, suggesting that the model fits the data well (Hu and Bentler 1999; Kline 2005; Hair et al. 2010). The Tucker-Lewis Index (TLI=0.94) is greater than 0.8

and close to 1.00, indicating a good fit as well (Hu and Bentler, 1999). The Root Mean Square Error of Approximation (RMSEA) is 0.08 (p = 0.15), that is, equal or lower than 0.8; and the lower bound of its 90% confidence interval (CI.lower=0.03) is close to 0.0, suggesting a reasonable fit (Browne and Cudeck, 1993). Overall, the fit indices suggest that the model in Figure 5-2 is plausible for the data.

Internal Validity of Measurements: Factor loadings (i.e., path coefficients between latent variables and their respective indicators (Figure 5-2)) for indicators *Kapp2, Iden2, Und2,* and *ComK2* are 0.93, 0.79, 0.92, and 0.86, respectively. In addition, they are statistically significant (p<0.001), and with confidence intervals (95%) with high lower and upper limits: (0.81, 1.23), (0.39, 1.12), (0.78, 1.18), and (0.61, 1.03) respectively.

The factor loadings were calculated using the "marker indicator" method (Hoyle, 2012). This method initially fixes one factor loading to 1.00 between a latent variable and one of its indicators (i.e., between *Kapp1, Iden1, Und1,* and *ComK1* and their respective latent variables in this case). This allows using the path coefficient between the latent variable and the indicator as a reference to calculate the variance of the latent variable. Therefore, data suggests that indicators used to measure *Receiver Knowledge Application; Understand; Identify; and Receiver-Senders Common Knowledge* are valid. In addition, path coefficients between *Receiver Absorptive Capacity's* and its dimensions, i.e., *Identify* and *Understand*, are high, 0.84 and 0.89, respectively. Thus, data do not reject the multi-dimensionality of *Receiver Absorptive Capacity*. Finally, results suggest a weak and not statistically significant factor loading between *Senders' Articulating Capacities* and its second indicator (i.e., factor loading=0.22 with *Art2T1*). Therefore, data reject the validity of the indicators used to measure *Senders' Articulating Capacities* at time point 1 (i.e., *Art1T1 and Art2T1).*

Reliability of Measurements: Reliability of measurements was calculated via Cronbach's alpha. If this coefficient is greater than 0.7, then it can be assumed that indicators consistently measure the latent variable they intend to measure (Nunnally, 1978). Results showed that measurements are reliable for all latent variables except for the fourth: *Receiver Knowledge Application* (α=0.92), *Identify* (α=0.82), *Understand* (α=0.94), *Senders' Articulating Capacities* (α=0.32) and *Receiver-Senders Common Knowledge* (α=0.85).

Hypothesis 1A at Time Point 1 Validity: SEM yields that the only latent variable statistically significant at time point 1 is *Receiver Absorptive Capacity* with a path coefficient equal to 1.37 ($p<0.0001$). The confidence interval at the 95% significance level for this path coefficient includes high lower and upper boundaries (0.89, 1.98), thus suggesting a strong relation between the latent variables *Receiver Absorptive Capacity* and *Receiver Knowledge Application*. However, data reject that *Receiver Knowledge Application* is significantly influenced by *Senders' Articulating Capacities*, and *Receiver-Senders Common Knowledge*. Nevertheless, Table 5-3 displays a high correlation between *Receiver Absorptive Capacity* and *Receiver-Senders Common Knowledge* (0.50). This can raise multi-collinearity issues hiding the real effect of *Receiver-Senders Common Knowledge* on the dependent variable. This is discussed in Section 5.3.3.2.

5.3.2. Multi-Linear Regression (MLR) at Time Point 2

This section evaluates Hypothesis 1A at time point 2 via multi-linear regression (MLR) of the model depicted in Figure 5-3. Results of the analysis are detailed below.

Measurement of Variables: SEM analysis of Hypothesis 1A at time point 1 indicated that indicator *Art2* (Figure 5-2) to measure *Senders' Articulating Capacities* might not be valid. Thus, this suggests dropping out this indicator at time point 2 to perform MLR. However, as opposed to time point 1, at time point 2 indicators *Art1T2* and *Art2T2* are highly correlated (r=0.92), suggesting that they might be measuring the same latent variable (i.e., *Senders' Articulating Capacities*). Therefore, in the analysis below, *Senders' Articulating Capacities* is calculated as the average of *Art1T2* and *Art2T2*. The appropriateness of doing this is further examined in Section 5.3.3.3 assessing the internal validity of the variables at Time 2 via Confirmatory Factor Analysis.

Data Sampling Transformation: Before proceeding with MLR, since the dependent variable's sampling data seemed left-skewed, the Shapiro-Wilk normality test was performed for time point 2 (Rossiter, 2014). The test yielded a statistic W equal to 0.86 with p = 8.011e-05, thus rejecting that data was normally distributed. Several transformations were performed, raising the data to the power of 2, 3, 4, and 5, but they failed to normally distribute data per the Shapiro-Wilk normality test. The underlying reason was that many values of the 44 observations of the dependent variable's sampling data were equal to the upper bound. Therefore, nine observations in which the dependent variable's value equaled the upper bound were randomly selected and eliminated. The data was still left-skewed (W=0.89, p=0.002), thus a transformation raising it to the power of 4 was applied. A Shapiro-Wilk normality test of the transformed data results in W = 0.95 with p = 0.14, thus not rejecting that data can be normally distributed. Descriptive statistics of the transformed sampling data are contained in Table 5-6. In addition, Table 5-7 illustrates descriptive statistics of the data with the transformation reverted.

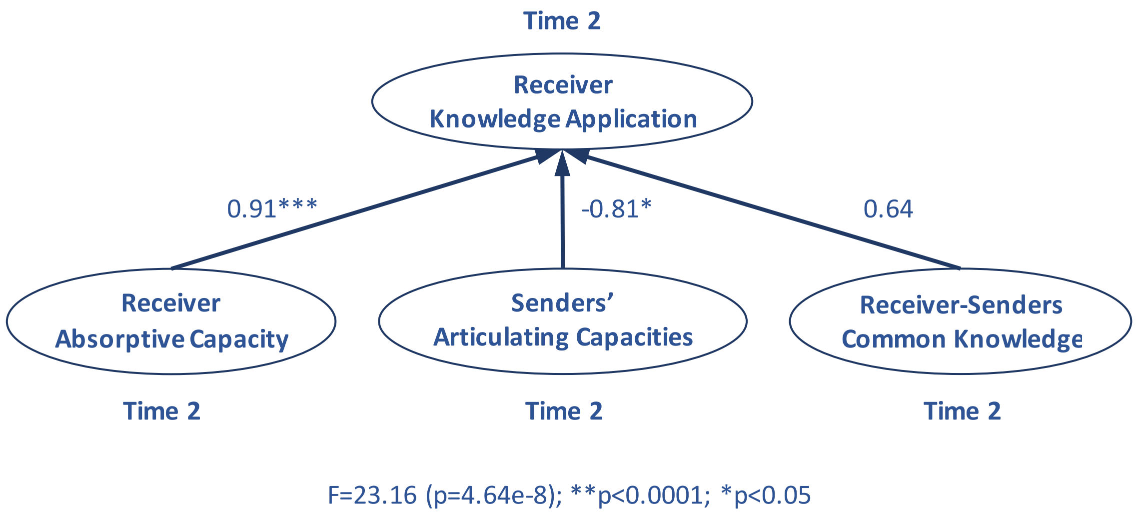


Figure 5-3. Model to test Hypothesis 1A at Time Point 2 Including Path Coefficients, and Model Fit Indices

Table 5-6. Sampling Data Distribution and Correlations of Study Variables in Hypothesis 1A at Time Point 2 (With Transformed Data)

Variable	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	KappT2	AbsT2	ArtT2	CkT2
KappT2	16.0	226.9	326.3	321.7	410.1	625.0	-	-	-	-
AbsT2	1.0	266.6	326.3	334.2	432.4	625.0	0.79	-	-	-
ArtT2	1.0	298.8	338.7	342.8	375.7	625.1	-0.60	-0.53	-	-
CkT2	65.1	256.0	348.3	364.3	436.3	625.0	0.20	0.16	0.15	-

Sample Size: 35
KappT2: *Receiver Knowledge Application* at Time 2
AbsT2: *Receiver Absorptive Capacity* at Time 2
ArtT2: *Senders' Articulating Capacities* at Time 2
CkT2: *Receiver-Senders Common Knowledge* at Time 2

Table 5-7. Sampling Data Distribution and Correlations of Study Variables in Hypothesis 1A Time Point 2 (With Data Transformation Reverted)

Variable	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.	KappT2	AbsT2	ArtT2	CkT2
KappT2	2.00	3.88	4.25	4.24	4.50	5.00	-	-	-	-
AbsT2	1.00	4.04	4.25	4.28	4.56	5.00	0.94	-	-	-
ArtT2	1.00	4.16	4.29	4.30	4.40	5.00	-0.88	-0.85	-	-
CkT2	2.84	4.00	4.32	4.37	4.57	5.00	0.67	0.63	0.62	-
Sample Size: 35; Meaning of abbreviations are displayed in Table 5-6										

Model Fit: MLR was performed over 35 observations. The model's F-statistic is 23.16 (p=4.64e-08), thus rejecting the null hypothesis that data fit the intercept-only model or, that all the path coefficients relating the dependent with independent variables are 0.

Regression Diagnosis: A regression diagnosis was conducted to check the validity of the model's assumption that the errors are normally distributed. The diagnosis is satisfactory if the model's residuals are normally distributed (Boomsma, 2014). The Shapiro-Wilk normality test (W=0.93, p=0.03) indicates that residuals are not normally distributed at the 1% significance level but not at the 5%. To better assess residuals' normal distribution, the *Residuals vs Fitted* and *Normal Q-Q* graphs were depicted (Figure 5-4). In the first graph residuals do not seem to follow any specific pattern which would reject a non-normal distribution; however, in the second graph residuals are not perfectly adjusted to a straight line which would reject a normal distribution of residuals as opposed to the previous graph.

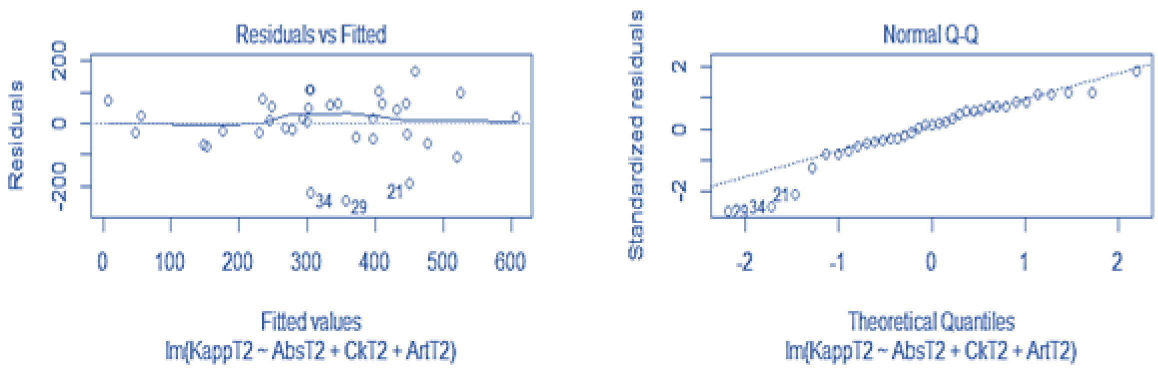


Figure 5-4. Distribution of Residuals of Model to Test Hypothesis 1A at Time 2: Residuals versus Fitted Plots (Left), and Normal Q-Q Plot of Residuals (Right)

Hypothesis 1A at Time Point 2 Validity: Results show that, as suggested previously by SEM at time point 1, at time point 2 *Receiver Absorptive Capacity* is positively correlated with *Receiver Knowledge Application* (β=0.91, p<0.0001, confidence interval (0.80, 1.00)). Furthermore, at time point 2, *Receiver Knowledge Application* is significantly and negatively correlated with *Senders' Articulating Capacities* (β=-0.81 with p<0.05, and confidence interval (-0.93, -0.55)). In addition, there is a strong negative correlation between *Receiver Absorptive Capacity* and *Senders' Articulating Capacities* (r=-0.85, Table 5-7). *Receiver-Senders Common Knowledge* does not significantly impact the dependent variable. Nevertheless, Table 5-7 displays a high correlation between *Receiver Absorptive Capacity* and *Receiver-Senders Common Knowledge* (0.63). This can raise multi-collinearity issues that hide the real effect of *Receiver-Senders Common Knowledge* on the dependent variable. This is further discussed in Section 5.3.3.2.

5.3.3. Complementary Analyses

This section offers additional statistical analyses to better assess Hypothesis 1A. Previous analyses in Sections 5.3.1 and 5.3.2 examine the relationship between the independent and dependent variables using cross-sectional data. Therefore, no causal-effect arguments could be made. In addition, it was not assessed the optimal number of independent variables to predict the dependent variable, or the internal validity of indicators at time point 2. Thus, this section analyzes casual-effect direction, adequacy of selection of independent variables, multi-collinearity, and internal validity of measurements at time point 2 in Hypothesis 1A.

5.3.3.1. Causality Direction

Previous analyses in Sections 5.3.1 and 5.3.2 examined Hypothesis 1A using cross-sectional data at time points 1 and 2 respectively (Table 5-1). The main drawback of using cross-sectional data is that they impede establishing a unique direction of causality in a model. For example, in the model tested for Hypothesis 1A at time point 2 (Figure 5-3), it was suggested that absorptive capacity positively influences knowledge application. However, data also fit another model where this causal relation is inverted, that is, knowledge application causes absorptive capacity.

Therefore, aiming to support a single causal-effect direction in Hypothesis 1A (e.g., absorptive capacity causes knowledge application and not the other way around), two additional models for Hypothesis 1A were tested utilizing longitudinal data as described in Table 5-2. These models are depicted in Figures 5-5 and 5-6. Correlations between study variables at time points 1 and 2 are contained in Table 5-8.

The model in Figure 5-5 establishes a unique causal-effect direction where the variable *Receiver Knowledge Application* at time point 2 is the effect due to controlling it at time point 1. Controlling for *Receiver Knowledge Application* at time point 1 means that variations in the independent variables caused by the dependent variable (i.e., control variable) are accounted for. Thus, this allows establishing a single causal-effect direction where the independent variables are the cause, and the dependent variable is the effect.

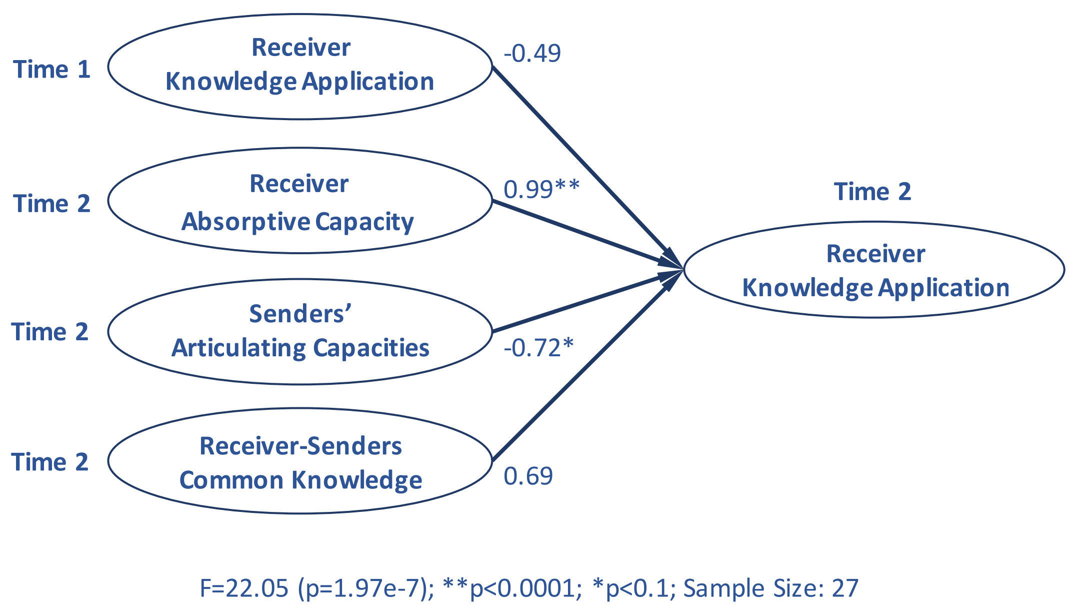
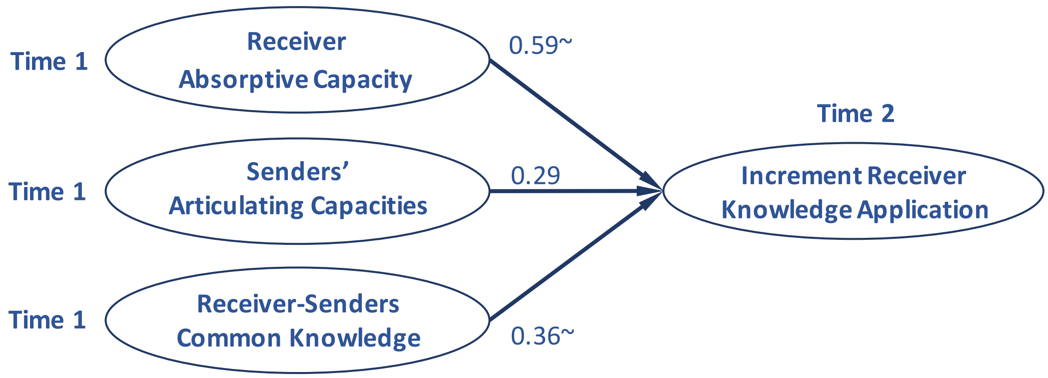


Figure 5-5. Model to Test Causality Direction in Hypothesis 1A Using Dependent Variable at Previous Time Point as Control Variable



F=1.50 (p=0.24); Sample Size: 29
~Would be statistically significant if considered as the only independent variable in the model (Appendix D) (probably due to multi-collinearity which is later discussed)

Figure 5-6. Model to Test Causality Direction in Hypothesis 1A Using Increment of Dependent Variable

Table 5-8. Correlations of Study Variables in Hypothesis 1A at Time Points 1 and 2

Variable	KappT1	AbsT1	ArtT1	CkT1	KappT2	AbsT2	ArtT2	CkT2
KappT1	-	-	-	-	-	-	-	-
AbsT1	0.80	-	-	-	-	-	-	-
ArtT1	0.04	-0.11	-	-	-	-	-	-
CkT1	0.39	0.26	-0.25	-	-	-	-	-
KappT2	0.21	0.003	0.04	-0.16	-	-	-	-
AbsT2	0.19	-0.12	0.04	-0.12	0.89	-	-	-
ArtT2	-0.08	0.11	-0.29	-0.04	-0.23	-0.15	-	-
CkT2	0.40	0.33	-0.28	0.55	0.18	0.13	0.38	-

Sample Size: 29
KappT(i): *Receiver Knowledge Application* at Time (i)
AbsT(i): *Receiver Absorptive Capacity* at Time (i)
ArtT(i): *Senders' Articulating Capacities* at Time (i)
CkT(i): *Receiver-Senders Common Knowledge* at Time (i)

On the other hand, the model in Figure 5-6 determines a unique causal-effect direction due to considering increments of the dependent variable over time. This means, for example, that the higher a receiver's absorptive capacity at time point 1, the higher will be the increment of his/her knowledge application between time points 1 and 2. In the sampling data, there were some observations where receivers had the highest possible absorptive capacity and knowledge application (i.e., 5 points in the five-level Likert scale) at both time points. In such cases, the highest absorptive capacity would lead to null improvement of knowledge application. Therefore, these observations were removed to run the analysis because they lacked a margin to capture improvement of knowledge application.

The model in Figure 5-5 was tested via multi-linear regression. Results showed that data fit the model. More details of the statistical analyses are included in Appendix D. Due to non-normal distribution of the dependent variable in the model in Figure 5-5, data had to be transformed (i.e., raised to the power of four). Thus, path coefficients in Figure 5-5 do not coincide with the values in Appendix D because the transformation was reverted. The distribution of residuals of the model in Figure 5-5 are depicted in Figure 5-7 which suggests that they are normally distributed. Overall results of model in Figure 5-5 which used longitudinal data to test Hypothesis 1A are similar to the results of the model in Section 5.3.2 which used cross-sectional data. However, the results in this section allows asserting that high receivers' absorptive capacities cause high receivers' knowledge application and not the other way around. In addition, *Receiver-Senders Common Knowledge* can be deemed an important since its path coefficient is high and close to statistical significance ($\beta=0.69$, $p=0.11$). Finally, the negative path coefficient of *Senders' Articulating Capacities* is further discussed in Section 6.1.3, since, per theory, it does not seem logical that low levels of articulating capacities cause high knowledge application.

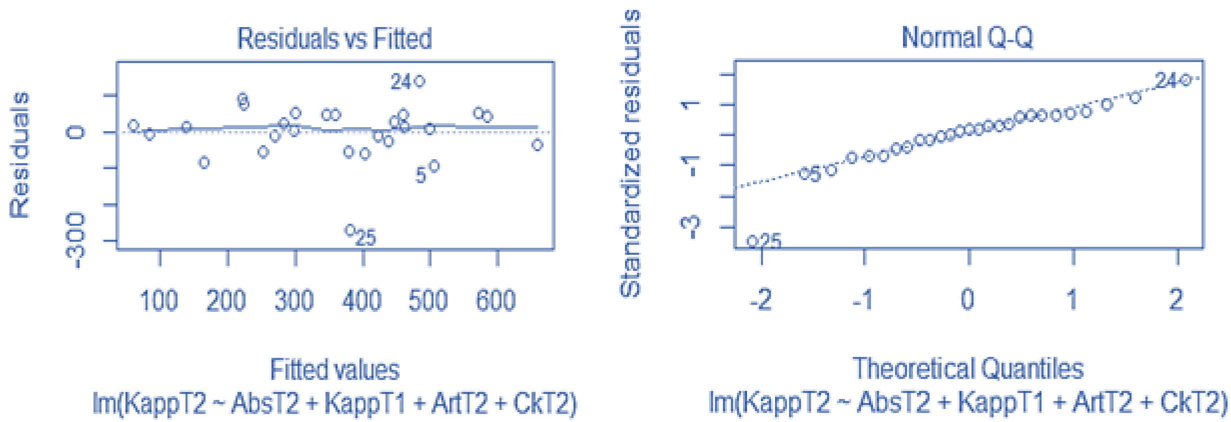


Figure 5-7. Distribution of Residuals of Model to Test Causality Direction in Hypothesis 1A (Figure 5-5): Residuals versus Fitted Plots (Left), and Normal Q-Q Plot of Residuals (Right)

Finally, data did not fit the model in Figure 5-6. Additional analyses were conducted to examine the influence of each independent variable separately (Appendix D). In doing so, *Receiver Absorptive Capacity* and *Receiver-Sender Common Knowledge* would become statistically significant if each is considered alone in the model. This occurred probably because of multi-collinearity since they are correlated (Tables 5-5, 5-7, and 5-8). This issue is further discussed in the following section.

5.3.3.2. <u>Selection of Independent Variables and Multi-Collinearity</u>

In the models previously used to examine Hypothesis 1A (i.e., Figures 5-2, 5-3, 5-4, and 5-6), it was not examined whether adding three independent variables in the models (i.e., *Receiver Absorptive Capacity, Senders' Articulating Capacities,* and *Receiver-Senders Common Knowledge*) would cause multi-collinearity issues, or improve the fit of the same models containing only one or two independent variables.

Examination of multi-collinearity and suitable independent variables to include in the models to optimize their fit was performed using the model in Figure 5-5. This model tests Hypothesis 1A using longitudinal data. The examination was performed as follows: First a model including only *Receiver Absorptive Capacity (time 2)* as an independent variable was assessed. Then other independent variables were introduced, first *Receiver Knowledge Application (time 1),* second *Senders' Articulating Capacities (time 2),* and third *Receiver-Senders Common Knowledge (time 2).* While doing so, variations in the standard error of the independent variables was observed to examine whether adding new independent variables would improve the fit of the model. If the standard error notably increases, it might suggest that the added independent variable should be dropped because it does not improve the fit of the model, or that there is multi-collinearity between the added variable and other independent variables in the model.

Detailed results of the analysis described above are included under Appendix E. They show that adding variables does not significantly affect the model fit since the standard errors of the independent variables increase only around 0.01 units. For example, the standard error for *Receiver Absorptive Capacity (time 2)* is 0.110 if considered the only independent variable in the model. After adding three more independent variables (i.e., *Receiver Knowledge Application (time 1), Senders' Articulating Capacities (time 2),* and *Receiver-Senders Common Knowledge (time 2)*), the standard error becomes 0.117. Therefore, this suggests that all the variables included in the model in Figure 5-5 to test Hypothesis 1A are properly selected, and that there are not multi-collinearity issues.

Additional models were tested to further examine potential multi-collinearity issues within models tested in Sections 5.3.1 and 5.3.2 (i.e., models in Figures 5-2 and 5-3) due to the high correlation between *Receiver Absorptive Capacity* and *Receiver-Senders Common Knowledge* (Tables 5-5 and 5-7). The tested models are illustrated in Figure 5-8.

Detailed results of the statistical analyses for models in Figure 5-8 are shown in Appendix E. Path coefficients displayed in Figure 5-8 do not coincide with the ones in Appendix E because data had to be transformed by raising them to the power of four to normally distribute the residuals of the models. The path coefficients in Figure 5-8 were calculated reverting this transformation.

Overall, results suggest that multi-collinearity impeded revealing the real relation between *Receiver-Sender Common Knowledge* and the dependent variable. For example, in Figure 5-2, this relation was negative and not statistically significant, whereas in Figure 5-8 (B) it becomes positive and significant at the 0.1 level. Overall, Figure 5-8 shows that the influence of *Receiver Absorptive Capacity* on the dependent variable is stronger than that of other independent variables. Nevertheless, it seems that all independent variables might significantly affect *Receiver Knowledge Application.*

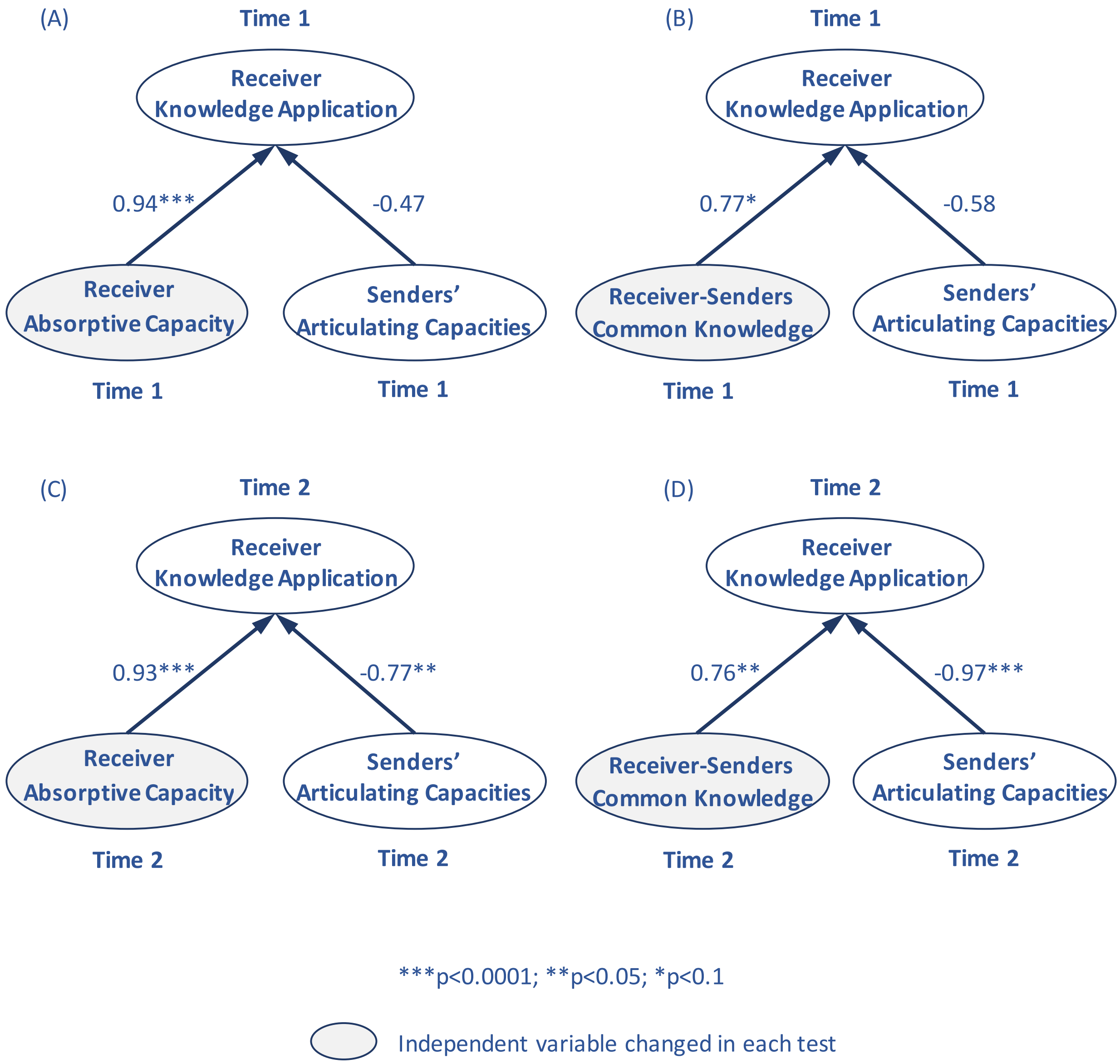


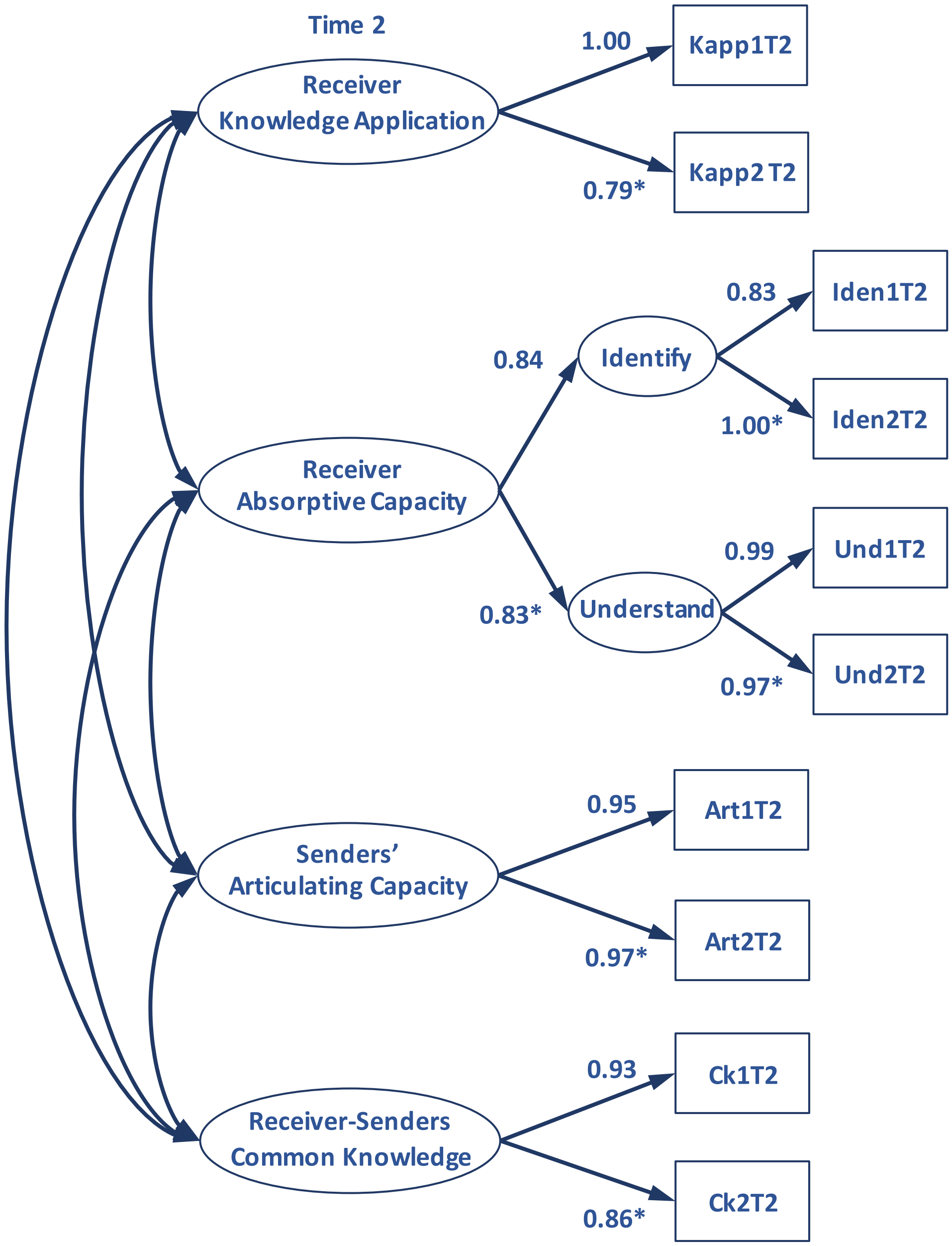
Figure 5-8. Models to Examine Multi-Collinearity in Hypothesis 1A

5.3.3.3. Internal Validity of Study Variables at Time Point 2

The model in Figure 5-2 was tested via structural equation modeling (SEM) which allows assessing the internal validity of indicators used to measure latent variables. Thus, internal validity of indicators was tested at time point 1. However, at time point 2, internal validity was not analyzed due to using multi-linear regression to test the model in Figure 5-3. Therefore, this section tests the model in Figure 5-9 via confirmatory factor analysis (CFA) to test whether indicators are valid measurements of the study latent variables.

Factor loadings were calculated utilizing the "marker indicator" method (Hoyle, 2012). Results show that data fit the model (F=51.46 (p=0.006); CFI=0.96; TLI=0.94; RMSEA=0.10). In addition, factor loadings between each latent variable and their second indicators are high and statistically significant. Thus results suggest that all indicators are valid measurements of the latent variables they intend to measure. The analysis of internal validity at time point 1 suggested that indicators for *Senders' Articulating Capacities* were not valid. Differences in results at time points 1 and 2 might have been caused due to a transient error, that is, "a causal force (e.g., emotional factors) that impacts a measurement, but which varies across time" Boster (2012).

Since *Und1* (i.e., indicator in Figure 5-9 to measure *Receiver Absorptive Capacity*) is measured partly in terms of shared knowledge, this could create an artefactual error if the indicator *Und1* is also measuring the latent variable *Receiver-Senders Common Knowledge*. Indicator *Und1* refers to the survey question *"This person's expertise in design-construction projects made it easy for him/her to understand the knowledge conveyed to him/her."* Whereas *Receiver-Senders Common Knowledge* is measured with indicators such as *Ck1* which refers to the survey question *"This person's expertise in design-construction projects overlapped with mine."*



Sample Size: 79 (including estimates of missing values)
F=51.46 (p=0.006); CFI=0.96; TLI=0.94; RMSEA=0.10
*p<0.0001

Latent Variable Indicator

Kapp(i)T2: Survey item no. (i) to measure *Receiver Knowledge Application* at Time 2
Iden(i)T2: Survey item no. (i) to measure *Identify* (1st dimension - *Receiver Absorptive Capacity*) at Time 2
Und(i)T2: Survey item no. (i) to measure *Understand* (2nd dimension - *Receiver Absorptive Capacity*) at Time 2
Art(i)T2: Survey item no. (i) to measure *Senders' Articulating Capacities* at Time 2
Ck(i)T2: Survey item no. (i) to measure *Receiver-Senders Common Knowledge* at Time 2
Survey items can be found in Table 4-3 (Section 4.5)

Figure 5-9. Model to Examine Internal Validity of Indicators of Study Variables in Hypothesis 1A at Time Pont 2 via CFA

Hence, to evaluate whether there is an artefactual error, a new model was tested consisting of the model in Figure 5-9 with one modification: The indicator *Und1* under *Receiver Absorptive Capacity* was also added as an indicator under *Receiver-Senders Common Knowledge*. If implementing this modification improves the model fit, then there might be an artefactual error. This model was tested via confirmatory analysis. Results, which can be found in Appendix E, show that using *Und1* as an indicator of *Receiver-Senders Common Knowledge* does not improve the fit of the model. The fit indices are similar to those of the model in Figure 5-9, but the RMSEA is slightly higher. In addition, the standard errors of all indicators slightly increase (i.e., around 0.05 units), and the path coefficient between *Receiver-Senders Common Knowledge* and *Und 1* is not statistically significant. Therefore, it can be discarded that the way *Receiver Absorptive Capacity* was measured generates an artefactual error.

5.3.4. Summary of Results of Hypothesis 1A

Hypothesis 1A was first tested with cross-sectional data at time points 1 and 2. Results showed that *Receiver Absorptive Capacity* is the main factor influencing *Receiver Knowledge Application*. In addition, *Receiver-Senders Common Knowledge* also exerts an important influence but weaker. And *Senders' Articulating Capacities* were negatively correlated with *Receiver Knowledge Application* at time point 2, whereas there was no significant correlation at time point 1. In addition, results suggest a strong negative correlation between *Receiver Knowledge Application* and *Senders' Articulating Capacities.* A detailed explanation of this is offered in Section 6.1.3. Finally, Hypothesis 1A was also tested with longitudinal data. Results suggested that it can be argued that *Receiver Absorptive Capacity* and *Receiver-Sender Common Knowledge* can be considered as factors causing variations in *Receiver Knowledge Application.*

5.4. Hypothesis 1B: Receiver Knowledge Transfer

Hypothesis 1B relates a receiver's knowledge application in a network position at time point 1 with his/her knowledge transfer interactions at time point 2. The hypothesis is tested via simple linear regression (SLR) of the model in Figure 5-10. *Receiver Knowledge Transfer Interactions* in this model refers to whether the receiver maintained at time 2 those connections established in the network at time 1. The value of this variable was calculated following the three steps below

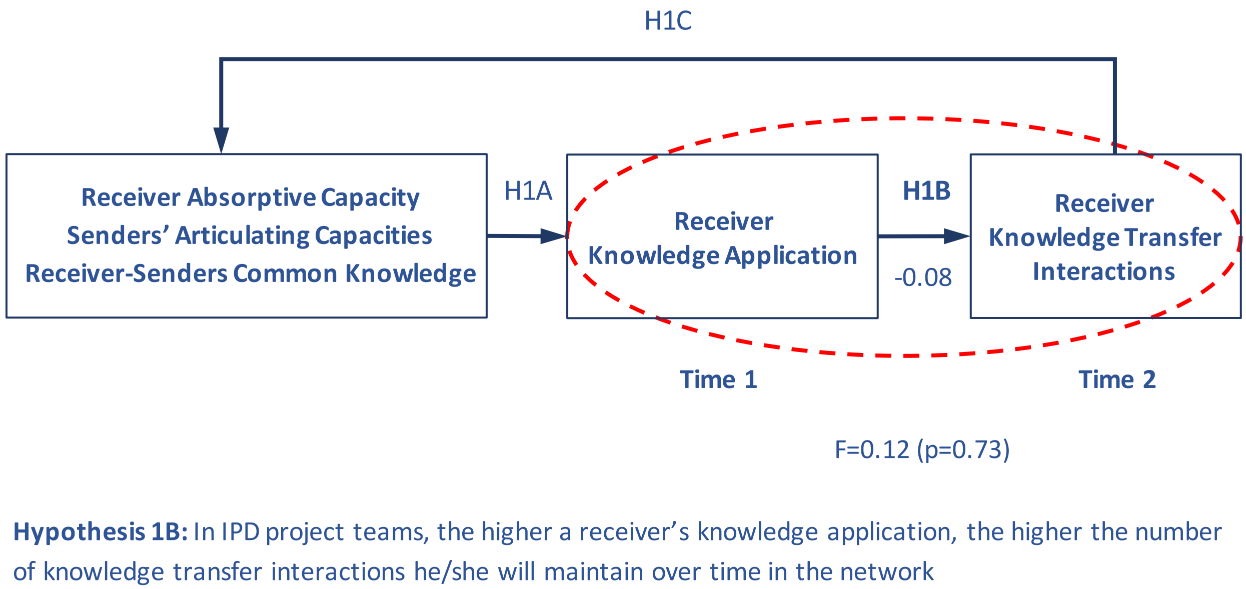


Figure 5-10. Model to test Hypothesis 1B (Dash Line) Including Path Coefficients and Model Fit Indices

1) At time point 1, receiver X fills out a survey reporting his/her interactions including team members A, B, and C. In addition, other team members D and E also complete the survey and report interacting with X. Thus, team member X interacts with A, B, C, D, and E at time point 1. Therefore, he/she has 5.00 connections at time point 1. We want to know how many of these interactions are maintained at time 2 to calculate receiver X's *Receiver Knowledge Transfer Interactions*.

2) At time point 2, receiver X reports interacting with A and B again. Team members C and D, neither fill out the survey nor are nominated by X as interactions at time point 2. Thus, it is assumed that they are not involved in the project anymore and are excluded from the analysis. Individual E completes the survey at time point 2 but does not report interacting with X.
3) Summarizing the previous two steps, receiver X's interactions at time point 1 included A, B, C, D, and E; of these interactions, C and D are removed from the analysis due to not being involved in the project anymore at time point 2; from the remaining interactions (i.e., A, B, and E), individual X keeps only A and B at time point 2. Therefore, receiver X's *Receiver Knowledge Transfer Interactions* equals 2/3 = 0.6667, meaning that he/she kept 66.67 % of his/her connections (i.e., 2 out of 3) from time point 1 to 2.

The approach above is appropriate to control for those team members that are not involved in either time point 1 or 2. Only individuals that completed the survey at both time points were considered in the analysis. There were four months approximately between time points. At each time point they nominate 5 interactions, and missing this information impedes an accurate estimate of those interactions maintained between the two time points. And second, *Receiver Knowledge Transfer Interaction* was calculated without considering interactions' frequency. Low frequent interactions might be as important as highly frequent ones, or some interactions might be less frequent due to participants' characteristics allowing them to grasp knowledge faster. Therefore, what matters is whether an interaction happened regardless of the frequency. The results of the statistical analysis are offered below.

Model fit: A Shapiro-Wilk normality test reveals that *Receiver Knowledge Transfer Interaction* is normally distributed (W=0.96, p=0.50). SLR was performed over 21 observations. Descriptive statistics of the data are shown in Table 5-9. Results reject that data fit the model testing Hypothesis 1B ($F=0.12$, $p=0.73$).

Hypothesis 1B Validity: Since the model fails to fit data, then it is rejected that receivers with high knowledge application at time point 1 tend to maintain their knowledge transfer interactions at time point 2.

Table 5-9. Sampling Data Distribution and Correlations of Study Variables in Hypothesis 1B

Variables	Min	1st Qu.	Median	Mean	3rd Qu.	Max.	KappT1	InterT2
KappT1	3.75	4.00	4.40	4.41	4.67	5.00	-	-
InterT2	0.40	0.67	0.78	0.75	0.80	1.00	-0.03	-

Sample Size: 21
KappT1: *Receiver Knowledge Application* at Time 1
InterT2: *Receiver Knowledge Transfer Interactions* at Time 2

5.5. Hypothesis 1C: Receiver Characteristics

This section tests Hypothesis 1C. The upper part of Figure 5-11 shows the portion of the multi-level model presented in Chapter 3 (Figure 3-1) corresponding to Hypothesis 1C. The purpose is to assess Hypothesis 1C which states that, in IPD teams, *a receiver's interactions transferring knowledge that he/she can apply improve his/her absorptive and articulating capacities, and common knowledge with senders*. Thus, Hypothesis 1C is tested via the model in the lower part of Figure 5-11.

In the model to test Hypothesis 1C, the independent variable is *Receiver Knowledge Application,* referring to receiver's application of knowledge transferred by his/her interactions at time point

1. And the dependent variables refer to increments in a receiver's characteristics since the purpose is to capture their improvement between time points 1 and 2. Their value is calculated subtracting the value at time point 1 to the value at time point 2. The effect of the independent variable on each of the three dependent variables in the model to test Hypothesis 1C (Figure 5-11, lower part) is tested separately in the following sub-sections.

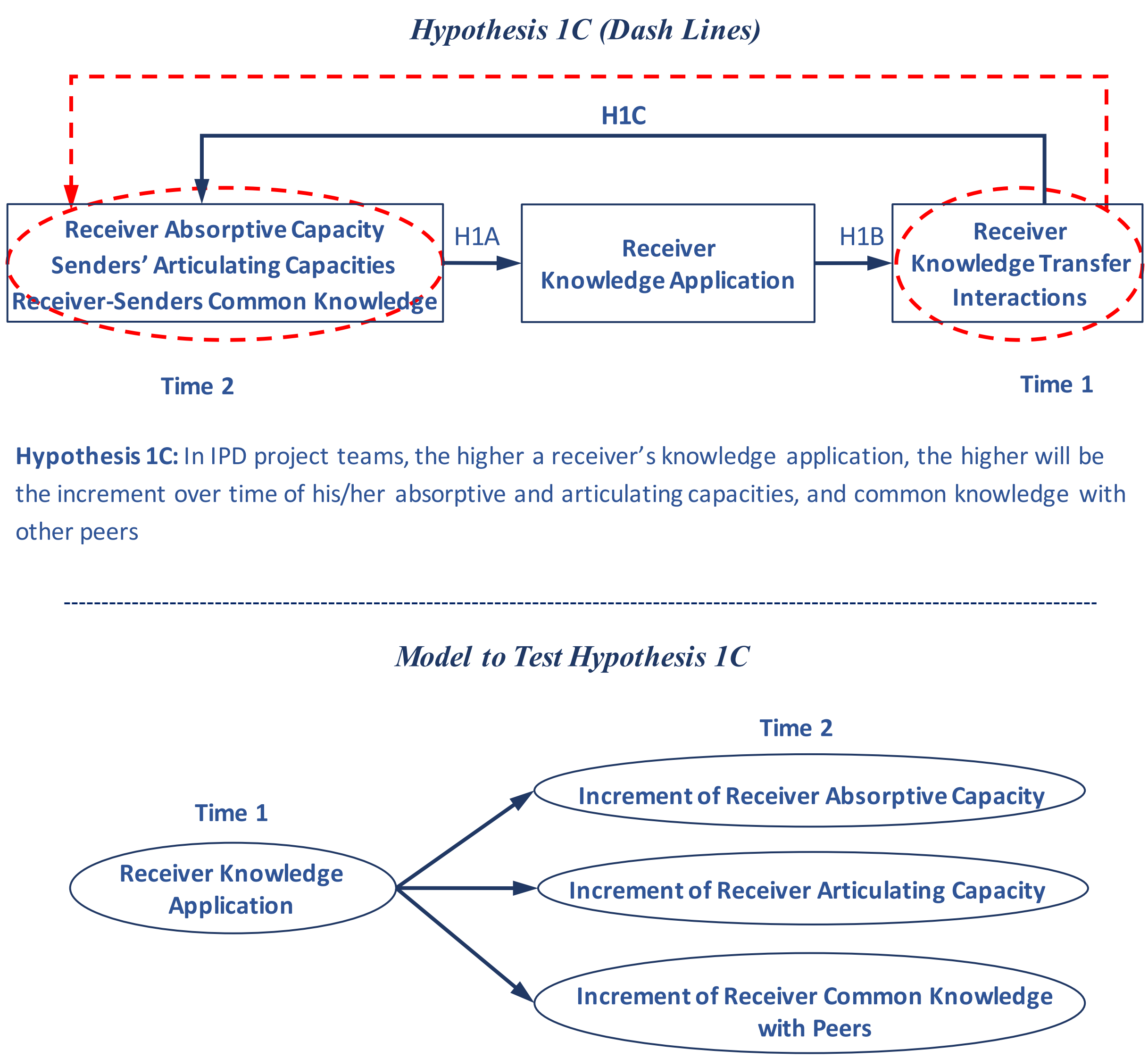


Figure 5-11. Hypothesis 1C (Top), and Model to Test Hypothesis 1C (Bottom)

5.5.1. Increment of Receiver Absorptive Capacity

This section tests part of the validity of Hypothesis 1C via simple linear regression (SLR) of the model shown in Figure 5-12. Results are described below.

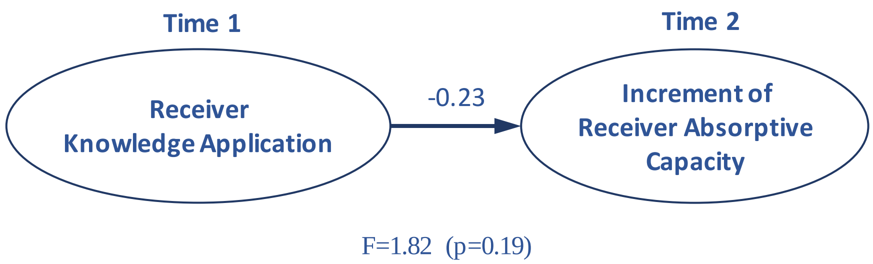


Figure 5-12. Model to Partially Test Hypothesis 1C Including Path Coefficients and Model Fit Indices (Receiver Absorptive Capacity)

Data Sampling Modifications: There were some observations in which *Receiver Absorptive Capacity* was rated with the maximum possible score in both time points 1 and 2. In these cases, *Increment of Receiver Absorptive Capacity* equaled zero, meaning that there was not improvement between time points 1 and 2. This was misleading since it could hide a positive improvement. Therefore, these observations were removed.

Model Fit: After removing outliers, SLR was performed over 27 observations. Results reject that data fit the model since the F-statistic is 1.82 with p=0.19. Descriptive statistics are shown in Table 5-10. A Shapiro-Wilk normality test of the model residuals yielded W = 0.95 (p = 0.24), thus discarding a non-normal distribution.

Hypothesis 1C Validity: Due to data failing to fit he model, then it is rejected that *Receiver Knowledge Application* is significantly correlated with *Increment of Receiver Absorptive Capacity*.

Table 5-10. Sampling Data Distribution and Correlations of Study Variables in Hypothesis 1C (Receiver Absorptive Capacity)

Variables	Min	1st Qu.	Median	Mean	3rd Qu.	Max.	KappT1	AbsT12
KappT1	3.00	4.00	4.38	4.31	4.53	5.00	-	-
AbsT12	-0.86	-0.17	0.13	0.04	0.30	0.75	-0.26	-

Sample Size: 27
KappT1: *Receiver Knowledge Application* at Time 1
AbsT12: Increment of *Receiver Absorptive Capacity* between Time 1 and 2

5.5.2. Increment of Receiver Articulating capacity

This section tests part of the validity of Hypothesis 1C via simple linear regression (SLR) of the model depicted in Figure 5-13. Results are provided below.

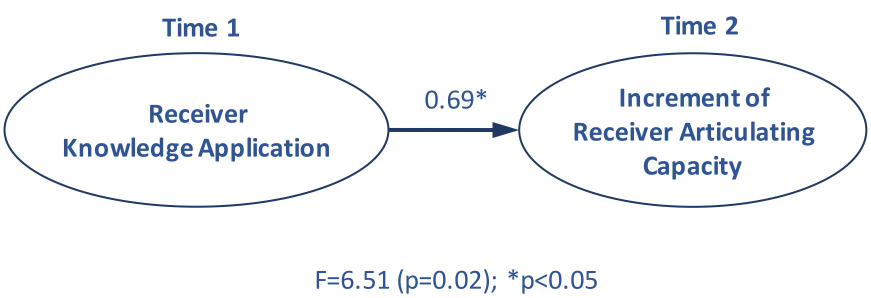


Figure 5-13. Model to Partially Test Hypothesis 1C Including Path Coefficients and Model Fit Indices (Receiver Articulating Capacity)

Data Sampling Modifications: There were some observations in which *Receiver Articulating Capacity* was rated with the maximum possible score in both time points 1 and 2. In these cases, *Increment of Receiver Articulating Capacity* equaled zero, meaning that there was not improvement between time points 1 and 2. This was misleading since it could hide a positive improvement. Therefore, these observations were removed.

Model Fit: SLR was conducted including 28 observations after removing a few outliers. Results show that data fit the model (F=6.51, p=0.02). Descriptive statistics are contained in Table 5-11. A Shapiro-Wilk normality test of the model residuals yielded W = 0.98 (p = 0.74), thus discarding a non-normal distribution.

Hypothesis 1C Validity: Data does not reject that *Receiver Knowledge Application* is positively correlated with *Increment of Receiver Articulating Capacity* (β=0.69, p<0.05).

Table 5-11. Sampling Data Distribution and Correlations of Study Variables in Hypothesis 1C (Senders' Articulating Capacities)

Variables	Min	1st Qu.	Median	Mean	3rd Qu.	Max.	KappT1	ArtT12
KappT1	3.67	4.00	4.40	4.37	4.63	5.00	-	-
ArtT12	-1.00	-0.50	0.07	0.01	0.42	1.00	0.44	-

Sample Size: 28
KappT1: *Receiver Knowledge Application* at Time 1
ArtT12: Increment of *Senders' Articulating Capacities* between Time 1 and 2

5.5.3. Increment of Receiver Common Knowledge

This section tests the validity of a portion of Hypothesis 1C via simple linear regression (SLR) (Figure 5-14). Results are presented below.

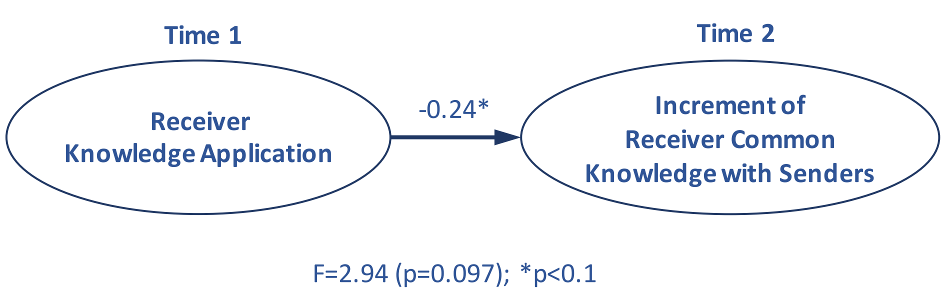


Figure 5-14. Model to Partially Test Hypothesis 1C Including Path Coefficients and Model Fit Indices (Receiver-Senders Common Knowledge)

Data Sampling Modifications: There were some observations in which *Receiver Common Knowledge with Senders* was rated with the maximum possible score in both time points 1 and 2. In these cases, *Increment of Receiver Common Knowledge with Senders* equaled zero, meaning that there was not improvement between time points 1 and 2. This was misleading since it could hide a positive improvement. Therefore, these observations were removed.

Model Fit: Simple linear regression was conducted including 30 observations after removing a few outliers. Results show that data fit the model ($F=2.94$, $p=0.097$). Descriptive statistics are contained in Table 5-12. A Shapiro-Wilk normality test of the model residuals yielded $W = 0.96$ ($p = 0.27$), thus discarding a non-normal distribution.

Hypothesis 1C Validity: Data does not reject that *Receiver Knowledge Application* is negatively correlated with *Increment of Common Knowledge with Senders* ($\beta=-0.24$, $p<0.1$). This outcome was unexpected. The most plausible reason is that team members keep changing their knowledge transfer interactions over time. Thus, their common knowledge with new peers with whom they interact might be lower than with previous peers.

Table 5-12. Sampling Data Distribution and Correlations of Study Variables in Hypothesis 1C (Receiver-Senders Common Knowledge)

Variables	Min	1st Qu.	Median	Mean	3rd Qu.	Max.	KappT1	CkT12
KappT1	3.00	4.00	4.34	4.31	4.57	5.00	-	-
CkT12	-0.57	-0.18	0.01	0.07	0.34	0.71	-0.30	-

Sample Size: 30
KappT1: *Receiver Knowledge Application* at Time 1
CkT12: Increment of *Receiver-Senders' Common Knowledge* between Time 1 and 2

5.6. Hypothesis 2A: Sub-Team Absorptive Capacity

This section first describes identification and validation of sub-teams mentioned in Hypothesis 2A, and then tests the hypothesis via statistical methods.

5.6.1. Identification of Sub-Teams

Before presenting identified sub-teams at time points 1 and 2, it is described below the response rate to develop sub-teams, how missing data affected sub-teams' identification, and how sub-teams were validated.

Response Rate: As previously mentioned, the project included 164 and 162 team members at time points 1 and 2 respectively. Sociograms displaying sub-teams were built based on team members responses to Survey #1 (Section 4.5). The response rate was 53 (32.3%) and 62 (38.3%) at time points 1 and 2 respectively. The researcher distinguished between key team members strongly involved in the project, and those with a tangential participation. Key team members strongly involved in the project can exert a notable impact on project outcomes with their input. They included owners' representatives, architect or designers, general constructor, mechanical, electrical, steel, structural, glazing and other subcontractors. Whereas those with a tangential participation are barely involved and their impact on project outcomes is very low. In this project, they mostly included owner's representatives interacting monthly with three or less project team members. After differentiating these two types of participants, it was observed that 68.5% (37 out of 54) and 72.2% (39 out of 54) of key participants strongly involved in the project responded at time points 1 and 2 respectively. Since each individual reported his/her top 5 most important interactions, this response rate was deemed sufficiently good to capture all the key team members and sub-teams involved in the project.

Missing Data: Some team members did not report their interactions. They might be problematic since adding their missing interactions may join sub-teams or form new ones. Therefore, the researcher experimented with data making up interactions with diverse team members that did not complete the survey. He observed that those team members nominated by less than 5 peers would not significantly modify sub-teams by adding the interactions that they did not report. Based on this, only two team members that did not complete the survey were problematic. Since the researcher was involved in the project attending weekly meetings, he could observe their interactions and reported them.

Sub-Teams' Validation: KliqueFinder identified the sub-teams (i.e., maximization of the concentration of ties within versus across sub-teams' boundaries). Members with only one connection in the team network do not appear in any sub-team since they do not work closely with any sub-team. KliqueFinder does not allow a team member to belong to more than one sub-team. However, in IPD project teams, an individual could work closely with his/her peers within two or more sub-teams. This was detected when a team member with high centrality in a sub-team network was requested to confirm the existence of the sub-team. He reported that some team members, which KliqueFinder already assigned to another sub-team, were missing in his sub-team. Thus, if an individual belonging to a sub-team had a high number of interactions with individuals from another sub-team, then he/she was also considered a member of the other sub-team. Sub-teams were validated by the sub-team members with higher centrality who responded to Survey #2 (Section 4.5). In total, 8 and 12 members confirmed the existence of sub-teams to develop specific tasks at time points 1 and 2 respectively. Sub-teams' at time points 1 and 2 are depicted in Figures 5-15 and 5-16 respectively. Tables 5-13 and 5-14 show members' distance to sub-teams' network center (i.e., the lower the distance, the higher the centrality), sub-teams' distance to the project team's network center, and sub-teams' composition.

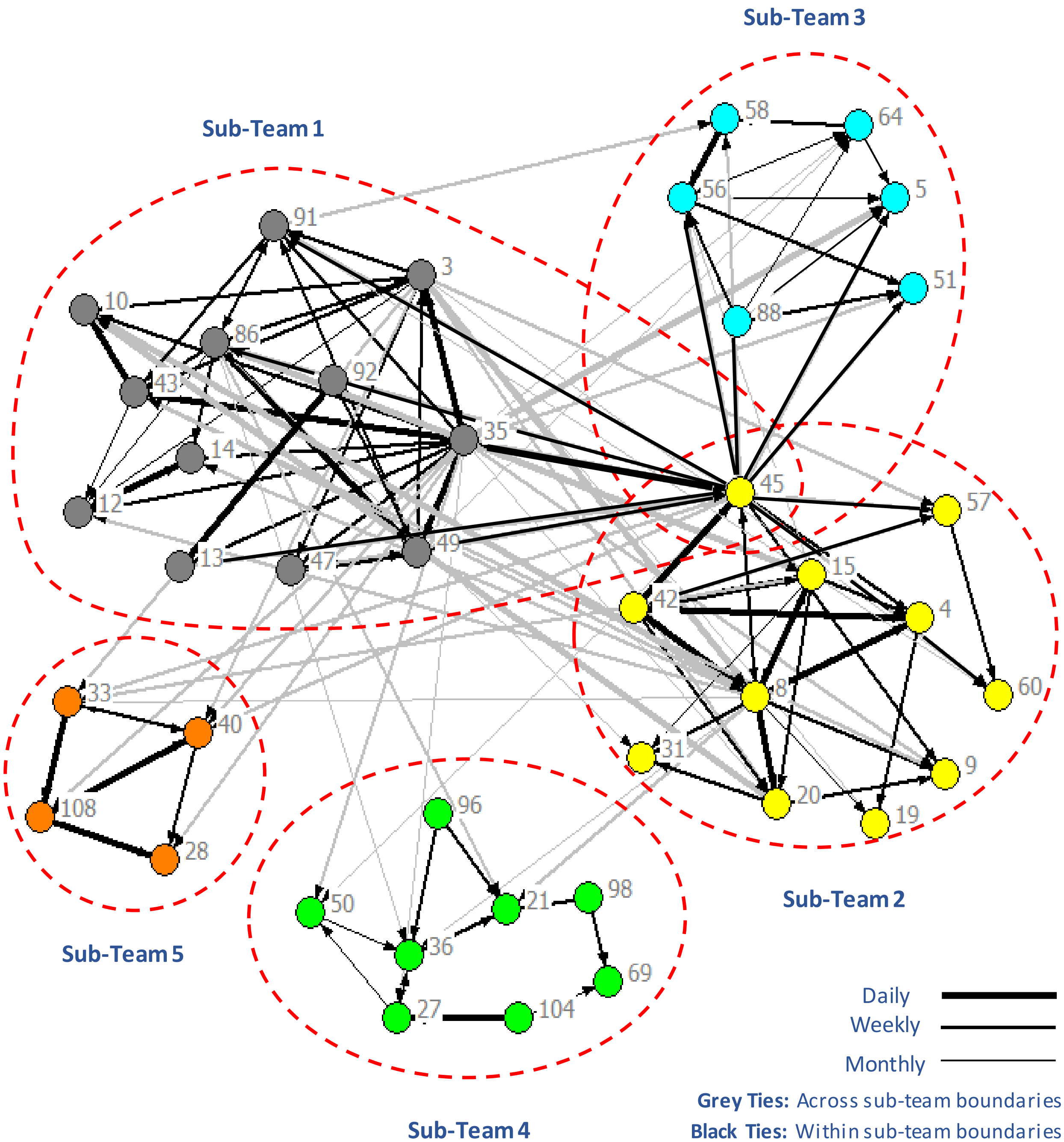


Figure 5-15. Sub-Teams at Time Point 1

Table 5-13. Sub-Team Members' and Sub-Teams' Centralities at Time Point 1

Sub-Team (ST)	ST Member ID	ST Member Distance to SNC*			ST Distance to PNC**	ST Composition
1	3	25.89	45	25.89	6.48	7 organizations.
	10	63.34	47	60.01		Disciplines: Architect, fire protection, mechanical, glazing, general constructor, and owner's representatives.
	12	55.51	49	36.60		
	13	67.26	86	14.30		
	14	58.80	91	42.61		
	35	6.87	92	68.97		
	43	44.24				
2	4	46.08	31	67.37	26.28	4 organizations.
	8	29.82	42	33.66		Disciplines: Electrical, mechanical, architect, plumbing, fire protection, and information technology.
	9	49.33	45	15.15		
	15	49.88	57	67.00		
	20	47.79	60	60.00		
3	5	48.47	58	44.65	186.58	4 organizations.
	45	31.67	64	48.47		Disciplines: Constructor, architect, landscape, and civil engineering.
	51	56.88	88	41.13		
	56	22.21				
4	21	45.23	69	60.62	368.23	3 organizations.
	27	52.29	96	56.90		Disciplines: Owner's representatives, controls, and mechanical.
	36	41.22	98	55.69		
	50	63.83	104	58.56		
5	28	45.67	40	23.66	402.23	2 organizations.
	33	28.10	108	21.34		Disciplines: Structural and steel.

*SNC: Sub-team Network Center; **PNC: Project team network center.

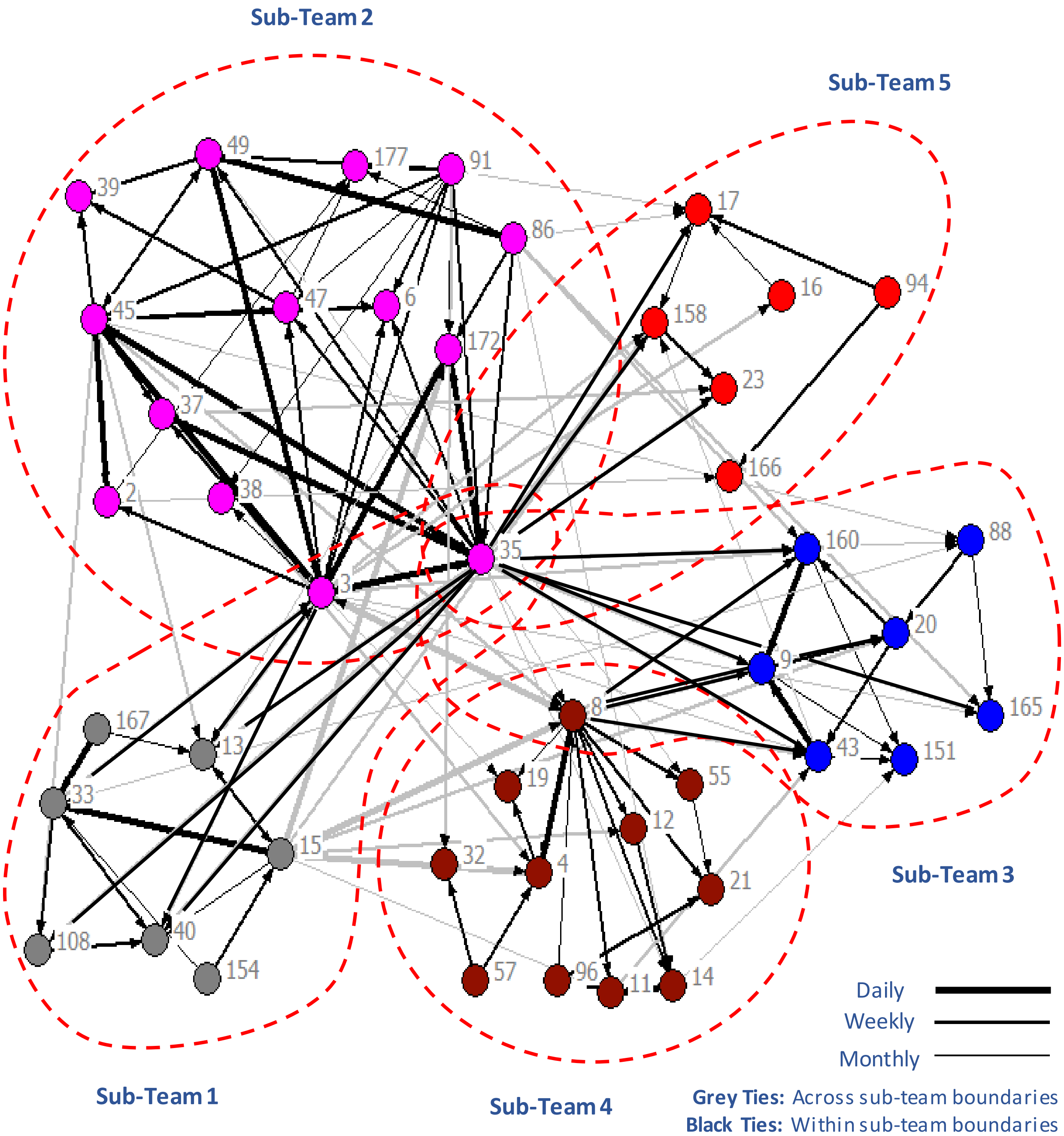


Figure 5-16. Sub-Teams at Time Point 2

Table 5-14. Sub-Team Members' and Sub-Teams' Centralities at Time Point 2

Sub-Team (ST)	ST Member ID	ST Member Distance to SNC*			ST Distance to PNC**	ST Composition
1	3	10.06	40	13.04	10.48	5 organizations.
	13	17.72	108	17.80		Disciplines: Architect, glazing, structural, constructor, and steel.
	15	10.06	154	18.38		
	33	5.41	167	17.34		
	35	10.06				
2	2	16.71	45	9.74	13.65	5 organizations.
	3	4.70	47	13.97		Disciplines: Architectural, owners' representatives, constructor, and sustainability.
	6	15.89	49	1.28		
	35	11.33	86	19.91		
	37	18.52	91	8.21		
	38	22.56	172	18.00		
	39	20.08	177	19.43		
3	8	9.41	88	17.90	47.83	3 organizations.
	9	10.54	151	18.03		Disciplines: Mechanical, plumbing, fire protection, constructor, and civil engineering.
	20	8.27	160	14.58		
	35	8.27	165	21.60		
	43	11.70				
4	4	13.57	21	16.62	161.70	4 organizations.
	8	5.74	32	21.41		Disciplines: Electrical, mechanical, owner's representatives, IT, energy and environment,
	11	16.94	55	18.81		
	12	17.98	57	18.86		
	14	16.16	96	19.76		
	19	18.89				
5	16	20.41	94	14.12	202.47	3 organizations.
	17	10.42	158	14.88		Disciplines: Electrical, and constructor.
	23	18.88	166	18.75		
	35	11.33				

*SNC: Sub-team Network Center; **PNC: Project team network center.

Figure 5-17 shows that the distribution of members' distances to sub-team network center is left-skewed. Therefore, differential equations in Section 4.6 for hypotheses 2A and 3A use logarithms for the factor equaling absorptive capacity divided by distance to the network center. This impedes that team members with very low distance to a sub-team network center make the factor too high.

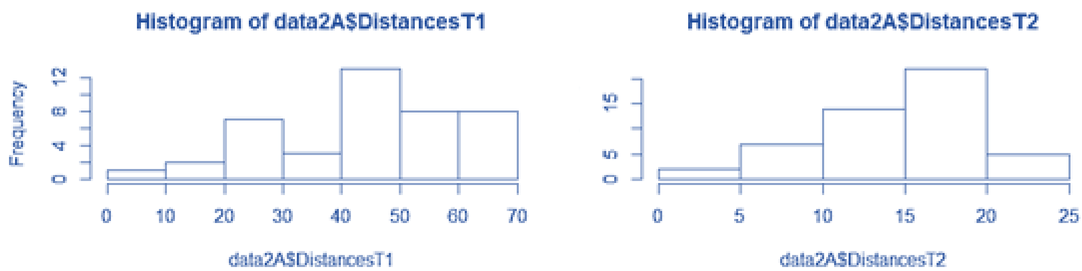
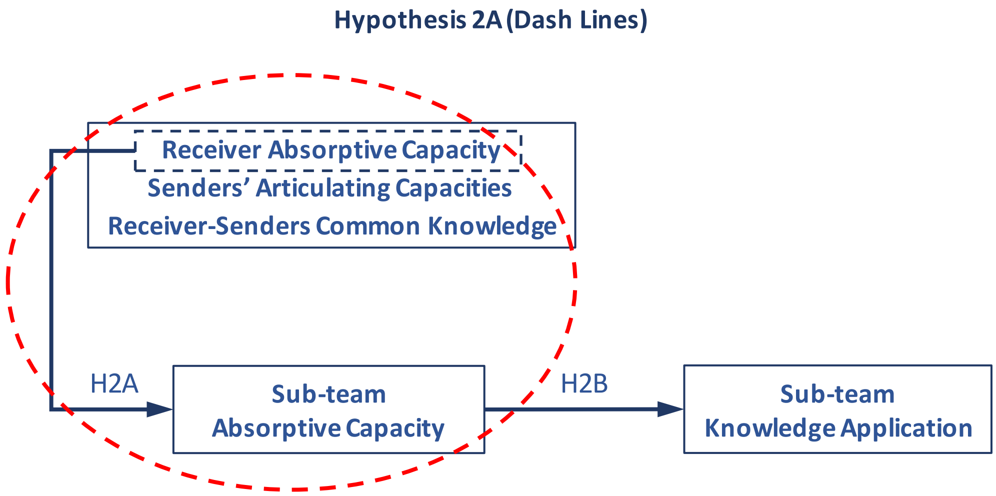


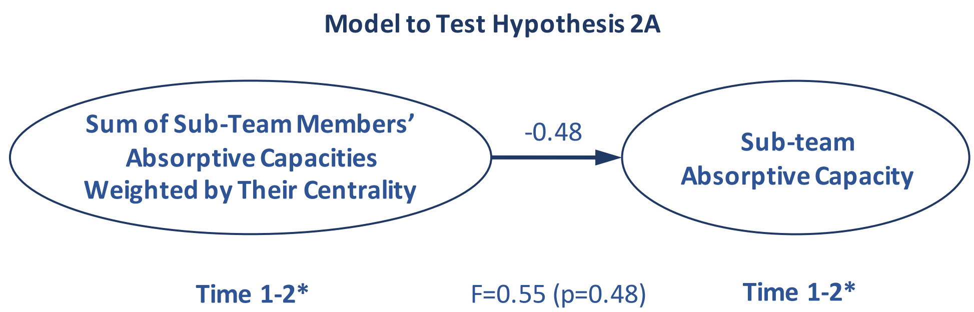
Figure 5-17. Histogram of Members' Distances to Sub-Team Network Centers at Time Points 1 (Left) and 2 (Right)

5.6.2. Hypothesis Test

This section evaluates the validity of Hypothesis 2A shown in the upper part of Figure 5-18. The lower part of Figure 5-18 illustrates the model with which Hypothesis 2A was tested via simple linear regression (SLR). Sub-teams included in the analysis are shown in Figures 5-15 and 5-16. Data for calculating the values of the dependent variable *Sum of Sub-Team Members' Absorptive Capacities Weighted by Their Centrality* are contained in Tables 5-13 and 5-14. Results are written below.



Hypothesis 2A: In IPD project teams, the influence of a member's absorptive capacity on a sub-team's absorptive capacity is moderated by his/her centrality in the sub-team's network



*Data at time points 1 and 2 was merged due to having different sub-teams at each time point. Therefore, variation of variables across time for a specific sub-team could not be assessed

Figure 5-18. Hypothesis 2A (Top), and Model to Test Hypothesis 2A Including Path Coefficients and Model Fit Indices (Bottom)

Data Quality: The sample size with which this model was tested is very low (i.e., 9 sub-teams). This might result in Type II error, that is, a wrong rejection of the null hypothesis and, consequently, wrong rejection of the model fit and significant correlations among study variables (Cohen et al., 2015).

Model Fit: SLR was performed with 9 observations. The results of SLR reject that data fit the model (F=0.55, p=0.48). Descriptive statistics can be found in Table 5-15. A Shapiro-Wilk normality test of the model residuals yielded W = 0.98 (p = 0.94), thus discarding a non-normal distribution.

Hypothesis 2A Validity: Data does not fit the model, rejecting that the sum of sub-team members' absorptive capacities weighted by their centrality equals the *Sub-Team Absorptive Capacity*. However, the low sampling size impedes making a reliable inference (Cohen et al., 2015).

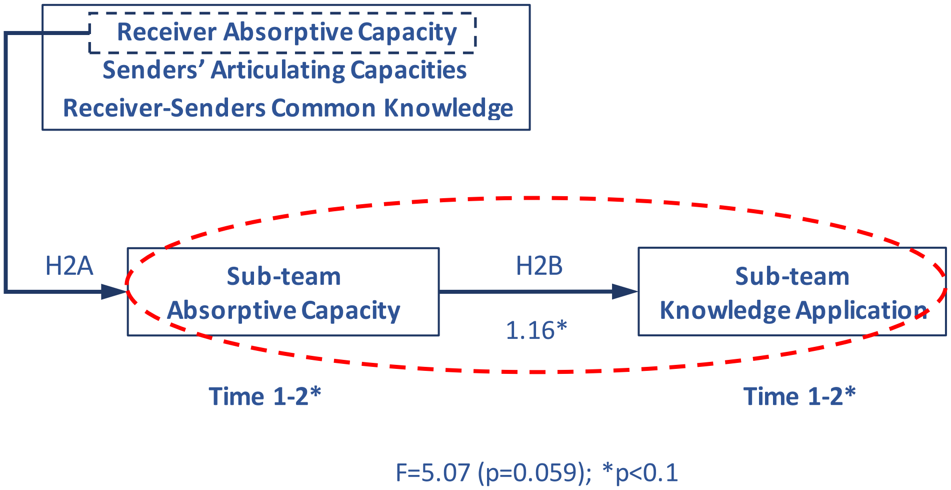
Table 5-15. Sampling Data Distribution and Correlations of Study Variables in Hypothesis 2A

Variables	Min	1st Qu.	Median	Mean	3rd Qu.	Max.	SumAbs	StAbs
SumAbs	4.11	4.20	4.24	4.29	4.38	4.52	-	-
StAbs	4.13	4.50	4.50	4.54	4.63	5.00	-0.27	-

Sample Size: 9
SumAbs: *Sum of Sub-Team Members' Absorptive Capacities Weighted by Their Centrality*
StAbs: *Sub-team Absorptive Capacity*

5.7. Hypothesis 2B: Sub-Team Knowledge Application

This section tests via simple linear regression (SLR) Hypothesis 2B with the model highlighted in Figure 5-19. Test results are offered below.



*Data at time points 1 and 2 was merged due to having different sub-teams at each time point. Therefore, variation of variables across time for a specific sub-team could not be assessed

Hypothesis 2B: In IPD project teams, the higher a sub-team's absorptive capacity, the higher the sub-team's knowledge application

Figure 5-19. Model to Test Hypothesis 2B (Dash Line) Including Path Coefficients and Model Fit Indices

Data Quality: As for Hypothesis 2A, the sample size with which Hypothesis 2B was tested is very low, including 9 sub-teams. This posits problems of high instability of results, and low power to examine the model fit, and significant correlations when running regression analyses (Cohen et al., 2015).

Model Fit: SLR was developed using 9 observations. SLR does not reject that data fit the model (F=5.07, p=0.059). Descriptive statistics can be found in Table 5-16. A Shapiro-Wilk normality test of the model residuals yielded $W = 0.92$ ($p = 0.35$), thus rejecting a non-normal distribution.

Hypothesis 2B Validity: SLR does not reject that *Sub-Team Absorptive Capacity* and *Sub-Teams Knowledge Application* could be positively correlated (β=1.16, p<0.1). Nevertheless, the low sampling size impedes making a reliable inference.

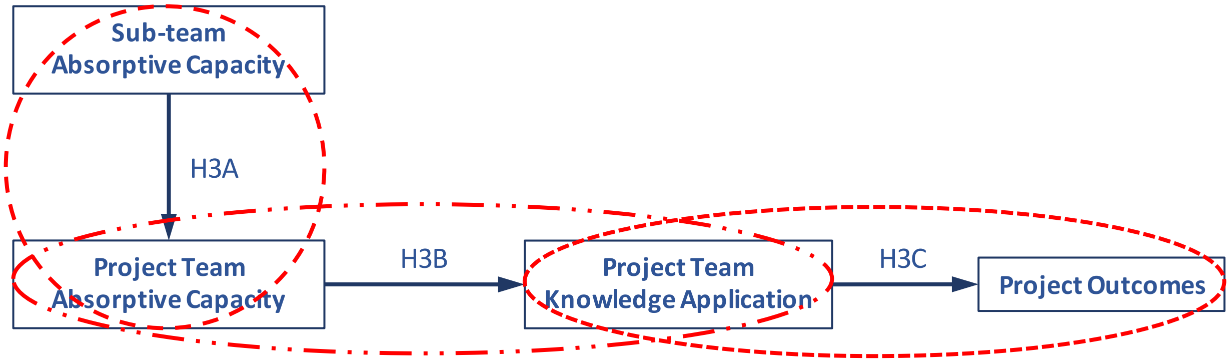
Table 5-16. Sampling Data Distribution and Correlations of Study Variables in Hypothesis 2B

Variables	Min	1st Qu.	Median	Mean	3rd Qu.	Max.	StAbs	StKapp
StAbs	4.13	4.50	4.50	4.54	4.63	5.00	-	-
StKapp	3.67	4.00	4.50	4.32	4.50	5.00	0.65	-

Sample Size: 9
StAbs: *Sub-team Absorptive Capacity*
SumAbs: *Sub-Team Knowledge Application*

5.8. Hypotheses 3A, 3B, and 3C: Project Team Absorptive Capacity and Knowledge Application, and Project Outcomes

This section aimed to examine Hypothesis 3A, B, and C via simple linear regression using the models illustrated in Figure 5-20. However, the low sampling size (i.e., one project team) impedes running a reliable test. Section 6.2.3 discusses the importance of these models and proposes them for future research with a larger sample size.



Hypothesis 3A: In IPD project teams, the influence of a sub-team's absorptive capacity on the project team's absorptive capacity is moderated by its centrality in the project team's network

Hypothesis 3B: The higher an IPD project team's absorptive capacity, the higher its knowledge application

Hypothesis 3C: The greater an IPD project team knowledge application, the better project outcomes (i.e., time, cost, and quality).

Figure 5-20. Models to Test Hypotheses 3A, 3B, and 3C from Left to Right Respectively (Dash Lines)

5.9. Summary

This chapter empirically tested study hypotheses via structural equation modeling or linear regression. Results of the analyses are summarized in Table 5-17 below. Further information regarding coding used in RStudio to perform the statistical analyses, or additional statistical parameters of the analyses performed for study hypotheses can be found in Appendices G and H, respectively.

Table 5-17. Summary of Results of Study Hypotheses

Study Hypotheses	**Results**
In IPD project teams…	
1A. The higher a receiver's knowledge application, the higher the…	
▪ Receiver's absorptive capacity	Not rejected
▪ Senders' articulating capacities	Not rejected[1]
▪ Common knowledge between the receiver and senders	Rejected
1B. The higher a receiver's knowledge application, the higher the number of knowledge transfer interactions he/she will maintain over time in the network.	Rejected
1C. The higher a receiver's knowledge application, the higher will be the increment over time of his/her …	
▪ Articulating capacity	Not rejected
▪ Absorptive capacity	Rejected
▪ Common knowledge with other peers	Not rejected[1]
2A. The influence of a member's absorptive capacity on a sub-team's absorptive capacity is moderated by his/her centrality in the sub-team's network.	Rejected[2]
2B. The higher a sub-team's absorptive capacity, the higher the sub-team's knowledge application	Not rejected[2]
3A. The influence of a sub-team's absorptive capacity on the project team's absorptive capacity is moderated by its centrality in the project team's network.	Undetermined[2]
3B. The higher an IPD project team's absorptive capacity, the higher its knowledge application.	Undetermined[2]
3C. The greater an IPD project team knowledge application, the better project outcomes (i.e., time, cost, and quality).	Undetermined[2]

[1]Negative correlation; [2]Low statistical power

CHAPTER 6: DISCUSSIONS

The study research goal is to ***examine the key factors shaping knowledge transfer networks facilitating knowledge application in IPD project teams.*** Key findings and propositions emanating from results are compiled in Table 6-1 and explained in detail in the following sections. The following sections first discuss in detail the study key findings based on results. For this, the terms knowledge "sender" and "receiver" are used. They refer to members involved in AEC project teams including owners, designers, engineers, general contractors, subcontractors, consultants, suppliers, and/or others. Second, a set of propositions are offered mainly based on the study hypotheses that could not be thoroughly tested. Third, it is analyzed the influence of AEC project delivery methods on knowledge transfer and application based on the study key findings. Lastly, the generalizability of study findings and propositions is discussed.

Table 6-1. Outcomes (i.e., Key Findings and Propositions) of Results of Study Hypotheses

Study Hypotheses and Results *(In IPD Project Teams)*	**Outcomes** *(In IPD Project Teams)*
H1A: The higher a receiver's absorptive capacity, then the higher the receiver's knowledge application ***(<u>Not Rejected</u>);*** and **H1B:** The higher a receiver's knowledge application, the higher the number of knowledge transfer interactions he/she will maintain over time in the network ***(<u>Rejected</u>).***	**Key Finding 1 (Section 6.1.1):** Receivers occupy network positions where their absorptive capacities enable application of transferred knowledge.
H1A: The higher a receiver's absorptive capacity, then the higher the receiver's knowledge application ***(<u>Not Rejected</u>);*** and **H1A:** The higher the common knowledge between a receiver and senders, then the higher the receiver's knowledge application ***(<u>Rejected</u>).***	**Key Finding 2 (Section 6.1.2):** Receivers' absorptive capacities can help to identify and understand valuable new knowledge without sharing large portions of common knowledge with senders.

Table 6-1. (cont'd)

H1A: The higher a receiver's absorptive capacity, then the higher the receiver's knowledge application ***(<u>Not Rejected</u>);*** and **H1A:** The higher the senders' articulating capacities, then the higher the receiver's knowledge application ***(<u>Not Rejected – Negative Relation</u>).***	**Key Finding 3A (Section 6.1.3):** Receivers with high absorptive capacity can easily apply transferred knowledge regardless of senders' articulating capacities; and **Key Finding 3B (Section 6.1.3):** Senders preferably make the effort to properly articulate knowledge to those peers with low absorptive capacity struggling with knowledge application.
H1C: The higher a receiver's knowledge application, the higher will be the increment over time of his/her articulating capacity ***(<u>Not Rejected</u>).***	**Key Finding 3C (Section 6.1.3):** Receivers applying knowledge acquired across disciplines and organizations improve their articulating capacities when acting as knowledge senders.
H2A and **H2B** (these hypotheses were built upon the premise that sub-teams were formed within project teams; the existence of these sub-team was confirmed).	**Key Finding 4 (Section 6.1.4):** IPD teams break down into temporary sub-teams concentrating and applying adequate expertise across disciplines and organizations to develop specific tasks.
H2A: The influence of a member's absorptive capacity on a sub-team's absorptive capacity is moderated by his/her centrality in the sub-team's network ***(<u>Undetermined</u>).***	**Proposition 1 (Section 6.2.1).**
H2B: The higher a sub-team's absorptive capacity, the higher the sub-team's knowledge application ***(<u>Undetermined</u>).***	**Proposition 3 (Section 6.2.3).**

Table 6-1. (cont'd)

H3A: The influence of a sub-team's absorptive capacity on the project team's absorptive capacity is moderated by its centrality in the project team's network ***(Undetermined).***	**Proposition 2 (Section 6.2.2).**
H3B: The higher an IPD project team's absorptive capacity, the higher its knowledge application ***(Undetermined).***	**Proposition 3 (Section 6.2.3).**
H3C: The greater an IPD project team knowledge application, the better project outcomes (i.e., time, cost, and quality) ***(Undetermined).***	**Proposition 4 (Section 6.2.3).**

6.1. Key Findings

6.1.1. Individual Absorptive Capacity

Results suggest that, in IPD teams, individuals' absorptive capacities enhance their knowledge application. Team members' absorptive capacities is dependent on the common knowledge that they share with received knowledge (Cohen and Levinthal, 1990). This common knowledge allows them to assimilate acquired knowledge via "associative learning" (Reagans and McEvily, 2003). Thus, team members search network positions where their interactions transfer knowledge with which they share common knowledge. This allows them to use their absorptive capacities to identify and understand valuable knowledge. In addition, results suggest that, once receivers find such network position, they do not necessarily maintain it over time (Hypothesis 1B). Although preserving previous interactions might be preferred due to easing knowledge transfer and application (Szulanski, 1996; Hansen, 1999; Reagans and McEvily, 2003), receivers might need other interactions in the network providing new knowledge to develop their tasks or to address varying project demands. Thus, this suggests that in the Receiver Absorptive Capacity

Model (Figure 6-1) receivers' knowledge application always functions as a mediator. That is, receivers' absorptive capacities help them select those knowledge transfer interactions favoring knowledge application. Since individuals' absorptive capacities depend on their common knowledge with received knowledge, then individuals might occupy diverse network positions where their absorptive capacities are high (Lane and Lubatkin, 1998). Therefore, during project delivery, team members might occupy different positions in the team knowledge transfer network where their absorptive capacities enable knowledge application. In doing so, they can favor application of the knowledge that best suits project demands at each moment of the delivery process.

The Receiver Absorptive Capacity Model (Figure 6-1) could not be entirely tested as a causal string model with the collected data. Doing so would be a notable challenge. It would require figuring out what specific knowledge constitutes team members' absorptive capacities, and how this knowledge relates to knowledge transferred by their interactions to ease application.

Summarizing, **Key Finding 1** posits that, **receivers occupy network positions where their absorptive capacities enables application of transferred knowledge in IPD teams.** Implications for AEC Project Teams are detailed below.

Figure 6-1. Receiver Absorptive Capacity Model in IPD Project Teams

Knowledge Transfer Networks: Finding 1, which highlights individuals' absorptive capacities as a key factor driving selection of interactions in IPD teams, expands current literature about formation of knowledge transfer networks in AEC project teams. This literature points out factors such as information technologies, trust, economic incentives, availability of resources, effortless altruism, social pressure, collaborative culture, evaluation of peers' knowledge value, or perceived capacity to transfer knowledge (Chinowski et al., 2008; Javernick, 2012; Zhang and Fai, 2013; Zhang and Fai, 2013).

Absorptive Capacity and Project Delivery Methods (PDMs): PDMs determine the timing of involvement of key parties and the degree to which they can create interactions in the knowledge transfer network. Hence, distinct PDMs can constrain to a different degree team members' power to create interactions based on their absorptive capacities. They might be forced to hold a position where they receive knowledge with which they lack common knowledge, thus hindering their ability to identify and understand valuable knowledge. Individuals freely interacting in IPD teams look for positions receiving knowledge related with their own, thus optimizing the use of their absorptive capacity. Consequently, PDMs imposing free interactions such as IPD might take greater advantage of team members' absorptive capacities.

Tacit Knowledge Management and Project Delivery Methods (PDMs): The AEC industry is greatly concerned about how to take advantage of individuals' tacit knowledge (Carrillo and Chinowsky, 2006). Tacit knowledge is acquired via experience, unique, and unlikely to be found anywhere else but in holders' brains (Smith, 2001). Individuals' absorptive capacities may use this tacit knowledge to identify interactions transferring valuable knowledge. Therefore, PDMs such as IPD allowing the formation of knowledge transfer networks based on team members' absorptive capacities, might constitute an effective tool to optimally manage tacit knowledge.

Team Integration Based on Knowledge Transfer and Application: Improved AEC project teams' integration is frequently seen as a stronger degree of knowledge transfer across disciplinary and/or organizational boundaries (Baiden et al., 2006; Troy et al., 2008; Mollaoglu et al., 2013; Franz et al., 2016). This can result in highly cohesive networks where team members transfer large amounts of diverse knowledge. However, if they cannot apply acquired transferred, then integration of diverse knowledge might fail. In such case, integrated team performance might be the same as non-integrated teams. Finding 1 helps to better understand AEC teams' integration. Team integration in AEC project teams is not a mere increase of knowledge transfer across disciplinary and organizational boundaries. In addition, team integration involves the degree to which team members can freely interact across these boundaries, and take network positions where their absorptive capacities allow them to apply transferred knowledge. Summarizing, higher team integration should entail an increase of both knowledge transfer and application.

Practical Applications: Owners adopting project delivery methods allowing free interactions among key parties since early on during project delivery, can optimize project outcomes (i.e., time, cost, and quality) because of the following:

- *Enhanced exploitation of team members' absorptive capacities:* Since members can freely interact, they select those knowledge transfer interactions that best adapt to their absorptive capacities. These interactions provide them with knowledge that they can apply benefiting project performance. Additionally, since key parties interact early on during of the design phase, their absorptive capacities lead them to detect and apply valuable knowledge when its impact on projects' outcomes is greater;

- *Elicitation and utilization of greater portions of team members' knowledge:* Members' absorptive capacities are partially built upon their tacit knowledge, that is, knowledge acquired via experience and difficult to identify, extract, or articulate. This knowledge is not entirely captured by information technologies (e.g., design or cost estimating software) or team management tools (e.g., lean tools such as pull planning meetings). Via free interactions since design, team members can utilize their tacit knowledge to assess what valuable knowledge they can absorb for application to enhance project outcomes; and

- *They improve team integration:* Team integration is especially important in complex projects requiring intense knowledge transfer across AEC teams' disciplinary and organizational boundaries (e.g., sustainable projects adopting holistic approaches to planning, design, and construction). Unconstrained interactions since design can ensure not only increased knowledge transfer across the boundaries but also the involvement of team members with adequate absorptive capacities to apply transferred knowledge.

Future Research: Results rejected that receivers' absorptive capacities improve if they apply transferred knowledge. However, this was examined during a period of four months within the same project. This period might be short for team members to capture a sufficiently large amount of new knowledge that significantly expands their absorptive capacities. Future research should examine individuals' absorptive capacities improvement from one project to another rather than within the same project. This would help to better assess team members' absorptive capacities based on their experience.

6.1.2. Individual Common Knowledge

Results suggested that, receivers' knowledge application is not dependent on sharing high levels of common knowledge with senders but primarily on receivers' absorptive capacities in IPD project teams (Hypothesis 1A). However, results did not discard the importance of common knowledge since it was very close to statistical significance. Common knowledge is vital to understand received knowledge via "associative learning" (Grant, 1996; Alavi and Leidner, 2001; Reagans and McEvily, 2003). Moreover, individuals' absorptive capacities are built upon the common knowledge that they share with acquired knowledge (Cohen and Levinthal, 1990). Nevertheless, per results, receivers might only necessitate to share key small portions of common knowledge with senders so their absorptive capacities enable application of transferred knowledge.

Low levels of common knowledge are frequently vital to promote innovation. They lead individuals to use their absorptive capacities to identify and understand unfamiliar knowledge that is valuable for them. Consequently, individuals are likely to test novel combinations and deliver innovative solutions (Nooteboom et al., 2007). Therefore, members in IPD project teams might be able to identify and understand valuable knowledge across disciplinary and organizational boundaries although sharing low levels of common knowledge with other peers. For example, a structural designer developing a sustainable building might interact across disciplinary boundaries to get information about the mechanical system. Maybe, the only portion of the mechanical system that is valuable for him/her to understand is the impact of the location of the mechanical room on energy performance. Locating this room in a central position within the structural system might reduce energy consumption to pump fluids. Thus, with this small portion of common knowledge with the mechanical system, the structural designer might develop a structure contributing to building energy efficiency.

Hence, **Key Finding 2** suggests that **receivers' absorptive capacities can help to identify and understand valuable new knowledge without sharing large portions of common knowledge with senders.** Implications for AEC project teams are described below.

Team Integration: Finding 2 expands our understanding about how AEC project teams can achieve higher levels of team integration. Increased inter-disciplinary interactions in integrated teams should involve team members sharing key pieces of common knowledge to make interactions fruitful. This finding discards the need to create integrated AEC teams with only multi-disciplinary experts sharing large amounts of common knowledge which might be difficult to find or produce.

Future Research: Research should expand Finding 2 to determine the key pieces of common knowledge across disciplines to facilitate collaboration. This could be done via a qualitative research conducting interviews with multi-disciplinary AEC experts.

Practical Applications: Owners can ensure development of integrated teams in AEC projects via assessing team members' key pieces of common knowledge across disciplines and organizations during procurement processes. These pieces would allow them to absorb and apply each other's knowledge into combined solutions.

6.1.3. Individual Articulating Capacity

At time point 1, results show no correlation between receivers' knowledge application and senders' articulating capacities, whereas they suggest a negative correlation at time point 2 (Hypothesis 1A). This posits two questions:

1. Why is there a negative correlation at time point 2? Reagans and McEvily's (2003) work claims the opposite, that is, senders with high articulating capacity should improve receivers' knowledge application. However, this research examined simultaneously the effect of both senders' articulating capacities and receivers' absorptive capacities on receivers' knowledge application. Results showed that receivers' knowledge application is negatively correlated with senders' articulating capacities, but positively with receivers' absorptive capacities. This suggests that receivers with high absorptive capacity can easily apply knowledge even though senders do not effectively articulate it. In addition, results showed a strong negative correlation between receivers' absorptive capacities and senders' articulating capacities. Therefore, senders might preferably make the effort to properly articulate knowledge to only those individuals with lower absorptive capacity struggling with knowledge application.

2. Why are receivers' knowledge application and senders' articulating capacities correlated at time point 2 but not at time point 1? Time point 1 occurred around three months after all key parties came together in the design phase. IPD project teams gather team members from different organizations that never worked together before (Chiocchio et al., 2011). Therefore, at time point 1, it is likely that team members were still learning about their peers' ability to apply knowledge, thus making the effort to nicely articulate knowledge to everyone to facilitate application. Whereas at time point 2 (i.e., four months after time

point 1 when design was close to completion) team members probably already learned about their peers' ease to apply knowledge, and would focus their efforts on better articulating knowledge for those struggling with knowledge application as suggested above.

In conclusion, the above leads to two findings: **Key Finding 3A** suggests that **receivers with high absorptive capacity can easily apply transferred knowledge regardless of senders' articulating capacities in IPD teams**. In addition, **Key Finding 3B** posits that **senders preferably make the effort to properly articulate knowledge to those peers with low absorptive capacity struggling with knowledge application.**

Additionally, results suggest that individuals' articulating capacities improve over time if they apply transferred knowledge. In IPD project teams, team members frequently apply knowledge transferred from peers belonging to disciplines and organizations other than their own. This enables team members to improve their articulating capacities due to gaining a better understanding of diverse perspectives, approaches, and assumptions adopted by their peers to articulate knowledge and make it comprehensible to others (Reagans and McEvily, 2003; Thomas et al., 2014). For instance, during project delivery, a team member receiving and utilizing project schedules from his/her peers might learn their assumptions regarding resources' productivities or meaning of activities (e.g., *pouring concrete* might refer to *placing rebar, pour concrete, and concrete curing* or only to *pour concrete and concrete curing*). Consequently, the team member might later utilize the same assumptions to articulate schedules that his/her peers can easily comprehend.

Thus, **Key Finding 3C** indicates that, **receivers applying knowledge acquired across disciplines and organizations improve their articulating capacities when acting as knowledge**

senders in IPD teams. Implications for AEC project teams and limitations of Key Findings 3A and 3B are discussed below:

Articulating Capacity and Project Delivery Methods (PDMs): PDMs limit the extent of inter-disciplinary and inter-organizational interactions in AEC teams. Thus, they can constrain team members' opportunities to improve their articulating capacity (Reagans and McEvily, 2003). Although this study found out that increased levels of team members' articulating capacities do not affect knowledge application of peers with high absorptive capacity, they might enhance knowledge application of those peers with low absorptive capacity. Therefore, PDMs can influence the ability to apply diverse knowledge of team members with poor absorptive capacity.

Practical Applications: Owners adopting project delivery methods allowing free interactions among key parties since early on during project delivery, can optimize project outcomes due to enhanced management of team members' articulating capacities. Team members interacting early on during design can soon learn about each other's absorptive capacity. Then they focus on properly articulating knowledge to those peers with lower absorptive capacity to enhance their ability to apply knowledge. In addition, team members' interactions with multi-organizational and multi-disciplinary peers soon during project delivery grow their articulating capacities.

Future Research and Limitations: Upcoming research should examine again how to measure the articulating capacity construct. In this research, this latent variable was measured using two indicators: (1) "This person articulated his/her knowledge in such a manner that it was easy to understand;" and (2) "this person made complex knowledge look simple." Results at time point 1 suggest that these indicators might not be measuring the same latent variable. However, results at time point 2 indicate the opposite. This might have been caused due to a transient error, that is, an event (e.g., emotional factors) temporarily affecting measurements (Boster, 2012).

6.1.4. Formation of Sub-Teams

Results confirmed that IPD project teams form temporary sub-teams to perform different tasks (Comu et al., 2013; Gibson and Vermeulen, 2003). Since IPD team members can freely interact since early during design, sub-teams' composition is flexible and can vary to gather those individuals with the adequate expertise to develop specific tasks. This might constitute a key dynamic mechanism in IPD project teams to outperform AEC project teams imposing constrained structures for knowledge transfer (Grant, 1996).

Therefore, **Key Finding 4** indicates that **IPD teams break down into temporary sub-teams concentrating and applying adequate expertise across disciplines and organizations to develop specific tasks.** An important implication for AEC project teams is mentioned below.

Project Delivery Methods (PDMs): The degree to which PDMs in AEC projects constrain knowledge transfer interactions, determines the ability of sub-teams to be formed *ad hoc* to solve varying project demands.

Future research: This research drew AEC project team networks based on individuals top 5 interactions providing most valuable knowledge. Future research should consider also drawing networks based on individuals' top 5 most frequent interactions and examine their differences. This would significantly influence how Propositions 1 and 2 below are to be examined since individuals' centrality in sub-teams might change.

Practical Applications: Owners adopting project delivery methods allowing free interactions among key parties since early on during project delivery, can exert a higher control over projects' outcomes (i.e., time, cost, and quality) via ad hoc sub-teams' formation. If free knowledge transfer interactions are allowed, then IPD project teams can break down into temporary sub-teams embracing the required expertise to address changing project demands.

6.2. Propositions

This study developed a multi-level model of knowledge transfer and application in IPD teams that guided development of eight study hypotheses (Figure 3-1). Due to data collection limitations, Hypotheses 2A, 2B, 3A, 3B, and 3C could not be tested. They are offered below for future research along with potential implications for AEC project teams.

6.2.1. Sub-Team Absorptive Capacity

This study attempted to evaluate individuals' absorptive capacities influence on IPD sub-teams' absorptive capacities based on their network position (i.e., Hypothesis 2A). However, a low statistical power (i.e., nine sub-teams) impeded to make any strong inference. Thus, this study offers **Proposition 1** to be examined the future: **In IPD sub-teams, the greater an individual's centrality in a sub-team's network, the greater the contribution of his/her absorptive capacity to the sub-team's absorptive capacity.** Implications for AEC project teams are explained below.

Individual-Subteam Absorptive Capacities: Proposition 1 posits a first step to understand how absorptive capacities at the individual, and sub-team or team levels are related in IPD project teams (Volberda et al., 2010). Key Finding 1's implication regarding absorptive capacity posited that IPD teams optimize team members' contribution to the team absorptive capacity. However, it is still unknown the relative contribution of each team member. Their network position gives them access to varying types and amounts of knowledge; therefore, their opportunities to impact team absorptive capacity might be significantly different (Cohen and Levinthal, 1990).

Confirming Proposition 1 would suggest that Individuals taking central positions in a sub-team's networks might filter large amounts of knowledge to identify that one valuable. Then they transfer it to other sub-team members, thus determining what knowledge they can identify and understand (Lenox and King, 2004). Consequently, individuals in central network positions exert a stronger influence on a sub-team's absorptive capacity.

On the other hand, if Proposition 1 is rejected, then it could be inferred that sub-team members in central positions might not filter knowledge. Instead, they distribute it to those team members with the appropriate absorptive capacity to identify what is valuable and understand it. Thus, team members occupying decentralized or peripherical positions in sub-teams' knowledge transfer network may exert a significant influence on sub-teams' absorptive capacities.

Resources Management: Testing Proposition 1 would help managers to understand how to optimize the use of team members with high absorptive capacity. They would know how many and in what network positions they are needed to favor team absorptive capacity. Thus, gaining a strategy to manage human resources in AEC project teams (Carrillo and Chinowsky, 2006).

6.2.2. Project Team Absorptive Capacity

Hypothesis 3A aimed to examine the relation between sub-teams' and the entire team's absorptive capacities. However, the low sampling size (i.e., one project team) impeded to draw any conclusion from data analysis. Hence, presented **Proposition 2** is offered for future research: **in IPD project teams, the influence of a sub-team's absorptive capacity on the project team's**

absorptive capacity is moderated by its centrality in the project team's network. Future data collection to test this proposition could be a notable challenge. For example, identifying sub-teams within a reasonable sample size of project teams might entail collecting data from around a thousand individuals reporting their interactions. The main implication for AEC project teams is presented below.

Individual-Subteam-Team Absorptive Capacities: Concatenating Propositions 1 and 2 suggests that individuals' absorptive capacities would impact an IPD team's absorptive capacity via the formation of sub-teams. Both (1) individuals' centralities in sub-teams' networks, and (2) sub-teams' centralities in the entire project team network, moderate the extent to which individuals' absorptive capacities contribute to the project team's absorptive capacity. Examining this would clarify the relation of absorptive capacities at the individual, sub-team, and team levels (Volberda et al., 2010).

6.2.3. Sub-Team and Project Team Knowledge Application, and Project Outcomes

Hypotheses 2B, 3B, and 3C could not be tested due to low statistical power and are left as propositions for future research. 2B and 3B constitutes **Proposition 3** which claim that **sub-teams'/teams' absorptive capacities are positively correlated with their knowledge application.** They aim to reveal whether it is necessary for IPD sub-teams/project teams to understand multi-disciplinary knowledge to exploit it, or whether knowledge replication without assimilation is a suitable procedure for effective knowledge application (Zander and Kogut, 1995).

Finally, Hypothesis 3C constitutes **Proposition 4** which states that an **IPD project team's knowledge application is positively correlated with project outcomes (e.g., time, cost, and quality)**. Managing across knowledge across disciplinary and organizational boundaries since the beginning of design require more complex coordination mechanisms that might negatively impact project outcomes if not properly implemented (Baiden et al., 2006, 2011). The main implication for AEC project teams is presented below.

Absorptive Capacity, Knowledge Application, and Project Outcomes: Examining Proposition 3 would allow understanding whether IPD project teams need to understand rather than replicate knowle dge to effectively apply it. And Proposition 4 would allow to see if the efforts invested in applying multi-disciplinary and multi-organizational knowledge results in enhanced project outcomes in IPD teams.

6.3. Knowledge Transfer in Different AEC Project Delivery Methods

Based on key theories of the firm, Section 2.4 offered a discussion about knowledge transfer in AEC project teams based on project delivery methods (PDMs) implemented. This study focused on AEC teams implementing the IPD method; hence, no comparisons were made between AEC teams implementing different PDMs. However, the study findings can shed some light on how distinct PDMs manage knowledge transfer to impact knowledge application.

As argued in Section 2.4, PDMs manage knowledge transfer in AEC teams primarily via two factors: *Features of Knowledge Transfer Networks* (e.g., timing of involvement of team members, and constrained knowledge transfer interactions), and *Features of Relationships Between Individuals* (e.g., contractually imposed shared goals, risks, and decision-making power among team members to motivate knowledge transfer).

This section evaluates, based on the study key findings, how PDMs manipulate the former factor to optimize knowledge application within AEC teams. To manipulate *Features of Knowledge*

Transfer Networks, PDMs control the timing of involvement of key parties, and the degree of free knowledge transfer interactions among them as illustrated in Figure 6-2. Consequently, PDMs can influence team members' knowledge application, and formation of ad hoc sub-teams applying adequate knowledge for specific tasks as depicted in Figure 6-3. As shown in the same figure, this influence exerted by PDMs is mediated by four main factors according to Key Findings 1, 3B, 3C and 4 presented in this study, and additional references (i.e., Lane and Lubatkin (1998), and Reagans and McEvily (2003)). These mediating factors refer to: Team members' network positions, absorptive and articulating capacities, and availability of suitable expertise during AEC project delivery.

Figure 6-3 displays three different paths activated by PDMs in AEC teams to achieve team members' knowledge application, and ad hoc sub-team formation for applying adequate knowledge. Below it is explained how different PDMs including Design-Bid-Build (DBB), Construction Management at Risk (CMR), Design-Build (DB), and Integrated Project Delivery (IPD) (i.e., most common PDMs in the AEC industry (CMAA, 2012)) follow each path in AEC project teams:

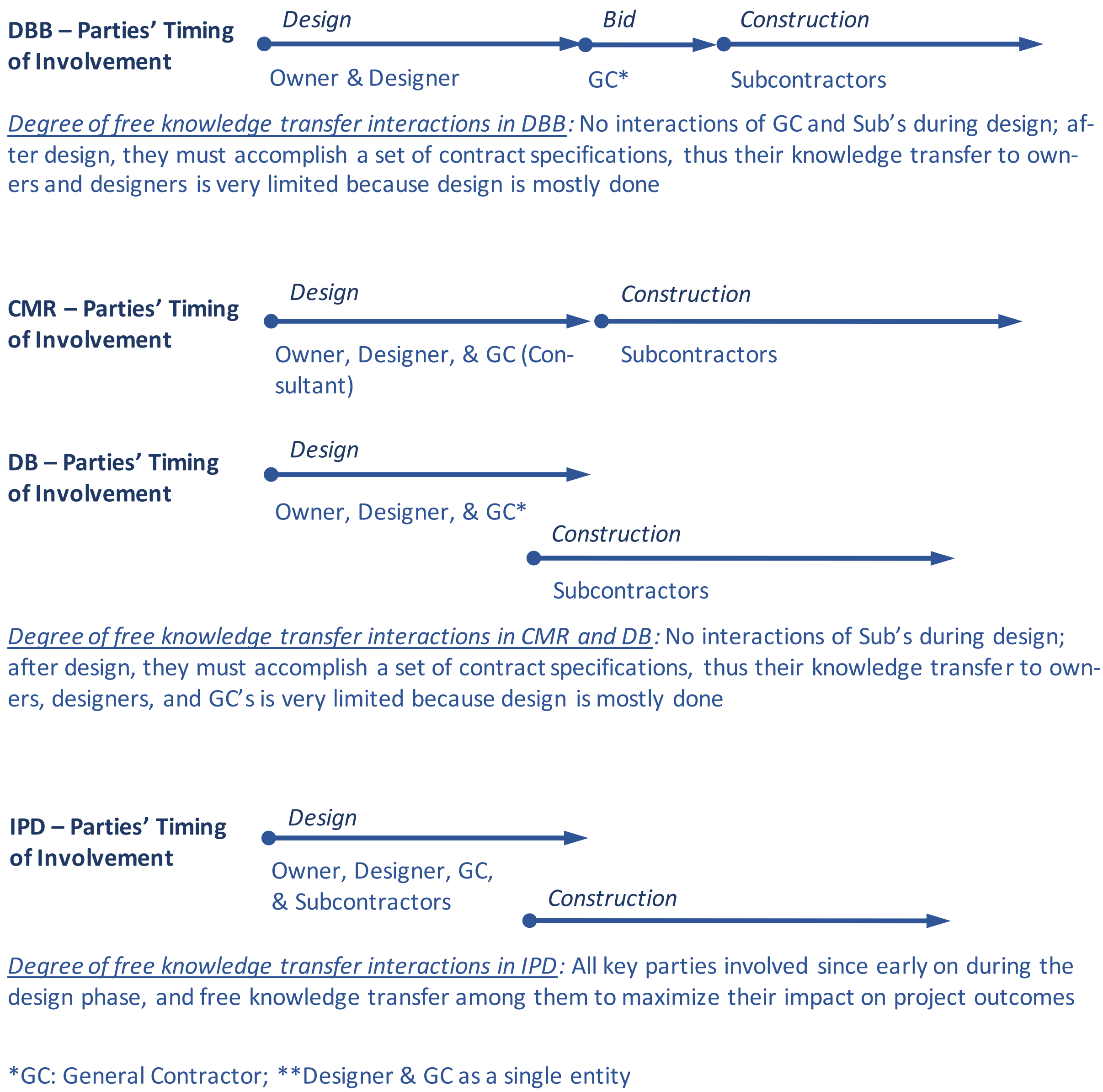
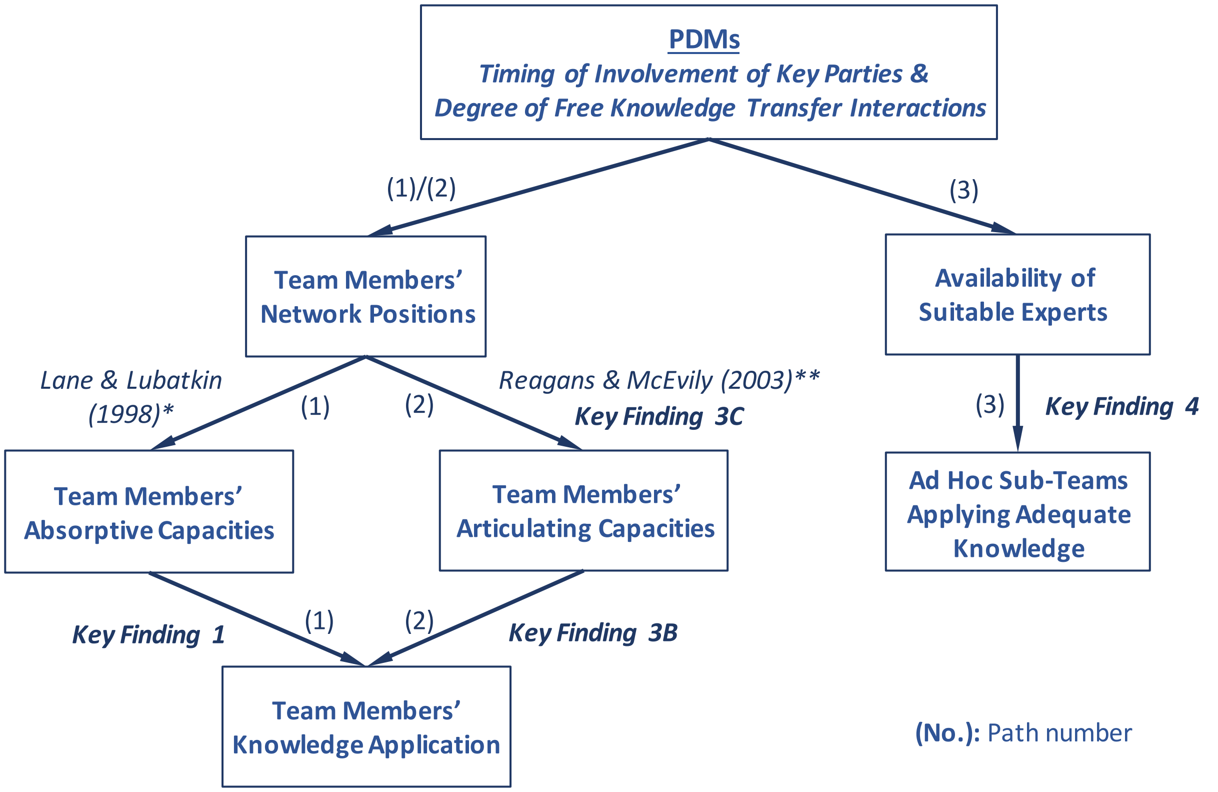


Figure 6-2. Project Delivery Methods in AEC Industry and Timing of Involvement of Key Parties



Key Finding 1: Receivers occupy network positions where their absorptive capacities enable application of transferred knowledge.

Key Finding 3B: Senders preferably make the effort to properly articulate knowledge to those peers with low absorptive capacity struggling with knowledge application.

Key Finding 3C: Receivers applying knowledge acquired across disciplines and organizations improve their articulating capacities when acting as knowledge senders.

Key Finding 4: IPD teams break down into temporary sub-teams concentrating and applying adequate expertise across disciplines and organizations to develop specific tasks.

***Lane & Lubatkin (1998):** Individuals' absorptive capacities are relative to their network position; if their positions provide them with knowledge with which they share common knowledge, then the higher are their absorptive capacities.

****Reagans & McEviliy (2003):** Individuals in network positions receiving knowledge from diverse backgrounds, improve their articulating capacities.

Figure 6-3. Influence of PDMs on Knowledge Application in AEC Project Teams

- *Path No. 1:* ***DBB*** brings general contractors and subcontractors into AEC projects after the design is complete. These team members receive a set of specifications regarding building design that they must accomplish. Therefore, since the design is complete, their input is minimized. Knowledge transfer primarily goes from designers to them. General contractors and subcontractors cannot choose network positions where their absorptive capacities enable acquired knowledge application (Lane and Lubatkin, 1998). Thus, they might receive large amounts of knowledge that they cannot fully exploit. For example, a mechanical subcontractor might receive a structural design that impedes placing the mechanical room in a location optimizing energy consumption. His/her absorptive capacity might not allow him/her to understand such structural design, thus failing to propose alternative solutions.

  CMR and ***DB*** partially mitigate the problem above by bringing general contractors into projects since during the design phase. This allows general contractors to freely interact with designers to receive knowledge that their absorptive capacities can handle to favor application. For example, they might receive information about multiple building systems and use their absorptive capacity to detect and understand constructability issues to propose solutions.

  Finally, ***IPD*** method brings together owners, designers, general contractors, and subcontractors since early on during the design phase. They can freely interact and take positions in the knowledge transfer network that best suit their absorptive capacities. Therefore, IPD method might optimize the use of team members' absorptive capacities and, subsequently, their knowledge application.

- *Path No. 2:* Per Key Finding 3C, while transferring knowledge in IPD teams, key parties from different organizations and disciplines can learn each other's approaches and assumptions to understand knowledge, thus improving their articulating capacities. Moreover, according to Key Finding 3B, the ability of a team member to properly articulate knowledge might improve knowledge application of other members with poor absorptive capacities. ***IPD*** method might improve key parties' articulating capacities more than ***DBB, CMR,*** and ***DB,*** thus favoring to a greater extent knowledge application of team members with lower absorptive capacity. This is because the IPD method gathers all key parties for knowledge transfer earlier than the rest of PDMs during the delivery process. Therefore, team members have available more time to learn their peers' methods to grasp knowledge. In addition, since free knowledge transfer interactions across multiple disciplines and organizations are promoted within IPD teams, team members are exposed to adopt a wider number of perspectives or assumptions to assimilate knowledge. Team members can use later these perspectives and assumptions to codify knowledge and make it comprehensible, thus enhancing their articulating capacities (Burt, 2002; Reagans and McEvily, 2003).

- *Path No. 3:* In each PDM, key parties get involved into AEC projects at different time points (Figure 6-2). Therefore, they possess different availability of team members with the adequate expertise to solve varying problems or demands during project delivery. This is because, as argued in Section 2.4, PDMs such as ***DBB*** are based on the transaction-cost (Williamson, 1981) and system-structural organizational theories of the firm (Astley and Van de Ven, 1983); whereas ***IPD*** is founded on the knowledge-based theory of the firm (Grant, 1996). Therefore, ***DBB*** avoids costs associated with having extra adequate expertise since the design phase, whereas ***IPD*** incurs in such costs due believing that they will later return a greater payoff than otherwise (Figure 2-6). Hence, AEC project teams following ***IPD*** method have access to a wider variety of expertise to form ad hoc sub-teams that apply timely knowledge to address changing project demands.

In conclusion, project delivery methods (PDMs) adopted in the AEC industry including DBB, CMR, DB, and IPD offer notably differing opportunities to team members for transferring and applying knowledge based on their timing of involvement, and degree to freely transfer knowledge.

6.4. Generalizability of Key Findings and Propositions

Generalizability of study findings and propositions was briefly discussed in Section 4.7.3. Findings and propositions were drawn from an inter-organizational and inter-disciplinary project team in the AEC industry following the IPD method by contract. However, study hypotheses were built upon a wide variety of research within diverse domains (e.g., construction management, communication, psychology, social networks, and knowledge management). Therefore, the study findings and propositions are expected to be applicable in other industries embracing inter-organizational and inter-disciplinary project teams similar to IPD project teams.

6.5. Summary

This chapter discussed the results of statistical analyses of the study hypotheses. The discussion offered some key findings and propositions along with their theoretical and practical applications in AEC project teams. Key findings include: First, individuals' absorptive capacities are the main factor determining their position in knowledge transfer networks within IPD project teams. Team members tend to occupy network positions transferring knowledge that they can absorb. In doing so, they can effectively apply acquired knowledge. In addition, individuals only need to share some common knowledge with received knowledge to absorb and apply it. Second, team members with high absorptive capacities can apply knowledge regardless of their peers' articulating capacities. Third, team members make the effort to nicely articulate knowledge only to those peers with low absorptive capacities to enhance their knowledge application. And fourth, IPD project teams form ad hoc sub-teams gathering the adequate expertise to devise solutions adapted to varying project demands. Practical applications of key findings suggest that owners adopting project delivery methods allowing free interactions among key parties since early on during project delivery, can optimize project outcomes (i.e., time, cost, and quality) due to enhancing exploitation of team members' absorptive and articulating capacities, improving team integration, and allowing the emergence of flexible sub-teams adapted to project demands. These findings are expected to be applicable to other industries using inter-organizational and inter-disciplinary project teams similar to IPD project teams. Finally, based on study key findings, it was discussed the influence of AEC project delivery methods on knowledge transfer and application based on team members' timing of involvement and degree of free knowledge transfer interactions. It seems that AEC teams following the IPD method take greater advantage of individuals' absorptive and articulating capacities to enhance their knowledge application.

CHAPTER 7: SUMMARY AND CONCLUSIONS

Architectural, Engineering, and Construction (AEC) project teams are temporarily formed by experts belonging to different organizations and disciplines. Unfortunately, these project teams frequently struggle with fragmentation, that is, team members' inability to merge diverse knowledge resulting in the pursuit of their personal interests at the expense of project performance. To overcome fragmentation, AEC project teams are progressively implementing relational contracting approaches to project delivery such as Integrated Project Delivery (IPD) method.

The IPD method allows unconstrained knowledge transfer interactions among key parties (i.e., owners, designers, contractors, and subcontractors) since early on during the design phase. IPD aims to significantly increase knowledge transfer interactions across disciplinary and organizational boundaries, thus potentiating team integration and avoiding fragmentation. However, an uncontrolled proliferation of such interactions also has the potential to negatively affect team performance: Team members might spend excessive time applying diverse knowledge, be unable to do so, and/or lack common knowledge to identify and understand diverse valuable knowledge.

To address the problem above, this researched established the following goal: To **examine the key factors shaping knowledge transfer networks facilitating knowledge application in IPD project teams.** The objectives accomplished to achieve this goal include:

1. Detection of key factors affecting knowledge management outcomes such as knowledge creation, transfer, retention, and application in diverse domains and units (e.g., individuals, teams, and organizations);

2. Definition and differentiation of knowledge transfer and application phenomena, and to determine the key factors influencing them;
3. Based on theory, discussion of knowledge transfer in AEC project teams under different project delivery methods (PDMs);
4. Development of a multi-level model of knowledge transfer and application in IPD project teams; and
5. Empirical test of study hypotheses, and development of practical and theoretical applications.

The sections in this dissertation where the objectives above were achieved, and the methods employed comprise:

1. *Objective 1 accomplished in Section 2.1:* Collected and reviewed relevant publications related to knowledge management in AEC project management, organization science, communication, psychology, and social networks domains; based on this literature, detected key factors for knowledge management; and classify the collected publications under the detected key factors for knowledge management.
2. *Objective 2 accomplished in Sections 2.2 and 2.3:* Reviewed literature within knowledge application, transfer, sharing, exchange, and diffusion domains to first create a definition for knowledge transfer and diffusion concepts, and, second, establish their differences.
3. *Objective 3 accomplished in Section 2.4:* Reviewed literature related to project delivery methods in AEC projects, relational contracting approaches to AEC project delivery,

AEC teams' integration, and theories of firm for knowledge management including transaction cost (Williamson, 1981), system-structural organizational (Astley and Van de Ven, 1983), and knowledge-based (Grant, 1996) theories.

4. *Objective 4 accomplished in Chapter 3:* Took as the point of departure to build the model the social network theory of influence and selection at the individual level (Frank and Farhbach, 1999) (Section 3.1), and using the literature in the domains specified in Objectives 1, 2, and 3 above, developed the entire model along with study hypotheses (Sections 3.2, 3.3, and 3.4).
5. *Objective 5 accomplished in Chapters 4, 5, and 6:* Collect longitudinal data via cross-sectional surveys at two time points from an AEC project team contractually following the IPD method (Chapter 4); using these data, test study hypotheses via structural equation modeling and linear regression (Chapter 5); and, combining the results of study hypotheses' tests and literature mentioned in Objectives 1 to 3 above, propose theoretical and practical applications (Chapter 6).

7.1. Summary of Key Findings

The study key findings and their practical applications for AEC project teams are compiled in Table 7-1.

Table 7-1. Summary of Key Findings and Practical Applications

Key Findings and Practical Applications	
In IPD project teams…	
Key Finding 1: *Individual Level*	*Receivers occupy network positions where their absorptive capacities enable application of transferred knowledge.* Practical Applications: Owners adopting project delivery methods allowing free interactions among key parties since early on during project delivery, can optimize project outcomes (i.e., time, cost, and quality) because of enhanced exploitation of team members' absorptive capacities, elicitation and utilization of greater portions of team members' knowledge, and improved team integration.
Key Finding 2: *Individual Level*	*Receivers' absorptive capacities can help to identify and understand valuable new knowledge without sharing large portions of common knowledge with senders.* Practical Applications: Owners can ensure development of integrated teams in AEC projects via assessing team members' key pieces of common knowledge across disciplines and organizations during procurement processes.
Key Finding 3: *Individual Level*	***A.** Receivers with high absorptive capacity can easily apply transferred knowledge regardless of senders' articulating capacities.* ***B.** Senders preferably make the effort to properly articulate knowledge to those peers with low absorptive capacity struggling with knowledge application.* ***C.** Receivers applying knowledge acquired across disciplines and organizations improve their articulating capacities when acting as knowledge senders.* Practical Applications: Owners adopting project delivery methods allowing free interactions among key parties since early on during project delivery, can optimize project outcomes due to enhanced management of team members' articulating capacities. In addition, team members' interactions with multi-organizational and multi-disciplinary peers early on during project delivery grow their articulating capacities.

Table 7-1. (cont'd)

Key Finding 4: *Sub-Team Level*	*IPD teams break down into temporary sub-teams concentrating and applying adequate expertise across disciplines and organizations to develop specific tasks.* Practical Applications: Owners adopting project delivery methods allowing free interactions among key parties since early on during project delivery, can exert a higher control over projects' outcomes (i.e., time, cost, and quality) via ad hoc sub-teams' formation.

The study's main contribution to the body of knowledge posits that individuals' absorptive capacities and free interactions constitute two key factors for the formation of knowledge transfer networks enabling knowledge application within AEC project teams. This expands our understanding about AEC project team integration which is frequently viewed as an increase of knowledge transfer interactions across disciplinary and organizational boundaries. In addition, effective integration in AEC project teams involves the extent to which team members can freely move in the knowledge transfer network to take positions where their absorptive capacities allow application of transferred knowledge.

7.2. Deliverables

The primary deliverable of this research is an assessment of the key factors shaping knowledge transfer networks improving knowledge application in IPD project teams. This deliverable refers to study key findings which are described in detail in Sections 6.1 and 6.2, and compiled in Section 7.1. In addition, this deliverable is accompanied by the following ones:

1) Review of relevant literature for knowledge management within AEC project teams (Sections 2.1, 2.2, and 2.3), and theoretical discussion PDMs' influence on knowledge transfer in AEC project teams during design and construction phases of project delivery (Section 2.4);

2) Description of how PDMs' differing practices to manage knowledge transfer result in different knowledge application outcomes during the design and construction stages of AEC project delivery (Section 6.3);

3) Theoretical implications of knowledge transfer and application in inter-organizational and inter-disciplinary project teams (i.e., as opposed to permanent organizations with expertise in limited disciplines) (Sections 6.1, 6.2, 6.3, 6.4, 7.1, and 7.4);

4) Practical applications of knowledge transfer and application for owners in the AEC industry to improve project outcomes (i.e., time, cost, and quality) (Sections 6.1, 6.2, 6.3, 6.4, and 7.1);

5) Multi-level model of knowledge transfer and application in IPD project teams (Figure 3-1), operationalization of study variables (Table 4-3), collected data, and propositions for future research (Sections 6.2 and 7.4); and

6) Differential equations at the individual, sub-team, and project team levels, mathematically describing knowledge transfer and application phenomena within IPD project teams (Section 4.6).

7.3. Limitations

Main limitations of this research include AEC projects teams' size, complexity, and adopted PDM. This research offered key findings after testing study hypotheses collected from one IPD project team relatively large developing a complex design (i.e., more than 160 team members, and $60 million budget approximately). Therefore, comparisons with smaller teams, and project teams developing simpler designs, or implementing non-IPD methods could not be empirically analyzed. Thus, study findings might not be applicable to project teams that notably differ from the IPD project team utilized in this research and described in Section 4.3.

7.4. Future Research

This study proposed a multi-level model connecting individuals', sub-teams', and project teams' absorptive capacities. Low statistical power impeded to draw any conclusion at the sub-team and team levels. Future research should continue examining the model. Propositions for future research are described in Section 6.2. The main ones with their potential theoretical contributions are compiled in Table 7-2. Testing these propositions would allow, for example, to detect what team members' absorptive capacities exert a greater influence on sub-teams' absorptive capacities depending on their network position. Owners could use this to effectively manage their employees according to their absorptive capacity.

Finally, based on study key findings, upcoming research could attempt to simulate the formation and evolution of knowledge transfer networks in IPD project teams. This could be done with the differential equations developed in Section 4.6, adjusting their parameters based on Key Findings 1, 2, and 3, and using social network analysis software such as NetLogo (Northwestern University, 2017). This would allow to predict knowledge transfer interactions within/across disciplinary and organizational boundaries, and predict project outcomes' performance based on the quality of team integration.

Table 7-2. Propositions and Theoretical Implications

Propositions and Theoretical Implications	
In IPD project teams…	
Proposition 1: *Sub-Team Level*	The greater an individual's centrality in a sub-team's network, the greater the contribution of his/her absorptive capacity to the sub-team's absorptive capacity. <u>Theoretical Implications</u>: Individuals taking central positions in a sub-team's networks might filter large amounts of knowledge to identify that one valuable. Then they transfer it to other sub-team members, thus determining what knowledge they can identify and understand. Consequently, individuals in central network positions exert a stronger influence on a sub-team's absorptive capacity.
Proposition 2: *Team Level*	In IPD project teams, the influence of a sub-team's absorptive capacity on the project team's absorptive capacity is moderated by its centrality in the project team's network. <u>Theoretical Implications</u>: If proposition 1 above is confirmed, then individuals' absorptive capacities would impact an IPD team's absorptive capacity via the formation of sub-teams. Both (1) individuals' centralities in sub-teams' networks, and (2) sub-teams' centralities in the entire project team network, moderate the extent to which individuals' absorptive capacities contribute to the project team's absorptive capacity.
Proposition 3: *Sub-Team/ Team Levels*	Sub-teams'/teams' absorptive capacities are positively correlated with their knowledge application. <u>Theoretical Implications</u>: Expand our understanding about whether IPD project teams need to understand rather than replicate knowledge to effectively apply it.
Proposition 4: *Team Level*	IPD project team's knowledge application is positively correlated with project outcomes (e.g., time, cost, and quality). <u>Theoretical Implications</u>: Expand our understanding about whether efforts invested in applying multi-disciplinary and multi-organizational knowledge results in enhanced project outcomes in IPD teams.

APPENDICES

APPENDIX A: Data Collection Protocol

Protocol Description

Data will be collected from four architectural, engineering and construction (AEC) project teams: two integrated project delivery (IPD) teams, and two non-IPD project teams comparable in size, complexity and budget. Each project team is expected to include from 60 to 100 participants and a budget over $30 million. The project teams were/will be found via:

- Personal contacts;
- Follow up with our existing contacts from our current NSF project database; and
- Web-search.

The following is to be performed for each project which will be referred to as Project X:

1. Introduction of our research project to the project owner representative(s) via phone calls and/or in-person meetings. The research project flyer (Protocol – Addendum A), and attached meeting agenda and a short version of the data collection protocol are sample documents to be used in such meetings or to be sent via e-mail for the owner's representative to review in case of phone call.

2. Attendance to a project team meeting at the beginning of project design for a presentation to cover the following points:

- Research team members' introductions;
- Research purpose;
- Type of data to be collected and procedure;

- Potential risks and benefits of participating in this research;
- Rights to participate and voluntary willingness to participate in this research;
- Confidentiality of collected data; and
- Data collection under the Human Research Protection Program of the MSU.

3. Email #1 (Protocol – Addendum B) with the information above will be sent to not only those team members that cannot attend the presentation but also the rest of participants so they can refresh their memory about the research and data collection description. This email will include the research flyer (Figure A-1 in Protocol – Addendum A).

4. After points 1, 2, and 3 are completed, the research team will ask the owner's representative whether there is any web-based document sharing system for the project team, and request access so that the researchers:

   a. Can collect project team participant contact information, and organizations; and

   b. Keep track of the project progress and relevant milestones for the longitudinal data collection.

5. Data from each project is to be collected at four points in time as shown below in Figure 4-1. Every AEC project is unique with differing timelines and overall schedules (e.g., varying from 6 months to 2 years for total project timeline for the type of AEC projects included in the study sample); nonetheless, they typically follow the phases displayed in Figure 3. The exact date for collecting the data will be determined after a short discussion with the project manager over the phone.

6. Before any data is collected, the researchers will have the project manager and five more randomly selected team members read the surveys #1, #2, #3, #4, #5, #6 and #7 (Protocol – Addendum E, F, G, H, I, L and M respectively) and provide in person feedback and comments regarding the clarity and accuracy of the survey items. This step will be only performed for the first case study project.

7. Once suitable dates for data collection points (Figure 3) are precisely known, PhD student #1 will ask permission to the project manager to personally attend a project team meeting. After this permission is obtained, the PhD student will attend the meeting and, before the end of the meeting, handout the surveys #1, #2, #3, #4 and #5, have team members read them, give instructions to complete them, set a due date for completion, and respond to any questions that may arise.

8. The PhD student will request team members to complete the survey #1 via web-based survey application (e.g., Qualtrics). The survey link will be sent via email #2 (Protocol – Addendum C) and participants will be encouraged to fill out the survey within two days after reception.

9. Two days after point 7 is accomplished, the follow-up email #3 (Protocol – Addendum D) will be sent to those team members that did not complete the survey #1 requesting them to do so within the next day.

10. Immediately after all surveys #1 are completed and collected, the PhD student #1 will develop a sociogram within two days displaying knowledge sharing interactions among all project team members, and identify boundary spanners across functional areas and cross-functional subteams. Afterwards, the PhD student will contact the project manager (i.e., owner's representative) via a phone call for a meeting for the following:

a. The sociogram highlighting boundary spanners and functional subteams will be shown to the project manager to have him/her verify this information; and

b. The project manager will be asked to identify the key team members in Project X that should rate other team members' performance.

11. Right after point 10 is complete, the PhD student will repeat previous steps 8 and 9 but utilizing surveys #2, #3, #4 and #5 together. Only survey #2 will be distributed to all team members; while survey #3 will be given to boundary spanners identified in sociograms in point **9**; survey #4 to specific team members based on point **9.b**, and survey #5 to the owner's representative.

12. The PhD student #1 will repeat steps **7, 8, 9, 10,** and **11** above for every time point for data collection as presented in Figure 3. Each time point is expected to take 10 days approximately where first survey #1 and then simultaneously surveys #2, #3, #4 and #5 are distributed and completed.

Protocol – Addendum

A. Research Flyer – Overall Research and Participants Information

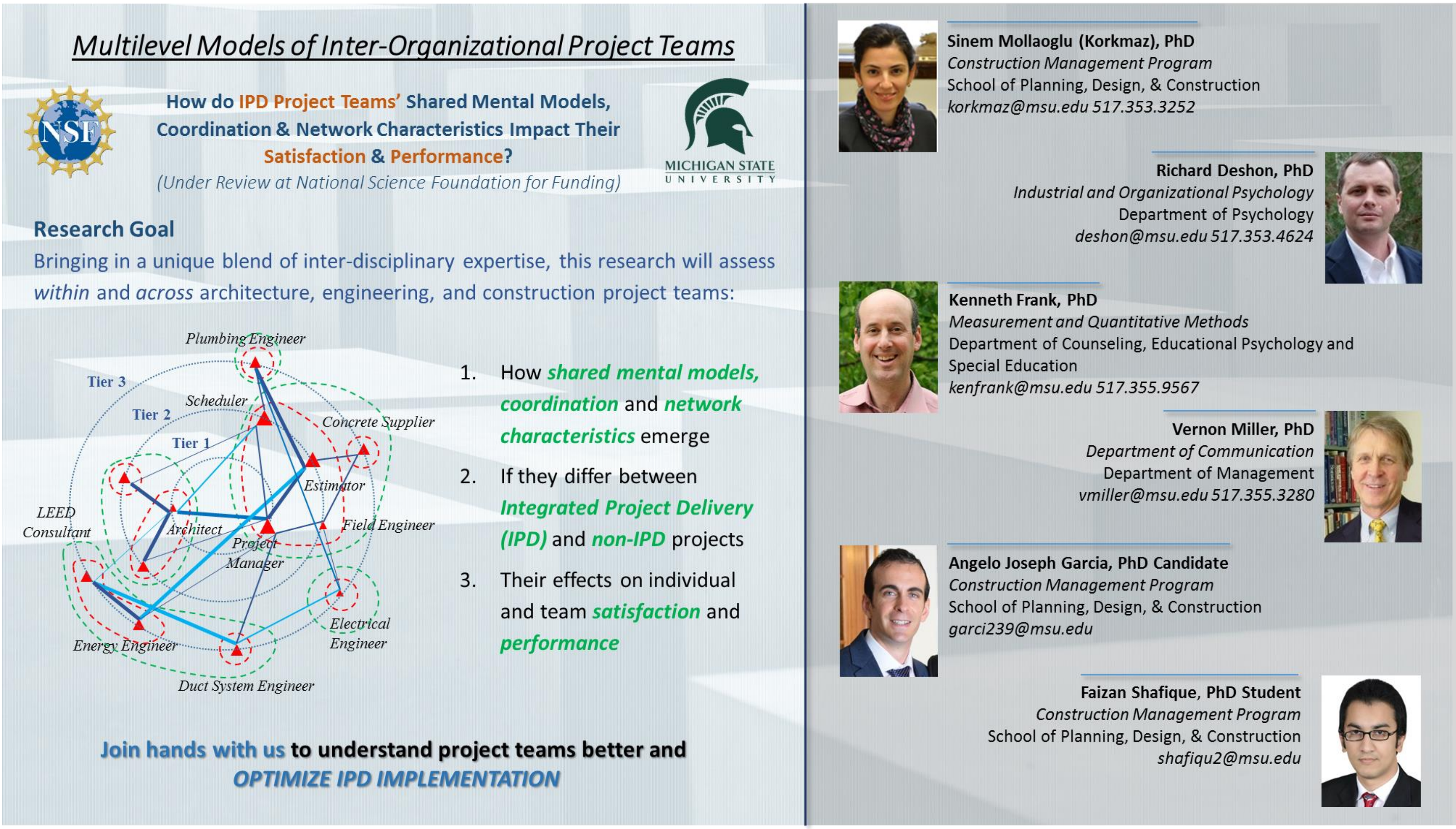


Figure A-1. Research Flyer

B. Email #1 – Research Information

Email Subject: MSU Research Study on *"Project Name Goes Here"* – Introduction

Dear Team Members of *"Project Name Goes Here"*:

Thank you very much in advance for your willingness to collaborate with us in this study, we appreciate your time and effort.

Attached we are sending a flyer (Protocol – Addendum A) showing the details of our study and investigators. Below is a detailed description of our expectations from you if you agree to participate in our research study.

PURPOSE OF RESEARCH

- Assess in IPD project teams the influence of individuals' cognitive abilities and common knowledge on the emergence and evolution of knowledge transfer networks, and knowledge application.
- Analyze the relation between IPD project teams' knowledge sharing networks, and the creation of coordination mechanisms and shared mental models.

WHAT YOU WILL DO

- You will be asked to complete series of web-based surveys at four different time points of the *"Project Name Goes Here"* for research purposes.
- Completing the surveys at each time point will take 20-30 minutes.
- The survey questions focus on the individuals' and team's knowledge sharing behavior, ability to handle knowledge, performance, and satisfaction.

- You need to answer the questions based on your experience and perceptions regarding the *“Project Name Goes Here”*.

POTENTIAL BENEFITS

- Your participation will contribute to a greater understanding of how knowledge flows throughout IPD project team networks enabling its exploitation, and allow the development of a theoretical foundation for the creation of new project management techniques optimizing IPD teams’ performance based on the relation between knowledge sharing networks and individuals’ cognitive abilities.

POTENTIAL RISKS

- There are no foreseeable risks associated with participation in this study.

PRIVACY AND CONFIDENTIALITY

- Your responses to survey items will be confidential. For research purposes, the researchers will be able to identify your responses. No one outside the research team will know how you responded to any particular question.
- The researchers will not disclose any specific information about case studies or study participants to the maximum extent allowable by law.
- Publications coming out from this study will present the data in aggregate form, so no participant will be identifiable.
- Electronic responses collected from surveys will be only accessible by the research team and stored in password protected computers. Hard copies from the collected data will be stored in a locked cabinet.
- The data will be stored for a minimum of three years after completion of the study.

YOUR RIGHTS TO PARTICIPATE, OR WITHDRAW

- Participation in this research is voluntary. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled.
- You may choose not to answer specific questions or to stop participating at any time.

If you have concerns or questions about this study, such as scientific issues, how to do any part of it, please contact the researchers:

- Angelo Joseph Garcia, PhD Candidate: garci239@msu.edu, 517-355-9682;
- Faizan Shafique, PhD Student: shafiqu2@msu.edu, 517-355-9682;
- Dr. Sinem Mollaoglu-Korkmaz: korkmaz@msu.edu, 517-353-3252;
- Dr. Richard Deshon: deshon@msu.edu, 517-353-4624;
- Dr. Vernon Miller, vmiller@msu.edu, 517-355-3280;
- Dr. Kenneth Frank, kenfrank@msu.edu, 517-355-9567.

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 207 Olds Hall, MSU, East Lansing, MI 48824.

Best regards,

Angelo Joseph Garcia
PhD Candidate and Graduate Research Assistant
Construction Management Program
Michigan State University
garci239@msu.edu / 517-355-9682

C. Email #2 – Request to Complete Online Survey

Email Subject: Web-Based Survey – MSU Research Study on *"Project Name Goes Here"* – Please Complete by Date X

Dear Team Member/s (All Team Members / Boundary Spanners / Specific Team Members / Owner's Representative) from *"Project Name Goes Here:"*

As I recently told you in the project meeting on Date X, we need you to complete the survey/s #1/#2/#3/#4/#5 following the link/s below. Please complete it/them within two days by Date X at 9pm. Completing the survey/s will take you around 5-15 min:

https://www.linktothesurvey#1.com; or/and

https://www.linktothesurvey#2.com; or/and

https://www.linktothesurvey#3.com; or/and

https://www.linktothesurvey#4.com; or/and

https://www.linktothesurvey#5.com

Thank you very much in advance for your time and effort.

Best regards,

Angelo Joseph Garcia
PhD Candidate and Graduate Research Assistant
Construction Management Program
Michigan State University
garci239@msu.edu / 517-355-9682

D. Email #3 – Follow-up Requesting Online Survey Completion if Incomplete

Email Subject: Follow-Up Web-Based Survey – MSU Research Study on *"Project Name Goes Here"*

Dear Team Member/s (All Team Members / Boundary Spanners / Specific Team Members / Owner's Representative) from *"Project Name Goes Here:"*

This is a friendly reminder asking you to complete, if you have not already done so, the survey/s #1/#2/#3/#4/#5 by Date X at 9pm. Find the link/s to the survey/s below. Completing them will take you around 5-15 min:

https://www.linktothesurvey#1.com; or/and

https://www.linktothesurvey#2.com; or/and

https://www.linktothesurvey#3.com; or/and

https://www.linktothesurvey#4.com; or/and

https://www.linktothesurvey#5.com

Thank you very much for your time. Your effort is greatly appreciated. Best regards,

Angelo Joseph Garcia
PhD Candidate and Graduate Research Assistant
Construction Management Program
Michigan State University
garci239@msu.edu / 517-355-9682

APPENDIX B1: Institutional Review Board Approval Letter

MICHIGAN STATE
UNIVERSITY

Revision Application Approval

October 14, 2016

To: Sinem Korkmaz
111-A Human Ecology Building
East Lansing

Re: **IRB# 16-110** Category: EXPEDITED 7
Revision Approval Date: October 14, 2016
Project Expiration Date: February 8, 2017

Title: Multilevel Models of Inter-organizational Project Teams: How do Shared Mental Models, Coordination and Network Characteristics Shape Project Teams and Performance?

The Institutional Review Board has completed their review of your project. I am pleased to advise you that **the revision has been approved**.

Approved revision to include changes in the consent, instrument, and protocol.

The review by the committee has found that your revision is consistent with the continued protection of the rights and welfare of human subjects, and meets the requirements of MSU's Federal Wide Assurance and the Federal Guidelines (45 CFR 46 and 21 CFR Part 50). The protection of human subjects in research is a partnership between the IRB and the investigators. We look forward to working with you as we both fulfill our responsibilities.

Renewals: IRB approval is valid until the expiration date listed above. If you are continuing your project, you must submit an ***Application for Renewal*** application at least one month before expiration. If the project is completed, please submit an ***Application for Permanent Closure***.

Revisions: The IRB must review any changes in the project, prior to initiation of the change. Please submit an ***Application for Revision*** to have your changes reviewed. If changes are made at the time of renewal, please include an ***Application for Revision*** with the renewal application.

Problems: If issues should arise during the conduct of the research, such as unanticipated problems, adverse events, or any problem that may increase the risk to the human subjects, notify the IRB office promptly. Forms are available to report these issues.

Please use the IRB number listed above on any forms submitted which relate to this project, or on any correspondence with the IRB office.

Good luck in your research. If we can be of further assistance, please contact us at 517-355-2180 or via email at IRB@msu.edu. Thank you for your cooperation.

Sincerely,

H. McGee

Harry McGee, MPH
SIRB Chair

c: Kenneth Frank, Richard Deshon, Vernon D. Miller, Angel Jose Garcia Cortes, Faizan Shafique

Office of Regulatory Affairs
Human Research Protection Programs

Biomedical & Health Institutional Review Board (BIRB)

Community Research Institutional Review Board (CRIRB)

Social Science Behavioral/Education Institutional Review Board (SIRB)

Olds Hall
408 West Circle Drive, #207
East Lansing, MI 48824
(517) 355-2180
Fax: (517) 432-4503
Email: irb@msu.edu
www.hrpp.msu.edu

APPENDIX B2: Institutional Review Board Consent Forms

Consent for Survey #1

PURPOSE OF RESEARCH

- Assess the emergence and evolution of knowledge transfer networks, and team performance in Integrated Project Delivery (IPD) teams.

WHAT YOU WILL DO

- You will be asked to complete this web-based survey regarding your knowledge sharing interactions in the case study project mentioned.
- Completing the surveys will take about 10 minutes.
- The survey questions focus on the individuals' and team's knowledge sharing behavior, ability to handle knowledge, performance, and satisfaction.
- You need to answer the questions based on your experience and perceptions regarding the case study mentioned.

POTENTIAL BENEFITS

- Your participation will contribute to understand if and why the IPD method improves project performance in design-construction teams.
- If you request via email at garci239@msu.edu, the research findings will be shared with you.

POTENTIAL RISKS

- There are no foreseeable risks associated with participation in this study.

PRIVACY AND CONFIDENTIALITY

- Your responses to survey items will be confidential. For research purposes, the researchers will be able to identify your responses. No one outside the research team will know how you responded to any particular question.
- The researchers will not disclose any specific information about case studies or study participants to the maximum extent allowable by law.
- Publications coming out from this study will present the data in aggregate form, so no participant will be identifiable.
- Electronic responses collected from surveys will be only accessible by the research team and stored in password protected computers. Hard copies from the collected data will be stored in a locked cabinet in the researchers' offices.
- The data will be stored for a minimum of three years after completion of the study.
- Only the appointed researchers and the Human Research Protection Program (HRPP) will have access to the research data.

YOUR RIGHTS TO PARTICIPATE, OR WITHDRAW

- Participation in this research is voluntary. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled.
- You may choose not to answer specific questions or to stop participating at any time.
- Some participants might report about your knowledge transfer abilities in the survey. If you would like to be excluded from this process, please email Angelo Garcia at garci239@msu.edu.

If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or report any injuries please contact the researchers:

- Angelo Joseph Garcia, PhD Candidate: garci239@msu.edu, 517-355-9682;
- Faizan Shafique, PhD Student: shafiqu2@msu.edu, 517-355-9682;
- Dr. Sinem Mollaoglu-Korkmaz: korkmaz@msu.edu, 517-353-3252;
- Dr. Richard Deshon: deshon@msu.edu, 517-353-4624; Dr. Vernon Miller, vmiller@msu.edu, 517-355-3280;
- Dr. Kenneth Frank, kenfrank@msu.edu, 517-355-9567.

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 207 Olds Hall, MSU, East Lansing, MI 48824.

By beginning this survey, you indicate your voluntary willingness to participate in this research project.

THE SURVEY MIGHT TAKE AROUND 10 MINUTES. PLEASE COMPLETE IT BASED ON YOUR PARTICIPATION IN THE CASE STUDY MENTIONED WITHIN 3 DAYS.

ONCE YOU START YOU CAN SAVE CHANGES AND COME BACK LATER TO THE POINT WHERE YOU LEFT.

This consent form was approved by a Michigan State University Institutional Review Board. Approved 10/14/16 through 02/08/17. This version supersedes all previous versions. IRB# 16-110.

Consent for Survey #2

This consent form is to be sent attached in Email #2 (see attached 'Email #2')

PURPOSE OF RESEARCH

- Assess the emergence and evolution of knowledge transfer networks, and team performance in Integrated Project Delivery (IPD) teams.

WHAT YOU WILL DO

- You will be asked to respond some questions in this email regarding your knowledge sharing interactions in the case study project mentioned.
- Completing this survey will take about 5-10 minutes.
- The survey questions focus on the individuals' and team's knowledge sharing behavior, ability to handle knowledge, performance, and satisfaction.
- You need to answer the questions based on your experience and perceptions regarding the case study project mentioned.

POTENTIAL BENEFITS

- Your participation will contribute to understand if and why the IPD method improves project performance in design-construction teams.
- If you request via email at garci239@msu.edu, the research findings will be shared with you.

POTENTIAL RISKS

- There are no foreseeable risks associated with participation in this study.

PRIVACY AND CONFIDENTIALITY

- Your responses to survey items will be confidential. For research purposes, the researchers will be able to identify your responses. No one outside the research team will know how you responded to any particular question.
- The researchers will not disclose any specific information about case studies or study participants to the maximum extent allowable by law.
- Publications coming out from this study will present the data in aggregate form, so no participant will be identifiable.
- Electronic responses collected from surveys will be only accessible by the research team and stored in password protected computers. Hard copies from the collected data will be stored in a locked cabinet in the researchers' offices.
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- Dr. Sinem Mollaoglu-Korkmaz: korkmaz@msu.edu, 517-353-3252;
- Dr. Richard Deshon: deshon@msu.edu, 517-353-4624; Dr. Vernon Miller, vmiller@msu.edu, 517-355-3280;
- Dr. Kenneth Frank, kenfrank@msu.edu, 517-355-9567.

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By responding the questions in this email, you indicate your voluntary willingness to participate in this research study.

This consent form was approved by a Michigan State University Institutional Review Board. Approved 10/14/16 through 02/08/17. This version supersedes all previous versions. IRB# 16-110.

Consent for Survey #3

This consent form is to be sent attached in Email #3 (see attached 'Email #3')

PURPOSE OF RESEARCH

- Assess the emergence and evolution of knowledge transfer networks, and team performance in Integrated Project Delivery (IPD) teams.

WHAT YOU WILL DO

- You will be asked to respond some questions in this email regarding your knowledge sharing interactions in the case study project mentioned.
- Completing this survey will take about 5-10 minutes.
- The survey questions focus on the individuals' and team's knowledge sharing behavior, ability to handle knowledge, performance, and satisfaction.
- You need to answer the questions based on your experience and perceptions regarding the case study project mentioned.

POTENTIAL BENEFITS

- Your participation will contribute to understand if and why the IPD method improves project performance in design-construction teams.
- If you request via email at garci239@msu.edu, the research findings will be shared with you.

POTENTIAL RISKS

- There are no foreseeable risks associated with participation in this study.

PRIVACY AND CONFIDENTIALITY

- Your responses to survey items will be confidential. For research purposes, the researchers will be able to identify your responses. No one outside the research team will know how you responded to any particular question.
- The researchers will not disclose any specific information about case studies or study participants to the maximum extent allowable by law.
- Publications coming out from this study will present the data in aggregate form, so no participant will be identifiable.
- Electronic responses collected from surveys will be only accessible by the research team and stored in password protected computers. Hard copies from the collected data will be stored in a locked cabinet in the researchers' offices.
- The data will be stored for a minimum of three years after completion of the study.
- Only the appointed researchers and the Human Research Protection Program (HRPP) will have access to the research data.

YOUR RIGHTS TO PARTICIPATE, OR WITHDRAW

- Participation in this research is voluntary. You may discontinue participation at any time without penalty or loss of benefits to which you are otherwise entitled.
- You may choose not to answer specific questions or to stop participating at any time.

If you have concerns or questions about this study, such as scientific issues, how to do any part of it, or report any injuries please contact the researchers:

- Angelo Joseph Garcia, PhD Candidate: garci239@msu.edu, 517-355-9682;
- Faizan Shafique, PhD Student: shafiqu2@msu.edu, 517-355-9682;
- Dr. Sinem Mollaoglu-Korkmaz: korkmaz@msu.edu, 517-353-3252;
- Dr. Richard Deshon: deshon@msu.edu, 517-353-4624; Dr. Vernon Miller, vmiller@msu.edu, 517-355-3280;
- Dr. Kenneth Frank, kenfrank@msu.edu, 517-355-9567.

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 207 Olds Hall, MSU, East Lansing, MI 48824.

By responding the questions in this email, you indicate your voluntary willingness to participate in this research study.

This consent form was approved by a Michigan State University Institutional Review Board. Approved 10/14/16 through 02/08/17. This version supersedes all previous versions. IRB# 16-110.

APPENDIX C1: Survey#1 for Data Collection

Consent form for Survey #1 (Appendix B) was displayed in the first page

Research Survey Related to The **BROAD COLLEGE OF BUSINESS PAVILION PROJECT**

MSU Construction Management Program
School of Planning, Design, and Construction

MICHIGAN STATE
UNIVERSITY

NOTE: This survey will work best in a laptop/computer rather than in a mobile device.

The survey will take you around **10 min.** Please, respond based on **<u>your perceptions</u>** during your participation in the **Broad College of Business Pavilion Project** and complete it by this **Friday Nov. 18th.**

Please provide the following information:

1. Name

2. Gender

Male	Female
◯	◯

3. Race

- ◯ American Indian or Alaska Native
- ◯ Asian
- ◯ Black or African American
- ◯ Native Hawaiian or Other Pacific Islander
- ◯ White
- ◯ Other

4. Which organization do you represent in this project?

5. How many years have you been working full time in the architectural, engineering and construction industry?

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6. In how many <u>IPD by contract projects</u>* did you participate in the past besides the Broad College of Business Pavilion Project?

**<u>IPD by contract project</u> refers to those projects in which a multi-party agreement is signed whereby participants share goals, benefits, risks, and decision-making power.*

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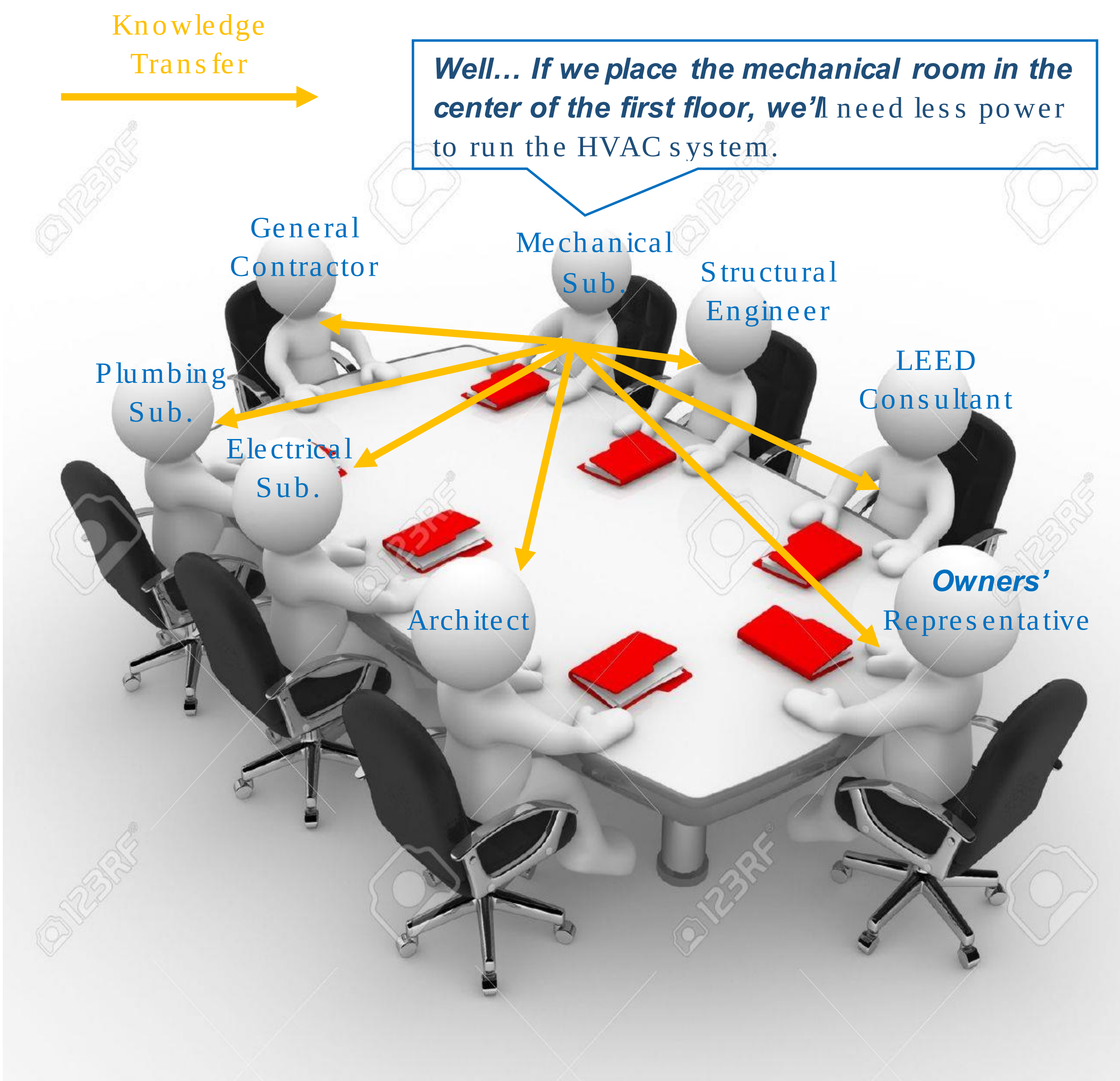
7. What is the primary role that you represent in this project?

Owner	Architect	Contractor	Mechanical Sub.	Electrical Sub.	Plumbing Sub.	Structural Engineer	Concrete Supplier	Other
○	○	○	○	○	○	○	○	○

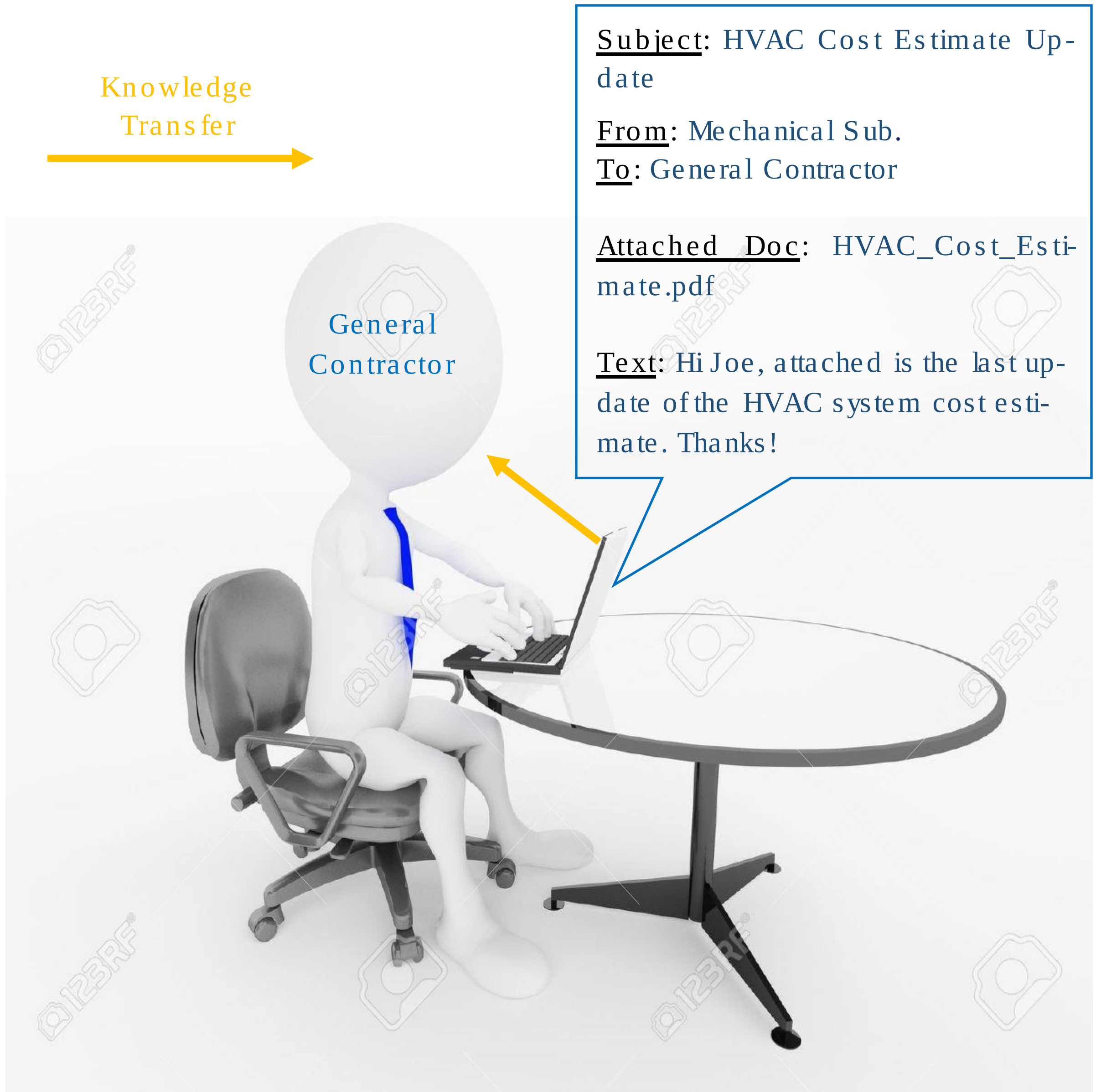
Survey Completion: 10%

Please consider the following examples of KNOWLEDGE TRANSFER scenarios frequently occurring within design-construction teams:

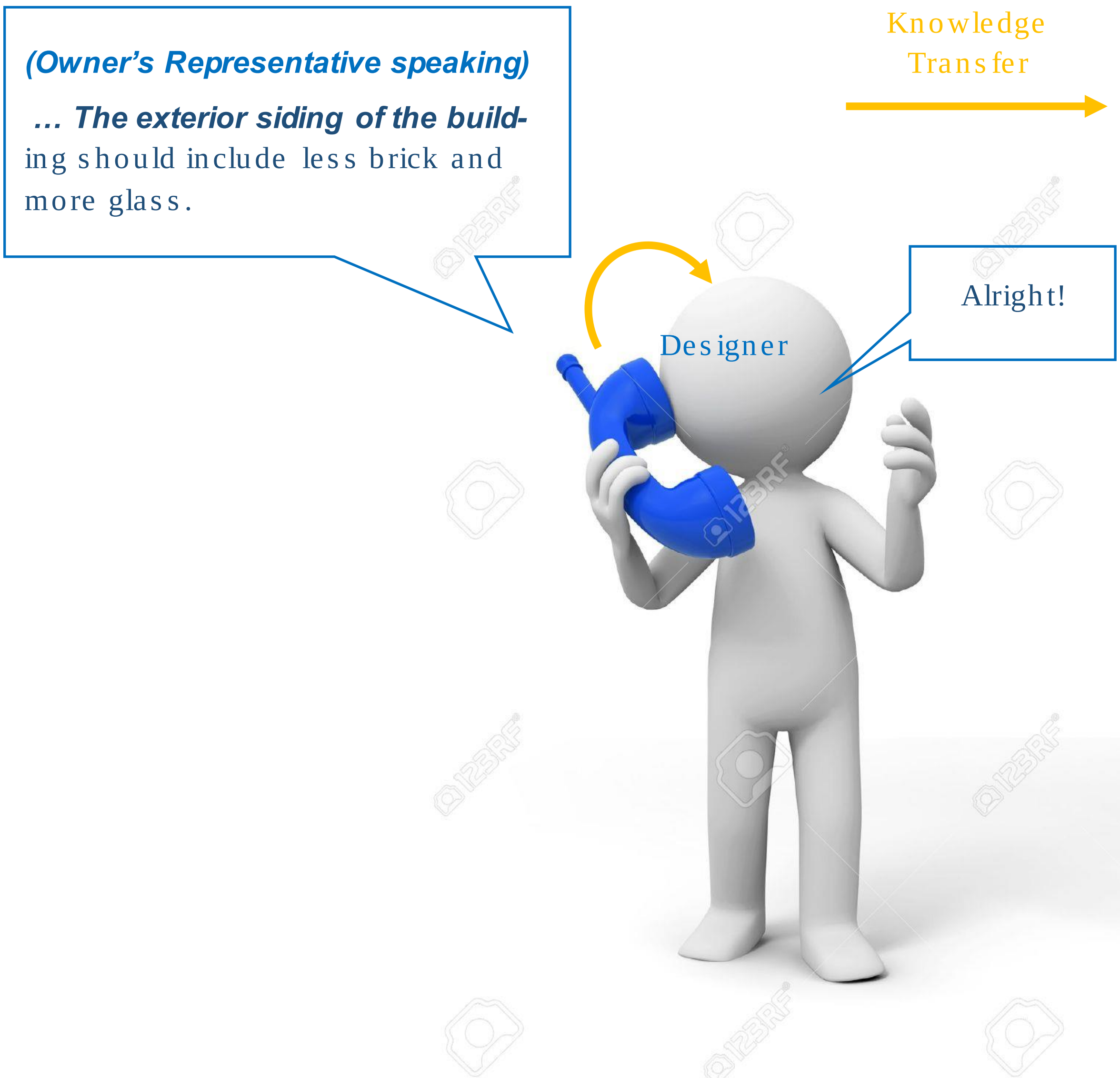
1. Knowledge transfer via face-to-face interaction in a meeting



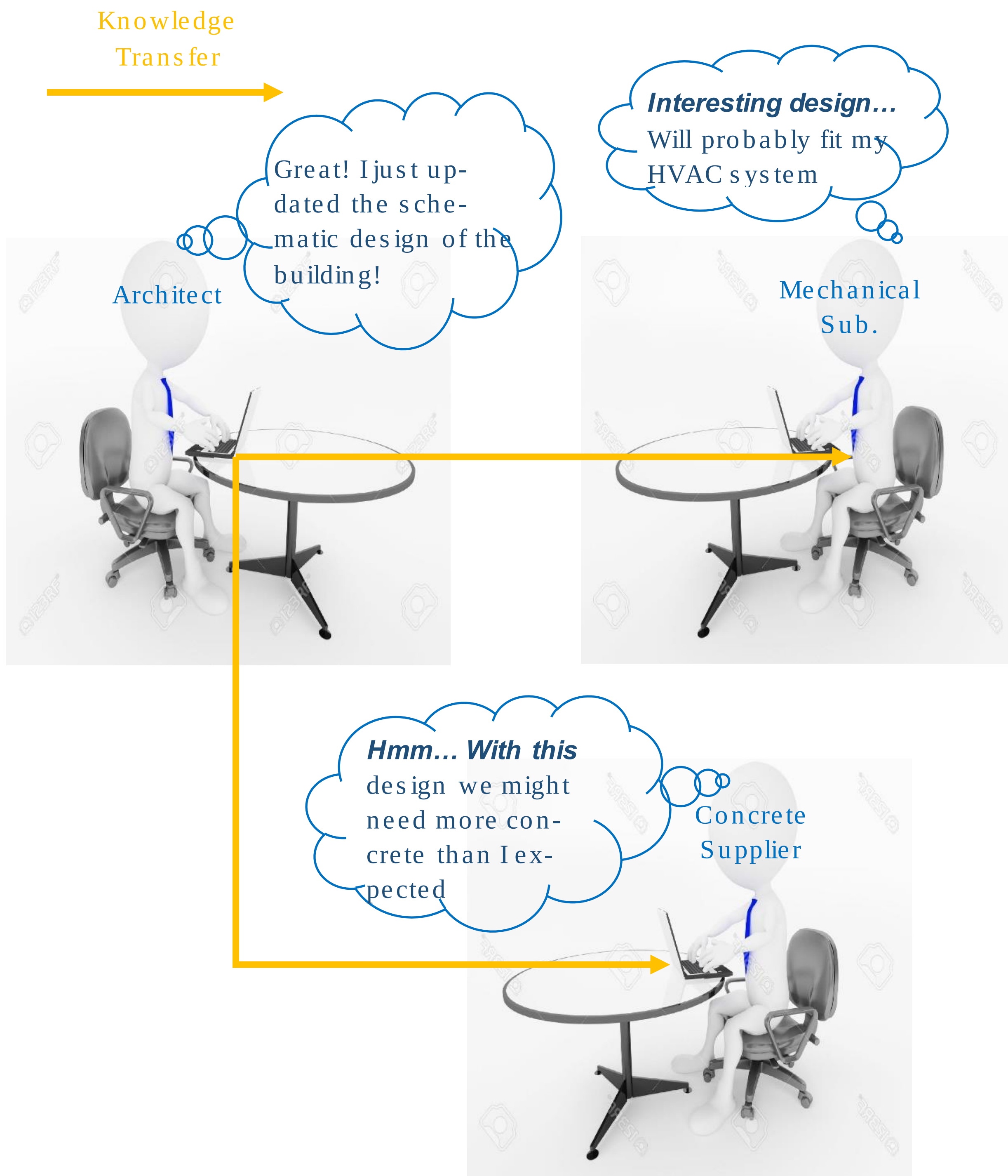
2. Knowledge transfer via email



3. Knowledge transfer via telephone conversation



4. Knowledge transfer via shared software



In Summary:

Knowledge Transfer refers to providing theoretical or practical information, insights, or skills that have value to the project.

Also, Valuable Knowledge is that knowledge that allows you to effectively accomplish your tasks, contributing to improve project performance.

In the Broad College of Business Pavilion Project...

List in order of importance the <u>top 5 individuals (within/outside your organization)</u> who provided you with the MOST VALUABLE knowledge DURING THE LAST MONTH *(or since you have been involved in the project if it has been less than one month):*

1.

2.

3.

4.

5.

Survey Completion: 30%

DURING THE LAST MONTH...

***How often* did you receive knowledge from these team members?** *Drag the names to the appropriate box.*

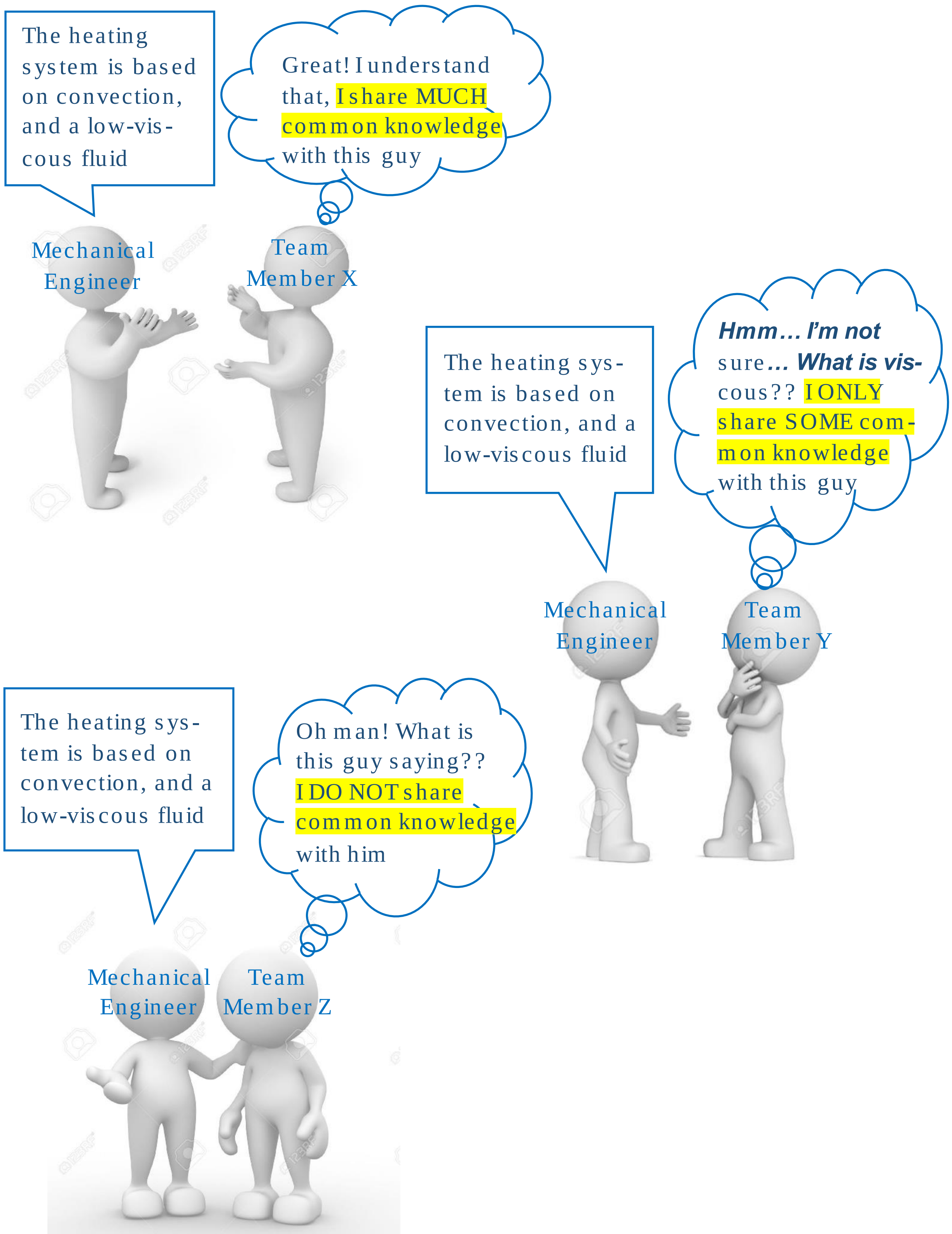
	Daily	Weekly
1. Team member 1		
2. Team member 2		
3. Team member 3	Monthly	
4. Team member 4		
5. Team member 5		

How did you PRIMARILY receive knowledge from these individuals? You may choose up to two options per person.

	Face-to-Face	***Video-Conference***	***Shared Software*** (e.g., Revit)	***Phone Call***	***Email*** (e.g., electronic docs or messages)	***Cell Phone SMS***	***Paper-based Docs***	***Other***
1. Team member 1	☐	☐	☐	☐	☐	☐	☐	☐
2. Team member 2	☐	☐	☐	☐	☐	☐	☐	☐
3. Team member 3	☐	☐	☐	☐	☐	☐	☐	☐
4. Team member 4	☐	☐	☐	☐	☐	☐	☐	☐
5. Team member 5	☐	☐	☐	☐	☐	☐	☐	☐

Survey Completion: 55%

Please consider also the following KNOWLEDGE TRANSFER scenario:



Respond the following 10 questions knowing that ***<1=Strongly Disagree; 2=Disagree; 3=Neutral; 4=Agree; 5=Strongly Agree>:***

DURING THE LAST MONTH...

	1. This person's expertise in design-construction projects overlapped with mine:					*2. This person and I had similar knowledge that helped us communicate easier:*				
	1	2	3	4	5	1	2	3	4	5
1. Team member 1	○	○	○	○	○	○	○	○	○	○
2. Team member 2	○	○	○	○	○	○	○	○	○	○
3. Team member 3	○	○	○	○	○	○	○	○	○	○
4. Team member 4	○	○	○	○	○	○	○	○	○	○
5. Team member 5	○	○	○	○	○	○	○	○	○	○

DURING THE LAST MONTH...

	3. This person articulated his/her knowledge in such a manner that it was easy to understand:					*4. This person made complex knowledge look simple:*				
	1	2	3	4	5	1	2	3	4	5
1. Team member 1	○	○	○	○	○	○	○	○	○	○
2. Team member 2	○	○	○	○	○	○	○	○	○	○
3. Team member 3	○	○	○	○	○	○	○	○	○	○
4. Team member 4	○	○	○	○	○	○	○	○	○	○
5. Team member 5	○	○	○	○	○	○	○	○	○	○

DURING THE LAST MONTH...

	5. This person was able to identify within the team the knowledge that would be most valuable to improve project performance:					*6. This person was able to determine what knowledge within the team was credible and trustworthy:*				
	1	2	3	4	5	1	2	3	4	5
1. Team member 1	○	○	○	○	○	○	○	○	○	○
2. Team member 2	○	○	○	○	○	○	○	○	○	○
3. Team member 3	○	○	○	○	○	○	○	○	○	○
4. Team member 4	○	○	○	○	○	○	○	○	○	○
5. Team member 5	○	○	○	○	○	○	○	○	○	○

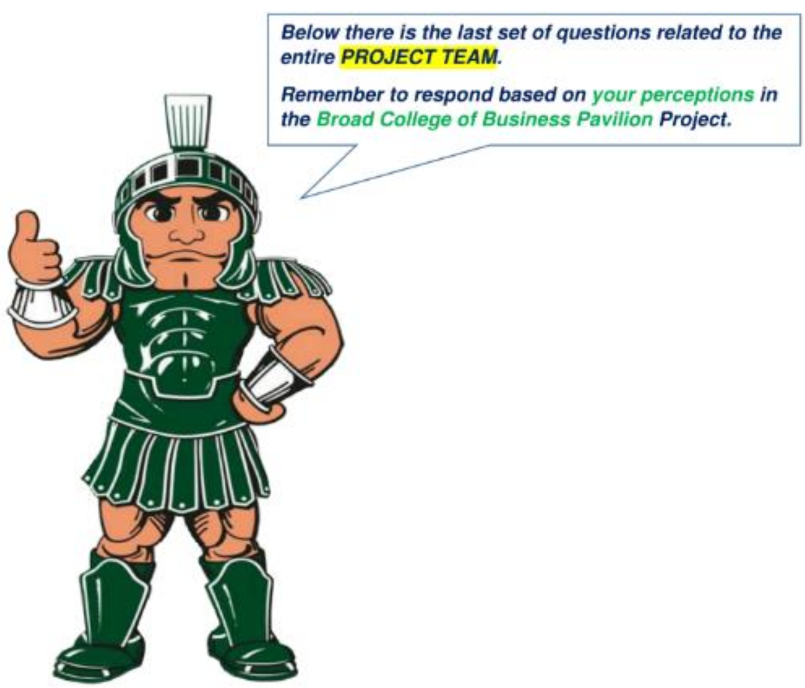
DURING THE LAST MONTH...

	7. This person's expertise in design-construction projects made it easy for him/her to understand the knowledge conveyed to him/her:					*8. This person was able to easily connect to his/her knowledge in design-construction projects the knowledge conveyed to him/her:*				
	1	2	3	4	5	1	2	3	4	5
1. Team member 1	○	○	○	○	○	○	○	○	○	○
2. Team member 2	○	○	○	○	○	○	○	○	○	○
3. Team member 3	○	○	○	○	○	○	○	○	○	○
4. Team member 4	○	○	○	○	○	○	○	○	○	○
5. Team member 5	○	○	○	○	○	○	○	○	○	○

DURING THE LAST MONTH...

	9. This person easily adapted his/her work to make use of the knowledge conveyed to him/her:					*10. This person quickly applied the knowledge conveyed to him/her to his/her work improving project performance:*				
	1	2	3	4	5	1	2	3	4	5
1. Team member 1	○	○	○	○	○	○	○	○	○	○
2. Team member 2	○	○	○	○	○	○	○	○	○	○
3. Team member 3	○	○	○	○	○	○	○	○	○	○
4. Team member 4	○	○	○	○	○	○	○	○	○	○
5. Team member 5	○	○	○	○	○	○	○	○	○	○

Survey Completion: 90%



DURING THE LAST MONTH...

1. People in this project team were able to identify the knowledge that would be most valuable to improve project performance.

Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
○	○	○	○	○

2. Our knowledge in design-construction projects allowed us to determine what knowledge within the team was credible and trustworthy to meet our client's demands.

Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
○	○	○	○	○

3. The shared knowledge within this project team made it easy to understand new knowledge brought up by team members.

Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
○	○	○	○	○

4. It was easy for my team to see the connections between different pieces of knowledge held jointly.

Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
○	○	○	○	○

5. It was easy to adapt our work to make use of the knowledge shared by project team members in this project.

Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
○	○	○	○	○

6 Knowledge shared by team members could be quickly applied to our work improving project performance.

Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
○	○	○	○	○

7. The knowledge that was shared with me from other functional areas (e.g., mechanical, electrical, plumbing, or structural areas) was easy to understand.

Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
○	○	○	○	○

8. The knowledge that was shared with me from other functional areas was easy to use.

Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
○	○	○	○	○

Survey Completion: 100%

Thank you very much for your time and invaluable help! Please click on next to close down the survey.

Previous

Next

APPENDIX C2: Survey#2 for Data Collection

(This survey was completed via email. Consent for was sent attached).

Hi *Team Member X*:

Hope you are doing great. May I ask you a question please?

After drawing a knowledge transfer network involving 150 team members from the **Broad College of Business Pavilion Project**, I have identified a highly cohesive sub-group comprising the 8 members below. The members of this sub-group showed a preference to interact with each other, especially with you, to get valuable knowledge.

1. Team member X – organization
2. Team member X – organization
3. Team member X – organization
4. Team member X – organization
5. Team member X – organization
6. Team member X – organization
7. Team member X – organization
8. Team member X – organization

<u>**During the last month, would you agree that the sub-group above has closely worked together to develop common tasks**</u> (e.g., developing design, cost estimates, or project planning)? - (Yes or Not)

(Let me know if you think there is any very important person missing).

Regarding this sub-group, may I ask you to score in one minute the six statements below with just a number between 1 and 5 at the end of each one?

(1 = Strongly Disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly Agree)

In the **Broad College of Business Pavilion Project,** during the last month...

1. The sub-group was able to identify the most valuable knowledge to improve project performance -
2. The sub-group's knowledge in design-construction projects was helpful to determine what knowledge was valuable -
3. The shared knowledge within the sub-group made it easy to understand new knowledge brought up -
4. It was easy for the sub-group to see the connections between different pieces of knowledge held jointly -
5. It was easy for the sub-group to adapt its work to make use of the knowledge shared by the sub-group members -
6. Knowledge shared by sub-group members could be quickly applied to the sub-group work improving project performance -

Thank you very much, *Team Member X*!

APPENDIX C3: Survey#3 for Data Collection

(This survey was completed via email. Consent for was sent attached),

Hi *Team Member X*:

Hope you are doing great. May I ask you to respond the 3 questions below with just a number between 1 and 5 at the end of each one please? *(1 = Strongly Disagree; 2 = Disagree; 3 = Neutral; 4 = Agree; 5 = Strongly Agree).*

In the **Broad College of Business Pavilion Project**, during the **last month...**

1. Project cost outcomes met targeted goals -
2. Project schedule outcomes met targeted goals -
3. Project quality met targeted goals -

(You may add other performance metrics if you wish).

Thank you very much, *Team Member X*!

APPENDIX D: Complementary Statistical Analysis for Hypothesis 1A: Causality Direction

The statistical analyses below use the following abbreviations:

- IncKappT12: Increment of receiver knowledge application between time points 1 and 2
- KappT(i): Receiver knowledge application at time (i);
- AbsT(i): Receiver absorptive capacity at time (i);
- ArtT(i): Senders' articulating capacities at time (i);
- CkT(i): Receiver-sender common knowledge at time (i).

▪ **Results of multi-linear regression for model in Figure 5-5. This model tests causality direction in Hypothesis 1A using the dependent variable at a previous time point as a control variable:**

```
Dependent variable: KappT2

Residuals:
    Min      1Q  Median      3Q     Max
-268.81  -30.32   11.35   47.44  140.83

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 40.29106   73.61069   0.547   0.5896
AbsT2        0.96500    0.11694   8.252 3.52e-08 ***
KappT1      -0.05998    0.14956  -0.401   0.6923
ArtT2       -0.26866    0.15455  -1.738   0.0961 .
CkT2         0.23264    0.14295   1.627   0.1179
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 82.64 on 22 degrees of freedom
Multiple R-squared:  0.8004,      Adjusted R-squared:  0.7641
F-statistic: 22.05 on 4 and 22 DF,  p-value: 1.966e-07

> confint(model1A, level=0.95)
                    2.5 %       97.5 %
(Intercept) -112.36817289 192.95029743
AbsT2          0.72247081   1.20752222
KappT1        -0.37015829   0.25019330
ArtT2         -0.58916953   0.05185949
CkT2          -0.06382188   0.52910027
```

- **Results of multi-linear regression for model in Figure 5-6. This model tests causality direction in Hypothesis 1A using increments of the dependent variable:**
  - ***Including all independent variables of the model in Figure 5-6:***

```
Dependent variable: IncKappT12

Residuals:
     Min       1Q   Median       3Q      Max
-2.29721 -0.30307  0.03101  0.62540  1.41740

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -5.0846     4.7608  -1.068    0.296
AbsT1         0.5855     0.5145   1.138    0.266
ArtT1         0.2858     0.8420   0.339    0.737
CkT1          0.3616     0.2877   1.257    0.220

Residual standard error: 0.828 on 25 degrees of freedom
Multiple R-squared:  0.1522,    Adjusted R-squared:  0.05048
F-statistic: 1.496 on 3 and 25 DF,  p-value: 0.2398
```

  - ***Including only Receiver Absorptive Capacity as an independent variable of the model in Figure 5-6:***

```
Dependent variable: IncKappT12

Residuals:
     Min       1Q   Median       3Q      Max
-2.21916 -0.45916 -0.06025  0.68527  1.51006

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -3.2690     2.0075  -1.628   0.1150
AbsT1         0.7964     0.4634   1.719   0.0971 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.8216 on 27 degrees of freedom
Multiple R-squared:  0.09862,   Adjusted R-squared:  0.06524
F-statistic: 2.954 on 1 and 27 DF,  p-value: 0.0971


Shapiro-Wilk normality test

data:  residuals(model1A)
W = 0.96382, p-value = 0.4065
```

○ ***Including only Receiver-Senders Common Knowledge as an independent variable of the model in Figure 5-6:***

```
Dependent variable: IncKappT12

Residuals:
    Min      1Q  Median      3Q     Max 
-2.2440 -0.3957  0.0972  0.4295  1.5459 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)  
(Intercept)  -1.7152     1.0570  -1.623   0.1163  
CkT1          0.4567     0.2532   1.804   0.0825 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.8175 on 27 degrees of freedom
Multiple R-squared:  0.1075,	Adjusted R-squared:  0.07446 
F-statistic: 3.253 on 1 and 27 DF,  p-value: 0.08247


Shapiro-Wilk normality test

data:  residuals(model1A)
W = 0.96539, p-value = 0.4425
```

APPENDIX E: Complementary Statistical Analysis for Hypothesis 1A: Selection of Independent Variables and Multi-Collinearity

Below there are the statistical analyses via multi-linear regression to test selection of independent variables of the model in Figure 5-5, and multi-collinearity following the steps in Figure 5-8. The abbreviations used have the following meaning:

- KappT(i): Receiver knowledge application at time (i);
- AbsT(i): Receiver absorptive capacity at time (i);
- ArtT(i): Senders' articulating capacities at time (i);
- CkT(i): Receiver-sender common knowledge at time (i).

- **Selection of independent variables (Figure 5-5): Multi-linear regression for model including *Receiver Absorptive Capacity (time 2)* as the independent variable, and *Receiver Knowledge Application (time 2)* as the dependent variable:**

```
Dependent variable: KappT2

Residuals:
    Min      1Q  Median      3Q     Max
-287.34  -39.32   11.84   42.75  128.13

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -6.8440    43.8816  -0.156    0.877
AbsT2         0.9895     0.1101   8.987 2.65e-09 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 84.36 on 25 degrees of freedom
Multiple R-squared:  0.7636,   Adjusted R-squared:  0.7542
F-statistic: 80.76 on 1 and 25 DF,  p-value: 2.645e-09
```

- **Selection of independent variables: Multi-linear regression for model including *Receiver Absorptive Capacity (time 2)* and *Receiver Knowledge Application (time 1)* as independent variables, and *Receiver Knowledge Application (time 2)* as the dependent variable:**

```
Dependent variable: KappT2

Residuals:
     Min       1Q   Median       3Q      Max
-293.923  -34.717    7.075   44.351  129.990

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) -21.28936   57.78664  -0.368    0.716
AbsT2         0.97320    0.11941   8.150 2.27e-08 ***
KappT1        0.05091    0.12930   0.394    0.697
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 85.83 on 24 degrees of freedom
Multiple R-squared:  0.7651,   Adjusted R-squared:  0.7456
F-statistic: 39.09 on 2 and 24 DF,  p-value: 2.817e-08
```

- **Selection of independent variables: Multi-linear regression for model including *Receiver Absorptive Capacity (time 2), Receiver Knowledge Application (time 1), and Senders' Articulating Capacities (time 2)* as independent variables, and *Receiver Knowledge Application (time 2)* as the dependent variable:**

```
Dependent variable: KappT2

Residuals:
     Min       1Q   Median       3Q      Max
-293.370  -36.343    6.305   47.841  118.391

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 31.99504   76.02003   0.421    0.678
AbsT2        0.95138    0.12075   7.879 5.57e-08 ***
KappT1       0.07148    0.13031   0.549    0.589
ArtT2       -0.15238    0.14187  -1.074    0.294
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 85.55 on 23 degrees of freedom
Multiple R-squared:  0.7764,   Adjusted R-squared:  0.7472
F-statistic: 26.61 on 3 and 23 DF,  p-value: 1.165e-07
```

- **Selection of independent variables: Multi-linear regression for model including *Receiver Absorptive Capacity (time 2), Receiver Knowledge Application (time 1), Senders' Articulating Capacities (time 2), and Receiver-Senders Common Knowledge* as independent variables, and *Receiver Knowledge Application (time 2)* as the dependent variable:**

```
Dependent variable: KappT2

Residuals:
    Min      1Q  Median      3Q     Max
-268.81  -30.32   11.35   47.44  140.83

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 40.29106   73.61069   0.547   0.5896
AbsT2        0.96500    0.11694   8.252 3.52e-08 ***
KappT1      -0.05998    0.14956  -0.401   0.6923
ArtT2       -0.26866    0.15455  -1.738   0.0961 .
CkT2         0.23264    0.14295   1.627   0.1179
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 82.64 on 22 degrees of freedom
Multiple R-squared:  0.8004,   Adjusted R-squared:  0.7641
F-statistic: 22.05 on 4 and 22 DF,  p-value: 1.966e-07
```

- **Multi-collinearity (Figure5-8): Multi-linear regression for Model (A) in Figure 5-8:**

```
Dependent variable: KappT2

Residuals:
    Min      1Q  Median      3Q     Max
-262.00  -41.65  -12.82   54.71  243.94

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 77.17893   94.99494   0.812    0.423
AbsT1        0.77527    0.12995   5.966 1.53e-06 ***
ArtT1       -0.04707    0.21801  -0.216    0.831
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 97.62 on 30 degrees of freedom
Multiple R-squared:  0.5535,   Adjusted R-squared:  0.5237
F-statistic: 18.59 on 2 and 30 DF,  p-value: 5.593e-06

        Shapiro-Wilk normality test

data:  residuals(model1A1)
W = 0.97264, p-value = 0.5563
```

- **Multi-collinearity (Figure5-8): Multi-linear regression for Model (B) in Figure 5-8:**

```
Dependent variable: KappT2

Residuals:
    Min      1Q  Median      3Q     Max 
-250.70  -94.04   19.63   81.91  333.14 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)  
(Intercept) 241.2562   133.1550   1.812   0.0800 .
CkT1          0.3587     0.1766   2.031   0.0512 .
ArtT1        -0.1129     0.3078  -0.367   0.7162  
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 135.3 on 30 degrees of freedom
Multiple R-squared:  0.1418,	Adjusted R-squared:  0.08459 
F-statistic: 2.478 on 2 and 30 DF,  p-value: 0.1009

        Shapiro-Wilk normality test

data:  residuals(model1A1)
W = 0.96483, p-value = 0.3518
```

- **Multi-collinearity (Figure5-8): Multi-linear regression for Model (C) in Figure 5-8:**

```
Dependent variable: KappT2

Residuals:
     Min       1Q   Median       3Q      Max 
-258.072  -50.557    8.894   68.073  170.973 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) 189.6872    90.9221   2.086   0.0450 *  
AbsT2         0.7590     0.1395   5.439 5.54e-06 ***
ArtT2        -0.3551     0.1620  -2.193   0.0357 *  
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 98.66 on 32 degrees of freedom
Multiple R-squared:  0.6704,	Adjusted R-squared:  0.6498 
F-statistic: 32.54 on 2 and 32 DF,  p-value: 1.941e-08

        Shapiro-Wilk normality test

data:  residuals(model1A2)
W = 0.96113, p-value = 0.2472
```

- **Multi-collinearity (Figure5-8): Multi-linear regression for Model (D) in Figure 5-8:**

```
Dependent variable: KappT2Residuals:
    Min      1Q  Median      3Q     Max 
-258.05  -73.31    6.38  111.46  198.02 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) 502.8151    77.9998   6.446 3.00e-07 ***
CkT2          0.3321     0.1464   2.269   0.0302 *  
ArtT2        -0.8815     0.1792  -4.918 2.52e-05 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 127 on 32 degrees of freedom
Multiple R-squared:  0.4536,	Adjusted R-squared:  0.4194 
F-statistic: 13.28 on 2 and 32 DF,  p-value: 6.315e-05

        Shapiro-Wilk normality test

data:  residuals(model1A2)
W = 0.94671, p-value = 0.08978
```

APPENDIX F: Complementary Statistical Analysis for Hypothesis 1A: Confirmatory Factor Analysis of Measurements at Time Point 2

This appendix includes results of Confirmatory Factors Analysis for two models. First, for the model in Figure 5-9. And second, for the model in Figure 5-9 but with one modification: The first indicator for *Ability to Understand* under *Receiver Absorptive Capacity* is also added as an indicator under *Receiver-Senders Common Knowledge*. This modification in the second model aims to examine potential artefactual errors. The meaning of the abbreviations utilized is the following:

- KappT(i): Receiver knowledge application at time (i);
- KappT(i)(j): Survey item number (j) to measure receiver knowledge application at time (i);
- AbsT(i): Receiver absorptive capacity at time (i);
- IdT(i): Receiver ability to identify valuable knowledge at time (i);
- IdT(i)(j): Survey item number (j) to measure receiver ability to identify valuable knowledge at time (i);
- UndT(i): Receiver ability to understand valuable knowledge at time (i);
- UndT(i)(j): Survey item number (j) to measure receiver ability to understand valuable knowledge at time (i);
- ArtT(i): Senders' articulating capacities at time (i);
- ArtT(i)(j): Survey item number (j) to measure senders' articulating capacities at time (i);
- CkT(i): Receiver-senders common knowledge at time (i).
- CkT(i)(j): Survey item number (j) to measure receiver-senders common knowledge at time (i).

- **Confirmatory Factor Analysis (CFA) of model in Figure 5-9:**

```
lavaan (0.5-23.1097) converged normally after  88 iterations

  Number of observations                            79

  Number of missing patterns                         4

  Estimator                                         ML      Robust
  Minimum Function Test Statistic               56.277      51.463
  Degrees of freedom                                29          29
  P-value (Chi-square)                           0.002       0.006
  Scaling correction factor                                  1.094
    for the Yuan-Bentler correction

Model test baseline model:

  Minimum Function Test Statistic              665.721     474.921
  Degrees of freedom                                45          45
  P-value                                        0.000       0.000

User model versus baseline model:

  Comparative Fit Index (CFI)                    0.956       0.948
  Tucker-Lewis Index (TLI)                       0.932       0.919

  Robust Comparative Fit Index (CFI)                         0.959
  Robust Tucker-Lewis Index (TLI)                            0.937

Loglikelihood and Information Criteria:

  Loglikelihood user model (H0)               -418.761    -418.761
  Scaling correction factor                                  2.111
    for the MLR correction
  Loglikelihood unrestricted model (H1)       -390.622    -390.622
  Scaling correction factor                                  1.657
    for the MLR correction

  Number of free parameters                         36          36
  Akaike (AIC)                                 909.521     909.521
  Bayesian (BIC)                               994.821     994.821
  Sample-size adjusted Bayesian (BIC)          881.311     881.311

Root Mean Square Error of Approximation:

  RMSEA                                          0.109       0.099
  90 Percent Confidence Interval          0.065  0.151       0.055  0.141
  P-value RMSEA <= 0.05                          0.017       0.037

  Robust RMSEA                                               0.104
  90 Percent Confidence Interval                             0.055  0.149

Standardized Root Mean Square Residual:

  SRMR                                           0.065       0.065

Parameter Estimates:
```

```
  Information                                      Observed
  Standard Errors                        Robust.huber.white

Latent Variables:
                   Estimate  Std.Err  z-value  P(>|z|)
  KappT2 =~
    KappT21           1.000
    KappT22           0.652    0.165    3.942    0.000
  IdT2 =~
    IdT21             1.000
    IdT22             1.217    0.124    9.853    0.000
  UndT2 =~
    UndT21            1.000
    UndT22            0.932    0.044   21.021    0.000
  AbsT2 =~
    IdT2              1.000
    UndT2             1.279    0.156    8.185    0.000
  ArtT2 =~
    ArtT21            1.000
    ArtT22            1.087    0.182    5.959    0.000
  CkT2 =~
    CkT21             1.000
    CkT22             0.854    0.128    6.692    0.000

Covariances:
                   Estimate  Std.Err  z-value  P(>|z|)
  KappT2 ~~
    AbsT2             0.443    0.170    2.609    0.009
    ArtT2            -0.053    0.048   -1.094    0.274
    CkT2              0.183    0.141    1.299    0.194
  AbsT2 ~~
    ArtT2            -0.019    0.043   -0.442    0.658
    CkT2              0.199    0.115    1.728    0.084
  ArtT2 ~~
    CkT2              0.276    0.173    1.601    0.109

Intercepts:
                   Estimate  Std.Err  z-value  P(>|z|)
   .KappT21           4.120    0.107   38.636    0.000
   .KappT22           4.180    0.087   47.958    0.000
   .IdT21             4.076    0.107   38.081    0.000
   .IdT22             4.093    0.108   38.049    0.000
   .UndT21            4.202    0.116   36.375    0.000
   .UndT22            4.233    0.111   38.239    0.000
   .ArtT21            4.291    0.113   38.111    0.000
   .ArtT22            4.077    0.110   37.157    0.000
   .CkT21             3.970    0.110   36.051    0.000
   .CkT22             4.061    0.102   39.783    0.000
    KappT2            0.000
    IdT2              0.000
    UndT2             0.000
    AbsT2             0.000
    ArtT2             0.000
    CkT2              0.000

Variances:
```

	Estimate	Std.Err	z-value	P(>|z|)
.KappT21	0.000			
.IdT22	0.000			
.KappT22	0.166	0.062	2.693	0.007
.IdT21	0.193	0.065	2.959	0.003
.UndT21	0.017	0.019	0.888	0.375
.UndT22	0.042	0.023	1.858	0.063
.ArtT21	0.032	0.047	0.672	0.502
.ArtT22	0.024	0.065	0.373	0.709
.CkT21	0.130	0.143	0.910	0.363
.CkT22	0.219	0.084	2.619	0.009
KappT2	0.642	0.173	3.708	0.000
IdT2	0.124	0.040	3.118	0.002
UndT2	0.211	0.071	2.960	0.003
AbsT2	0.303	0.162	1.867	0.062
ArtT2	0.320	0.241	1.327	0.184
CkT2	0.828	0.225	3.678	0.000

	lhs	op	rhs	est	se	z	pvalue	ci.lower	ci.upper	std.lv
1	KappT2	=~	KappT21	1.000	0.000	NA	NA	1.000	1.000	0.801
2	KappT2	=~	KappT22	0.652	0.165	3.942	0.000	0.328	0.976	0.523
3	IdT2	=~	IdT21	1.000	0.000	NA	NA	1.000	1.000	0.654
4	IdT2	=~	IdT22	1.217	0.124	9.853	0.000	0.975	1.459	0.796
5	UndT2	=~	UndT21	1.000	0.000	NA	NA	1.000	1.000	0.841
6	UndT2	=~	UndT22	0.932	0.044	21.021	0.000	0.845	1.019	0.784
7	AbsT2	=~	IdT2	1.000	0.000	NA	NA	1.000	1.000	0.842
8	AbsT2	=~	UndT2	1.279	0.156	8.185	0.000	0.973	1.585	0.838
9	ArtT2	=~	ArtT21	1.000	0.000	NA	NA	1.000	1.000	0.565
10	ArtT2	=~	ArtT22	1.087	0.182	5.959	0.000	0.729	1.444	0.614
11	CkT2	=~	CkT21	1.000	0.000	NA	NA	1.000	1.000	0.910
12	CkT2	=~	CkT22	0.854	0.128	6.692	0.000	0.604	1.104	0.777
13	KappT21	~~	KappT21	0.000	0.000	NA	NA	0.000	0.000	0.000
14	IdT22	~~	IdT22	0.000	0.000	NA	NA	0.000	0.000	0.000
15	KappT22	~~	KappT22	0.166	0.062	2.693	0.007	0.045	0.287	0.166
16	IdT21	~~	IdT21	0.193	0.065	2.959	0.003	0.065	0.320	0.193
17	UndT21	~~	UndT21	0.017	0.019	0.888	0.375	-0.020	0.054	0.017
18	UndT22	~~	UndT22	0.042	0.023	1.858	0.063	-0.002	0.087	0.042
19	ArtT21	~~	ArtT21	0.032	0.047	0.672	0.502	-0.061	0.125	0.032
20	ArtT22	~~	ArtT22	0.024	0.065	0.373	0.709	-0.103	0.151	0.024
21	CkT21	~~	CkT21	0.130	0.143	0.910	0.363	-0.150	0.411	0.130
22	CkT22	~~	CkT22	0.219	0.084	2.619	0.009	0.055	0.383	0.219
23	KappT2	~~	KappT2	0.642	0.173	3.708	0.000	0.303	0.981	1.000
24	IdT2	~~	IdT2	0.124	0.040	3.118	0.002	0.046	0.202	0.291
25	UndT2	~~	UndT2	0.211	0.071	2.960	0.003	0.071	0.351	0.299
26	AbsT2	~~	AbsT2	0.303	0.162	1.867	0.062	-0.015	0.621	1.000
27	ArtT2	~~	ArtT2	0.320	0.241	1.327	0.184	-0.152	0.791	1.000
28	CkT2	~~	CkT2	0.828	0.225	3.678	0.000	0.387	1.269	1.000
29	KappT2	~~	AbsT2	0.443	0.170	2.609	0.009	0.110	0.777	1.006
30	KappT2	~~	ArtT2	-0.053	0.048	-1.094	0.274	-0.147	0.042	-0.116
31	KappT2	~~	CkT2	0.183	0.141	1.299	0.194	-0.093	0.460	0.252
32	AbsT2	~~	ArtT2	-0.019	0.043	-0.442	0.658	-0.102	0.065	-0.061
33	AbsT2	~~	CkT2	0.199	0.115	1.728	0.084	-0.027	0.425	0.398
34	ArtT2	~~	CkT2	0.276	0.173	1.601	0.109	-0.062	0.615	0.537
35	KappT21	~1		4.120	0.107	38.636	0.000	3.911	4.329	4.120
36	KappT22	~1		4.180	0.087	47.958	0.000	4.009	4.351	4.180
37	IdT21	~1		4.076	0.107	38.081	0.000	3.866	4.285	4.076

```
38   IdT22 ~1          4.093 0.108 38.049  0.000    3.882    4.304  4.093
39  UndT21 ~1          4.202 0.116 36.375  0.000    3.976    4.428  4.202
40  UndT22 ~1          4.233 0.111 38.239  0.000    4.016    4.450  4.233
41  ArtT21 ~1          4.291 0.113 38.111  0.000    4.070    4.511  4.291
42  ArtT22 ~1          4.077 0.110 37.157  0.000    3.862    4.292  4.077
43   CkT21 ~1          3.970 0.110 36.051  0.000    3.755    4.186  3.970
44   CkT22 ~1          4.061 0.102 39.783  0.000    3.861    4.261  4.061
45  KappT2 ~1          0.000 0.000     NA     NA    0.000    0.000  0.000
46    IdT2 ~1          0.000 0.000     NA     NA    0.000    0.000  0.000
47   UndT2 ~1          0.000 0.000     NA     NA    0.000    0.000  0.000
48   AbsT2 ~1          0.000 0.000     NA     NA    0.000    0.000  0.000
49   ArtT2 ~1          0.000 0.000     NA     NA    0.000    0.000  0.000
50    CkT2 ~1          0.000 0.000     NA     NA    0.000    0.000  0.000
   std.all std.nox
1    1.000   1.000
2    0.788   0.788
3    0.830   0.830
4    1.000   1.000
5    0.988   0.988
6    0.967   0.967
7    0.842   0.842
8    0.838   0.838
9    0.954   0.954
10   0.969   0.969
11   0.930   0.930
12   0.857   0.857
13   0.000   0.000
14   0.000   0.000
15   0.379   0.379
16   0.311   0.311
17   0.023   0.023
18   0.065   0.065
19   0.091   0.091
20   0.060   0.060
21   0.136   0.136
22   0.266   0.266
23   1.000   1.000
24   0.291   0.291
25   0.299   0.299
26   1.000   1.000
27   1.000   1.000
28   1.000   1.000
29   1.006   1.006
30  -0.116  -0.116
31   0.252   0.252
32  -0.061  -0.061
33   0.398   0.398
34   0.537   0.537
35   5.141   5.141
36   6.306   6.306
37   5.177   5.177
38   5.144   5.144
39   4.940   4.940
40   5.224   5.224
41   7.238   7.238
42   6.434   6.434
43   4.056   4.056
```

```
44   4.476   4.476
45   0.000   0.000
46   0.000   0.000
47   0.000   0.000
48   0.000   0.000
49   0.000   0.000
50   0.000   0.000
```

- **Confirmatory Factor Analysis for the model in Figure 5-9 but with one modification: The first indicator for *Ability to Understand* under *Receiver Absorptive Capacity* is also added as an indicator under *Receiver-Senders Common Knowledge:***

```
lavaan (0.5-23.1097) converged normally after  96 iterations

  Number of observations                            79

  Number of missing patterns                         4

  Estimator                                         ML      Robust
  Minimum Function Test Statistic               56.165      51.149
  Degrees of freedom                                28          28
  P-value (Chi-square)                           0.001       0.005
  Scaling correction factor                                  1.098
    for the Yuan-Bentler correction

Model test baseline model:

  Minimum Function Test Statistic              665.721     474.921
  Degrees of freedom                                45          45
  P-value                                        0.000       0.000

User model versus baseline model:

  Comparative Fit Index (CFI)                    0.955       0.946
  Tucker-Lewis Index (TLI)                       0.927       0.913

  Robust Comparative Fit Index (CFI)                         0.958
  Robust Tucker-Lewis Index (TLI)                            0.932

Loglikelihood and Information Criteria:

  Loglikelihood user model (H0)               -418.705    -418.705
  Scaling correction factor                                  2.080
    for the MLR correction
  Loglikelihood unrestricted model (H1)       -390.622    -390.622
  Scaling correction factor                                  1.657
    for the MLR correction

  Number of free parameters                         37          37
  Akaike (AIC)                                 911.409     911.409
  Bayesian (BIC)                               999.079     999.079
  Sample-size adjusted Bayesian (BIC)          882.416     882.416

Root Mean Square Error of Approximation:
```

```
  RMSEA                                          0.113       0.102
  90 Percent Confidence Interval          0.069  0.156       0.058  0.144
  P-value RMSEA <= 0.05                          0.013       0.029

  Robust RMSEA                                               0.107
  90 Percent Confidence Interval                             0.059  0.153

Standardized Root Mean Square Residual:

  SRMR                                           0.065       0.065

Parameter Estimates:

  Information                                 Observed
  Standard Errors                   Robust.huber.white

Latent Variables:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
  KappT2 =~
    KappT21           1.000                               0.802    1.000
    KappT22           0.652    0.165    3.942    0.000    0.523    0.789
  IdT2 =~
    IdT21             1.000                               0.654    0.830
    IdT22             1.217    0.124    9.853    0.000    0.796    1.000
  UndT2 =~
    UndT21            1.000                               0.836    0.982
    UndT22            0.937    0.049   19.317    0.000    0.784    0.967
  AbsT2 =~
    IdT2              1.000                               0.843    0.843
    UndT2             1.270    0.161    7.892    0.000    0.837    0.837
  ArtT2 =~
    ArtT21            1.000                               0.563    0.952
    ArtT22            1.090    0.189    5.765    0.000    0.613    0.971
  CkT2 =~
    CkT21             1.000                               0.922    0.942
    CkT22             0.831    0.178    4.674    0.000    0.767    0.845
    UndT21            0.017    0.052    0.333    0.739    0.016    0.019
```

APPENDIX G: Coding in RStudio For Statistical Analyses

Below are compiled the codes used in RStudion to develop the statistical analyses of this study. The abbreviations utilized refer to the following:

- KappT(i): Receiver knowledge application at time (i);
- KappT(i)(j): Survey item number (j) to measure receiver knowledge application at time (i);
- AbsT(i): Receiver absorptive capacity at time (i);
- IdT(i): Receiver ability to identify valuable knowledge at time (i);
- IdT(i)(j): Survey item number (j) to measure receiver ability to identify valuable knowledge at time (i);
- UndT(i): Receiver ability to understand valuable knowledge at time (i);
- UndT(i)(j): Survey item number (j) to measure receiver ability to understand valuable knowledge at time (i);
- ArtT(i): Senders' articulating capacities at time (i);
- ArtT(i)(j): Survey item number (j) to measure senders' articulating capacities at time (i);
- CkT(i): Receiver-senders common knowledge at time (i).
- CkT(i)(j): Survey item number (j) to measure receiver-senders common knowledge at time (i).

- **Setting Up a Work Directory and Downloading Packages for Statistical Analyses**

```
setwd("C:/Users/Angelo/Desktop/PhD Data")
install.packages("lavaan")
library(lavaan)
install.packages("CRAN")
install.packages("MASS")
update.packages("MASS")
library("MASS")
require(MASS)
install.packages("car")
library(car)
install.packages("psych")
library(psych)
install.packages("psy")
library(psy)
```

- **Importing Coded Data**

```
ColNames = c("KappT11", "KappT12", "IdT11", "IdT12", "UndT11", "UndT12", "CkT11",
        "CkT12", "ArtT11", "ArtT12", "KappT21", "KappT22", "IdT21", "IdT22",
        "UndT21", "UndT22", "CkT21", "CkT22", "ArtT21", "ArtT22")
# read data
data1A = read.csv(file = "1A.MLRlong.IncrKapp.csv", header = T, na.strings = ".")
data1A = read.csv(file = "1A.MLRlong.IncrKapp-modified.csv", header = T, na.strings = ".")
data1A = read.csv(file = "1A.MLRlong.ControlKapp.csv", header = T, na.strings = ".")
data1A = read.csv(file = "1A.MLRlong.ControlKapp^4.csv", header = T, na.strings = ".")
data1A = read.csv(file = "1A.MLRlong.ControlKapp-normal.csv", header = T, na.strings = ".")
data1A = read.csv(file = "1A.MLRlong.ControlKapp-normal^2.csv", header = T, na.strings =
".")
data1A = read.csv(file = "1A.MLRlong.ControlKapp-normal^4.csv", header = T, na.strings =
".")
data1A1 = read.csv(file = "1A.Model.SEM.t1.csv", header = T, na.strings = ".")
```

```
data1A1 = read.csv(file = "1A.Model.MLR.t1.csv", header = T, na.strings = ".")
data1A1 = read.csv(file = "1A.Model.MLRN.t1.csv", header = T, na.strings = ".")
data1A1 = read.csv(file = "1A.Model.MLRN^4.t1.csv", header = T, na.strings = ".")
data1A1 = read.csv(file = "1A.Model.SEM.t1.Nomissing.csv", header = T, na.strings = ".")
data1A1 = read.csv(file = "1A.DataTime1.LVcorrelations.csv", header = T, na.strings = ".")
data1A2 = read.csv(file = "1A.Model.MLR.t2^4.csv", header = T, na.strings = ".")
data1A2 = read.csv(file = "1A.Model.MLR.t2^4.all.csv", header = T, na.strings = ".")
data1A2 = read.csv(file = "1A.Model.MLR.t2^4trial.csv", header = T, na.strings = ".")
data1A2 = read.csv(file = "1A.Model.MLR.t2.csv", header = T, na.strings = ".")
data1A2 = read.csv(file = "1A.Model.MLR.t2.item2^4.csv", header = T, na.strings = ".")
data1A2 = read.csv(file = "1A.CFA.Time2.all.csv", header = T, na.strings = ".")
data1A12 = read.csv(file = "1A.CorrelationsT1-T2.csv", header = T, na.strings = ".")
data1B = read.csv(file = "1B.Model.csv", header = T, na.strings = ".")
data1CAbs = read.csv(file = "1C.Model.Abs.csv", header = T, na.strings = ".")
data1Cck = read.csv(file = "1C.Model.ck.csv", header = T, na.strings = ".")
data1Art = read.csv(file = "1C.Model.Art.csv", header = T, na.strings = ".")
data2A1 = read.csv(file = "2A.Model.AbsAbs.csv", header = T, na.strings = ".")
data2A2 = read.csv(file = "2A.Model.AbsKapp.csv", header = T, na.strings = ".")
data2A = read.csv(file = "DistancesT1.csv", header = T, na.strings = ".")
data2A = read.csv(file = "DistancesT2.csv", header = T, na.strings = ".")
head(data1A)
cor(data1A1$ArtT21, data1A1$ArtT22)
hist(data2A$DistancesT1)
hist(data2A$DistancesT2)
cor(data1A12)
summary(data1A1)
# get the 1st 6 rows of data
head(data1A2)
tail(data1B)
```

- **Structural Equation Modeling (SEM) of Hypothesis 1A at Time Points 1 and 2**

```
# Model Definition
Model1A1 <- '
KappT1 =~ KappT11 + KappT12
IdT1 =~ IdT11 + IdT12
UndT1 =~ UndT11 + UndT12
AbsT1 =~ IdT1 + UndT1
CkT1 =~ CkT11 + CkT12
ArtT1 =~ ArtT11 + ArtT12
# Structural equations
KappT1 ~ AbsT1 + CkT1 + ArtT1
# Set Variances to zero
KappT1 ~~ 0*KappT1
# model covariances
UndT11 ~~ ArtT12
UndT1 ~~ CkT1'
# Model Fit
fitT1 <- sem(Model1A1, data=data1A1, missing = "fiml", estimator = "MLR")
summary(fitT1, fit.measures = T, standardized = TRUE)
vif(fitT1)
modindices(fitT1)
parameterEstimates(fitT1, ci = TRUE, level = 0.95, standardized = TRUE)
standardizedSolution(fitT1, ci = TRUE, level = 0.95)
# create dataframe with items and compute alpha
alpha(data.frame(data1A1), check.keys=TRUE)

# Model Definition
Model1A2 <- '
KappT2 =~ KappT21 + KappT22
IdT2 =~ IdT21 + IdT22
UndT2 =~ UndT21 + UndT22
```

```
AbsT2 =~ IdT2 + UndT2
CkT2 =~ CkT21 + CkT22
ArtT2 =~ ArtT21 + ArtT22
# Structural equations
KappT2 ~ AbsT2 + CkT2 + ArtT2
KappT21 ~~ 0*KappT21
IdT22 ~~ 0*IdT22
KappT2 ~~ 0*KappT2'
# Model Fit
fitT2 <- sem(Model1A2, data=data1A2, missing = "fiml", estimator = "MLR")
summary(fitT2, fit.measures = T, standardized = TRUE)
modindices(fitT2)
parameterEstimates(fitT2, standardized = TRUE, ci = TRUE, level = 0.95)
summary(data1A1)
hist(data1A1$KappT11)
hist(data1A1$KappT12)
skewness(data1A1$IdT12)
```

- **Multi-Linear Regression of Hypothesis 1A at Time Point 2**

```
# Data Transformation
Trdata1A2 = (data1A2)
hist(Trdata1A2$KappT2)
hist(Trdata1A2$AbsT2)
hist(Trdata1A2$CkT2)
hist(Trdata1A2$ArtT2)
shapiro.test(Trdata1A2$KappT2)
shapiro.test(Trdata1A2$AbsT2)
shapiro.test(Trdata1A2$ArtT2)
shapiro.test(Trdata1A2$CkT2)
head (Trdata1A2)
head (data1A2)
```

```
# Multilinear regression
model1A2 <- lm(KappT2 ~ AbsT2 + CkT2 + ArtT2, data = Trdata1A2)
model1A2 <- rlm(KappT2 ~ AbsT2 + CkT2 + ArtT2, data = data1A2)
summary(model1A2)
predict(model1A2,interval="confidence", standardized=TRUE)
confint(model1A2, level=0.95)
library(car)
vif(model1A2)
shapiro.test(residuals(model1A2))
hist(data1A2$KappT2)
hist(data1A2$AbsT2)
hist(data1A2$CkT2)
hist(data1A2$ArtT2)
shapiro.test(data1A2$KappT2)
shapiro.test(data1A2$AbsT2)
shapiro.test(data1A2$ArtT2)
shapiro.test(data1A2$CkT2)
summary(data1A2)
```

- **Simple Linear Regression of Hypothesis 1B**

```
model1B <- lm(Ktransfer ~ Kapp, data = data1B)
summary(model1B)
hist(data1B$Ktransfer)
hist(data1B$Kapp)
shapiro.test(data1B$Kapp)
shapiro.test(data1B$Ktransfer)
summary(data1B)
```

- **Simple Linear Regression of Hypothesis 1C**

```
# Linear Regression – Increment of Absorptive Capacity
model1CAbs <- lm(IncAbs ~ Kapp, data = data1CAbs)
```

```
summary(model1CAbs)
hist(data1CAbs$IncAbs)
hist(data1CAbs$Kapp)
summary(data1CAbs)
shapiro.test(residuals(model1CAbs))
shapiro.test(data1CAbs$IncAbs)
shapiro.test(data1CAbs$Kapp)
summary(data1CAbs)

# Linear regression 1C2 – Increment of Articulating Capacity
model1CArt <- lm(IncArt ~ Kapp, data = data1Art)
summary(model1CArt)
hist(data1CArt$IncArt)
hist(data1CArt$Kapp)
summary(data1CArt)
shapiro.test(residuals(model1CArt))
shapiro.test(data1CArt$IncArt)
shapiro.test(data1CArt$Kapp)
summary(data1CArt)

# Linear regression 1C3 – Increment of Common Knowledge
model1Cck <- lm(Incck ~ Kapp, data = data1Cck)
summary(model1Cck)
hist(data1CArt$Incck)
hist(data1CArt$Kapp)
summary(data1Cck)
shapiro.test(residuals(model1Cck))
shapiro.test(data1Cck$Incck)
shapiro.test(data1Cck$Kapp)
summary(data1Cck)
```

- **Simple Linear Regression of Hypothesis 2A**

```
# Linear regression
model2A1 <- lm(StAbs ~ InAbs, data = data2A1)
model2A1 <- rlm(StAbs ~ InAbs, data = data2A1)
summary(model2A1)
shapiro.test(data2A1$StAbs)
shapiro.test(data2A1$InAbs)
summary(data2A1)
```

- **Simple Linear Regression of Hypothesis 2B**

```
# Linear regression
model2A2 <- lm(StKapp ~ StAbs, data = data2A2)
model2A2 <- rlm(StKapp ~ StAbs, data = data2A2)
summary(model2A2)
shapiro.test(data2A2$StAbs)
shapiro.test(data2A2$StKapp)
summary(data2A2)
```

- **Multi-Linear Regression Model with Longitudinal Data – Controlling for *Receiver Knowledge Application* at Time 1**

```
model1A <- lm(KappT2 ~ AbsT2, data = data1A)
model1A <- lm(KappT2 ~ AbsT2 + KappT1, data = data1A)
model1A <- lm(KappT2 ~ CkT2 + KappT1, data = data1A)
model1A <- lm(KappT2 ~ AbsT2 + KappT1 + ArtT2, data = data1A)
model1A <- lm(KappT2 ~ AbsT2 + KappT1 + ArtT2 + CkT2, data = data1A)
model1A <- lm(KappT2 ~ AbsT2 + ArtT2 + CkT2, data = data1A)
summary(model1A)
confint(model1A, level=0.95)
shapiro.test(residuals(model1A))
shapiro.test(data1A$KappT2)
```

```
hist(residuals(model1A))
hist(data1A$KappT2)
qqnorm(residuals(model1A))
plot(model1A)
```

- **Multi-Linear Regression Model with Longitudinal Data – Using Increment of *Receiver Knowledge Application* between Time 1 and 2**

```
model1A <- lm(IncrKappT12 ~ AbsT1, data = data1A)
model1A <- lm(IncrKappT12 ~ CkT1, data = data1A)
model1A <- lm(IncrKappT12 ~ AbsT1 + ArtT1, data = data1A)
model1A <- lm(IncrKappT12 ~ AbsT1 + CkT1, data = data1A)
model1A <- lm(IncrKappT12 ~ ArtT1 + CkT1, data = data1A)
model1A <- lm(IncrKappT12 ~ AbsT1 + ArtT1 + CkT1, data = data1A)
summary(model1A, standardized = TRUE)
confint(model1A, level=0.95)
shapiro.test(residuals(model1A))
shapiro.test(data1A$IncrKappT12)
hist(residuals(model1A))
```

- **Confirmatory Factor Analysis of Study Variables of Hypothesis 1A at Time 2**

```
CFAmodel <- '
KappT2 =~ KappT21 + KappT22
IdT2 =~ IdT21 + IdT22
UndT2 =~ UndT21 + UndT22
AbsT2 =~ IdT2 + UndT2
ArtT2 =~ ArtT21 + ArtT22
CkT2 =~ CkT21 + CkT22
#Correcting Variances
KappT21 ~~ 0*KappT21
IdT22 ~~ 0*IdT22'
```

```
fit <- cfa(CFAmodel, data = data1A2, missing = "fiml", estimator = "MLR")
summary(fit, fit.measures = TRUE, standardized = TRUE)
parameterEstimates(fit, ci = TRUE, level = 0.95, standardized = TRUE)
modindices(fit)
```

- **Confirmatory Factor Analysis of Study Variables of Hypothesis 1A at Time 2 – Checking for Artefactual Error Caused by Indicator UndT21**

```
CFAmodel <- '
KappT2 =~ KappT21 + KappT22
IdT2 =~ IdT21 + IdT22
UndT2 =~ UndT21 + UndT22
AbsT2 =~ IdT2 + UndT2
ArtT2 =~ ArtT21 + ArtT22
CkT2 =~ CkT21 + CkT22 + UndT21
#Correcting Variances
KappT21 ~~ 0*KappT21
IdT22 ~~ 0*IdT22'
fit <- cfa(CFAmodel, data = data1A2, missing = "fiml", estimator = "MLR")
summary(fit, fit.measures = TRUE, standardized = TRUE)
parameterEstimates(fit, ci = TRUE, level = 0.95, standardized = TRUE)
modindices(fit)
```

- **Calculation of Reliabilities via Cronbach's Alpha**

```
cronbach(data.frame(data1A1$KappT11, data1A1$KappT12))
cronbach(data.frame(data1A1$IdT11, data1A1$IdT12))
cronbach(data.frame(data1A1$UndT11, data1A1$UndT12))
cronbach(data.frame(data1A1$ArtT11, data1A1$ArtT12))
cronbach(data.frame(data1A1$CkT11, data1A1$CkT12))
alpha(data.frame(data1A1), check.keys=TRUE)
```

APPENDIX H: Summary of Statistical Analyses for Study Hypotheses

Below is presented a summary of the statistical analyses developed in Chapter 5. The abbreviations used have the following meanings: refer to the following:

- KappT(i): Receiver knowledge application at time (i);
- KappT(i)(j): Survey item number (j) to measure receiver knowledge application at time (i);
- AbsT(i): Receiver absorptive capacity at time (i);
- IdT(i): Receiver ability to identify valuable knowledge at time (i);
- IdT(i)(j): Survey item number (j) to measure receiver ability to identify valuable knowledge at time (i);
- UndT(i): Receiver ability to understand valuable knowledge at time (i);
- UndT(i)(j): Survey item number (j) to measure receiver ability to understand valuable knowledge at time (i);
- ArtT(i): Senders' articulating capacities at time (i);
- ArtT(i)(j): Survey item number (j) to measure senders' articulating capacities at time (i);
- CkT(i): Receiver-senders common knowledge at time (i).
- CkT(i)(j): Survey item number (j) to measure receiver-senders common knowledge at time (i).

- **Structural Equation Modeling (SEM) of Hypothesis 1A at time point 1**

```
lavaan (0.5-23.1097) converged normally after  94 iterations

  Number of observations                           101

  Number of missing patterns                         5

  Estimator                                         ML      Robust
  Minimum Function Test Statistic               54.537      43.709
  Degrees of freedom                                28          28
  P-value (Chi-square)                           0.002       0.030
  Scaling correction factor                                  1.248
    for the Yuan-Bentler correction

Model test baseline model:

  Minimum Function Test Statistic              620.989     403.980
  Degrees of freedom                                45          45
  P-value                                        0.000       0.000

User model versus baseline model:

  Comparative Fit Index (CFI)                    0.954       0.956
  Tucker-Lewis Index (TLI)                       0.926       0.930

  Robust Comparative Fit Index (CFI)                         0.964
  Robust Tucker-Lewis Index (TLI)                            0.943

Loglikelihood and Information Criteria:

  Loglikelihood user model (H0)               -462.990    -462.990
  Scaling correction factor                                  1.687
    for the MLR correction
  Loglikelihood unrestricted model (H1)       -435.721    -435.721
  Scaling correction factor                                  1.498
    for the MLR correction

  Number of free parameters                         37          37
  Akaike (AIC)                                 999.979     999.979
  Bayesian (BIC)                              1096.739    1096.739
  Sample-size adjusted Bayesian (BIC)          979.876     979.876

Root Mean Square Error of Approximation:

  RMSEA                                          0.097       0.075
  90 Percent Confidence Interval          0.058  0.135       0.031  0.111
  P-value RMSEA <= 0.05                          0.028       0.147

  Robust RMSEA                                               0.083
  90 Percent Confidence Interval                             0.027  0.129

Standardized Root Mean Square Residual:

  SRMR                                           0.073       0.073

Parameter Estimates:
```

```
  Information                                 Observed
  Standard Errors                   Robust.huber.white

Latent Variables:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
  KappT1 =~
    KappT11           1.000                               0.694    0.934
    KappT12           1.019    0.108    9.457    0.000    0.707    0.931
  IdT1 =~
    IdT11             1.000                               0.787    0.951
    IdT12             0.754    0.185    4.079    0.000    0.593    0.785
  UndT1 =~
    UndT11            1.000                               0.637    0.953
    UndT12            0.982    0.101    9.703    0.000    0.625    0.924
  AbsT1 =~
    IdT1              1.000                               0.839    0.839
    UndT1             0.853    0.110    7.772    0.000    0.885    0.885
  CkT1 =~
    CkT11             1.000                               0.810    0.975
    CkT12             0.820    0.107    7.651    0.000    0.664    0.860
  ArtT1 =~
    ArtT11            1.000                               0.275    1.000
    ArtT12            0.285    0.222    1.286    0.199    0.078    0.218

Regressions:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
  KappT1 ~
    AbsT1             1.439    0.278    5.181    0.000    1.369    1.369
    CkT1             -0.428    0.224   -1.915    0.055   -0.500   -0.500
    ArtT1             0.099    0.245    0.403    0.687    0.039    0.039

Covariances:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
 .UndT11 ~~
   .ArtT12           -0.050    0.021   -2.434    0.015   -0.050   -0.707
  AbsT1 ~~
    CkT1              0.428    0.131    3.263    0.001    0.800    0.800
    ArtT1            -0.057    0.031   -1.834    0.067   -0.311   -0.311
  CkT1 ~~
    ArtT1            -0.013    0.027   -0.490    0.624   -0.059   -0.059

Intercepts:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
   .KappT11           4.390    0.088   50.083    0.000    4.390    5.909
   .KappT12           4.368    0.089   48.827    0.000    4.368    5.753
   .IdT11             4.189    0.097   43.034    0.000    4.189    5.062
   .IdT12             4.380    0.090   48.461    0.000    4.380    5.795
   .UndT11            4.432    0.076   58.467    0.000    4.432    6.633
   .UndT12            4.395    0.075   58.254    0.000    4.395    6.494
   .CkT11             4.147    0.084   49.507    0.000    4.147    4.994
   .CkT12             4.191    0.078   53.803    0.000    4.191    5.428
   .ArtT11            4.485    0.032  140.816    0.000    4.485   16.304
   .ArtT12            4.176    0.041  102.396    0.000    4.176   11.611
   .KappT1            0.000                               0.000    0.000
    IdT1              0.000                               0.000    0.000
    UndT1             0.000                               0.000    0.000
```

```
    AbsT1           0.000                               0.000    0.000
    CkT1            0.000                               0.000    0.000
    ArtT1           0.000                               0.000    0.000

Variances:
                   Estimate  Std.Err  z-value  P(>|z|)   Std.lv  Std.all
   .KappT1          0.000                               0.000    0.000
   .ArtT11          0.000                               0.000    0.000
   .KappT11         0.071    0.031    2.256    0.024    0.071    0.128
   .KappT12         0.077    0.043    1.770    0.077    0.077    0.133
   .IdT11           0.066    0.057    1.152    0.249    0.066    0.096
   .IdT12           0.219    0.088    2.485    0.013    0.219    0.384
   .UndT11          0.041    0.023    1.790    0.073    0.041    0.092
   .UndT12          0.067    0.029    2.317    0.021    0.067    0.146
   .CkT11           0.034    0.057    0.596    0.551    0.034    0.049
   .CkT12           0.156    0.060    2.597    0.009    0.156    0.261
   .ArtT12          0.123    0.038    3.262    0.001    0.123    0.952
    IdT1            0.183    0.087    2.112    0.035    0.296    0.296
    UndT1           0.088    0.036    2.432    0.015    0.217    0.217
    AbsT1           0.436    0.157    2.776    0.006    1.000    1.000
    CkT1            0.656    0.168    3.898    0.000    1.000    1.000
    ArtT1           0.076    0.011    6.767    0.000    1.000    1.000

> modindices(fitT1)
       lhs op     rhs    mi mi.scaled    epc sepc.lv sepc.all sepc.nox
16   KappT1 ~~  KappT1 1.587     1.272 -0.065  -0.134   -0.134   -0.134
17   ArtT11 ~~  ArtT11 0.000     0.000 -0.002  -0.002   -0.029   -0.029
52   KappT1 =~   IdT11 5.139     4.119  0.693   0.481    0.581    0.581
53   KappT1 =~   IdT12 0.029     0.023 -0.053  -0.037   -0.049   -0.049
54   KappT1 =~  UndT11 1.175     0.941 -0.192  -0.133   -0.199   -0.199
55   KappT1 =~  UndT12 0.155     0.124 -0.073  -0.051   -0.075   -0.075
56   KappT1 =~   CkT11 0.133     0.106 -0.056  -0.039   -0.047   -0.047
57   KappT1 =~   CkT12 0.133     0.106  0.046   0.032    0.041    0.041
58   KappT1 =~  ArtT11 0.975     0.781  0.243   0.168    0.612    0.612
59   KappT1 =~  ArtT12 0.975     0.781 -0.069  -0.048   -0.133   -0.133
60     IdT1 =~ KappT11 0.685     0.549  0.108   0.085    0.115    0.115
61     IdT1 =~ KappT12 1.412     1.132  0.159   0.125    0.165    0.165
62     IdT1 =~  UndT11 0.217     0.174  0.039   0.031    0.046    0.046
63     IdT1 =~  UndT12 2.558     2.050 -0.153  -0.120   -0.178   -0.178
64     IdT1 =~   CkT11 3.582     2.871 -0.286  -0.225   -0.271   -0.271
65     IdT1 =~   CkT12 1.031     0.827  0.141   0.111    0.144    0.144
66     IdT1 =~  ArtT11 0.166     0.133 -0.042  -0.033   -0.121   -0.121
67     IdT1 =~  ArtT12 0.119     0.095  0.020   0.016    0.044    0.044
68    UndT1 =~ KappT11 0.617     0.494  0.175   0.111    0.150    0.150
69    UndT1 =~ KappT12 1.187     0.951 -0.247  -0.158   -0.207   -0.207
70    UndT1 =~   IdT11 1.615     1.294 -0.265  -0.169   -0.204   -0.204
71    UndT1 =~   IdT12 0.068     0.055  0.060   0.038    0.051    0.051
72    UndT1 =~   CkT11 1.085     0.869  0.254   0.162    0.195    0.195
73    UndT1 =~   CkT12 0.442     0.354  0.143   0.091    0.118    0.118
74    UndT1 =~  ArtT11 1.739     1.393  0.226   0.144    0.524    0.524
75    UndT1 =~  ArtT12 3.449     2.764 -0.137  -0.087   -0.243   -0.243
76    AbsT1 =~ KappT11 1.603     1.285  0.340   0.224    0.302    0.302
77    AbsT1 =~ KappT12 1.603     1.284 -0.347  -0.229   -0.301   -0.301
82    AbsT1 =~   CkT11 0.198     0.159 -0.094  -0.062   -0.075   -0.075
83    AbsT1 =~   CkT12 0.198     0.159  0.077   0.051    0.066    0.066
84    AbsT1 =~  ArtT11 1.713     1.373  0.312   0.206    0.750    0.750
85    AbsT1 =~  ArtT12 1.712     1.373 -0.089  -0.059   -0.163   -0.163
```

86	CkT1	=~	KappT11	1.652	1.324	0.100	0.081	0.109	0.109
87	CkT1	=~	KappT12	1.652	1.324	-0.102	-0.083	-0.109	-0.109
88	CkT1	=~	IdT11	5.311	4.256	-0.290	-0.235	-0.284	-0.284
89	CkT1	=~	IdT12	0.042	0.034	0.026	0.021	0.028	0.028
90	CkT1	=~	UndT11	0.858	0.687	0.068	0.055	0.082	0.082
91	CkT1	=~	UndT12	0.331	0.266	0.044	0.036	0.053	0.053
92	CkT1	=~	ArtT11	2.442	1.958	0.270	0.219	0.796	0.796
93	CkT1	=~	ArtT12	2.442	1.958	-0.077	-0.062	-0.173	-0.173
94	ArtT1	=~	KappT11	0.399	0.320	0.135	0.037	0.050	0.050
95	ArtT1	=~	KappT12	0.399	0.320	-0.138	-0.038	-0.050	-0.050
96	ArtT1	=~	IdT11	1.332	1.068	-0.306	-0.084	-0.102	-0.102
97	ArtT1	=~	IdT12	0.141	0.113	0.101	0.028	0.037	0.037
98	ArtT1	=~	UndT11	1.259	1.009	-0.178	-0.049	-0.073	-0.073
99	ArtT1	=~	UndT12	3.387	2.715	0.304	0.084	0.124	0.124
100	ArtT1	=~	CkT11	2.056	1.648	0.311	0.085	0.103	0.103
101	ArtT1	=~	CkT12	2.056	1.648	-0.255	-0.070	-0.091	-0.091
102	KappT11	~~	KappT12	1.587	1.272	-0.066	-0.066	-0.117	-0.117
103	KappT11	~~	IdT11	0.288	0.231	-0.010	-0.010	-0.017	-0.017
104	KappT11	~~	IdT12	0.969	0.776	0.020	0.020	0.036	0.036
105	KappT11	~~	UndT11	0.028	0.022	0.002	0.002	0.004	0.004
106	KappT11	~~	UndT12	0.064	0.052	-0.003	-0.003	-0.006	-0.006
107	KappT11	~~	CkT11	0.642	0.515	0.013	0.013	0.022	0.022
108	KappT11	~~	CkT12	0.066	0.053	-0.004	-0.004	-0.007	-0.007
109	KappT11	~~	ArtT11	0.070	0.056	0.004	0.004	0.018	0.018
110	KappT11	~~	ArtT12	0.133	0.107	0.006	0.006	0.021	0.021
111	KappT12	~~	IdT11	5.354	4.291	0.046	0.046	0.074	0.074
112	KappT12	~~	IdT12	1.353	1.084	-0.024	-0.024	-0.043	-0.043
113	KappT12	~~	UndT11	1.465	1.174	-0.014	-0.014	-0.028	-0.028
114	KappT12	~~	UndT12	1.449	1.161	0.015	0.015	0.030	0.030
115	KappT12	~~	CkT11	0.402	0.322	-0.011	-0.011	-0.017	-0.017
116	KappT12	~~	CkT12	0.148	0.119	-0.007	-0.007	-0.011	-0.011
117	KappT12	~~	ArtT11	0.006	0.004	-0.001	-0.001	-0.005	-0.005
118	KappT12	~~	ArtT12	0.716	0.574	-0.013	-0.013	-0.049	-0.049
120	IdT11	~~	UndT11	0.415	0.333	0.009	0.009	0.016	0.016
121	IdT11	~~	UndT12	3.329	2.668	-0.028	-0.028	-0.050	-0.050
122	IdT11	~~	CkT11	0.000	0.000	0.000	0.000	0.000	0.000
123	IdT11	~~	CkT12	0.983	0.788	-0.023	-0.023	-0.036	-0.036
124	IdT11	~~	ArtT11	0.513	0.411	-0.012	-0.012	-0.055	-0.055
125	IdT11	~~	ArtT12	0.992	0.795	0.019	0.019	0.065	0.065
126	IdT12	~~	UndT11	0.123	0.098	-0.005	-0.005	-0.010	-0.010
127	IdT12	~~	UndT12	0.396	0.317	0.011	0.011	0.021	0.021
128	IdT12	~~	CkT11	3.326	2.665	-0.044	-0.044	-0.070	-0.070
129	IdT12	~~	CkT12	4.984	3.994	0.054	0.054	0.093	0.093
130	IdT12	~~	ArtT11	0.057	0.045	-0.004	-0.004	-0.020	-0.020
131	IdT12	~~	ArtT12	6.086	4.878	0.053	0.053	0.196	0.196
133	UndT11	~~	CkT11	1.026	0.822	-0.014	-0.014	-0.025	-0.025
134	UndT11	~~	CkT12	3.600	2.885	0.025	0.025	0.049	0.049
135	UndT11	~~	ArtT11	2.382	1.909	-0.016	-0.016	-0.089	-0.089
136	UndT12	~~	CkT11	4.602	3.689	0.032	0.032	0.056	0.056
137	UndT12	~~	CkT12	3.828	3.068	-0.028	-0.028	-0.054	-0.054
138	UndT12	~~	ArtT11	3.999	3.205	0.022	0.022	0.118	0.118
139	UndT12	~~	ArtT12	3.846	3.083	-0.038	-0.038	-0.157	-0.157
140	CkT11	~~	CkT12	1.587	1.272	-0.288	-0.288	-0.450	-0.450
141	CkT11	~~	ArtT11	4.710	3.775	0.033	0.033	0.145	0.145
142	CkT11	~~	ArtT12	6.146	4.926	-0.039	-0.039	-0.131	-0.131
143	CkT12	~~	ArtT11	3.496	2.802	-0.024	-0.024	-0.111	-0.111
144	CkT12	~~	ArtT12	2.994	2.400	0.027	0.027	0.098	0.098

```
145  ArtT11 ~~  ArtT12 0.000     0.000  0.000   0.000   -0.001   -0.001
146  KappT1 ~~    IdT1 5.965     4.781  0.071   0.130    0.130    0.130
147  KappT1 ~~   UndT1 0.143     0.115 -0.009  -0.021   -0.021   -0.021
151    IdT1 ~~   UndT1 1.587     1.272 -0.027  -0.053   -0.053   -0.053
152    IdT1 ~~   AbsT1 5.714     4.580  0.082   0.157    0.157    0.157
153    IdT1 ~~    CkT1 6.721     5.387 -0.094  -0.147   -0.147   -0.147
154    IdT1 ~~   ArtT1 0.007     0.006 -0.002  -0.009   -0.009   -0.009
155   UndT1 ~~   AbsT1 5.714     4.580 -0.070  -0.166   -0.166   -0.166
156   UndT1 ~~    CkT1 6.721     5.387  0.080   0.155    0.155    0.155
157   UndT1 ~~   ArtT1 0.007     0.006  0.002   0.009    0.009    0.009

> parameterEstimates(fitT1, ci = TRUE, level = 0.95, standardized = TRUE)
       lhs op     rhs    est    se       z pvalue ci.lower ci.upper std.lv st
d.all std.nox
1   KappT1 =~ KappT11  1.000 0.000      NA     NA    1.000    1.000  0.694
0.934   0.934
2   KappT1 =~ KappT12  1.019 0.108   9.457  0.000    0.808    1.231  0.707
0.931   0.931
3     IdT1 =~   IdT11  1.000 0.000      NA     NA    1.000    1.000  0.787
0.951   0.951
4     IdT1 =~   IdT12  0.754 0.185   4.079  0.000    0.392    1.116  0.593
0.785   0.785
5    UndT1 =~  UndT11  1.000 0.000      NA     NA    1.000    1.000  0.637
0.953   0.953
6    UndT1 =~  UndT12  0.982 0.101   9.703  0.000    0.784    1.180  0.625
0.924   0.924
7    AbsT1 =~    IdT1  1.000 0.000      NA     NA    1.000    1.000  0.839
0.839   0.839
8    AbsT1 =~   UndT1  0.853 0.110   7.772  0.000    0.638    1.069  0.885
0.885   0.885
9     CkT1 =~   CkT11  1.000 0.000      NA     NA    1.000    1.000  0.810
0.975   0.975
10    CkT1 =~   CkT12  0.820 0.107   7.651  0.000    0.610    1.029  0.664
0.860   0.860
11   ArtT1 =~  ArtT11  1.000 0.000      NA     NA    1.000    1.000  0.275
1.000   1.000
12   ArtT1 =~  ArtT12  0.285 0.222   1.286  0.199   -0.150    0.720  0.078
0.218   0.218
13  KappT1  ~   AbsT1  1.439 0.278   5.181  0.000    0.894    1.983  1.369
1.369   1.369
14  KappT1  ~    CkT1 -0.428 0.224  -1.915  0.055   -0.867    0.010 -0.500  -
0.500  -0.500
15  KappT1  ~   ArtT1  0.099 0.245   0.403  0.687   -0.381    0.578  0.039
0.039   0.039
16  KappT1 ~~  KappT1  0.000 0.000      NA     NA    0.000    0.000  0.000
0.000   0.000
17  ArtT11 ~~  ArtT11  0.000 0.000      NA     NA    0.000    0.000  0.000
0.000   0.000
18  UndT11 ~~  ArtT12 -0.050 0.021  -2.434  0.015   -0.091   -0.010 -0.050  -
0.707  -0.707
19 KappT11 ~~ KappT11  0.071 0.031   2.256  0.024    0.009    0.132  0.071
0.128   0.128
20 KappT12 ~~ KappT12  0.077 0.043   1.770  0.077   -0.008    0.161  0.077
0.133   0.133
21   IdT11 ~~   IdT11  0.066 0.057   1.152  0.249   -0.046    0.177  0.066
0.096   0.096
```

22	IdT12	~~	IdT12	0.219	0.088	2.485	0.013	0.046	0.392	0.219	0.384	0.384
23	UndT11	~~	UndT11	0.041	0.023	1.790	0.073	-0.004	0.086	0.041	0.092	0.092
24	UndT12	~~	UndT12	0.067	0.029	2.317	0.021	0.010	0.124	0.067	0.146	0.146
25	CkT11	~~	CkT11	0.034	0.057	0.596	0.551	-0.077	0.144	0.034	0.049	0.049
26	CkT12	~~	CkT12	0.156	0.060	2.597	0.009	0.038	0.273	0.156	0.261	0.261
27	ArtT12	~~	ArtT12	0.123	0.038	3.262	0.001	0.049	0.197	0.123	0.952	0.952
28	IdT1	~~	IdT1	0.183	0.087	2.112	0.035	0.013	0.353	0.296	0.296	0.296
29	UndT1	~~	UndT1	0.088	0.036	2.432	0.015	0.017	0.159	0.217	0.217	0.217
30	AbsT1	~~	AbsT1	0.436	0.157	2.776	0.006	0.128	0.744	1.000	1.000	1.000
31	CkT1	~~	CkT1	0.656	0.168	3.898	0.000	0.326	0.986	1.000	1.000	1.000
32	ArtT1	~~	ArtT1	0.076	0.011	6.767	0.000	0.054	0.098	1.000	1.000	1.000
33	AbsT1	~~	CkT1	0.428	0.131	3.263	0.001	0.171	0.685	0.800	0.800	0.800
34	AbsT1	~~	ArtT1	-0.057	0.031	-1.834	0.067	-0.117	0.004	-0.311	-0.311	-0.311
35	CkT1	~~	ArtT1	-0.013	0.027	-0.490	0.624	-0.066	0.039	-0.059	-0.059	-0.059
36	KappT11	~1		4.390	0.088	50.083	0.000	4.218	4.561	4.390	5.909	5.909
37	KappT12	~1		4.368	0.089	48.827	0.000	4.193	4.543	4.368	5.753	5.753
38	IdT11	~1		4.189	0.097	43.034	0.000	3.999	4.380	4.189	5.062	5.062
39	IdT12	~1		4.380	0.090	48.461	0.000	4.203	4.557	4.380	5.795	5.795
40	UndT11	~1		4.432	0.076	58.467	0.000	4.283	4.581	4.432	6.633	6.633
41	UndT12	~1		4.395	0.075	58.254	0.000	4.248	4.543	4.395	6.494	6.494
42	CkT11	~1		4.147	0.084	49.507	0.000	3.983	4.311	4.147	4.994	4.994
43	CkT12	~1		4.191	0.078	53.803	0.000	4.038	4.343	4.191	5.428	5.428
44	ArtT11	~1		4.485	0.032	140.816	0.000	4.422	4.547	4.485	16.304	16.304
45	ArtT12	~1		4.176	0.041	102.396	0.000	4.096	4.256	4.176	11.611	11.611
46	KappT1	~1		0.000	0.000	NA	NA	0.000	0.000	0.000	0.000	0.000
47	IdT1	~1		0.000	0.000	NA	NA	0.000	0.000	0.000	0.000	0.000
48	UndT1	~1		0.000	0.000	NA	NA	0.000	0.000	0.000	0.000	0.000
49	AbsT1	~1		0.000	0.000	NA	NA	0.000	0.000	0.000	0.000	0.000

```
50    CkT1 ~1           0.000 0.000       NA      NA     0.000     0.000   0.000
0.000   0.000
51   ArtT1 ~1           0.000 0.000       NA      NA     0.000     0.000   0.000
0.000   0.000
```

- **Multi-Linear Regression of Hypothesis 1A at time point 2**

```
Residuals:
    Min      1Q  Median      3Q     Max 
-245.28  -40.42   13.41   64.97  167.62 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) 170.9228    90.2905   1.893   0.0677 .  
AbsT2         0.6996     0.1431   4.890 2.94e-05 ***
CkT2          0.1699     0.1166   1.457   0.1551    
ArtT2        -0.4230     0.1659  -2.550   0.0159 *  
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 96.98 on 31 degrees of freedom
Multiple R-squared:  0.6915,	Adjusted R-squared:  0.6617 
F-statistic: 23.16 on 3 and 31 DF,  p-value: 4.641e-08

> predict(model1A2,interval="confidence", standardized=TRUE)
          fit       lwr      upr
1  153.309820  68.27432 238.3453
2  293.253267 244.71399 341.7925
3   46.991960 -44.58937 138.5733
4  396.652575 357.21224 436.0929
5  446.444476 385.88241 507.0065
6  404.417990 352.73807 456.0979
7  244.476913 205.09418 283.8596
8  444.531988 391.47932 497.5847
9  606.079089 515.34293 696.8152
10 176.100512  74.60831 277.5927
11 300.508005 248.04186 352.9742
12 229.067582 172.39461 285.7406
13 333.560746 286.69032 380.4312
14 410.217967 364.29920 456.1367
15 457.375381 388.54516 526.2056
16   6.716007 -86.43738  99.8694
17 247.854795 195.67344 300.0362
18 396.189266 335.28475 457.0938
19 298.675202 255.37695 341.9734
20 233.717622 157.47232 309.9629
21 449.446670 390.34962 508.5437
22 147.777007  82.24559 213.3084
23 476.348133 364.34474 588.3515
24 370.716278 323.28592 418.1466
25 430.653589 376.13437 485.1728
26 277.894450 227.41853 328.3704
27  55.035181 -37.57146 147.6418
28 524.966828 447.80925 602.1244
29 356.851859 310.37093 403.3328
30 343.907017 275.14300 412.6710
```

```
31 268.516254 224.61057 312.4219
32 302.068945 262.48812 341.6498
33 519.675311 441.46129 597.8893
34 304.165133 230.78400 377.5463
35 304.165133 230.78400 377.5463
```

- **Simple Linear Regression of Hypothesis 1B**

```
lm(formula = Ktransfer ~ Kapp, data = data1B)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.32693 -0.09373  0.02711  0.06091  0.27307 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)  
(Intercept)  0.89125    0.41946   2.125    0.047 *
Kapp        -0.03286    0.09468  -0.347    0.732  
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.1668 on 19 degrees of freedom
Multiple R-squared:  0.006302, Adjusted R-squared:  -0.046 
F-statistic: 0.1205 on 1 and 19 DF,  p-value: 0.7323
```

- **Simple Linear Regression of Hypothesis 1C**

```
lm(formula = IncAbs ~ Kapp, data = data1CAbs)

Residuals:
    Min      1Q  Median      3Q     Max 
-1.0462 -0.1820  0.0795  0.2599  0.6413 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   1.0481     0.7547   1.389    0.177
Kapp         -0.2349     0.1742  -1.348    0.189

Residual standard error: 0.4114 on 26 degrees of freedom
Multiple R-squared:  0.06535,  Adjusted R-squared:  0.0294 
F-statistic: 1.818 on 1 and 26 DF,  p-value: 0.1892



lm(formula = IncArt ~ Kapp, data = data1Art)

Residuals:
     Min       1Q   Median       3Q      Max 
-1.44603 -0.39894  0.06069  0.32089  1.00126 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)  
(Intercept)  -3.0231     1.1923  -2.535   0.0173 *
Kapp          0.6938     0.2719   2.552   0.0167 *
```

```
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.5664 on 27 degrees of freedom
Multiple R-squared:  0.1943,   Adjusted R-squared:  0.1644
F-statistic:  6.51 on 1 and 27 DF,  p-value: 0.0167

lm(formula = Incck ~ Kapp, data = data1Cck)

Residuals:
     Min       1Q   Median       3Q      Max
-0.64511 -0.23746 -0.01373  0.29274  0.59766

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   1.1162     0.6135   1.819   0.0792 .
Kapp         -0.2428     0.1416  -1.714   0.0972 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.354 on 29 degrees of freedom
Multiple R-squared:  0.09198, Adjusted R-squared:  0.06067
F-statistic: 2.938 on 1 and 29 DF,  p-value: 0.09721
```

- **Simple Linear Regression of Hypothesis 2A**

```
lm(formula = StAbs ~ InAbs, data = data2A1)

Residuals:
     Min       1Q   Median       3Q      Max
-0.36828 -0.10447  0.02102  0.06929  0.42449

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)   6.6123     2.7997   2.362   0.0502 .
InAbs        -0.4827     0.6528  -0.739   0.4838
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.2479 on 7 degrees of freedom
Multiple R-squared:  0.07243, Adjusted R-squared:  -0.06008
F-statistic: 0.5466 on 1 and 7 DF,  p-value: 0.4838
```

- **Simple Linear Regression of Hypothesis 2B**

```
lm(formula = StKapp ~ StAbs, data = data2A2)

Residuals:
    Min      1Q  Median      3Q     Max
-0.6044 -0.2744  0.1478  0.2256  0.3643

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept)  -0.9258     2.3340  -0.397    0.703
```

```
StAbs         1.1556     0.5131   2.252    0.059 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.3494 on 7 degrees of freedom
Multiple R-squared:  0.4202,   Adjusted R-squared:  0.3374
F-statistic: 5.073 on 1 and 7 DF,  p-value: 0.059
```

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