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Aligning Contractual, Technological, and Organizational Elements to Achieve Higher
Performance buildings: A Qualitative Comparative Analysis Approach

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A dissertation

submitted in partial fulfillment of the
requirements for the degree of

Doctor of Philosophy

University of Washington

2015

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Built Environment

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Abstract

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High Performance (HP) buildings are rapidly growing phenomena in Architecture Engineering and Construction industry, addressing many criteria affecting the buildings' design and construction such as sustainability, functionality and cost-effectiveness. Responding to all these criteria, however, requires a transitioning from the traditional design process towards the whole system approach in which team members can effectively collaborate to analyze the tradeoffs between various interdependent systems and products, and be able to optimize the building as a whole.

Construction, engineering and management (CEM) scholars have identified effective elements to facilitate such transition. Fostering Integrated Project Teams (IPT), and implementation of Building Information Modeling (BIM) are two of the fundamental elements presented. However, there is still a gap within the literature, in terms of contextualizing these elements, considering the causal complexities embedded in delivery of HP projects.

Using Fuzzy sets Qualitative Comparative Analysis approach, this study presents a framework for analyzing interdependencies within contractual, organizational and social elements that foster IPT practices and BIM implementation within HP projects. The proposed framework is used to construct three major typologies of HP projects with superior reduction in their energy use: “information driven”, “process driven”, and “organizationally driven” projects.

Comparison among the fundamental differences among the three typologies shows that formation of trust and approaches to learning and innovation has different drivers in each typology: information technology such as BIM, and inter-organizational scope understanding are the driving forces in Information Driven Projects. Process Driven Projects, however, depend on contractual settings and early involvement of the construction team, while Organizationally Driven Projects rely on an experienced architectural firm and their already established collaborative work practices.

The study also found that in addition to the exclusive elements that facilitate design and construction of HP buildings in each typology, several elements are necessary to be present in all HP projects. Such elements include setting ambitious environmental goals, owner engagement in the design process, close working relationship among architects and engineers, and frequent inter-organizational meetings.

The findings of this study provide a platform for CEM scholars to investigate complementarities among various contractual, organizational, and social elements facilitating design and construction of HP projects. In addition, Identifying similarities between their projects with the proposed typologies, practitioners will be able to better strategize and make informed decisions about incorporating new IPT and BIM work processes within their projects. Finally, this project can be served as an example for implementation of configurational set theoretic methods such as fsQCA within CEM domain, helping to bridge the sharp divide that currently exists between large N quantitative and small N qualitative studies on construction projects.

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ACKNOWLEDGEMENTS

Working with causal complexity theories and complementarities among causal elements, I realize more than ever how my accomplishments are beholden to other causal factors that have inspired, improved and complemented me! The devoted and inspiring people without whom all my hard work would have not lead to this destination. I would like to take a moment and acknowledge the value of their presence and supports in my life.

First of all, it is a pleasure to state my gratitude to my supervisor, Prof. Carrie Dossick, for being an inspirational teacher, and a caring advisor who has continuously supported me beyond my expectations. Carrie, I am very grateful for having you as my advisor, and I hope I can someday pass the caring mentorship of yours to my fellow students.

I would also like to thank my committee members, Prof. Gina Neff, Prof. Philip Howard, Prof. Heather Burpee, and Prof. Jessica Kaminsky for their continuous support for improving this research, and for their generosity and openness in sharing their knowledge. My appreciation also goes to friends and colleagues in Built Environment program as well as CTOP for providing such warm, cooperative and stimulating environment for studying.

Words fail to express my sincere appreciations to my parents who have been always the warmth of my heart! Thank you for being there for me and teaching me to love to learn! My last but not least gratitude belongs to my beloved husband and two beautiful daughters. Without you, none of the accomplishments in the world would mean as much to me. I am the proudest with you and you are the greatest sense of accomplishment for me! Every day, I study, research, teach, and live with the positive energy that you always put in me. I love you and I can't thank you enough.

DEDICATION

Dedicated to those who are striving to care for the environment....

Chapter 1. INTRODUCTION

Buildings, from construction to occupancy, are major sources of environmental degradation and global warming. According to United States Green Building Council (USGBC, 2009) buildings in United States account for 40% of primary energy use and 40% of CO₂ emissions. To alleviate these major negative impacts, several movements and practice paradigms (such as green building, sustainable architecture, low-impact developments) have emerged to produce buildings that are built and operated with higher standards in terms of their environmental impacts (Fischer, 2010). Among these practices High Performance (HP) buildings, which are chosen as the target population in this research, are sustainable buildings with an emphasis on their energy conservation.

HP buildings, however, are much more than energy conservative buildings. The U.S. Energy Independence and Security Act of 2007 defines a high-performance building as “a building that integrates and optimizes on a life cycle basis all major high performance attributes, including energy conservation, environment, safety, security, durability, accessibility, cost-benefit, productivity, sustainability, functionality, and operational considerations.” To achieve this, designers and builders use a holistic approach to respond to occupants, environment, and societies’ needs. Achieving such holistic vision, requires a “whole system approach” that allows optimization among envelope, structural, mechanical, electrical, and architectural systems, by considering their long-term impact of social, ecological, and economic consequences. This highly complex process indicates the need for a shift from traditional sequential design and construction process towards a more integrated approach that is capable of utilizing a range of new skills, outlooks, and resources (Kibert, 2012; Reed and 7 Group, 2009; Yudelsohn, 2008).

Many studies are conducted to find and rank the techniques associated with integrated approaches and design of higher performance projects (Korkmaz et al., 2010; Nofera and Korkmaz, 2010; Vellalos and Gordon, 2013). Emerging practices such as implementation of Building Information Modeling (BIM) Technologies, and inter-organizational collaboration techniques, referred to as Integrated Project Teams (IPT) in this study, are introduced to the industry as major facilitators

(Azhar, 2011; Gu et al., 2008; Homayouni et al., 2010). However, there is little work done in contextualizing those practices and finding complementarities among them. Such studies would provide a better understanding of the causal complexities embedded in design and construction of HP projects and can provide guidelines for practitioners to help them in strategizing and choosing the techniques that best matches with the context of their organization and project characteristics. This dissertation attempts to address this existing gap by creating three typologies of successful HP projects: information driven, process driven, and organizationally driven.

While some of the strategies associated with design and construction of HP projects are found to be necessary for achieving all HP projects in general such as owner's involvement in the design process, projects ambitious environmental goals, close working relationships among architects and engineers, as well as frequent inter-organizational meetings, other strategies are found to be exclusive to certain typologies. The study, therefore presents tailored strategies for practitioners pursuing HP projects with lower energy consumption based on the characteristics of their projects and organizations.

The next chapter, literature review, aims to review the literature on HP buildings, BIM, and IPT practices. This section also reviews the role of BIM and IPT practices on desired HP project outcomes such as energy performance, and demonstrates the need for implementing a new methodology to bridge the existing gap within the literature in terms of finding complementarities among IPT practices and BIM implementation for drawing causal inferences about their effect on buildings' energy performance.

The third chapter begins by laying out objectives of this research and discusses the research settings and its limitations. The chapter further introduces the three main methodologies used in this research: case studies and interviews, questionnaire survey and fuzzy sets Qualitative Comparative Analysis approach.

The fourth chapter introduces Qualitative Comparative Analysis (QCA), as an emerging research methodology in social science, discussing how the method is capable of addressing causal complexity within organizations with various inter-dependent structural, organizational and social elements. Next, a variation of the method called fuzzy set-QCA (fsQCA), used in this research, is introduced and discussed. The second half of the chapter discusses the application of fsQCA

method in Construction, Engineering, and Management (CEM) domain by comparing the underlying conditions that make fsQCA applicable in social science and organizational research with similar circumstances in CEM domain. The section also addresses the challenges of applying fsQCA in research questions analyzing causal complexities within HP projects with regards to use of IPT practices, and BIM implementation and discusses potential resolutions.

Chapter five discusses antecedents of IPD practices and BIM implementation using literature in organizational studies as well as CEM domain, discussing various contractual, organizational, and social strategies that lead to achievement of these elements. These antecedents, are enhanced with the case study and interview data in chapter six to build a framework for capturing required elements of IPD practices and BIM implementation within a questionnaire survey. The section also highlights the interdependencies within these elements through the constructed framework, emphasizing on the suitability of QCA method for such analysis.

Chapter seven demonstrates the process of implementing fsQCA. The first step, calibrating the outcome condition is explained through overcoming difficulties of comparing energy performance of buildings reported using different code and rating systems. The section also discusses calibrating the “energy consumption” condition based on the buildings’ reduced energy consumption, as opposed to the buildings’ reduced purchased energy, eliminating the effect of on-site renewable energy uses from the reported energy performance of the rating and coding systems. Next, calibration of the causal conditions based on the framework created in chapter six is explained. Finally, the fsQCA procedure to create typologies of HP projects according to their IPT practices and BIM implementation is explained.

Chapter eight presents the constructed typologies of successful BIM implementation and IPT practices for achieving HP buildings with lower energy consumption. The core differences among these typologies are then discussed under two categories of formation of trust and approaches to learning and innovation. At the end, the tailored strategies that can help to achieve success within each typology are presented.

Lastly, chapter nine concludes the dissertation discussing the implications and applications of the study on different conceptual levels: research studies unfolding causal complexities of construction projects in CEM domain, research studies on BIM, IPT practices and HP projects, studies

involving comparison of various codes, rating, and operational systems, and practitioners attempting to achieve higher energy performance buildings. Within each area, the potentials that the study holds for future research is presented.

Chapter 2. **LITERATURE REVIEW: HP BUILDINGS, INTEGRATED PROJECT TEAMS & BIM TECHNOLOGIES**

High-Performance (HP) buildings are known for their responsiveness to sustainability goals and their dedication to conserve energy. HP buildings are getting more attention as the cost of energy grows and the environmental degradations resulting from use of fossil fuels becomes more problematic (Kibert, 2012). Design and construction of these buildings, however, requires a holistic approach to architectural design for optimizing building components with regards to various functional, environmental, and social elements that affect buildings' performance during its life cycle (Reed and 7 Group, 2009). Inter-organizational collaboration and implementation of the new information technologies are emerging as promising approaches for providing the comprehensiveness required for producing such buildings. Yet, successful inter-organizational collaboration requires a fundamental change in contractual agreements, organizational structures, as well as individual behaviors within construction projects (Homayouni et al., 2010). On the other hand, costly implementation of BIM as well as the required adaptation of people and processes to adopt the new technologies makes it challenging for organizational leaders to take a leap in making such a major technical, social and organizational change.

Qualitative studies showing the value of inter-organizational collaboration on design and construction of HP buildings (Reed and 7 Group, 2009) are pushing the industry towards more collaboration and integration. Likewise, qualitative studies showing how BIM capabilities can technically facilitate design and operation of HP buildings (Krygiel and Nies, 2008) are helpful for organizations who have already adopted the tools and want to maximize their benefits. Other studies showing trends, benefits, risks and challenges of BIM adoption in the industry (Azhar, 2011) also assist organizations in making an informed decision on adopting such tools. However, there is still an untouched area. The complex causal relationships that exist between implementation of BIM technologies and collaborative work practices that leads to design and construction of higher performance buildings.

Understanding this relationship would help practitioners aiming to achieve higher performance buildings to gain an understanding of how to strategize for successful implementation based on the specific social, organizational, and contractual context of their projects. In addition, studying

BIM implementation and collaborative practices to achieve higher performance buildings, opens new doors for researchers in CEM domain to study adoption of the new work practices in configurations, considering the social, organizational, and project related factors that affect promotion of change within construction projects.

As organizational scholars argue, effective promotion of a change within organizations structure, people, tasks, or technologies requires considering the effects of change on all other components (Cherns, 1976; Leavitt, 1964). Such consideration is feasible by creating typologies of cases in which the effect of the new change on other components can be studied based on the lessons learned from previous cases of the same type (Miller, 1996).

This study is an attempt to create typologies of successful HP projects with regards to BIM implementation and inter-organizational collaboration to assist organizations in strategizing on promoting collaboration techniques and implementation of BIM technologies based on their organization as well as the project characteristics.

This chapter is presented in four sections. The first three sections introduce and discuss the importance of the three notions that are fundamental in this study: Green and sustainable developments and their relation to HP buildings, collaboration and its practices in construction projects, and Building Information Modeling (BIM) as the new information technology in the AEC industry. The last section reviews the existing literature on how BIM implementation and collaboration in construction projects affect project outcomes. The section further discusses the existing gap in the literature in identifying typologies of successful HP buildings in terms of their implementation of BIM technologies and inter-organizational collaboration.

2.1 GREEN, SUSTAINABLE, AND HIGH PERFORMANCE BUILDINGS

In order to define and understand the concept of High-Performance building, it is helpful to introduce two similar but higher level concepts first: green and sustainable developments. While these two phrases are sometimes used interchangeably, they are in fact different. Green, according to the definition of Presidential Executive Order 13101 (Clinton, 1998) is referred to “environmentally preferable means products or services that have a lesser or reduced effect on

human health and the environment when compared with competing products or services that serve the same purpose.”

Sustainable development, on the other hand, is a broader concept defined by United Nations World Commission on Environment and Development (WCED) as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (Brundtland Commission, 1987). The United Nations Millennium Declaration issued principles and treaties on sustainable development covering three main categories of economic development, social development, and environmental protection. The Circle of Sustainability further distinguishes the cultural sustainability as the fourth aspect necessary for sustainable developments (Hasna, 2006).

In the context of the built environment, while the two terms are still different, they are closer in definition and use. Green Building is defined as a broader concept and is referred to environmentally considerate and resource efficient process of construction, occupancy and even demolition of buildings. A building is considered “green” if it reduces the harmful impacts on the environment and its inhabitants. The green building design revolves around four notions (US Green Building Council, 2009):

- Reducing energy use, including the use of renewal energy sources.
- Creating a healthy indoor air quality with adequate ventilation.
- Using building materials and resources that produce a minimal amount of upstream environmental impact.
- Facilitating efficient use of water using water efficient appliance, faucet, and shower head choices, recycling grey water, and capturing rain water for landscaping and other non-potable uses.

Based on the definition of sustainability, sustainable architecture has a more encompassing meaning (although often diluted) and refers to buildings that are socially, economically, environmentally, and culturally sustainable. This is a very restricting definition as fulfilling only the environmental aspect requires construction of net zero energy buildings. Fulfillment of economic, social and cultural issues puts further restrictions in development of sustainable architecture (Garret, 2012).

High Performance Buildings, chosen as the target population in this study, lie midway, conceptually speaking, between the two notions of Green and Sustainable Buildings. While sustainable architecture uses absolute concepts to define its products, and green building uses relative terms, HP building is more about “optimizing” the contributing elements on life cycle basis (U.S. Congress, 2007). These elements according to The U.S. Energy Independence and Security Act of 2007 include energy conservation, environment, safety, security, durability, accessibility, cost-benefit, productivity, sustainability, functionality, and operational considerations.

The three main principles of high performance building according to the “High Performance Guidelines: Triangle Region Public Facilities” (Triangle J Council of Governments, 2001) are:

1. Sustainability: to balance economics, equity, and environmental impacts in long terms.
2. Project team integration: to engage various stakeholders throughout the design and construction process to work collaboratively toward shared goals.
3. Feedback and Data Collection: to quantify success of the integrated process and constructed building for generating guidelines for future practices.

As components of buildings are inter-connected, optimizing the performance of each system affects other systems and their optimization as well. Therefore, buildings need to be optimized as a whole system. This notion requires an integrated design approach in which all the stakeholders in the design and construction process can actively contribute to the decision-making processes as a team during the design phase. Interestingly, during such integrated optimization processes, some component systems are found to have multiple cascading effects, meaning optimization of a single system might lead to downsize or elimination of other systems (Reed and 7 Group, 2009).

Researchers argue that delivering complex HP buildings that work as a united system, needs a systematic design process, arguing that the design process needs to be designed itself (Reed and 7 Group, 2009). This requires a different practical model that changes the conventional design process to an integrated one, in which designers can explore the interrelationships of building elements, environment, and human well-being; a design process in which integrated project teams can approach the building design as a whole.

2.2 DRIVERS OF HP PROJECTS

Researchers have undertaken case study observations and post construction interviews to identify key success elements in design and construction of HP buildings. While some of the identified elements are related to contextual settings, such as team members experience (Nofera and Korkmaz, 2010), other strategies are related to project ambitious environmental goals, collaborative practices, and BIM implementation.

Factors related to project ambition to achieve sustainability goals include owners' investment and strong commitment to sustainability goals (Korkmaz, 2007; Krygiel and Nies, 2008; Pitt et al., 2009), early inclusion of green strategies in the project (Nofera and Korkmaz, 2010) and contractual conditions such as building regulations, taxes and levies, as well as incentives/penalties for achieving/not achieving project sustainability goals (Korkmaz, 2007; Pitt et al., 2009).

The key collaboration factors in successful achievements of sustainability goals in HP projects include team members collaborative decision making in the delivery process (Enache-Pommer, 2008; Korkmaz, 2007; Lapinski et al., 2006), owners commitment to the process (Enache-Pommer, 2008; Korkmaz, 2007; Lapinski et al., 2006), Successful communication and compatibility within project teams (Enache-Pommer and Horman, 2009; Lapinski et al., 2006; Reed and 7 Group, 2009), as well as early involvement of key project participants (Riley and Horman, 2005), leveraging BIM capabilities to achieve sustainability goals, on the other hand, include using BIM for building orientation, massing, analyzing building form and optimizing the building envelope in terms of energy conservation, and using BIM for daylighting (Krygiel and Nies, 2008; Wong and Fan, 2013; Zanni et al., 2013a).

Yet, successful collaboration and implementation of BIM technologies requires a more in-depth understanding of the two phenomena and how they can help in achieving higher performance buildings. The two notions are introduced and discussed in this section.

2.2.1 **Collaboration & Integrated Project Teams (IPT)**

Collaboration is a process through which parties seeing and working on different aspects of a problem can constructively share their knowledge, explore their differences, and search for solutions, to gain a more comprehensive vision for the problem (Gray, 1989). The proposed framework by Thomson et al., (2009) for conceptualizing and measuring collaboration suggests that collaboration is multidimensional composed of five key dimensions: two structural dimensions of governance and administration, two social aspects of mutuality and norms, and a dimension which involves agency: organizational autonomy.

The “governance” aspect is about making joint decisions about the rules that will govern the team’s behavior and relationship. The “administration” dimension is about choosing administrative structures that move from governance to action, in order to achieve the overall purpose of the collaboration. The “mutuality” construct of collaboration is about having mutually beneficial interdependencies that could be based on complementarities among the team members or their shared interests. The fourth dimension, “norms”, is about creating a culture of reciprocity, trust and mutual respect within the project teams. Once this construct of collaboration is present, project teams are willing to bear disproportional costs at first, knowing that their good will will be reciprocated over time out of a sense of duty. Although developing trust takes time and the need for repeated interaction among team members, there are still strategies that can help teams in HP projects develop trust. The final dimension, “organizational autonomy”, is about finding the right balance between fulfilling obligations to the parent organization and commitment to collaboration mission as team members face a dual identities of their organizational authority, and the collaborative identity (Thomson et al., 2009).

The term “project team integration” is interchangeably used with the term collaboration in the CEM literature and is described as the process of sharing information, joint problem-solving and joint decision-making, which requires alignment of disciplinary cultures and goals towards a single cohesive and mutually supporting team (Baiden and Price, 2011; Baiden et al., 2006; Dulaimi et al., 2002). Consequently, the term Integrated Project Teams (IPT) can be used to denote practices that incorporate project team integration.

There are three main reasons that construction projects, and HP projects in particular, are subject to gaining benefits from IPT practices:

1. Improving the quality of architecture: Being able to share information among all project participants including suppliers and subcontractors gives a holistic view of the projects' requirements, and limitations to the team enabling them to design and optimize the building as a whole. For example, in traditional design process, although the construction team might have superior knowledge to perform alternatives to the specified design, but they may refrain from offering such knowledge in order to retain a competitive advantage. By removing physical as well as incentive based obstacles for sharing information in IPT practices, the quality of architecture can be improved (Allen et al., 2005).
2. Decreasing waste in construction time and cost: By overlapping the design and construction process, the legendary inefficiency existing in traditional design process can be overcome. Other than saving the overlapping time, the sooner the construction team is brought onboard, the sooner the design mistakes are found. As shown by Patrick MAcLeamy, the sooner the design issues are solved, the less it costs to correct them (Yudelson, 2008).
3. Avoiding adversarial relationship between design and construction team by aligning the interests of team members towards a shared goal, the traditional adversarial relationship between the two teams with competing interests can be replaced by collaborative and mutual relationships. For example, in traditional design teams, the role of architect is defined as one of observation disclaiming any responsibility for means, methods or existing conditions. Yet, the architect is very much in control of the means and methods that needs to be employed by construction team by specifying products, materials, and equipment. Within traditional delivery methods, the architects also retain their authority to judge the buildings' compliance with the architects' intent, which creates conflict of interests when the intent cannot be clarified in the contract documents (Allen et al., 2005).

2.2.2 **Building Information Modeling (BIM)**

Building Information Modeling (BIM) is a process of generating and managing digital representations of physical and functional characteristics of a facility (National BIM Standard, 2015). Building Information Models (BIMs) are beyond simple database of information, but they can be object oriented models that integrate the three dimensional (3D) document to various dimensions such as schedule, cost, means, methods, and the facility life cycle (Allen et al., 2005). The focus of BIMs, thus, is on producing parametric objects rather than the drawings and 3D images. The parametric objects have various attributes such as: geometric definitions and provisions for their consistency; parametric rules for automatically modifying objects and their associated data; rules for prohibiting changes that violate object feasibility regarding size, manufacturability, etc; and ability to link to, import to, and export data from other BIM related applications (Eastman et al., 2011).

Accordingly, BIM technology can bring many technical advantages such as comprehensiveness, accessibility, and durability of information throughout the project life cycle (Campbell, 2006). As construction projects inevitably generate massive and complex sets of information (Hendrickson and Au, 1989), successful transformation of such information, in construction projects, is key in achieving success in project outcomes such as higher production quality and environmental achievements (Azhar et al., 2008; Homayouni et al., 2011).

Strategies to successfully implement BIM technologies, however, do not only depend on the characteristics of the technology being implemented, but also to the context and the human actors and non-human actors that are affected by the technology. The notion of relative boundedness (Harty, 2008) can be used to better explain the problem. Relative boundedness is about avoiding making coherent and unilateral assumptions about the context in which the change is taking place. This concept sheds light on the range of pre-existing conditions and practices into which the new technology is being implemented. As a study in sociology of technology shows, by implementing a new technology both the artifact and its uses are co-produced in ways that might be unpredicted by developers and implementers (Bijker and Law, 1992). Accordingly, as explained by Whyte (2003) users in different organizations, with different contexts, and sets of requirements, need tailored rather than standardized approaches to implementation of the new technologies.

This section discusses how BIM technologies can bring such achievements by studying some of the major potential applications of BIM in various building project phases from pre-design to occupation and demolition.

BIM in Pre-Design and Planning Phase

Implementation of BIM in construction projects is usually determined in the pre-design architectural phase. During this phase, BIM technologies can help in solving siting issues as well as building orientation and massing, space layout planning and satisfying the building programs, feasibility studies, and setting and aiming for sustainability goals including energy performance (Eastman et al., 2011; Ham et al., 2008; Krygiel and Nies, 2008).

Once the initial schematic architectural model is designed, BIM tools can facilitate presentation of the project to the owner by providing 3D rendered views, which can be enhanced with walkthrough features. BIM tools can also help with the process of decision making via their ability to immediately propagate a change through the model and across all representations, making it easier to compare various design options within a short time (Boland et al., 2007).

Construction scheduling and cost estimating are also involved during the pre-design phase. Here, BIM tools can help designers with providing 4D modeling (including the time dimension) and 5D modeling (including the cost dimension) to perform feasibility studies insuring the building can be built within both allotted timeframe and budget (Eastman et al., 2011).

Once the project is progressed within the pre-design phase, BIM can provide a platform for various team members to collaborate asynchronously, accessing the model from different locations (Lee et al., 2008). Finally, the BIM tools can help in receiving better feedback and inputs from regulatory agencies on code deviances, which can help in shortening the project timeline and reducing redundancies (Glick and Guggemos, 2009).

BIM in Design Phase

One of the major contribution that BIM tools can have in facilitating collaboration and pursuing higher architectural goals is their ability to facilitate design review (Sullivan, 2007). The graphical

information provided in BIM tools helps designers to present their design virtually, making it tangible to be assessed visually as well as rationally (Kalay, 2004).

The built-in features provided in BIM tools, on the other hand, allow rapid reconfiguration and exploration of alternative design scenarios and better analysis and optimization of building systems. This optimization can include many different functional aspects such as structural performance, temperature control, lighting analysis, ventilation, acoustics, circulation, energy distribution and consumption, use of new materials or systems, detailed analysis of user behavior, and other environmental and design requirements. This can result in many design improvements such as sustainability and environmental achievements as well as better facility management (Zanni et al., 2013a, 2013b).

Having the capability to add two other dimensions of cost and time to the 3D model, BIM tools can also help to better manage cost and schedule during the design phase. These capabilities also provide designers with the advantages of performing early logistics and constructability evaluation (Azhar, 2011).

The shift from paper documents to digital files also can result in a shift in official processes resulting in less paper work and faster delivery. Moreover, availability of BIM products with embedded building code requirements can further shorten the review process by regulatory agencies (Ibrahim and Krawczyk, 2003).

Finally, BIM tools facilitate retrieval of knowledge and best practices from one project, to the others. This results in less redundant effort in creating knowledge and standards of practice (Meadati and Irizarry, 2010).

BIM in Construction Phase

Use of BIM technologies can bring many potentials to the construction phase as well. Within the construction phase, use of BIM visualization capabilities for documentation has the potential of adding clarity to construction details, to the extent that the advanced BIM-enabled projects have reported significantly less number of Requests For Information (RFIs) (Hill, 2012). During this

phase, BIM technologies also help with quantitative take offs, estimating quantitative requirements, such as areas, materials, and cost estimates (Eastman et al., 2011).

Another major contribution that BIM tools can have during the construction phase is their ability to automatically detect interferences between architectural, mechanical, electrical, and plumbing systems, known as clash detection. This capability radically improves coordination between engineers, contractors, and subcontractors and provides more cost-effective resolutions to systems' interferences (Eastman et al., 2011).

BIM tools can further track construction activities and phases, which can help in component ordering and delivery and their coordination with spaces and schedules. This could be especially helpful in large projects on urban sites where staging areas are at the premium (Schley, 2014).

Moreover, use of coordinated detailed construction models can help with direct generation of shop drawings, production of materials for install, enhancing productivity and safety while reducing errors and rework or costly resolutions in the field (Aranda-Mena et al., 2009; Azhar, 2011; Barlish and Sullivan, 2012; Sulankivi et al., 2010; Zhang et al., 2013). Coordinated detailed construction models can also be used for prefabrication of systems, which can further help with shortening schedules and risks associated with natural environments, as well as reduce buildings' ecological footprints (Hergunsel, 2011).

Availability of BIMs in construction fields also can help inspectors with comparing the 3D models with actual practices. Implementation of advanced field technologies associated with BIM models, such as Radio-frequency identification (RFID) technologies, also enhances schedule and visualization for material install (Meadati et al., 2010; Xie et al., 2010).

BIM in Occupancy Phase

Use of BIM technologies during the occupancy phase is more challenging and has more room for improvement, as the database used for building design and construction is separate from the information related to human behavior and actual energy data which is needed for effective facility management (Schley, 2014).

Yet, there are areas in which BIM technologies help during the occupancy phase. First, the information about building mechanical equipment available in BIMs can be used for creating a database for ongoing preventive maintenance of the building. This database can be used during the occupancy phase to schedule equipment maintenance based on their life expectancy (Schley, 2014).

BIMs can also be used for space and occupancy management. Large organizations can integrate space related data stored in BIMs with human resource data to optimize space use and vacancy to reduce energy consumption as well as other operating expenses (Schley, 2014).

Another benefit of using BIM during occupancy phase is the relative ease of producing as-built documents. Since BIMs can be detailed with regards to assemblies, finishes, and equipment it can better facilitate management of accurate record drawings (Schley, 2014).

Furthermore, ability of BIMs to store data related to life expectancy and replacement costs of equipment as well as their annual costs helps owners to consider the life cycle costs of buildings during the design phase, therefore invest more on materials and systems that have better performances during the building life cycle. Finally, integrating BIMs with Building Automation Systems (BAS), which provides real-time monitoring and control of the buildings' electrical and mechanical systems, helps in optimizing buildings' energy use (Schley, 2014).

BIM in Demolition Phase

Once buildings reach their end of expected life two scenarios can happen: demolition/deconstruction or adaptive reuse. During the demolition or deconstruction phase, BIMs can provide useful information such as component types which helps to identify which elements can be recycled, reused, or land filled. Moreover, BIMs can provide information with regards to quantities and sequencing to facilitate safe deconstruction. If a building is going for the adaptive reuse scenario, BIMs can help with the buildings' redesign, component reuse, and reduced time and cost. In addition, BIMs can facilitate gaining points in green building rating systems, if one is pursued (Glick and Guggemos, 2009).

2.3 THE NEED FOR A DIFFERENT APPROACH

While adoption of BIM technologies and IPT practices are fast growing concepts within the CEM literature, leading practitioners to adopt the new work processes (Becerik-Gerber and Kensek, 2009), there is a scarcity of literature in contextualizing these elements and providing practitioners with an insight into how to strategize in adopting these processes based on their organizations and projects' characteristics to achieve buildings with higher standard goals such as energy efficiency (Homayouni et al., 2011).

Within organizational and social science, there are numerous studies that indicate organizations can be best studied in configurations, i.e., a combination of different characteristics that usually occur together (Milgrom and Roberts, 1995; Miller, 1993, 1996). This concept is especially used when organizations are about to promote a change within their structure, people, tasks, or technologies (Cherns, 1976). Imposing a change in one of these components without considering its effects on other components may limit the organizations' effectiveness, or result in sub-optimal products or services (Leavitt, 1964).

Within Architecture, Engineering, and Construction (AEC) industry, there are number of studies that point towards the need for the joint consideration of the causal elements and contexts. Chiochinno et al.'s study (Chiocchio et al., 2011) on a number of construction projects shows that without collaboration, trust and conflict have no bearing on performance in construction projects. Other studies point toward selection of inter-organizational collaboration elements such as project delivery method based on project characteristics and acknowledge that misunderstanding other contextual elements is likely to lead to defective delivery processes and/or higher costs (USGBC 2003).

Another study, similarly, points toward the complementary relationship between contributing elements to implementation of BIM by showing that among companies that use energy simulation, less than 25% use energy simulations only on less than a quarter of their projects (Young et al., 2009). This finding indicates that choosing to use energy simulation on a project does not only depend on companies competence to use such tools, but also other project characteristics such as project sustainability goals.

Yet, within CEM domain, there has not been many studies on finding the interdependencies between social, organizational and other contextual elements affecting delivery of HP projects, and understanding how IPT, BIM and other project contextual elements come together to result in higher performance buildings. This study was an attempt to address this existing gap.

Chapter 3. **RESEARCH SETTINGS AND METHODOLOGY**

3.1 **RESEARCH OBJECTIVES**

This study was performed to advance the understanding of IPT practices and implementation of BIM technologies within HP buildings. The following objectives were of interest in this research (in the order of appearance within the thesis):

1. To demonstrate the application of fsQCA method in AEC and CEM domain.
2. To provide a framework for assessing IPT practices and BIM implementation considering the comprehensiveness and versatility of conditions required for fsQCA methodology (the proposed framework can be used to answer other research questions around IPT practices and BIM implementation leading to other desired construction project outcomes such as lower cost and faster schedule).
3. To investigate how different contributing elements to IPT practices and BIM implementation come together to result in lower energy consumption within HP buildings in United States (main body of this research).
4. To provide a strategizing guideline for practitioners to achieve Higher Performance buildings.

3.2 **RESEARCH METHODOLOGIES**

The applied methodology in this study includes case study and interviews, surveys, and fsQCA method:

3.2.1 **Case Study and Interviews**

This study is built on a series of interviews and a case study performed by the Collaboration, Technology and Organizational Practices (CTOP) research group in University of Washington. The team observed the social, organizational, and technological strategies that multidisciplinary integrated design teams used to collaborate on the design and pre-construction process for a scientific research lab project in a U.S. city. The field notes (over a total of 300 field hours of work) taken from the observations were compared using an iterative coding scheme based on the methods of “grounded theory” development (Corbin and Strauss, 1990; Glaser and Strauss, 1967).

Similarly, using a semi-structured interview tool on collaboration, communication, organizational culture, and BIM, the CTOP group performed 70 interviews with architects, engineers, and builders for 60-90 minutes. This research built theoretical categories of IPT and BIM implementation by analyzing all the case study field notes and a purposive subsample of the interview data on experiences with BIM.

3.2.2 Questionnaire Survey

To come up with fuzzy-set values for the conceptual categories of project IPT practices and BIM implementation, constructed from the case study and interviews, a survey was designed to measure various aspects and extent of BIM implementation and IPT practices for a set of HP projects (explained in Chapter 6). The survey was sent to 90 Architects from the AIA COTE Award-winning HP projects. Data was calibrated into fuzzy sets and formulated to quantitatively combine the values in each condition using fuzzy sets.

3.2.3 FsQCA

By performing fsQCA in this research, the created conditions and their fuzzy scores were used to find the most stable and statistically reliable configurations of conditions resulting in the most energy efficient HP buildings. Studying how projects populate the property space, made it feasible to recognize the complementarities among conditions and comprehend the existing patterns. This research, thus, proposed configurations of BIM conditions that when combined by (presence or absence of) integration strategies result in greater energy efficiency within HP buildings.

3.3 SCOPE LIMITATIONS

The scope of the main body of this research (the third listed objective) is limited in several aspects:

1. Among different practices that are developed to reduce environmental impacts of buildings, only HP buildings are chosen to work with in this study. Choosing HP buildings over other practices is due to HP buildings' promise to reduce energy consumption, which is the subject of interest in this research. Furthermore, in contrast with green buildings, for which buildings' stakeholders go through a specific process to meet the requirements of the green rating systems such as LEED, or BREEM, any building that is built with higher standards in terms of environmental impacts can be recognized as an HP building.

2. While there are other HP buildings available to study, this research included only AIA top ten Committee On The Environment (COTE) awarded projects. This database was selected because of the recognition the buildings have received as HP buildings (eliminating the need for further assessments of buildings to meet the required criteria to be considered HP buildings). Convenience of accessing case studies and contact information of the architects, provided with the AIA website, was another consideration for choosing this database.
3. Within the chosen AIA awarded projects only the projects awarded between 2005 and 2013 are selected to work with. This is in part due to inability of project participants to recall events happened far in the past, which would affect validity of the study. Furthermore, BIM technologies studied in this study are changing and advancing every year, lessening the relevancy of the projects delivered far in the past.
4. Only the buildings within the United States are included in our study. This is because our outcome condition (equivalent of dependent variable in conventional quantitative studies) is mainly built by the buildings energy reduction, which is calculated by comparing the energy use of buildings with the baseline building that has similar function and geographical condition. Since we have access to such baseline targets only for regions within the U.S., other AIA awarded buildings outside the U.S. were excluded from the study.
5. In this study, only the projects' architects were asked to fill out the survey. The research results, thus, are subjective to architects' points of view. This choice is also made based on the convenience factor and the complication of analyzing various points of view with fsQCA method. After all, architects are the sources who know the most about the states of IPT practices and BIM implementation within the project.

Chapter 4. QUALITATIVE COMPARATIVE ANALYSIS AND CAUSAL COMPLEXITY

Qualitative Comparative Analysis (QCA) is a methodology developed by Charles Ragin (Ragin, 1987) to bridge the sharp divide that existed between small- N qualitative analysis and large-N quantitative studies within social science research. Small-N qualitative study is case-oriented research relying upon depth of analysis while large-N quantitative study is variable-oriented research that relies on breadth of analysis. Table 1 compares and contrasts the two common approaches.

Table 4-1- Comparison between variable oriented and case study method (Ragin, 2000).

Variable-oriented research (large N)	Case study research (small N)
Correlation study	Causality study
Cases are almost invisible; the set of cases are almost fixed	Cases have clear identities and are chosen specifically because of their theoretical significance.
Elements compete to produce an outcome	Causal elements combine to produce an outcome- Researchers use their in-depth knowledge to explain the causation.
Variables have autonomous existence; Underlying homogeneity assumption among cases	Variables are defined in their context; all cases are unique

Qualitative Comparative Analysis defines a middle ground between these two extremes, studying medium-sized number of cases (i.e. 25-50) (Schneider and Wagemann, 2006). As in variable-oriented studies, using QCA method, causal elements can be studied broadly, but without imposing homogenizing assumptions at the outset of the research. In these studies the boundaries between case categories are not assumed, nor are they fixed. Instead, they are fluid. As in case study research, QCA investigators may disaggregate and differentiate, but not to the point that every case seems unique. Researchers seek to define classes and categories, kinds and types. “Studying social phenomena in terms of their different kinds or types lies midway, conceptually speaking, between studying general patterns across all cases, on the one hand, and attending to the complexity of specific cases, on the other.” (Ragin 2000, pg 35)

QCA is based on the idea that causal relationships are not easily understood due to several characteristics of causation for social and organizational phenomenon. First, there are almost

always multiple causes resulting in the same outcome; second, causal relationships in a single phenomenon are usually interrelated; and lastly, causal elements may have different and even opposite effects in different contexts (Greckhamer et al., 2007). In QCA method the interpretation of data is based on the context, meaning two conditions (variables are called conditions in QCA) with the same values are interpreted differently if they have different values in other related conditions. In other words, a single change observed in one of the aspects can qualitatively change the whole configuration. QCA method enables the researcher to define cases as sets of qualitatively derived causal attributes to determine causal pathways by comparing sets of cases with shared attributes and outcomes, and use theory to interpret the results.

QCA is capable of analyzing complexities embedded in causal mechanisms in various social and organizational phenomena, and is based on the premise of finding equi-final causal recipes for producing an outcome. Each causal recipe consists of a combination of “INUS” conditions. An “INUS” condition is a causal condition that when considered alone is “Insufficient” for producing an outcome but is a “Necessary” part of a causal recipe, which is itself “Unnecessary” but “Sufficient” for producing the outcome. In other words, an INUS condition needs the context of the other conditions to achieve the desired outcome; and there are several sufficient recipes for achieving the same outcome. QCA allows researchers to deal with this complexity and draw causal inferences (Schneider and Wagemann, 2006; Wagemann and Schneider, 2010).

QCA is applied in three main forms: crisp set QCA (csQCA), Multi Value QCA (mvQCA), and fuzzy set QCA (fsQCA). In csQCA, conditions can take only crisp values of 0 and 1. MvQCA, on the other hand, is applied when conditions take categorical conditions with more than two categories. Similarly, fsQCA aims to handle variation in conditions, and are applied in cases where number of categories become too large to use mvQCA. This method will be discussed in more detail in next section.

The first phase of QCA approach is constructing a property space out of a set of theoretically relevant causal conditions. In this phase, the causal and outcome conditions are built from theory and each case is represented as a configuration of the causal and the outcome conditions.

The second phase of QCA approach is to examine the distribution of cases across the property space (demonstrated in section 7.4). Here, researchers employ methods of numerical taxonomy,

clustering algorithms and hypothesis testing techniques to identify combinations of conditions that appear as clusters and are sufficient for producing the outcome (Miller, 1996; Ragin, 2000).

In csQCA, the second phase is performed by constructing and analyzing the “truth table”, built by creating a table with “k” (k=number of causal conditions) columns and 2^k rows. Each row represents a unique configuration of conditions in terms of their presence/absence (with the two crisp values of 0=absence and 1=presence). All cases are then associated to one of the rows with the same configuration of conditions. The configurations that do not represent any cases, called “logical remainders”, will be eliminated from the truth table. Next, Boolean algebra is used to combine configurations and present them in more parsimonious way.

For each configuration, the percentage of cases in which the outcome is present is calculated. This number is called “consistency value”. Evaluation of the truth table can be performed deterministically or probabilistically. In deterministic QCA, only configurations with consistency values of 1 are evaluated as causal recipes. In probabilistic QCA, on the other hand, the “consistency” value is set to be more than certain value (usually between 0.75 and 1). If the consistency threshold is set to 0.8, for instance, less than 20% of cases can be contradictory to the existing causal recipe (Ragin, 2008).

The other set theoretic term used to report the results of QCA is called “coverage”. The coverage value represents the degree to which a causal recipe accounts for incidence of an outcome. As an example, if a raw coverage threshold is set to 0.3, at least 30% of cases should exhibit the presented causal recipe. The more the coverage value, the more applicable and noteworthy the presented causal recipe becomes.

After constructing the truth table, the researcher uses Boolean minimization techniques to combine sets of configurations into more parsimonious ones. They may also use theory and their substantive knowledge and engage in thought experiments to use logical remainders in favor of reaching more parsimonious solutions, or leave them out of the analysis and create more complex configurations, without relying on imagination and thought experiments.

During the final stage of the analysis, the resulted configurations (causal recipes) are evaluated and interpreted. If they show inconsistency with researchers’ substantive knowledge, the

conditions are re-defined/recalibrated and the analysis will repeat in order to reach comprehensible results. To verify that the identified configurations have causal relationship with the outcome, other methods such as process tracing, formal logic, intervening variables, or multidisciplinary knowledge is used to establish existence of causal mechanisms. During this stage, researchers might selectively add cases to the analysis to insure existence of causal mechanisms. The intervening variables method is demonstrated in section 7.4-Construction of the Truth Table.

4.1 FUZZY SET-QCA

Since Lotfi Zadeh (Zadeh, 1965) expanded set-theoretic methods by introducing fuzzy sets in 1965, these techniques have received great attention from researchers in a wide variety of scientific areas. Ragin (Ragin, 2000, 2008) combines fuzzy sets with QCA method creating a powerful methodology that is able to analyze causal complexities by addressing the diversity that exist in configurations of sets (with QCA) as well as the diversity in which elements belong to a set (with fuzzy sets). In contrast with dichotomized conditions in crisp sets, where elements can have either membership scores of 0 or 1 in sets, in fuzzy sets, elements can have any membership score within the range of 0 to 1.

Fuzzy sets, however, are much more than continuous variables. They are in fact heavily infused with theory and experimentation in that they reflect diverse nature of the characteristics being studied. This infusion allows researchers to refine and adjust the sets numerous during the course of a research, providing new possibilities for interpretation of data and representation of results (Ragin, 2000).

Since with fuzzy sets we can have numerous partial memberships in a set, Boolean algebra might not seem adequate for working with such sets. However, Ragin (2000) used fuzzy logic and data analysis techniques to focus on set-theoretic relationships in fuzzy sets and showed how they can be used with QCA method.

The main developed technique is on construction of the property space and the truth table. Using the same method as csQCA for construction of the property space in fuzzy sets would result in a table with infinite number of columns, and for the truth table would result in a table with infinite number of rows. Ragin's new methodology uses the correspondence that exist between rows of

the truth table in csQCA to corners of the multi-dimensional vectors space created by fuzzy set causal conditions and maps the multi-dimensional vector space in fsQCA analysis to a two dimensional truth table. In created fsQCA truth table, for each fuzzy set causal condition, the crisp value that is closer to the fuzzy value is considered for finding the closest crisp configuration for each case with fuzzy values. This lack of precision, however, is reflected in the corresponding consistency and coverage values, creating a firm methodology for applying QCA on fuzzy sets (Ragin, 2000).

4.2 QCA AND FUZZY SETS IN CEM DOMAIN

In the special issue on Research Methodologies in the Journal of Construction Engineering and Management, Taylor and Jaselskis (Taylor and Jaselskis, 2009) argue that “the interdisciplinary project-based nature of the work, industry fragmentation, one-of-a-kind end products, site-based production, and other factors combine in ways that make following established research methodologies difficult.” (pg 1) One of the biggest challenges of variable oriented-studies in AEC research is the number of variables that determine the success or failure of projects and the unique nature of construction activities. For instance, correlations between the introduction of new technologies or work processes and the resulting benefits on a project are often very difficult to measure. Causation is even more difficult to prove, where individual attitudes, group dynamics, local market conditions, luck, and project momentum can impact the performance on projects before researchers even begin to consider variations across business practices, management techniques and technology applications (Taylor et al., 2010).

In response to the complexity of organizational and technological processes, case-based research is growing in the AEC domain. According to Taylor and Jaselskis (Taylor and Jaselskis, 2009), 16% of papers published from 1993–2007 were qualitative or quantitative case research. Researchers in the AEC domain are seeking methods that deal with the complex and diverse nature of construction sites while providing rigor in terms of breadth and generalizability.

While rigorous quantitative, “large N” analysis provides convincing evidence of correlations between dependent and independent variables, case-study research is an opportunity to describe the process by which a complex phenomenon unfolds. Case-study research is criticized as not

being generalizable, while conversely it is difficult to ascertain and conclude causal connections through so-called “large N” statistical methods (Taylor and Jaselskis, 2009).

Analyzing the applications of set-theoretic methods in the business management and organizational literatures shows that there remains a middle ground that has a great potential to grow in AEC domain—smaller numbers, related cases, fuzzy sets. It is this middle ground that arguably has great potential for social, organizational and technological research in the AEC domain.

While causal complexity is being more and more addressed in organizational science and management research using QCA, there are differences between the cases studied in those disciplines and those in the AEC domain. For example,

- Construction projects are temporary efforts with a less certain start and end time. Thus Construction project managers require different skills from managers governing an organization with repetitive and permanent business plans (Davies et al., 2010).
- Clients who are not a part of the design and construction supply side determine project goals in construction projects (Cornick and Mather, 1999).
- Team composition is not necessarily defined by the team members’ ability to form an effective team but because of their attractive design and a competitive price for construction (Cornick and Mather, 1999).
- Method of working is based on the conventions of how each entities including owners, architects, and contractors carry out their normal practices through traditional contractual arrangements (Cornick and Mather, 1999).

While the nature of organizations in construction differ from that of other fields, fsQCA can still be applied to help researchers address causal complexity within—and across—the AEC domain. Table 4-2, presents the motivations of scholars in management and related fields to move toward fuzzy sets and QCA research and compares those with similar conditions found existing in the CEM domain.

Table 4-2- Similarities between research in management and CEM domain that indicate the significance of applications of QCA in CEM domain.

	Underlying conditions for use of fuzzy sets and QCA in organizations and management studies	Presence of similar conditions in CEM domain
Conditions	Fuzzy sets can be used in domains in which classes of objects do not have precisely defined criteria of membership (Zadeh, 1965).	Many classes of objects in AEC domain such as building performance, IPT, etc do not have precisely defined criteria of membership.
Population	Existing gap between large N-quantitative research and small N case studies in social science (Ragin 2000).	A similar division exists between large N-quantitative research and small N case studies in AEC domain. (Taylor and Jaselskis 2010)
Complementarities among Elements	Firms face complementarities between multiple elements influencing the organizational performance, such as strategy, structure, leadership, and technology (Fiss, 2007).	Complementarity exists between factors influencing the performance on projects such as individual attitudes, group dynamics, local market conditions, luck, and project momentum (Taylor et al., 2010).
Comprehensibility of Patterns	Cultures and processes of successful organizations tend to fall into comprehensible patterns (Miller 1993).	Organizational cultures in AEC can be analyzed to understand patterns of choices of strategies such as technology adoption (Dossick and Neff, 2009, 2011; Homayouni et al., 2010).
Integrating Strategies	Achieving a match among structures, activities, and the environment is essential for organizational success (Miller 1996).	Achieving a match among project-related factors, project procedures, project management actions, human-related factors and external environment is essential for successful delivery of projects in AEC domain (Chan et al., 2004).

As shown in Table 4-2, five conditions can be identified as underlying conditions in organizations and management studies that make fsQCA ideal for studies in those domains (one addressing the fuzzy set aspects and four addressing the QCA method). The same conditions can be found present in CEM domain, which indicate fsQCA method can be appropriate for exploring causal complexities existing in CEM domain as well.

The main underlying point that explains the applications of QCA in organizations is that activities in manufacturing firms are usually complementary, which means that using or applying more of any of them increases the returns on using or applying more of others (Milgrom and Roberts, 1995). These complementarities exist between organizational elements such as strategy, structure,

leadership, and technology (Fiss, 2007). On the other hand, identifiable changes in technology and demand as well as coherent business strategies that exploit existing complementarities can lead to coherency of patterns (Milgrom and Roberts, 1995).

In the CEM domain, critical success factors of construction projects can be grouped under five main interrelated categories of human-related factors, project-related factors, project procedures, project management actions and external environment (Chan et al., 2004). Conventional quantitative research approaches collapse, ignore to some degree, the underlying homogeneity assumptions of these complementary elements or factors, thus making it difficult to tease out the distinctions among them. QCA methods, however, offer a new solution that enables researchers to empirically study complementarities as well as substitution effects. These methods would empower researchers to address questions such as “which activities may be successfully removed without harming performance” (Fiss, 2007).

Strategy researchers can also use QCA methods because activities, strategies, cultures, processes and goals in organizations show a tendency to fall into coherent patterns (Miller, 1993). These patterns, such as the strategic choices that fundamentally shape which elements or aspects of project organization are implemented or configured, can overwhelmingly determine other outcomes. For example, there are several strategic choices in construction projects that are fundamental determinants of how elements are configured into specific business patterns, such as how decisions about responsibility and risk help to determine which business model to pursue on a particular type of project (Davies et al., 2010). Organizational cultures, too, can have a wide-ranging impact on how construction projects pursue project outcomes, making certain pathways or collections of elements more likely to occur together (Dossick and Neff, 2009, 2011; Homayouni et al., 2010).

In organizational research, “configuration itself is the very essence of strategy” (Miller, 1996). Organizations can benefit from research that shows how to match structures, activities, and the environment. Successful delivery of construction project depends on finding such a match among these factors (Chan et al., 2004). Thus, methods to study which configuration of elements makes the most sense strategically could have a significant impact on the research in the CEM field. In addition to helping to identify these configurations of business elements, QCA allows for the study

of complementarities among causal elements and comprehensibility of patterns in organizational cultures and processes, and for these reasons this method can be highly applicable to the studies in CEM domain.

4.2.1 FsQCA and Analyzing Complexity of IPT Practices and Use of BIM Technologies within HP Projects

This section presents the underlying circumstances that make fsQCA specifically appropriate for this study and similar studies around BIM and IPT.

Fuzzy Sets and Qualitative States of Conditions

As it is noticeable in Figure 4-1 most of the conditions around the subject of BIM implementation and IPT practices are qualitative attributes that are not best represented with quantitative means. Fuzzy sets, however, facilitate interpretation of qualitative states in a way that the fuzzy values are consistent across the study and can be incorporated with other set-theoretic methods such as QCA (Ragin, 2000; Zadeh, 1965).

QCA and Complementarity among Elements

As discussed in section 2.3, factors affecting successful design and construction of HP projects, including contextual factors, project's environmental goals, IPT practices, and BIM implementation are complementary. This inter-relationship, depicted in Figure 4-1, makes it unpractical to use conventional quantitative methods of analysis for finding the net effects of each element on the outcome. In fact, some of these elements might have opposite effects within different contextual elements. As a general example, Implementation of BIM within the right structural settings, such as a highly integrative project team, and within a complex project might have a positive effect on desired project outcomes such as achieving sustainability goals. However, the same causal element of BIM implementation might have disastrous outcomes on a project with the same complexity but with non-collaborative atmosphere. In fact, a single change observed in one of the aspects (IPT practices) can qualitatively change the whole configuration.

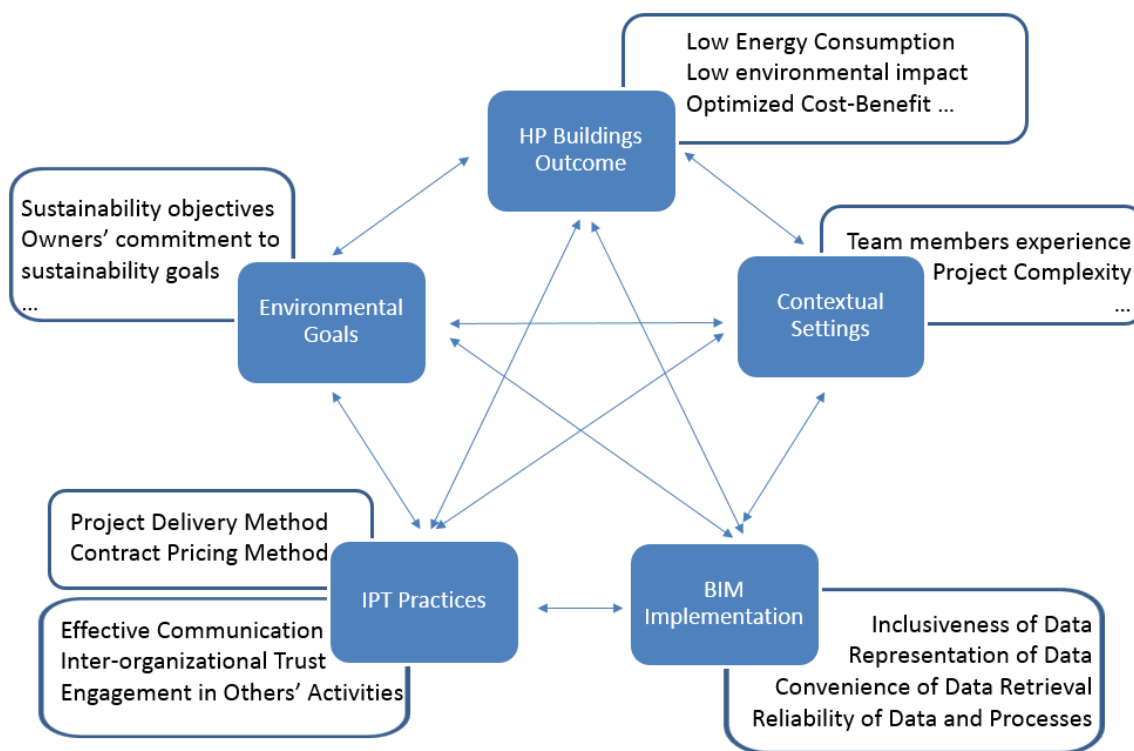


Figure 4-1- Inter-relationship between factors affecting delivery of HP buildings

In contrast, complementarity among elements, shown here, provides a suitable and rich context for using QCA method to explore the existing causal complexity to find some of the core relationships among the elements resulting in higher performance buildings.

QCA and Comprehensibility of Patterns in Organizational Cultures and Processes

Organizational cultures in AEC show comprehensible patterns around adoption of new technologies (Dossick and Neff, 2009, 2011; Homayouni et al., 2010). As an example, construction companies with slack resource and strong leadership are often more open to accepting risks such as adoption of new technologies, and are more likely to foster construction innovation (Tatum, 1989). This comprehensibility of patterns makes it possible to analyze clusters of data around certain social, organizational and structural elements, and form classes and types of HP projects based on similarity of patterns within each type. QCA empowers researchers to engage in data analysis and thought experiments to find and comprehend existing patterns.

QCA and Need for Strategizing

Construction industry is a highly competitive industry in which strategizing is key for success. Organization leaders try to achieve a match among project-related factors, project procedures, project management actions, human-related factors and external environment to achieve success (Chan et al., 2004). Required configurational thinking, which lies at the heart of QCA method, empowers researchers to propose a strategizing framework for organizational leaders and practitioners to increase their chance of achieving project goals such as sustainability achievements.

QCA and Lack of Large Number of Cases

Another reason that makes QCA method practically appropriate for studying BIM and IPT practices within HP projects is the limited availability of HP projects. Accordingly, studying IPT and BIM practices within HP projects with conventional statistical methods is highly challenging as reaching a significant result with these methods is directly related to the number of cases under the study. QCA method, on the other hand, allows inferences to be drawn from the maximum number of comparisons that can be made across the cases under analysis (Goldthorpe, 1997) and is capable of reaching significant results based on medium number of cases (i.e. 25-50) (Schneider and Wagemann, 2006).

4.2.2 Challenges of Using fsQCA Method in Analyzing BIM Implementation & IPT Practices in HP Projects

Despite the many characteristics that research studies on BIM implementation and IPT practices within HP projects possess that make fsQCA method appropriate for such studies, exploring these areas with this method has some limitations as well:

FsQCA and Required In-Depth Knowledge of Cases and Conditions

There are three steps in which familiarity with cases is required in using QCA. First, before the analysis stage, familiarity with cases is important for identifying analytically relevant conditions and to specify each case's membership in them (Schneider and Wagemann, 2010). Second, during the analysis, familiarity with cases helps to select parameters such as consistency threshold with

QCA (Schneider and Wagemann, 2010). Familiarity with cases and conditions is also crucial in this stage, as it facilitates working with fuzzy sets for adjusting the fuzzy values, going back and forth between theory and substantial knowledge (Ragin, 2000). Finally, after the analysis, in-depth knowledge of cases is required to facilitate interpretation of results (Schneider and Wagemann, 2010). While gaining such familiarity with the cases using BIM and IPT is not impossible, it is challenging as the industry is highly fragmented and in-depth knowledge of cases requires familiarity with all the fragments and attributes that affect adoption of the new technology and facilitate IPT practices.

This problem can be addressed by coupling the QCA method with in-depth qualitative field studies of few number of cases (as in this research). This exercise, although cumbersome, can provide the insight required for objective judgment throughout all phases of QCA method.

QCA and Large Number of Causal Conditions

The large number of conditions associated with implementation of BIM and IPT practices illustrated in Figure 4-1, is an important impediment for using QCA method. This is due to the fact that as the number of causal conditions increase, the number of configurations associated with the conditions increases exponentially. Working with large number of cases, practitioners recommend selection of 10 or fewer causal conditions which leads to 1024 configurations of causal pathways (Ragin et al., 2008). This number would be less with fewer number of cases as reliability of the analysis depends on the extent in which cases populate the property space (representing all configurations) as will be demonstrated in section 7.4. This is due to the fact that increase in the number of configurations results in having more configurations without any case representing them. Thus, as the number of conditions increase, researchers need to rely more on supposition and theory rather than data and knowledge of cases (Ragin, 1987).

As an example, if 32 cases are in the study, working with 3 causal conditions would result in $2^4=16$ configurations, which means there is a good chance that all 16 configurations are represented by a case (Best scenario each configuration can be represented by $32/16=2$ cases. However, if the number of conditions increase to 6, there would be $2^6=64$ possible configurations, meaning at least $64-32=32$ configurations would not be represented by any cases.

To reduce causal conditions that are related to the subject matter four approaches can be used:

1. Grouping of conditions: One way of reducing the number of causal conditions is to combine them under a larger and more comprehensive condition. This categorization, however, needs to be informed by theory with attempt to minimize the amount of useful information that will be lost in combining process. For instance, the BIM implementation factors represented in Figure 4-1 can be categorized under a single more comprehensive category representing BIM maturity of projects. This categorization might be concise enough for answering some research questions such as the one subject to this study. If the study calls for it, this category can be broken down to more specified categories such as BIM maturity within design phase verses construction phase.
2. Use of two phase fsQCA analysis: Another method to deal with large number of causal conditions, proposed by Schneider and Wagemann (2006) is use of two step fsQCA method. This method suggests to divide causal conditions to two sets of factors; remote and proximate. Remote factors are contextual conditions that are relatively stable over time, while proximate factors vary over time and are subject to changes by human actions or agencies.

Accordingly, the analysis in the first step can be limited to the remote factors and finding the different combinations of contextual factors that make the outcome possible. Such combinations of contextual factors are called ‘outcome-enabling conditions’. During the second phase, the proximate factors within the outcome-enabling conditions can be analyzed to find the combinations of proximate factors and outcome-enabling conditions that lead to a given outcome. The two-phased method increases the researchers’ ability to draw solid inferences from their findings, by eliminating the irrelevant combinations of attributes in the first phase and decreasing the exponential effect of increasing the conditions in the second phase (Schneider and Wagemann, 2006).

Within the research domain of BIM implementation, the remote factors can be defined as environmental and structural settings, BIM features, and organizational level IPT practices. These are the conditions that are relatively stable during the course of a project. Consequently, BIM strategies, and individual and team level collaboration strategies can be analyzed as proximate factors.

3. **Eliminating Conditions with minimal variation:** Conditions that show low variation within existing cases can be recalibrated or combined with theoretically relevant conditions, as explained above, and be incorporated into the study. However, if the variation is very low that cannot be captured by recalibration or cannot add meaning to the study by its addition to other conditions, they should be eliminated from the study.
4. **Tapering the scope of research:** Another strategy for dealing with large number of conditions is reducing the research scope by keeping several elements constant at a time and exploring how other elements would interact within the given circumstances. In this study, for instance, it is possible to keep the market condition constant by selecting cases within certain time frame where construction market has remained relatively unchanged.

The next section will discuss the two main elements of IPT practices and BIM implementation and the inter-related factors contributing to their achievements.

Chapter 5. CATEGORIZATION OF LITERATURE ON ANTECEDENTS OF IPT PRACTICES AND BIM IMPLEMENTATION

This section presents the literature review pertaining contributing elements to IPT practices and BIM implementation. Gaining an understanding of how each contributing element facilitates IPT and/or BIM implementation provides researchers with the substantive knowledge required for analyzing cases and calibrating the causal conditions within fsQCA. First, the common contractual approaches to IPT practices are introduced from the CEM literature. Then the organizational approaches to collaboration and IPT practices are discussed using organizational management as well as CEM literature. Finally, the organizational management and CEM literature is used to review antecedents of successful BIM implementation within AEC industry.

5.1 CONTRACTUAL APPROACHES TO IPT PRACTICES

Within construction projects, construction delivery contracts work as principal tools for allocating risks among the core team members (usually owner, architect and contractor) to the extent that they do not violate higher level risk allocation means: case law, regulation, or statute (Allen et al., 2005). Contractual agreements can implement five major approaches to influence IPT practices within construction projects: 1) selection of a more integrated type of delivery method, 2) selection of a pricing method that allows change within the design after the construction contract award, 3) provisioning shared incentives, 4) transparency of operations and financial transactions, and 5) limiting litigations (Schaufelberger and Holm, 2002, Cholakis, 2013; Thomsen, 2010).

While within the traditional Design-Bid-Build delivery method, the contract document is awarded to the construction firm with the lowest hard bid, at the end of the design process, today, various delivery method structures are utilized, to provide different forms of authority and communication channels among core team members. Yet, the choice of delivery methods are more restricted on public projects because of public procurement and bidding requirements imposed on some projects.

Figure 5-1 through 5-5 show a number of typical delivery method structures representing different levels of hierarchies and separation of functions within them (The vertical lines show existence of

a contractual agreement between the two entities). In facilitating communication and collaboration among the core team members (owner, architect, and general contractors) via the project delivery method, three factors are found effective:

1. Bringing the contractor early into the process, which, other than the design-bid-build method can be achieved in other delivery methods.
2. Selection of contractors based on previous relationship, good reputation and compatibility with other core teams, rather than the hard bid. This approach can be used in all methods including variations of Design-Bid-Build such as negotiated and invited Bids.
3. Allowing partnership or Joint ventures among core team members. This can be achieved partially through Integrated Design Build and completely within Integrated Project Delivery methods, explained at the end of this section.

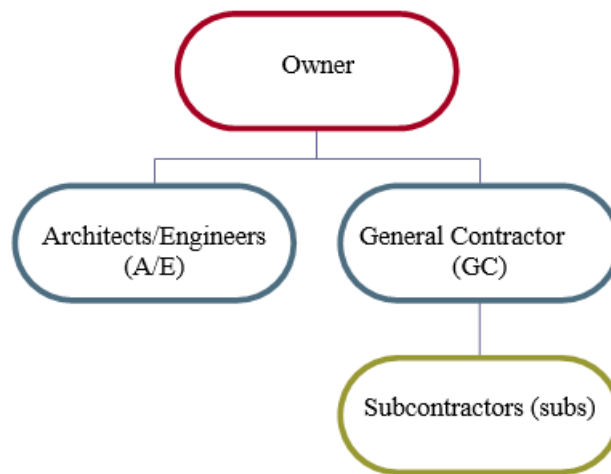


Figure 5-1- Typical model for Design-Bid-Build delivery method

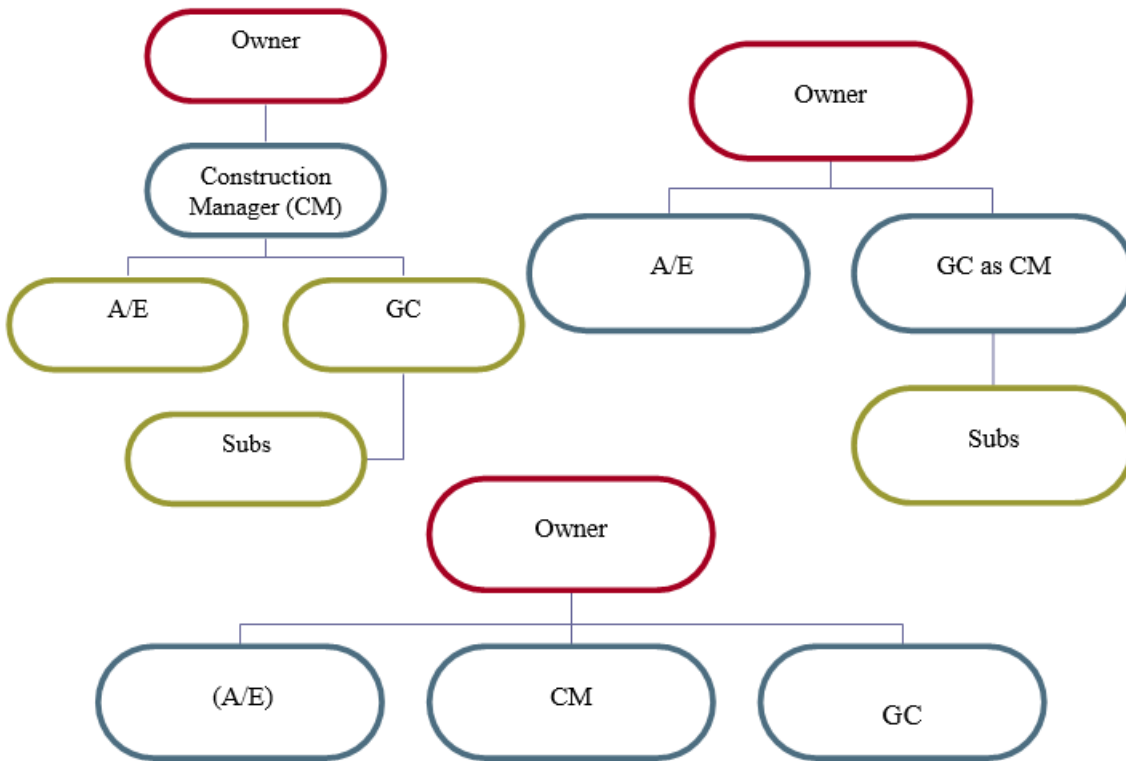


Figure 5-2- Three models for Construction Management at Risk delivery method

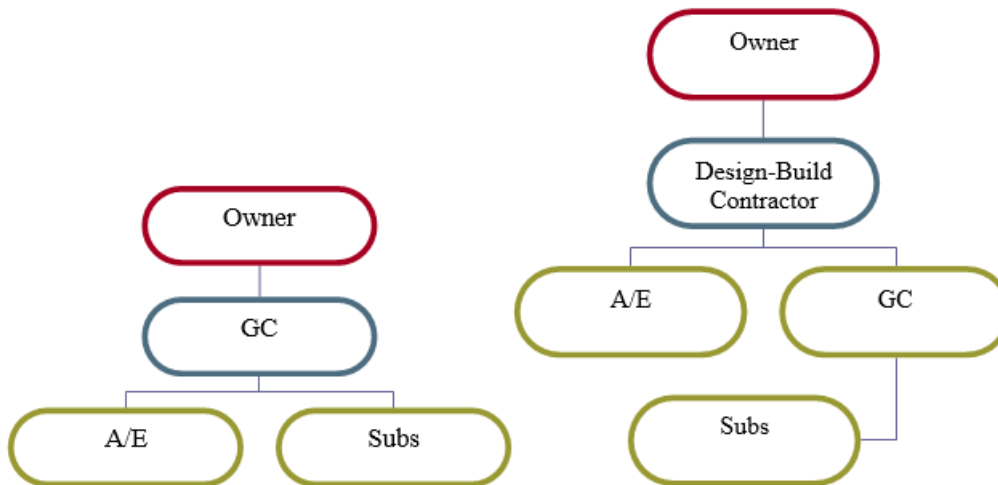


Figure 5-3- Two models for Design Build delivery method

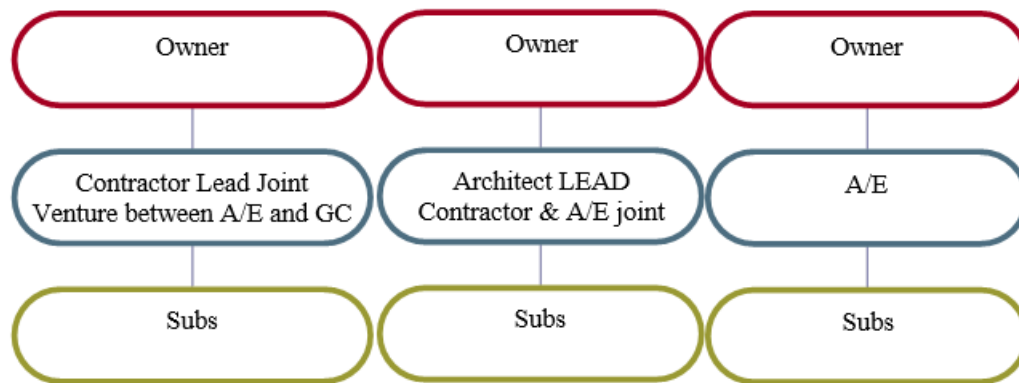


Figure 5-4- Three models for Integrated Design Build delivery method

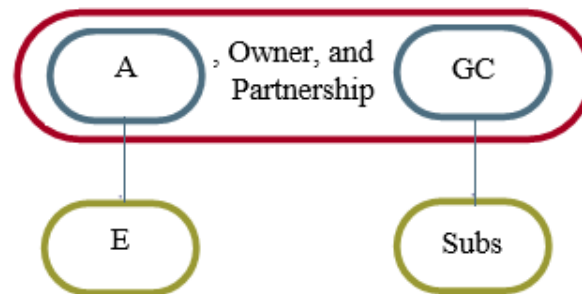


Figure 5-5- Typical model for IPD delivery method

The choice of the contract pricing method, also has a great impact on the IPD practices within construction teams. The three main types of cost acquisition contracts in building construction projects are lump sum (also known as stipulated-sum or fixed-price), cost-plus, and cost plus with Guaranteed Maximum Price (GMP) contracts (The unit price contract is mostly used in infrastructure projects where the scope of work is not determined at the time of contract award). The owner, usually selects the pricing method based on the risk associated with the project and his decision on the portion of the risk to assume and the portion to impose on the contractor (Schaufelberger and Holm, 2002).

The lump sum contract is used on projects where the scope of construction work can be defined. In such cases owner agrees to pay a fixed price to the contractor compensating his work in constructing the project based on the provided set of design drawing and specifications. In construction projects where contractor is performing the construction work under Lump sum contracts, the value of resources or time expended by construction team does not affect the

contractors' payment (Schaufelberger and Holm, 2002). Therefore, contractors under lump sum contract have the tendency of using resources that meet the design specification with lowest prices which usually equals lowest quality. In addition, finding discrepancies in design documents and specifications in lump sum contracts would result in an increase in the agreed lump sum amount. Thus, contractors and architects relationship has a tendency to become adversarial as the contractors usually put some effort in finding such discrepancies and architects tend to argue against it to protect their own interest. As a result lump sum contracts are the least supporting methods for IPT (Al Khalil, 2002).

However, lump sum contracts can also be used on design-build projects, in which case the design-build contractor agrees to design and build a project based on owners' specified design criteria (Schaufelberger and Holm, 2002). In such cases, since architects and contractors are working as a single entity, they would have more friendly relationship, although the owner and the design-build contractor might not be as collaborative as other contract pricing methods (Al Khalil, 2002).

Cost-plus contracts, on the other hand are used when the scope of work cannot be defined at the time of contract award. In cost-plus contracts all specified contractors' project related costs are reimbursed by the owner and a pre agreed upon fee is added to cover profit and company overhead. There are various methods for calculating the fee amounts which will be specified in the contract (i.e. fixed fee, percentage fee, etc.)(Schaufelberger and Holm, 2002). This contract pricing method has ultimate opportunity for designers and contractors, as well as owners to collaborate in a friendly environment, as their interests do not conflict. In addition, the project duration tends to become shorter in cost-plus contracts mainly due to the overlap in design and construction phase, while the cost as well as quality tends to go higher (Bajari and Tadelis, 1999).

GMP contracts are a type of cost-plus contracts in which contractor agrees to construct the project at or below a certain price. If the project cost overruns the specified price, the contractor needs to pay for the extra costs. On the other hand, some GMP contracts have saving-sharing clauses to split the difference between the project cost and the agreed upon maximum price, if the project cost ends up lower than the GMP. In addition to supporting IPT, this contract pricing method provides some incentive for contractors to lower the project cost (Schaufelberger and Holm, 2002).

In addition to choosing the right project delivery and contract pricing methods, incentive clauses can be added to contracts to encourage core team members to pursue higher level project financial goals as opposed to mere organizational profits. Shared incentives within contracts may include some or the entire project profits and contingencies and may include bonuses for meeting or exceeding defined goals. Depending on the delivery method and project nature consultants and sub-contractors may or may not be included inside the circle of shared risks and rewards (Cholakis, 2013; Thomsen, 2010).

Furthermore, transparency in operations and especially financial transactions can lead to higher level of trust during the course of delivery of the construction project. The created trust, in turn can help build/grow integration within the team members. In IPD projects where risks and rewards are shared among the key team members such transparency is very important (Thomsen, 2010).

Finally, to embrace the spirit of integration and avoiding adversarial relationships litigations can be constrained by conflict resolution procedures or in the case of IPD projects sharply curtailed by non-sue clauses (Thomsen, 2010).

IPD is the delivery method that is perceived to have the potential to leverage all the discussed contractual settings for better IPT practices (Thomsen, 2010). As shown in Figure 5-5, IPD model is the most collaborative form of delivery method, with a multiple-party contract that stipulates the duties that core team members (including the owner) owe to one another (Cholakis, 2013; Thomsen, 2010). IPD can be simply described as a repeating pattern of research/analysis and team workshops. Through such iteration of developing holistic learning processes, team members can regain a holistic approach towards building design and construction.

Within IPD contracts IPT is facilitated using all three integration elements discussed above. The key aspects of IPD as defined by American Institute of Architects (AIA) C191-2009 agreement include (AIA, 2019):

1. Owner, designer, and contractor are parties to the contract.
2. Because of the overlap in design and construction phase, competitive bidding and setting a fixed price in the beginning of the project is not possible. However, it is possible to set a target cost and envision incentives for cost savings and/or penalties for passing the target.

3. All parties share in the potential cost savings of the project over the target cost.
4. The project can have several aspirational goals such as having a tight schedule or achieving certain level of LEED certification, for all of which the owner can put incentive for the team to achieve them.
5. Current insurance products do not cover IPD. As it becomes more clear what types of insurance policies can be developed to cover IPD, the contractual model can have a more usable structure and terms.
6. All parties share the risks involved in the project. All claims against the others, except several specific ones such as willful misconduct and warranty obligations, are waved.
7. There are indemnification clauses to protect all parties to the contract as well as third parties from claims of personal injuries and property damages.

While IPD contracts have high potentials for IPT practices, because they are a fairly new delivery method it is not clear how they will play out in real-world applications. There are still several major barriers that IPD contracts face, which needs resolution. These obstacles include requirement of having a sophisticated owner, not having a fixed price which affects the owners' ability to finance, lack of insurance products, and that there is no guidance from courts for dealing with potential claims. As such, IPD is not the right procurement method for every project, but it is certainly helping to move the construction industry towards greater collaboration.

5.2 ORGANIZATIONAL APPROACHES TO COLLABORATION AND IPT PRACTICES

This section reviews antecedents of successful collaboration and IPT practices within three main categories of “effective communication”, “engagement in others’ activities”, and “inter-organizational trust” as emerged from the case study analysis presented in chapter Chapter 6.

5.2.1 Effective Communication

Contributing factors to effective communication can be categorized under three main elements of “settings and timing”, “medium of communication”, and “overcoming contextual barriers” (Jarvenpaa and Leidner, 1998)

Settings and Timing

Choices of the proximity among communicators is critical on quality of communication and is often discussed in the literature along with the timing as an important factor embedded within the proximity choice. The four existing types of settings for proximity and timing are termed synchronous physical presence, synchronous virtual meetings, asynchronous distance conversations and asynchronous web-based communication.

Selection of physical meetings, web-enabled meetings or other types of telecommunication methods depends on the occupational groups involved and the amount of work context they share. However, in most cross-occupational cases, the choice of physical meeting is more productive as it promotes interactions across occupational communities and alleviates the problem of multiple understandings that exist across occupational communities (Bechky, 2003a). Synchronous physical meetings are also argued to be enhancing communication and collaboration as they provide a better environment for conveying trust, warmth and attentiveness (Jarvenpaa and Leidner, 1998).

The choice of web-based communication methods or synchronous virtual meetings are sometimes prioritized for their flexibility, responsiveness, lower costs, and improved resource utilization (Snow et al., 1996). However, virtual teams are often more exposed to dysfunctions such as low individual commitment, role overload, role ambiguity, absenteeism, and social loafing (O'Hara-Devereaux and Johansen, 1994). Most importantly, virtual teams lack trust as "trust needs touch"(Handy, 1995). Instead, virtual teams are subject to experiencing "swift trust" which is a fragile and temporal form of trust which requires its own guidelines (Jarvenpaa and Leidner, 1998).

However, a study on the challenges of web-based communications with team members that transcend time, space and culture shows that there are several characteristics that team members can possess for creating and maintaining trust. These characteristics include predictability of communication, substantial and timely response, positive leadership, unemotional response to crises, uncertainty management, good first impression, explicit statements about commitment, support and excitement, early response to emotions, and finally successful transition from social to procedural to task focus (Jarvenpaa and Leidner, 1998).

On the other hand, virtual communication and collaboration can be improved by providing features that enhance communication such as avatars, texts, polls, etc. Use of such features during communication can augment collaborators' sense of "co-presence," or being there together, in synchronous virtual meetings (Anderson et al., 2011).

Medium of Communication

The characteristics of the communication medium also influence the communication behaviors mostly based on the amount of social context cues that they transmit. The more context cue a social medium can transmit, the more parties can express information and monitor feedback and regulate their interactions (Straus and McGrath, 1994). In the group interactions where parties have diverse social, occupational and cultural backgrounds, however social media transmitting less social cues such as electronic mails can increase the perceived similarity among members by making cultural differences less noticeable, while the asynchronous mode of interactions in such media gives parties more time to process the information and respond more accurately (Jarvenpaa and Leidner, 1998).

Within construction projects, the nature of communication is often described as chaotic and unpredictable, which leads to delays in communication, misunderstandings, and consequently to displeasure (O'Brien, 2000). According to Whyte et al. (2008) desired characteristics of the media within construction and manufacturing projects is highly depended on the project development phase. Within the early phases of project development team members try to find, frame, and structure problems. In this phase, which is called "exploration phase" practices involve joint sense-making and mutual adjustment. Within the second phase, called "exploitation phase", however, team members mostly analyze alternatives and solve structured problems. Practices in this phase are, therefore, highly fragmented.

Accordingly, within the exploration phase, the media needs to support effective sense-making through rapid interaction and iteration among team members across firms, with an emphasis on translating developed knowledge to the firm (Whyte et al., 2008). Visual representations in this phase, thus, need to be effective trans-epistemic objects; embody knowledge and assist understanding (Ewenstein and Whyte, 2009). Trans-epistemic objects need to have the capacity to unfold over time and across different organizations and disciplines (Ewenstein and Whyte, 2009).

Thus, the characteristics that they need to possess include: embodiment of a wide range of knowledge (Vincenti, 1990), mobility (Ewenstein and Whyte, 2009), Enablement of objective judgment (so that different professionals can interpret them according to their knowledge and contribute to their evolvement) (Henderson, 1991), Flexibility and ability to evolve and shift form (raise questions while answering others) (Cetina, 2009; Dossick and Neff, 2011), informality, activity to allow discussion over changes (Dossick and Neff, 2011), and capability of signifying on multiple levels to function as “boundary objects” (Ewenstein and Whyte, 2009).

On the other hand, adequately possessing all of these characteristics requires exploitation of multiple physical entities for visual representation during the exploration phase (Ewenstein and Whyte, 2009). Successful Examples of using individual or group entities as trans-epistemic objects during the exploratory phase of the architectural design process include use of sketches and loosely formed physical models coupled with 3D models as visual representation tools (Henderson, 1991; Huang et al., 2006; Yoo et al., 2006). Example of an extreme method in facilitating exploration phase is using an immersive projection display system (Messner et al., 2006) which creates a navigable 3D augmented reality allowing team members to interact with and within the projected virtual model, creating a common graphic language for understanding the project and drawing upon team members’ knowledge to contribute to the design.

During the exploitation phase, however, communication media need to support efficient decision-making by making the work structure explicit. During this phase, the emphasis needs to be on translating knowledge that has been developed in the firm to the project (Ewenstein and Whyte, 2009). Examples of physical entities that facilitate efficient decision-making during this phase include maps and protocols as visual representation devices (Ewenstein and Whyte, 2009), and permanent displays to allow information to be absorbed by the team members through time (Huang et al., 2006).

Contextual Barriers

The final factor affecting effectiveness of inter-organizational and cross-occupational communication is the ability of team members to overcome contextual barriers, described here as cross cultural and inter-organizational barriers.

The difficulty of cross cultural communication arises from the fact that transferring tacit knowledge is difficult as “knowledge is not primarily a factual commodity...it takes on the character of a process of knowing.” (Lave, 1988) The “process of knowing” inherent in understanding within all occupations results in having situated work practices and development of local understandings among firms (Bechky, 2003a). Accordingly, successful transformation of knowledge requires effective codification, transfer, and subsequent replication of routines and standards of operation, which is difficult because of the social, motivational and cognitive constraints (Nelson and Winter, 2009; Szulanski, 1996).

Suggestions for overcoming difficulties of transferring tacit knowledge include de-contextualization, by avoiding the use of jargon language (Bechky, 2003a); and use of tangible objects to provide what Bechky (2003a) describes as “... a concrete referent that individuals could manipulate to embed the understandings of others into their own understanding of their work context.” Increased interactions for cross-occupational knowledge sharing is also an important factor facilitating transferring of tacit knowledge as it allows local understandings to move across occupations. This strategy will be discussed in more detail within the next section “engagement in others’ activities.” (Bechky, 2003a)

To overcome the organizational barriers for effective communication, on the other hand, several practices are found useful for pushing organizational structures to conversations. These practices include bringing uncertainty, voice, and opinion into documentation, layering multiple meanings onto existing documentation, and reflecting reality through collaborative edits. Other practices that can be used for bringing conversation into organizational structure include fitting conversation into existing document structure, and changing the medium to fit documentation space and time requirements (Fiore-Silfvast et al., 2011).

5.2.2 **Engagement in Others’ Activities**

From organizational science standpoint, the significance of engagement in others’ activities can be described as its facilitation of knowledge transformation as “process of knowing” (Bechky, 2003a). As knowledge is developed within particular social context while people are engaged in situated activities, it can be more accurately transferred by engaging in similar activities. Otherwise, knowledge of one community might seem unintelligible to other communities, or some

of its important aspects might be lost during the transformation (Bechky, 2003a). On the other hand, the strength of task area boundaries across occupations is an important impediment for engagement in other's activities. People usually guard their core task domains against other occupations, as they can become their competitors by gaining the core task knowledge (Bechky, 2003b).

The higher level strategies that can be used by organizations management to increase permeability of occupational and organizational boundaries include selecting Institutional conditions that allow joint problem solving (team focused verses hierarchical, collaborative verses individualistic and learning oriented verses competitive)(Boland et al., 2007; Yoo et al., 2006), and appropriate assignment of responsibilities, and control structure (Kellogg et al., 2006; Lawler, 1994).

Engagement in others' activities can be further facilitated using strategies such as generating new patterns of interaction, intensifying interactions, and pulling complementary skills within the trading zones (Boland et al., 2007; Dossick and Neff, 2011). This is due to the fact that rich trading zones allow learning to move among various roles and occupations within the trading zone, leading to coproduction of the new knowledge (Boland et al., 2007). Forming small productive communication groups within trading zones provides a suitable environment for innovation as it encourages the team members to negotiate, argue, invent and therefore innovate (Boland et al., 2007).

Managing uncertainty by talking about the process (Boland et al., 2007), making the process more flexible (Jarvenpaa and Leidner, 1998), and aligning visions and practices by initiating "focus groups" are other effective strategies in increasing permeability of occupational and organizational boundaries (Harty, 2005).

Working on a shared workspace can further reinforce social similarities, shared values, expectations, and increases commitments and trust (Jarvenpaa and Leidner, 1998; Latané et al., 1995). In cases which providing a shared workspace is not possible for workers within the same building, even designing traffic patterns of the building in a way that increases interactions among team members can increase permeability of boundaries (Boland et al., 2007).

Use of the new technologies can also affect permeability of organizational and occupational boundaries. The richness of the body of information that can be embodied within IT technologies has the potential of increasing the interactions among team members, creating a potential for new solution or design alternatives to emerge (Yoo et al., 2006). The many features of the new technologies that facilitate networking across global teams, increase knowledge permeability across occupational as well as geographical boundaries and allow knowledge to be created and distributed in new and faster ways (Boland et al., 2007).

Finally, development of friendship among team members, mentor-student relationship, and membership in committees, as well as lack of strong focus on formal routines are also effective strategies that both organizations and individuals can benefit from for more engagement in others' activities (Bechky, 2003b; Boland et al., 2007).

The importance of engagement in others' activities in construction projects and in particular HP projects comes from the fact that such engagement allows people across organizations and occupations to gain a holistic understanding of the project and to better understand the trade-offs among different scopes of projects and accordingly make contributions that better fit the whole systems.

While all organizational literature discussed in this section are applicable and important in construction projects, conducting inter-organizational meetings specifically are of paramount importance in fostering IPT practices (Homayouni et al., 2010). There is a balance that must be struck between structuring meetings to handle detailed scopes of work versus exploring a wider range of solutions and involving team members in the decision-making process. In IPT, such meetings cannot cover the requirements for all scopes and situations. General coordination meetings can break into smaller scope meetings, or "pocket meetings," where architects and engineers would work on specific issues in smaller groups during a general meeting. These informal pocket meetings can occur spontaneously as small groups of three to five people would break out for twenty minutes for a more detailed discussion after general group discussions. If needed, the group can draw someone into their conversation with a question or join another huddle with a comment, clarification, or question. Architects can circulate among these pockets to keep the issues moving (Homayouni et al., 2010).

In the context of HP construction projects aligning visions and practices can be in the form of holding environmental design charrettes, especially during the pre-design phase (Reed and 7 Group, 2009). The term charrette denotes a form of multi-stakeholder involvement and intensive collaboration in a design process within a short period of time to frame key programming issues and develop a preliminary conceptual design. In the case of sustainable projects, such design charrettes are held with a special emphasis on sustainable building practices and are called eco-charrettes. Having all project teams in one room at a certain time enables the teams to understand the complex tradeoffs between building components and empowers them to manage such interdependencies in a whole systems approach (Abraham, 2005).

5.2.3 **Inter-organizational Trust**

Successful collaboration with partnering organizations requires a continuous effort to maintain the collaborative processes. Developing trust is a key element to success in this effort (Cahill, 2003). Trust can be defined as perception of the likelihood of future cooperation. As trust declines, people are unwilling to risk or compromise as they demand a greater protection to cover for the possibility of them being betrayed (Kramer and Tyler, 1995). Developing trust in organizations can be best described as the repeated cycle of coping in situations where trust is lacking and building trust in situations where it is possible (Cahill, 2003).

One of the major strategies to develop trust is to proactively communicate at interpersonal and inter-firm levels as it provides the basis for continued interaction (Lau and Rowlinson, 2009). Other strategies to build trust for practitioners according to Cahil (2003) include: having clear goals; dealing with the issues of power differences, investing in the time dimension of relationships and allowing time for creating mutual understanding, willingness to communicate over a range of issues, being fair, and resolving conflicting obligations. Therefore, at organizational level, trust can be facilitated by project staffing with full time/ long term team members to have enough time for developing trust, and objective project reward criteria (Maurer, 2010).

On the other hand, the concept of trust goes hand in hand with the concept of reciprocal obligations, as when a trusting act is reciprocated, a basis for co-operation is created (Axelrod et al., 1988), meaning that trust creates trust (McAllister, 1995).

Development of trust among team members in construction projects differ from the type experienced in other organizations in the form of partnership, as organizations collaborate for a short period of time and do not have the time required for gradually developing trust. Thus the type of trust formed in construction projects, especially projects with short duration or at the beginning of all projects, is a type called swift trust (Askay and Spivack, 2010).

The theories of swift trust explain the nature of swift trust in temporary groups such as construction teams (Debra et al., 1995). In such teams, members import expectations of trust from similar settings that they are familiar with using stereotypical impressions of others (Jarvenpaa and Leidner, 1998). Once the initial trust is imported, it is maintained by team members' highly active, proactive, enthusiastic, and generative style of action (Debra et al., 1995). The importance of action in maintaining swift trust comes from the fact that action helps team members maintain their confidence in the team's effort to manage uncertainty and risk (Debra et al., 1995).

5.3 ANTECEDENTS OF BIM IMPLEMENTATION

To create a framework for benchmarking BIM performance within AEC organizations, National BIM Standards (NBIMS) has developed a matrix called Capability Maturity Model (CMM) composed of a set of interlocking elements that facilitate full implementation of BIM on various dimensions (NIST, 2007). These complementary elements were used as a basis for categorization of this work.

This section reviews the literature discussing the implementation of BIM technologies within four major areas in which BIM implementation can help facilitate IPT practices (derived from CMM): 1) Inclusiveness of data, 2) Representation of data, 3) Convenience of data retrieval and 4) reliability of data and processes.

5.3.1 Data Inclusivity

The concept of data inclusivity with regards to BIM applications indicates that once the effort for creating the BIM model is done, it is best to use the model for as many processes as possible to make the BIM model more efficient (Hill, 2012).

Inclusivity of data can be achieved by facilitating information sharing along three major scopes: various roles and disciplines, building life cycles (discussed in section 2.2.2), and even different projects. Inclusivity of data among discipline, roles, and building life cycles is called supply chain integration of data, indicating that all processes and activities related to design and construction from specification and design to manufacturing, construction, commissioning, management and operation of the facility can be integrated within a single model (Messner et al., 2006). Sharing information within different projects, on the other hand, happens when BIMs work as central repositories of information allowing the translation of learning at project level into reusable organizational resources (Harty, 2005). This section introduces some of the most common solutions and techniques proposed within CEM literature to help with supply chain integration of data and discusses the existing barriers.

First, the underlying strategy for supply chain integration of data is supply chain integration itself and building lasting and trusting relationship between the parties. Such integration can be mostly achieved using IPT techniques such as top management commitment to creating a culture of openness, trust and mutual respect. Yet, there are several BIM related technical strategies that can help achieve supply chain integration of data. Examples include providing project extra nets such as FTP servers for sharing digital documents among team members; provisioning web-enabled design which can start from hyperlinking BIMs to manufacturers' websites providing a more comprehensive link to availability, delivery, cost, and scheduling information of their products (Allen et al., 2005); and developing standards of interaction such as setting up coordination between disciplines so that the architect does not edit the structural model and vice versa (Taylor, 2007).

On the other hand, the barriers to supply chain integration of data include several standard practices by some trade organizations such as AIA which hinder digital sharing of information and gaining inclusivity of data (Allen et al., 2005). For instance proprietary ownership of data needs to be addressed especially in BIM enabled projects that use interactive, or web enabled documents, which do not necessarily have a known single author/owner (Allen et al., 2005). Proprietary ownership of data also hinders using the building information data for the facility management, limiting the inclusivity of data throughout the building lifecycle.

Another example is defining documents as static (within AIA-A201 General Conditions) which is not in line with the essence of technology enabled collaborative design, as team members collaborate in real-time and use hyperlinked information and data from suppliers, making the documents dynamic (Allen et al., 2005). The notion of shop drawings is also another standard procedure which hinders collaborative work in BIM enabled projects, as the data within BIM model can be easily transferred to fabricators digitally. The very time consuming submittal process within paper-based traditional design and construction paradigm can be avoided in BIM enabled projects where a single model can be inclusive of all building related data (Allen et al., 2005).

The last example, is assigning all means and methods of construction to the contractor within AIA standard language, which causes more harm for collaboration within BIM enabled projects, as BIMs incorporate sequencing, means, and methods, other team members should also have leverage as well as liability in assigning such tasks (Allen et al., 2005).

5.3.2 **Representation of Data**

Visual representations of data, in general, have two main roles in facilitating distributed cognition among team members: The first one, as boundary objects, they facilitate creating the shared understanding among team members (Bechky, 2003a; Ewenstein and Whyte, 2009; Henderson, 1991; Star and Griesemer, 1989; Taylor, 2007). The second one, as conscription devices, they call for and organize participation of the team members by storing the knowledge that is created and adjusted through team members' interactions towards their common goal (Henderson, 1991). When BIM technologies take on the role of visual representation, it is crucial for them to maintain the flexibility that is necessary for such important roles to take place (Henderson, 1991).

Representation of data in construction projects in the form of architectural sketches and drawings is especially important as these visual representations act as “social glue” between team members from various occupations and organizations (Henderson, 1991). Having an evolving graphical information capacity, and the adjustability to represent the same data in various representation formats based on project need, BIM technologies facilitate selective interpretation of data (Ewenstein and Whyte, 2009), web-based communication, as well as exploration of opportunities, as described by Whyte et al. (2008). BIM representation tools are also known for their ability to

promote informal representation of design products due to their high quality of drawing and rendering with minimal effort and time (Maher et al., 1996).

The strategies proposed for maintaining flexibility of BIM documents as visual representations, includes avoiding overloading of the documents used as boundary objects, so that the documents still remain and seem flexible (Henderson, 1991; Huang et al., 2006).

5.3.3 Convenience of Data Retrieval

BIM technologies provide the means for making documents generated from unrelated systems commensurable and coordinated through standardization of formats and processes. As the data retrieval process becomes easier using BIM technologies, the easier the collaboration process becomes through exchange of documents, and data retrieval (as opposed to re-making data in conventional paper based documentation system).

The management strategies proposed for making the data retrieval process more convenient includes using formats that facilitate direct, proprietary exchange of information as opposed to read-only information exchange (Eastman et al., 2011); Developing details of implementation processes based on context (Harty, 2008; Orlikowski, 2000); providing descriptions or demonstrations presented by vendors, champions, etc. (Orlikowski, 1992); and providing Industry Foundation Classes (IFC) support to facilitate interoperability with various software tools (Taylor, 2007).

Other strategies that can be incorporated by BIM users (project participants) to facilitate data retrieval process includes consistent layering conventions for producing multiple and complex designs that can be understood, shared and combined across different users and disciplines (Harty, 2005, 2008).

In order to provide a framework to facilitate interoperability among various systems contributing in design and construction process throughout the building life cycle, National Building Information Systems Standard (NBIMS) is under development. However, until such comprehensive system is in place and is used by all team members and tested for its reliability, BIM data maybe lost or corrupted through exchange of information (Aslani et al., 2009).

Aligning all project team members through imposition of rigorous BIM standards, on the other hand, might have the opposite effect of excluding certain team members and technologies from the whole system (Harty, 2005). Choosing the right strategies for standardization of documents and processes in BIM enabled projects, therefore, is of paramount importance. As Harty (2008) has discussed, digitalization of data and processes is not equal with elimination of paper and other non-IT artifacts from design and construction process. Such elimination and transforming into exclusively digital activities is proved to be impossible (Harty, 2008). Accordingly, keeping the materials such as paper as an active part of the practices of designing and drafting, although not peripheral to digital processes, is crucial as they are vital elements of interactions between heterogeneous agents, and should not be completely eliminated.

5.3.4 **Reliability of Data and Processes**

Using BIM technologies, maintaining trust in leadership, information technology, skills of others and organizational processes are success elements in achieving a higher level of collaboration (Dossick and Neff, 2008). Yet, organizations might be skeptical for trusting and relying on BIM for various risks they are facing: the financial investment on BIM tools, financial and time investment on training employees on using the tools and learning the processes, time investment that 3D modeling requires during the design phase, and the uncertainty associated with using a new product which works within a blurry legal frame. Taking such risks become more severe in the absence of a standard tool for information sharing. Architects are especially prone to these risks as use of specific BIM tools are usually suggested by owners or contractors, and introduction of each new tool means repeating the cycle of facing the financial and organizational learning risks (Allen et al., 2005).

While performing cost-benefit analysis might help organizations to decide on their support and reliance on BIM technologies in some extreme cases, in others such analysis is impossible to perform as quantifying production functions is not possible in manufacturing operations and especially in design processes. Determining the return on investment (ROI) of use for technologies, also is not feasible as it cannot be separated from the process of using the technology, which itself is inter-related with many other processes. This make it unpractical to follow an individual technology's effect on a trailing indicator such as cost (Allen et al., 2005).

Yet, there are several techniques that organizations can use in order to increase reliability of their BIMs as well as BIM processes. These techniques are central in successful implementation of BIM technologies as they help team members develop trust in BIM data, competency of other BIM users, and the technology itself (Dossick and Neff, 2008). This section discusses these approaches in six major categories of cultural compatibility, establishing supportive policies and priorities, providing technical support (all being organizational-level strategies), as well as overcoming the law barriers, contractual support, and providing appropriate organizational structure (contractual-level strategies).

Cultural Compatibility

Despite all the benefits that implementation of BIM technologies brings to organizations, there are always some level of resistance to its adoption, as most innovations require a lengthy adoption period (Bill, 1997; Rogers, 1983). The magnitude and nature of this resistance is influenced by various factors including individual attitudes such as cognitive ability, race, age, gender, past experiences, values and beliefs, as well as organizational norms and operations (Bill, 1997; Mitropoulos and Tatum, 2000). In order to encounter less resistance and create a reliable process for team members, the leaders in organizations need to be sensitive towards the initial culture of their organizations with regards to technology adoption and select a learning system that has the most compatibility with the organizational culture (Bill, 1997).

Establishing Supportive Policies and Priorities

Organizational culture that values technological innovation can be specified by the existence of mechanisms, incentives, and resources for the identification and implementation of new technologies (Mitropoulos and Tatum, 2000). Once a new technology is identified for implementation, providing slack resources for experimentation is crucial in increasing reliability of the new tool and processes (Liker et al., 1999; Mitropoulos and Tatum, 2000; O'Brien, 2000; Orlikowski, 2000).

Maintaining an organizational culture that celebrates innovation is also crucial in successful implementation of BIM technologies and increasing the level of trust in using the new tools. Having an innovation culture can be achieved by setting ambitious goals, persistent pursuit of

improved productivity and having a sense of pride in always finding ways to improve (Mitropoulos and Tatum, 2000; Tatum, 1989). In addition, having an understanding of the longer-term benefits of the new technologies and allowing time for major return of the investment helps with successful implementation of the new tools especially in projects where implementation of a BIM technology is not dictated by market, a process problem, or a competitive goal (Mitropoulos and Tatum, 2000; Tatum, 1989).

Having a broader view of the risks associated with implementation of new BIM technologies is also effective in making organizations trust the new tools and processes. Considering all associated risks such as technical, financial and commercial risks with regards to each specific projects can be surprising in some projects and results in increasing reliability of the new implemented tools (Tatum, 1989).

Another element associated with successful implementation of BIM technologies within one firm, is considering the effect of integration on other phases of the project as well and proceed with the implementation based on shared interests of all team members (Tatum, 1989; Taylor, 2007). For instance, if a construction firm is considering implementation of certain BIM tools on a specific project, to increase reliability of such BIM tools, the construction firm should demonstrate the effect of implementation on other design and operation phases to the owner as well.

Finally, for insuring accuracy of BIM data, meaning that the information is correctly linked to its specified properties and that it is up to date, managers can assign data management to the people who are the best source of such data (Aslani et al., 2009), and provide accountability and knowledge approval processes within their organizations (Whyte and Lobo, 2010).

Providing Technical Support

Once an organization is in a good position in terms of having the right structure, goals, policies, and culture to implement a new BIM technology it is essential to provide technical support for team members so that the team members can trust the information in BIMs and the new processes. The first technical support that organizations can provide in this direction is redistributing work according to the requirements of the implemented technologies and providing a roadmap for team members to rely upon and learn the new tools and processes (Bechky, 2003a; Jarvenpaa and

Leidner, 1998; O'Brien, 2000; Taylor, 2007). As an example, organizations can develop a caveat for handling inconsistencies between models, drawings, and the specifications, helping the team members to overcome some of the ambiguities of the new processes.

Another technical support that organizations can provide that helps with accuracy of data as well as avoiding legal liability issues is developing protocols to maintain integrity of the model by allowing tracking of the data to its source. The technical challenge in developing such protocols, however, is in optimizing the process of data exchange while controlling the data to maintain proper lines of responsibilities (Aslani et al., 2009).

Overcoming the Law Barriers

The current legal system in AEC industry is still dominant by laws supporting the traditional paper-based design and construction practices, which hinder collaboration in BIM enabled projects. Examples include intellectual property laws which consider technologies as sophisticated tools or goods rather than professional services. The problem arises from the fact that a manufacturer of a good can disclaim or limit related liabilities, when providers of professional services are held to a standard of care and cannot disclaim such liabilities. In BIM enabled projects where the technology in some instances supplements professional judgments, such legal propositions become problematic, and can negatively affect trust and reliability of people on the technology (Allen et al., 2005).

Another law barrier for collaboration within BIM enabled projects is that of professional licensing. Architecture and engineering are considered professional licensing by law, which means all architectural and engineering documents need to be stamped by related professionals in order to be approved by state laws. Within BIM enabled projects, however, such requisition is problematic as within such projects all team members contribute to the design, and make it less certain who is the designer (Allen et al., 2005).

Building permitting regulations are also other legal barrier for BIM enabled collaborative work, as they require submission of stamped set of static documents, which is contradictory to the dynamic nature of BIMs as discussed previously (Allen et al., 2005).

As discussed in section 5.1 Contractual Approaches to IPT Practices, procurement of public projects is restricted to public bidding laws, which snuffles collaborative work by dividing the project to two completely separate phases of design and construction. This separation makes it impossible to fully benefit from capabilities of BIM technologies in facilitating collaborative work.

Contractual Support

The new work processes around BIMs require new contractual agreements for redistributing rights and liabilities as well as risks and rewards among core team members. While such agreements have been developed to some extent by AIA E203-2008 and ConsensusDOCS 301 (CD301), both systems are fairly new and there is still room for improvement.

One of the concerns in projects that openly share documents among team members is about solving security issues. As an example there are issues with team members having access to all the data including financial information, as they might leave and work for competitors. Another concern is about sharing the wrong data, which might have cascading negative effect on people using the data as well as personal liability or embarrassment for individuals that have made a mistake and publicly shared it without going through formal organization channels (Orlikowski, 1992) .

These issues have been addressed to some extent by two clauses within AIA E202-2008. The first one uses the concept of “Level of development” (LOD), defining authorized uses of BIMs at each stage of development (AIA, 2008). The second one discusses “Reliance on model elements” maintaining traditional notions of causation-based liability, implying that the drafter is responsible for any mistake causing from inaccuracy of the draft. Applications of this clause, however, is quite blurry as there might not be a clear distinguish between who or what is the cause of damage. CD 301, on the other hand, has a different approach to liability issues, maintaining mutual waiver of consequential damages (AIA, 2008).

The other issue is about intellectual property rights. As different people are contributing to development of the same model element, using traditional rules addressing intellectual property rights could be problematic. While AIA has developed clauses with regards to “model ownership”, with the intention of following traditional rules with regards to intellectual property rights, application of such rules are also somewhat blurry (AIA, 2008).

One technique that owners can use to encourage organizations to collaboratively use BIM, despite of all the legal ambiguities, is to balance associated risks and rewards (Dossick and Neff, 2009; Orlikowski, 1992). This can be done by considering the risks that certain organizations are taking for BIM implementation and compensate them, indemnify them, and/or provide them with project policy insurances (Aslani et al., 2009). Since the owners are the ones who ultimately benefit from an improved project, they should bear or compensate some of the associated risks.

Appropriate Organizational Structure

Selecting an appropriate organizational structures can also help in developing and maintaining a culture of innovation within construction firms to support implementation of new technologies as opposed to reliance on proven technology with its known limitations (Tatum, 1989). One of the main parameters of organizational structures is having a decentralized decision making structure and increase communication linkages between all teams. Enhancing informal communication between various groups inside each organizations and increasing the communication channels between various organizations help in gaining the required resources and building support from all involved teams such as regulatory agencies, owners, designers, manufacturers, and suppliers. Although gaining approval from all teams might not be necessary for implementation of a new technology, increased communication helps both with approval to proceed with the implementation and rapid implementation of the new technologies itself (Tatum, 1989).

Another effective structural factor in supporting a culture of innovation and implementation of new BIM technologies is having open project teams (Quinn, 1985; Tatum, 1989). One major instance of having open project teams in the context of implementation of new BIM technologies is having a small planning group that helps in driving the implementation and ensuring that this team remains in contact with all teams that are involved in the new processes for early evaluation of alternatives.

Another structural strategy in successful implementation of new BIM technologies is to support the implementation by allocating several positions within the organization to drive the new change. The specified positions can cover various roles such as an “operation iconoclast” who always searches for ways to improve everything including implementation of new BIM technologies; a “technical champion” for sponsoring the proposed BIM solutions and providing necessary

resources for its implementation; and a “technological gatekeeper” for identifying and transferring state-of-the-art technologies to the firm (Tatum, 1989).

Chapter 6. SURVEY DEVELOPMENT- ADDRESSING COMPLEMENTARITIES AMONG IPD PRACTICES & BIM IMPLEMENTATION

This section presents development of the web-based survey used to capture the quality of IPT practices and extent of BIM implementation within the population of HP projects under the study. The main strategies presented in chapter Chapter 5 to facilitate successful IPT practices and BIM implementation as well as the strategies identified within the case study field notes and interview transcripts, while not intended to be comprehensive, provided a platform for creating theoretical categories of successful IPT practices and BIM implementation, to be used in the survey. The created theoretical categories, furthermore, show the complementarities among IPD practices and BIM implementation, demonstrating their pertinence for use within QCA.

While for assessing the extent of IPT practices and BIM implementation within construction projects, one might need to measure all available aspects of the contributing elements to IPT, such comprehensive assessment was not needed in this work. In developing the survey, the goal was not to accurately measure all collaboration and BIM implementation aspects of the chosen HP projects, but to come up with few higher level elements contributing to IPT and roughly measuring those elements within the studied HP projects using fuzzy sets. Therefore, while it was not necessary to have all the detailed information about various strategies used on different theoretical dimensions of collaboration and BIM implementation, it was important to have data with regards to multiple contributing elements on few levels so that through the process of going back and forth between data and theory in fsQCA, the created fuzzy sets can be re-calibrated by bringing different dimensions into the sets when the analysis calls for it.

Once the survey data was collected, the search for typologies of IPT practices and BIM implementation resulting in higher performance buildings started through an iterative process of fsQCA. Through this process, the main elements captured in the survey as well as HP buildings' available case studies, were combined in multiple ways to find the most robust combination of elements, as causal conditions within the study (presented in section 7.3), that when combined with other causal conditions can lead to the specified outcome.

Practitioners identifying their work processes with one of the presented successful recipes at the end (presented in chapter Chapter 8), may then trace the elements back and find the presented strategies that help with implementation of each element.

6.1 ANTECEDENTS OF SUCCESSFUL IPT PRACTICES

Analyzing the collection of strategies to facilitate IPT practices combined with the case study field notes and interview transcripts resulted in creation of three conceptual categories to facilitate IPT practices: 1) effective communication, 2) engagement in others' activities, and 3) inter-organizational trust. (This framework were later used to categorize and present the literature in chapter Chapter 5). Each of these groups contain strategies addressing different collaboration dimension based on Thomson et al.'s frame work (2009) discussed in 2.2.1: governance, administration, organizational autonomy, mutuality, and norms.

As an example, "early construction contract award" is a strategy effective in successful "engagement in others' activities" that can be implemented using a single "governance" level strategy: "selecting a more integrated form of delivery method". Other strategies, however, can be promoted and measured using multiple collaboration dimensions. For instance, one of the strategies for successful engagement in others activities "compromising owns' scope of work for the sake of overall project good", can be promoted based on all five defined dimensions. Contractual agreements can facilitate this by creating shared goals for the project and monetary rewards for achieving the shared goals (governance dimension), organizations can promote this culture by educating their employees about it and defining their roles and responsibilities accordingly (administration dimension), as well as through team building (mutuality). Furthermore, organizations may empower their employees to autonomously make decisions and compromise their scope in favor of the projects' scope (organizational autonomy) and some employees might as well do this based on the inter-organizational culture of reciprocity (Norms).

Considering the limitations of survey questions in terms of architects required time commitment to complete the survey (under 20 minutes for both IPT and BIM sections of the survey), the three collaboration dimensions of "administration", "organizational autonomy", and "mutuality" were combined, producing a single collaboration dimension addressing "organizational level" IPT strategies. The two other dimensions of "norms" and "governance" were kept separate and were

respectively called “individual level” and “contractual level” strategies. The lower level strategies in each category obtained from the literature review, the case study, and interviews, were then combined to generate higher level elements contributing to IPT within each dimension.

Some of these higher level elements, as evident within the tables in this section, are shared within the three conceptual categories of “effective communication”, “engagement in others’ activities”, and “inter-organizational trust”, which demonstrates the interdependencies among the three conceptual categories.

To have a better visual design for the IPT practices section of the survey and for the sake of saving time, where possible, similar contractual, organizational, as well as individual level elements were grouped together forming matrix questions. Total of 3 multiple choice questions as well as 5 multiple choice matrix questions addressed IPT practices within the HP projects. Each multiple choice question and each row within the matrix question covered one of the discussed elements using a five level Likert scale and a choice of “I don’t know” (Appendix A).

6.1.1 Antecedents of Effective Communication

The first emerged category to foster IPT practices, were effective communication. Section 5.2.1 discussed the importance of this element in successful inter-organizational collaboration and IPT practices with construction projects. The strategies discussed in this section combined with the strategies found from the case study and interviews were categorized under four (three shared and one unique) major elements of “project delivery method”, “communication channels among organization”, “team members being effective communicators”, and “fulfillment of mutual obligations”, ranging from contractual level to individual level strategies.

The survey also included two higher questions to assess the overall effectiveness of communication within teams using two conditions of “lack of misunderstanding among project teams” and “effective communication among partner organizations”.

A major step in having an effective communication in construction projects is availability of channels of communication between separate organizational entities, as fabricators and subcontractors are often isolated from the design teams’ second team consultants (Dossick and Neff, 2009). This is mostly possible by choosing a more integrated form of delivery methods, a

contractual level strategy, as well as organizational strategies such as co-location and conducting regular meetings (Dossick and Neff, 2009).


Once the proper channels of communication exist, team members can use certain strategies to overcome difficulties of transferring tacit knowledge to facilitate effective communication. These strategies include de-contextualization, by avoiding the use of jargon language (Bechky, 2003a; Taylor, 2007); synthesizing information and making routines and knowledge explicit through codification (Nonaka, 1991), [Interview data]; strategic documentation to allow efficient transformation of knowledge [interview data], making assumptions and intentions clear on the documents [interview data], use of multiple medium of communications during the exploration phase of design (Ewenstein and Whyte, 2009) such as physical and virtual models, sketches, augmented reality, as well as tactile senses [interview data], and use of tangible objects to provide what Bechky (2003a) describes as "...a concrete referent that individuals could manipulate to embed the understandings of others into their own understanding of their work context." In the context of construction projects, such concrete referents can be virtual or physical architectural models, drawings, sketches, etc.


As shown in Table 6-1 all of these strategies can be also promoted on organizational-level by creating procedures to support such techniques. For example, avoiding use of disciplinary jargon can be practiced on individual level by commitment of the team members to use un-ambiguous words that are known in all disciplines. Institutions can also develop procedures that are both fun and preventive in terms of using jargon language. For instance, the person that uses a disciplinary jargon can be asked to buy a treat for others! [Interview data]

Team members can also facilitate IPT by striving to enhance their social skills such as openness, willingness to learn, respecting other ideas, being sympathetic, and not blaming attitudes to provide a healthy environment for communication. These strategies, however, require organizational support to create organizational cultures that value such attitudes.

Table 6-1- Antecedents of effective communication, and supporting strategies

Criteria Asked in the Survey				Strategies for Effective Communication
Overall	Contractual Level	Organizational Level	Individual Level	
Effective Communication among Partner Organizations		Project Delivery Method	Communication Channels among Organizations	Provisioning lines of communication within organizations
				Conducting Regular Meetings
				Co- location/ Shared workspace
	Lack of Misunderstanding among Project Teams		Team Members Being Effective Communicators	Use of multiple medium of communications during the exploration phase of design.
				Strategic documentation
				Making assumptions and intentions clear on documents.
				Use of trans-epistemic objects during the exploitation phase
				Avoiding Jargon language
				Making routines and knowledge explicit through codification
				Bringing uncertainty, voice, and opinion into documentation
				Fitting conversation into document structures.
				Developing issue logging processes
				Openly share ideas and perspectives
		Fulfilment of Mutual Obligations	Not Blaming	
			Respecting other ideas	
	Being Sympathetic			
	Being willing to learn			

 Exclusive criteria to facilitate successful engagement in others' activities

 Criteria facilitating engagement in others' activities shared among other antecedents of IPT practices.

6.1.2 Antecedents of Engagement in Others' Activities

Section 5.2.2 discussed the importance of engagement in others' activities to foster IPT practices and discussed several strategies that make occupational boundaries within organizations more permeable to allow engagement in others activities. These practices cover a wide range of dimensions from contractual to organizational and individual-level strategies. Thus, the proposed strategies are categorized under the three collaboration dimensions generating nine main elements (5 shared, 4 unique) contributing to engagement in others' activities within construction projects: 1) project delivery method, 2) contract pricing method, 3) provision of communication channels among organizations, 4) having shared goals, 5) inter-organizational trust 6) team members' understandings of others' scope of work 7) holding design charrettes (eco-charrettes in the case of HP projects), 8) conducting participatory coordination meetings as well as 9) organized and well run coordination meetings.

In addition to asking one question in the survey for each element, four more questions were asked to measure the overall quality of engagement in others' activities: 1) architects' involvement in construction process, 2) engineers working closely with architects, 3) successful coordination meetings, and 4) the overall organizations engagement in other's activities.

As discussed in section 5.1 contractual agreements such as selecting a more integrated form of delivery method and non-fixed types of contract pricing methods help achieving IPT practices in various ways such as resolving conflicting obligations and creating shared goals among team members.

As illustrated in Table 6-2 some of the discussed contractual strategies can be further reinforced or even replaced by other organizational and individual techniques discussed in previous sections. For instance, within projects where litigations are partially limited contractually (or are not limited at all), developing procedures to be proactive about preventing conflicts or encouraging team members to use other conflict resolution procedures such as mitigation (rather than law suits) can be helpful in building trust between organizations so that they can take more risks in engaging in others' activities. Developing trust between organizations is discussed separately in next section.

Strategies such as colocation and having a shared workspace are other organizational level strategies to facilitate provisioning of communication channels among organizations. These methods are effective in engaging team members in others' activities as they increase social interactions and informal exchanges of ideas, facilitating exploration of ideas, as discussed earlier, and informal communication (Dossick and Neff, 2009; Maher et al., 1996).

The performed interviews in this study also suggest that organizations can help individuals to realize their strength and weaknesses as well as other team members' strength and weaknesses in order to empower them to communicate and work better together [interview data]. An important strategy in creating such understanding is holding design charrettes, as discussed in section 5.2.2. Since the case studies provided required information about projects eco-charrettes, no additional question was asked in the survey with this regards.

Face-to-face coordination meetings play an essential role in fostering IPT as they provide the opportunity to brainstorm on the issues that are related to multiple disciplines. However, conducting efficient meetings in which all the team members actively participate is a challenge. Section 5.2.2 furthermore discussed how coordination meetings in construction projects can be structured to maintain a balance between detailed scopes of work and exploring a wider range of solutions, involving various team members in the decision-making process.

The majority of the interviews and cases studies performed in this research had put a lot of emphasis on conducting regular and efficient meetings, suggesting several strategies that can be used to increase productivity of these meetings.

Conducting participatory meetings is an important dimension of having successful meetings which can be achieved by selecting a meeting types such as general, intimate, and pocket meetings based on the scope of the work to be discussed. Other organizational strategies that help in conducting participatory meetings include having a scribe for general meetings, and having a facilitator in general meetings. The role of the meeting facilitator is to encourage participation and to include all the ideas in the conclusion so that everybody feels invested. The facilitator can also insure that no single scope or issue dominates the discussions thus providing equal opportunity for all team members to invest in and benefit from the collaboration [case study observations].

Another important dimension of having successful meeting as emerged from the case study and interview data is having well-run and organized meetings. Organizational strategies that can be reinforced/practiced by individual team members to achieve this state include starting and ending the meetings on-time, clearly stating meeting goals and agendas, and making the meetings fun. Such practices can increase team members' trust in the process and their willingness to openly share their ideas, compromise, and collaborate. Participants should also follow several basic ground rules such as respecting others' ideas, being active listeners, relying on dialog, and avoiding the use of disciplinary jargon. These strategies help in fulfilling the mutual obligations that team members owe to one another as well as setting high standard norms for work practices and interactions that encourage collaborative work [interview data]. Such strategies can be practiced by team members on individual level and also promoted by organizational management. Next section will discuss these strategies in more detail.

Table 6-2- Antecedents of engagement in others' activities and supporting strategies

Criteria Asked in the Survey				Strategies for successful engagement in others' activities
Overall	Contractual Level	Organizational Level	Individual level	
Engineers Working Closely with Architects Architects Involvement in Construction Process	Project Delivery Method	Contract Pricing Method	Having Shared Goals	Early construction contract award
				Reliability of Processes
	Providing individual leadership/ facilitator to obtain stronger cohesion within team members.			
	Resolving conflicting obligations			
	Limiting litigations			
	Qualification based selection of the construction team			
			Team members' Understanding of others' scope	Team members realize their own as well as others' strength and weaknesses.
				Team members learn about scope of other teams

Criteria Asked in the Survey				Strategies for successful engagement in others' activities
Overall	Contractual Level	Organizational Level	Individual level	
Successful Meetings			Communication Channels among Organizations	Provisioning lines of communication within organizations
				Conducting Regular Meetings
				Co- location/ Shared workspace
				Creating New Patterns of interaction
			Known from Case Studies	Holding Pre design eco-charrettes
			Conducting Participatory Meeting	Conducting various meeting types: general, intimate, and pocket meetings
				Carefully designing the layout of the meetings such that nobody's position receives more emphasize
				Having a facilitator to encourage participation
				Including all ideas in the conclusion
				Starting and ending the meetings on time
				Being active listeners
				Relying on dialog rather than talking
			Organized and Well-run Meetings	Respecting other ideas
				Clearly stating meeting goals and agendas in the beginning
				Making the meetings fun
				Having a scribe in general meetings

Exclusive criteria to facilitate successful engagement in others' activities
 Criteria facilitating engagement in others' activities shared among other antecedents of IPT practices.

6.1.3 Antecedents of Inter-Organizational Trust

Inter-organizational trust, as discussed in section 5.2.3, is an important antecedent of inter-organizational collaboration, which has slightly different nature in construction projects as

discussed under the subject of “swift trust.” Seven main elements (five shared, two unique) emerged as effective in promoting and maintaining trust in construction projects from the case study and interview data, ranging from contractual level to organizational level and individual level: 1) Selecting an integrated form of delivery method, 2) non-fixed contract pricing method, 3) provisioning communication channels among team members, 4) reliability of processes, 5) having shared project goals, 6) exceeding contractual obligations, and 7) fulfilment of mutual obligations. In addition to including a question for each of these seven elements, in the survey, one question addressed the overall quality of trust between collaborating organizations within the population of HP projects studied in this research. Table 6-3 shows the distribution of the defined antecedents of trust with regards to the strategies found helpful for promoting and maintaining inter-organizational trust.

Contractual strategies such as selecting a more integrated forms of delivery method and non-fixed types of contract pricing methods can help in providing an environment in which trust can be maintained by facilitating trust antecedents such as having shared goals and increased interactions. Increasing the interaction of team members to maintain trust can be also achieved through organizational strategies that envision communication channels among team members as discussed in effective communication section.

Increasing reliability of processes is another antecedent of inter-organizational trust which can be achieved by strategies such as building on prior relationships as well as training collaborators and explaining the processes for them [Case study observations].

Finally, maintaining trust among team members requires team member to fulfil mutual obligations they owe to one another such as respecting others and being willing to compromise. Organizational practices can also help to provide an environment in which individuals can practice these attitudes. Such environment is what one of the interviewed architects described as “a trust-built, incentive-based environment to produce collective values” [interview data]. Some of the organizational strategies identified to be effective in fostering a trust-built environment include training collaborators, building on prior relationships for choosing the collaborators, developing issue logging processes; and conducting integration sessions [interview data].

Table 6-3- Antecedents of inter-organizational trust and supporting strategies

Criteria Asked in the Survey				Strategies for Building and Maintaining Trust among Team Members				
Overall	Contractual Level	Organizational Level	Individual level					
Inter-organizational Trust	Project Delivery Method		Having Shared Goals	Membership in joint committees				
				Holding design charrettes				
				Providing individual leadership/ facilitator to obtain stronger cohesion within team members.				
				Resolving conflicting obligations				
		Contract Pricing Method	Communication Channels			Increased interaction among project teams		
						Provisioning lines of communication within organizations		
						Co- location/ Shared workspace		
						Conducting regular meetings		
								Qualification based selection of the construction team
								Limiting litigations
								Building on prior relationships
								Training collaborators
	Exceeding Contractual Requirements				Transparency of operations and financial transactions			
					Appropriate assignment of responsibilities, and control structure			
					Explaining the process			
					Fulfilment of Mutual Obligations	Respecting others		
						Team members being willing to compromise		
						Team members being flexible		
						Being a participant first and an organizational steward second		
						Team members being willing to learn		
						Developing Friendship		
					Team members' highly active, proactive, enthusiastic, and generative style of action			
					Taking Risks			
					Developing Mentor-student relationship			
Avoiding strong focus on formal routines								
Expressing duties to meet obligations to partner organizations								



Exclusive criteria to facilitate building and maintain trust among team members

Criteria facilitating trust shared among other antecedents of IPT practices.

6.2 ANTECEDENTS OF BIM IMPLEMENTATION

In order to come up with a framework to assess organizations' implementation of BIM on different dimensions, NBIMS CMM was used to categorize the information. This section discusses development of the survey accordingly and summarizes the strategies discussed in section 5.3, in addition to the strategies found from interviews within each category as a reference for practitioners use. The tables also demonstrate the interdependencies between IPD practices and BIM implementation by showing how antecedents of BIM implementation support IPD practices and vice versa.

The survey for this section was designed using the total of nine questions ranging from multiple choice and multiple answer to matrix with multiple choice, and matrix with multiple answer, depending on the nature of the question. The choices and answer types were also ranged from nominal types of data to ordinal with 3 Likert type as well as 5 Likert type based on the context. The choices of "I don't know", "not applicable", and "others..." were also provided where applicable.

Throughout the survey, use of the word BIM was avoided, due to its different connotations. Instead, the term 3D model was used and its exact features and characteristics intended to be measured were specified within each question (Appendix A).

6.2.1 Data Inclusivity and Interdependencies with IPT Practices

"Life cycle views" and "coverage of roles or disciplines" are two important elements of achieving Inclusivity of data that are addressed in CMM.¹ For each one of these elements, one question was included in the survey. Regarding the "life cycle coverage" the survey asks architects to identify the areas in which 3D model was used on the project, using a multiple answer question with the answers being Schematic Design, Design Development, Construction Documents, Shop Drawings, Site Conditions, Turn Over, and Operation And Maintenance.

Regarding the coverage of roles or disciplines, using a multiple answer question, the survey asks architects to specify the 3D modeling features used on their projects among existing conditions

¹ "data richness" is another related element to data inclusivity that was not covered in this survey.

modeling, cost estimation, 4D modeling or scheduling, Design Review, Energy Simulation or Lighting Analysis, 3D Coordination, Record Modeling, and Creating an Operations & Maintenance Model.

As illustrated in Table 6-4 all the strategies facilitating coverage of more roles or disciplines, as discussed in section Chapter 5, can also facilitate successful coverage of more projects' life cycle. The table, furthermore, demonstrates that all three antecedents of IPT practices can facilitate data inclusivity, while data inclusivity, in return contributes to IPT practices by facilitating inter-organizational trust. As an example, inter-organizational trust encourages team members to integrate data from the supply chain into their models. This integration, in return, facilitates effective communication and engagement in others activities. As the team members communicate effectively and interact more, the inter-organizational trust would increase.

Table 6-4- Antecedents of data inclusivity and supporting strategies

IPT Practices			Criteria Asked in the Survey	Strategies Facilitating Data Inclusivity
Effective Communication	Engagement in Others' activities	Inter-organizational Trust		
X	X	XY	Life cycle views Coverage of Roles or Disciplines	Supply Chain integration
		XY		Strategic long relationships with multiple key supplier.
X	X	XY		providing project extra nets
X		X		Maintaining integrity of the model by developing protocols to facilitate tracing of the information
X				Developing standards of interaction
		X		Addressing proprietary ownership of ^{BIM} data
	X			Addressing definition of documents as static
	X	Y		Assigning all means and methods to the contractors
	X			Addressing the shop drawing submittal procedure
X represents data inclusivity strategies that facilitate IPT practices. Y represents IPT practices that facilitate data inclusivity				

6.2.2 Representation of Data and Interdependencies with IPT Practices

NBIMS CMM addresses representation of data in BIMs using a single element of “graphical information”. Within the survey two matrix questions were included to measure different aspects of data representation as discussed in section 5.3.2. The first question addressed graphical representation of data within each of the design and construction phases, whereas the second question addressed format of the design exchange among various roles or disciplines.

The interview data in this study put emphasis on several organizational and individual level strategies to facilitate format of document exchange. As an example, always working with electronic documents instead of the printouts enables team members to immediately incorporate changes and keep the model flexible. The print outs can be used at the end of each of the major phases [interview data]. Other strategies such as formalizing a type of formatting that enhances the intelligibility of the documents can be helpful both for better graphical representation of data as well as facilitation of document exchanges [interview data].

As illustrated in Table 6-5, IPT practices facilitate “representation of data” by “effective communication”. For instance, effective communication can liberate team members from working with printouts and enable them to work more effectively with electronic documents. BIM’s capabilities on data representation, on the other hand, can facilitate effective communication, engagement in others’ activities and inter-organizational trust. As an example, once team members develop the habit of working with electronic documents, capabilities of BIM tools in data representation such as instance propagation of change within the model, helps team members with effective communication.

Table 6-5- Antecedents of representation of BIM data and supporting strategies

IPT Practices			Criteria Asked in the Survey	Strategies Facilitating Representation of Data
Effective Communication	Engagement in Others' Activities	Inter-Organizational Trust		
X			Format of Document Exchange	Staged Delivery of the model
XY		Y		Working with electronic documents rather than the printouts.
X	Y			Finding common parameters to work on the models.
X			Graphical Information/ Format of Document Exchange	Formalizing a type of formatting that enhances the intelligibility of the documents.
XY	X			Not overloading the boundary objects (maintaining flexibility of the model)
X represents data representation strategies that facilitate IPT practices. Y represents IPT practices that facilitate representation of data				

6.2.3 Convenience of Data Retrieval and Interdependencies with IPT Practices

“Timeliness/response” and “interoperability” are two important elements that contribute to convenience of data retrieval addressed in NBIMS CMM.² To capture convenience of data retrieval in the population of HP projects under the study, for each of these areas a multiple choice question was included in the survey. With regards to “timeliness/ response” dimension, participants were asked to specify the extent in which data was available in immediate usable formats. To address the interoperability dimension, participants were asked to specify if the programs were completely, partially or not interoperable.

As discussed in section 5.3.3, various strategies from contractual and organizational to individual level can facilitate convenience of data retrieval. Interview data, furthermore, emphasized on importance of some strategies. For instance, interviewees indicated the importance of following

² Delivery method of BIM (single point of access, network access, etc.) is another BIM implementation dimension included in NBIMS CMM that can contribute to convenience of data retrieval, but is excluded from the survey.

the right procedure for modeling objects, such as avoiding use of BIM objects with right appearance but incorrect properties [interview data].

As demonstrated in Table 6-6, “convenience of data retrieval” facilitates “effective communication” and “engagement in others’ activities”, as when data can be exchanged with less effort communication and engagement in others’ activities will be encouraged. On the other hand, “inter-organizational trust” empowers organizations to employ strategies that facilitate data retrieval, due to having less concern over BIM liability issues.

Table 6-6- Antecedents of convenience of data retrieval and supporting strategies

IPT Practices			Criteria Asked in the Survey	Strategies Facilitating Convenience of Data Retrieval
Effective Communication	Engagement in Others’ Activities	Inter-Organizational Trust		
X			Timeliness/ Response	Imposition of national BIM standards
	X			Web-enabled design
		X		Providing descriptions or demonstrations presented by vendors, champions, etc.
		X		Developing details of implementation process based on context.
X				Consistent layering conventions
X				Following the right procedure for creating objects
	X	Y	Interoperability	Using formats that facilitate direct, proprietary exchange of information.
	X	Y		Providing IFC support
X represents data representation strategies that facilitate IPT practices. Y represents IPT practices that facilitate representation of data				

6.2.4 **Reliability of Data and Processes and Interdependencies with IPT Practices**

“Spatial capability”, “change management”, and “information accuracy” are three major dimensions in NBIMS CMM contributing to reliability of data and processes.³ For each of these elements, a multiple choice question was designed to address the extent of its implementation. These questions respectively asked about sharing digital information within organizations or using it in house, addressing contractual liability issues, and the level of team members’ trust in data.

Table 6-7 shows a collection of strategies that can be used to increase reliability of BIM data and processes as discussed in section 5.3.4, and found through case study and interview observations. Most of these strategies, have a direct or indirect effect on IPT practices. As an example, one of the “change management” strategies is to pair people experienced in the field with people who are experienced with the technology, to increase experienced people’s confidence in the tool [interview data]. This strategy would directly help with people’s engagement in others’ activities and help people who know the technology well to also gradually engage in the field.

Another example is supporting implementation of the new BIM technologies by holding workshops and technical support throughout the process and by helping the team members to develop a system understanding of the project rather than only focusing on their specific scope of work [interview data]. While this strategy would benefit from effective communication, helping with the quality of workshops and inter-organizational trust, helping people to go beyond their scope of work, it pushes team members to engage in others activities. In other words, this strategy, similar to many other presented strategies, both facilitates and benefit from IPT practices.

Other strategies that help with increasing reliability of the tools would also indirectly help people in engaging in others’ activities and effective communication, as trust in the tool and processes would empower them to use the tools’ functionalities more effectively.

³ “Business processes” (i.e. data collection and maintenance in real life as opposed to non-integrated processes) is another dimension of BIM implementation addressed in NBIMS CMM that was left out of the analysis.

Table 6-7- Antecedents of increasing reliability of BIM data and processes with supporting strategies

<i>IPT Practices</i>			<i>Criteria Asked in the Survey</i>	Strategies to Increase Reliability of BIM data and Processes		
Effective Communication	Engagement in Others' Activities	Inter-Organizational Trust				
		X	Change Management	Cultural Compatibility	Considering individual attitudes, beliefs, values, past experience, gender, age, cognitive abilities	
					Considering compatibility with norms and operations	
X	X	X		Information Accuracy	Establishing Supportive Policies and Priorities	Establishing a longer term viewpoint
						Having a broader view of risk
						Implicit vertical integration
						Maintaining an innovative culture
				Providing Technical Support	Establishing mechanisms to identify and test new technologies	Assigning data management to people who are the best source of such data
Y	Y	X				Redistributing work and providing a roadmap
						Providing accountability and Knowledge approval processes
						Holding workshops and providing technical support
				Appropriate Organizational Structure	Supporting system understanding of the project	Pairing people experienced in the field with people experienced with the technology [interview data].
X		Y				Maintaining flexibility in grouping project teams
				Spatial Capability	Overcoming the Legal Barriers	Staffing to satisfy specific requirements for key positions
						Decentralized decision making structure/ Facilitating intra and inter-organizational communication
X	X	X			Contractual Support	Addressing Intellectual property laws
						Addressing Statutory and common Law
			Addressing Copyright and property interest			
			Addressing Building permitting regulations			
			Addressing Professional licensing law			
				Contractual Support	Addressing Public Bidding requirement	
X	X	X			Solving security issues, setting policies on confidentiality of data and access control	
					Dealing with issues of intellectual property rights	
					Overcoming the liability issues	
				Balancing risks and rewards		
				Sharing the costs, risks and benefits of new technologies with the owner		

X represents data representation strategies that facilitate IPT practices.

Y represents IPT practices that facilitate representation of data

As discussed in this section, the created framework for capturing fundamental elements of IPT practices and BIM implementation to be included in the survey, also helped in shedding light on the complementary nature of elements within IPT practices and BIM implementation. This finding indicates that implementing inter-organizational BIM and establishing collaborative project environments should be pursued in tandem; one cannot cause or lead to the other. Failure to implement BIM tools successfully could, in part, be due to pre-existing ineffective IPT strategies, and vice versa.

The next section will discuss how the captured elements within the survey helped in building the higher level causal conditions and their causal pathways in design and construction of higher performance buildings.

Chapter 7. **FSQCA- IMPLEMENTATION**

FsQCA method can be used for testing existing hypothesis, as well as formulating new theories (Berg-Schlosser et al., 2009; Jordan et al., 2011). While hypothesis testing method can be used to look for specific patterns among cases, in this study an exploratory approach was taken to identify and interpret existing patterns among selected cases for achieving outcome.

In selecting the population of cases, a set of HP projects from 2005- 2013 was chosen based on the recognition they received by the AIA Committee On The Environment (AIA/COTE). In QCA method, it is common to have a purposive sampling method to insure diversity in causal and outcome conditions. In fact, external validity of the results in QCA method comes from purposive selection of cases that do not support the hypothesis or support the counter intuitive ones, as will be explained in section 7.4. (Schneider and Rohlfing, 2014).

Next, the web-based survey was sent to a few local architects for pilot study to insure all questions were unambiguous and relatable to architects. After applying the edits, the survey was first sent to over 120 architects related to 70 AIA/COTE awarded projects, and initially received 24 responses associated with 24 different projects. After the first round of analysis the survey were sent to two more groups of architects (30 overall) related to 20 more projects and received consequently 4 and 5 more responses associated with 9 different projects, increasing the overall number of cases to 33.

7.1 CHALLENGES OF CALIBRATING THE OUTCOME CONDITION

Calibrating the outcome condition, “energy consumption” of HP buildings (set name “energy.c”), encountered several challenges. These challenges include 1) inconsistencies within code and rating systems used to report the energy performance of buildings, as well as 2) comparing energy efficiency of buildings based on their total energy consumption, rather than their net energy performance, which includes the amount of energy produced by on-site renewable sources. This section introduces these challenges and presents a methodology for comparing energy performance of various HP projects, and consequently calibrating the outcome condition within an acceptable uncertainty range that does not affect validity of the study.

7.1.1 **Inconsistencies within Code and Rating Systems**

This section presents some of the major inconsistencies that existed within different code and rating systems used for reporting energy performance of the studied set of HP projects:

Operational Rating vs. Asset Rating

Within the buildings that have used rating systems to report their energy performance, some have used operational rating systems such as Energy Star Portfolio Manager (EPA, 2007), whereas others have used asset rating systems such as Home Energy Rating System (HERS). Operational rating systems rate buildings based on both their energy efficiency features and how the features are operated based on metered data, representing how buildings actually perform. Buildings with the same physical characteristics would, thus, have different operational ratings due to different user behaviors.

Newly developed asset rating systems, on the other hand, represent the inherent energy efficiency of buildings based on their physical characteristics (i.e. buildings' envelopes, and their electrical, and mechanical systems), holding user-determined factors and behaviors constant (using standard assumptions of occupant behavior or building management). Asset rating systems also exclude energy features that are not considered fixed components of the building such as non-hardwired appliances, lighting, and other equipment. Asset rating systems, ultimately evaluate energy performance of buildings based on the ratio of the predicted energy use of the building through energy modeling (using standardized default assumptions for occupancy and equipment utilization), to the energy use of a reference or benchmark building. This rating is intended to inform occupants of buildings about energy performance of the building and how the building should perform as opposed to how it will actually perform (Bourassa et al., 2012).

Consequently, while both operational and asset rating systems normalize buildings' energy use by basic factors such as building size, weather, and building type so that the energy use of very different buildings can be compared accurately, the two rating systems cannot be compared. This is due to 1) natural uncertainties that exist in modeling for asset rating, as well as 2) fundamental differences that exist between the two systems.

Natural causes of uncertainty in asset rating systems include actual weather, and actual occupant behavior, which could be very different in modeling assumptions. Research has shown that occupant behavior could be the most significant determinant of actual energy use (Sonderregger, 1978; Stein and Meier, 2000). If the occupant behavior is unknown, the energy consumption predictions, at best, would be within the uncertainty range of $\pm 15\text{--}20\%$ (Pettersen, 1994). For instance, HVAC and lights left on in unoccupied spaces are two of the major sources of faults causing energy inefficiencies in commercial buildings (Mills, 2010) which are not considered in asset rating systems.

Other than natural uncertainties, there are several differences between the two rating systems that cause discrepancies between the two. Examples include:

1. Misconducting inspections in asset rating systems, which will result in ignoring deficiencies such as duct leakage or improper refrigerant charges.
2. Making inaccurate assumptions about default values in modeling permanent features of buildings such as building envelope, the distribution system and equipment efficiencies such as air infiltration rate, duct leakage rate, furnace efficiency, etc.
3. Making inaccurate assumptions about the existence and energy use of non-permanent features of buildings such as space heaters, portable air conditioners, refrigerators, TVs, etc.
4. The physics of simulation algorithms also affect predictive ability of the software tools.

Stein and Meier's study (Stein and Meier, 2000) demonstrates the potential gap between asset rating and operational rating by comparing HERS ratings and actual utility billing data for about 500 houses in four states. They found that on average, HERS is able to have a close prediction about actual energy performance of buildings by selecting average behavior assumptions. However, on an individual house basis, predicted energy cost and actual energy cost could be very different especially for older houses. This finding indicates the large uncertainty range that exists when comparing energy performance of individual buildings using the two different rating systems, which points out the challenge existing in this research for comparing energy performance of HP projects with different energy performance evaluation systems.

Multiple Codes and Code Updates

Other than the two discussed types of rating systems, multiple codes and code updates are also used to report energy performance of the studied set of HP projects. Various jurisdictions in the U.S. use different underlying building codes and standards to regulate the energy performance of various building components. Codes and standards have tended to progressively become more aggressive, with an aim of increasing energy efficiency in building operation. Among the buildings in the selected database that have used percent reduction of energy use compared to a baseline building in a specific energy coding system, most buildings have used ASHRAE 90.1 standards, while some have used California Title 24, and some have used state specific coding systems for assessing residential projects (i.e. Oregon Structural Specialty Code). Within each system, multiple updates are used based on the projects' completion dates. This made it harder to compare the projects in a cohesive way. As an example, California Title 24 was updated in 2001, 2005, and 2008, and each time energy use is reduced from between 5% to 8%. ASHRAE standard 90.1 also updated periodically with revisions in 1999, 2001, 2004, 2007, and 2010. Some of the most significant challenges of comparing multiple codes and updates include:

- Use of regulated vs. non-regulated energies: Comparing multiple ASHRAE code updates are particularly problematic as only regulated energies such as heating, cooling, ventilation, hot water, and interior lighting are addressed prior to 2004 version. Non-regulated energy types such as process energy, plug loads, and refrigeration are addressed in 2004 version. The new regulations make it harder for energy intensive buildings such as restaurants, laboratories, and supermarkets to bypass the energy codes. Non-regulated energy in these buildings can represent about two thirds of the total energy use. Even in buildings with moderate energy use such as commercial office buildings and schools, non-regulated energy represents approximately one third of the total energy (Eley et al. 2011).
- Use of Different Metrics: Use of multiple metrics happens even within single energy codes. Such metrics include site energy, source energy, Time Dependent Valuation (TDV) energy (used only in California Title 24), or energy cost. These metrics combine different fuels such as natural gas and electricity using different formulas to represent energy savings on different conceptual levels.

Comparing Predicted and Actual Energy Savings

Regardless of using asset rating systems or codes for assessing energy performance of buildings, energy modeling can never be precise enough to predict actual energy savings without some margin of error. A study on a sample of home energy retrofit projects in California has shown that the correlation coefficient between the two measures is only in the range of 0.05, indicating no linear relationship (Brown, 2012).

Another study on LEED certified projects has shown that on average, energy performance of the sample population is the same as their actual energy performance. However, on individual cases, deviation from design prediction for half of the projects is more than 25% (Turner et al., 2008). This study further shows that buildings with high energy intensity such as laboratories on average use more than twice as much energy as predicted in their energy model. This finding indicates further provision for comparing predicted energy use of energy intense buildings with other types of buildings in current research.

The differences that exist between predicted and actual savings can be attributed to all the factors that cause discrepancies between asset ratings and operational ratings discussed before.

7.1.2 Using HERS & zEPI to Compare Energy Performance Values in Different Rating and Coding Systems

To overcome the inconsistencies between various building codes and rating systems, Architectural Energy Corporation has developed the Zero Energy Performance Index (zEPI) to facilitate energy efficiency measurement and comparison of commercial buildings. This system is similar to the Home Energy Residential System (HERS) for residential buildings (Suyeyasu, 2011). The HERS score, developed by RESNET, an independent, non-profit organization, is the industry standard by which a home's energy efficiency is measured and ensures its accuracy and consistency.

In the national HERS index system, the 100 marker represents an average newly constructed American home based on International Energy Conservation Code (IECC) 2006 baseline and the zero marker represents homes that do not use any purchased energy. A net-producer of energy home gets a negative score on the scale. Similar to HERS index system, in zEPI the zero marker represents net-zero energy buildings, and the 100 marker represents average energy use of the

buildings adjusted with the neutral variables at the turn of the millennium (based on Commercial Buildings Energy Consumption Survey- CBECS 2003). As the zero marker is absolute and the 100 marker remains unchanged, HERS and zEPI scales are stable over time (CEC, 2009; Eley et al., 2011).

Utilizing the two rating systems, it is possible to compare energy performance of all building types on the same terms (mapping the residential buildings on HERS and commercial building types on zEPI). As all buildings on the HERS and zEPI scales are normalized (compared with similar buildings), the two scales are unitless. Normalization of various buildings with different energy intensity is possible by adjusting the average energy consumption for different buildings for neutral variables such as climate, building type, and hours of operation. Neutral variables are considered the same for the baseline and the rated building. Thus, they have little impact on the buildings' ratings. Commercial building types have different sets of neutral variables, determined by the EPA (2007) through a statistical analysis that identifies factors that significantly affect building's energy performance. On the other hand, residential buildings in HERS systems are normalized solely based on different climatic regions (and use national average numbers for other occupant-related energy use).

Figure 7-1 shows the average HERS and zEPI scores for baseline buildings in various energy code systems (only the ones used for reporting energy performance of the studied set of HP projects) (Eley et al. 2011; FAS, 2009). Based on the two diagrams, equation 7.1.2.1. can be used to calculate the HERS and zEPI scores of buildings that have used percentage of energy reduction over code baselines:

$$\mathbf{eScore = bScore (1 - pReduction)} \quad (7.1.2.1)$$

Where “eScore” represents the calculated HERS or zEPI energy score of the building, “bScore” represents the Baseline score for the coding or rating system used, and “pReduction” represents percentage of the building energy reduction based on the specified baseline.

Accordingly, a building with energy performance of 40% better than baseline using ASHRAE 90.1-2004 standards gets a zEPI score of $67(1 - 40/100) = 40.2$, while a building that performs 40%

better than California Title 24-2008 scores $53(1-40/100)=31.8$. Similarly, a residential building that performs 40% better than California Title 24-2005 gets a HERS score of $79(1-40/100)= 47.4$.

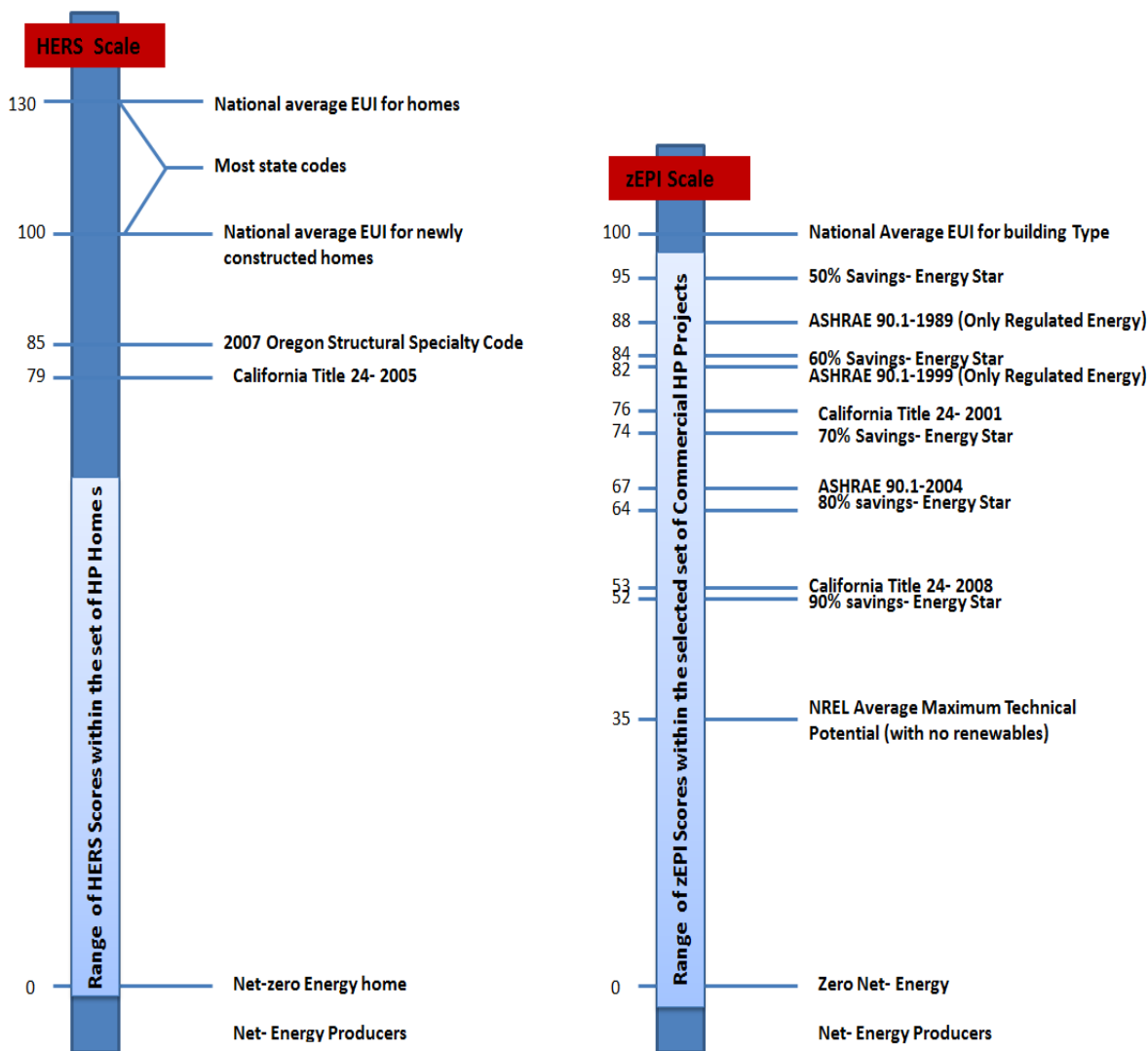


Figure 7-1- Projecting different energy coding systems into HERS/zEPI energy metrics (Eley et al., 2011; FAS, 2009)

However, assigning a score for a building that performs 40% better than ASHRAE 90.1-1999 standards (or previous versions) is more complicated than that of ASHRAE 90.1-2004, as the ASHRAE standards 1999 and 1989 account only for buildings’ regulated energy use (Eley et al., 2011). To account for the non-regulated energy used in such buildings, Table 7-1 and the following equation can be used:

$$pReduction= bRegulated* rReduction \quad (7.1.2. 2)$$

Where “pReduction” represents total percent energy reduction of the buildings that have used ASHRAE 90.1-1999 and 1989, considering the non-regulated energy use, “bRegulated” represents the percentage of regulated energy based on its’ type as demonstrated in Table 7-1; and “rReduction” represents percentage of the regulated energy reduction of the buildings as reported by the codes.

For an energy intensive building such as a laboratory in which about only 30% of energy is regulated, 40% regulated savings based on ASHRAE 1999 equals $40/100 * 30/100 = 12\%$. Using equation 7.1.2.2, this amount of reduction in total energy use leads to the zEPI score of $82 * (1 - 12/100) = 72.16$.

Table 7-1- Percentage of regulated energy for different building types based on source energy use (Codes and Standards Development, 2009)

Building Type	Percent Regulated
College (Codes and Standards Development, 2011)	75%
Retail (Codes and Standards Development, 2011)	73%
Assembly (Codes and Standards Development, 2011)	75%
Convention center (Codes and Standards Development, 2011)	70%
School (Codes and Standards Development, 2011)	74%
large office (Codes and Standards Development, 2011)	69%
Restaurants (Eley et al. 2011)	35%
Laboratory (Eley et al. 2011)	30%

The procedure of mapping buildings that have used ASHRAE 90.1- 1989 and 1999 coding system on the HERS/zEPI has a large uncertainty range because of the following reasons:

1. There is no available information about their non-regulated energy use. Even in cases in which there is energy savings in non-regulated energy use, this saving would not be reflected in the HERS/zEPI score.
2. The percentage of regulated energy for various building types is calculated using the average source energy EUI and the average regulated source energy EUI for buildings in Commercial End Use Survey (CEUS) database. Even if the calculated percentiles are accurate numbers, they are not necessarily accurate for individual cases.

3. Energy performance of buildings that have used ASHRAE 90.1-1999 standards are measured based on their percentage of energy cost savings, while the percentage of regulated energy use is calculated based on the source energy use. In the next section, strategies chosen for calibrating the “energy performance” condition to minimize the effect of this uncertainty range on internal validity of the study is discussed.

The zEPI scale is also technically consistent with ENERGY STAR Portfolio Manager program as both systems use the CBECS 2003 database as their baseline. Thus, in cases where “ENERGY STAR percentage better than median” is used to report energy performance of the buildings, the zEPI score can be calculated using the following equation:

$$\text{eScore} = 100 - \text{eStar} * 100 \quad (7.1.2.3)$$

Where “eScore” represents the calculated zEPI score, and “eStar” represents “ENERGY STAR percentage better than median.”

On the other hand, where “ENERGY STAR score” is used for reporting the energy performance, the mapping procedure would be different due to different structure of Energy STAR percentile scoring curve. Comparison of the ENERGY STAR percentile scoring curve for commercial office buildings with the zEPI scale shows that the score of 50 in energy star represents the score of 94 on the zEPI scale (CEC, 2009), the score of 60 represents 84 on the zEPI, 70 represents 74, 80 represents 64, and 90 represents 52. For buildings that use less than half of the energy of average buildings, the energy star scale ceases to properly measure progress toward net zero energy goals, as all such buildings would score around 99 in Energy Star scoring system (Eley et al. 2011).

After all, while feasible to find approximate zEPI score equivalent to energy star scoring system, as explained earlier, comparing asset rating and operational rating systems would not be possible without having a large uncertainty range. Section 7.2 discusses the calibration mechanism chosen for managing this inherent uncertainty.

7.1.3 Comparing Buildings Based on Their Net Energy Consumption

Another challenge in comparing energy performance of the studied set of HP projects was the accessibility of the data representing the amount of “purchased energy” as opposed to the “net

energy use” for most buildings in this study. The amount of purchased energy denotes net energy use of buildings excluding the amount of energy that comes from on-site renewable energy sources. Comparing the energy performance of buildings using their “energy consumption” over the amount of “purchased energy” has two advantages:

1. It is easier for buildings with low intensity energy use, such as residential buildings and schools, to achieve higher energy performance with the use of on-site renewable energy sources, since with the same amount of on-site energy production they can provide a greater proportion of their net energy use. Consequently, it is harder for energy intense buildings to generate enough energy on-site to operate the building and achieve net-zero energy status.
2. Increasing the amount of energy generated from on-site renewable sources could be causally related more to the project construction budget and owner having ambitious environmental goals as opposed to factors contributing to team collaboration and use of technology, which is the subject of this study.

The new HERS/ zEPI score after taking out the amount of energy that comes from renewable energy sources could be calculated using the following equation:

$$\mathbf{aScore = eScore * eUse / ePurchased} \quad (7.1.3. 1)$$

Where “aScore” represents the adjusted building HERS or zEPI score based on the building energy consumption; “eScore” represents the buildings’ HERS or zEPI score including their use of renewable resources, “eUse” represents the buildings’ total energy consumption, and “ePurchased” represents the buildings’ total purchased energy.

In the case of net-zero energy and net energy producer buildings, where this equation cannot be used, direct data indicating the net energy use reduction of the building is used. The new adjusted HERS/zEPI scores range from 97 to 14 (originally ranging from 97 to -12 as depicted in Figure 7-1.)

7.2 OUTCOME CONDITION CALIBRATION MECHANISM

For calibrating the outcome condition “energy consumption” comparing multiple coding and rating systems the following steps are taken:

1. For buildings using HERS asset rating system for reporting the energy performance of buildings, the HERS score is adjusted using equation 7.1.2.1. to eliminate the effect of on-site renewable sources from the “energy consumption” value.
2. For all buildings using percentage of energy reduction comparing to code baselines, the HERS/zEPI score of the buildings are calculated using equation 7.1.2.1. For buildings using ASHRAE 90.1 standards 1989 and 1999 equations 7.1.2.2., and 7.1.2.1. are respectively used for taking into account non-regulated energy use of buildings based on national average values for unregulated energy uses. The obtained HERS/zEPI scores are then adjusted for eliminating the effect of on-site renewable energy sources using equation 7.1.3.1.
3. For commercial projects using percentage of energy reduction based on Target Finder (an operational rating system), the zEPI score is calculated using equation 7.1.2.3. For commercial projects using Target Finder scores, the zEPI score is estimated using Figure 7-1.

After finding the related HERS/zEPI scores for all buildings, a general comparison between HERS/zEPI scores calculated using the above procedures showed no significant difference between the direct reports of HERS scores and HERS scores calculated using codes (procedures 1 and 2). However, for buildings that had reports of both Target Finder and percent saving over codes, the zEPI scores calculated using Target Finder, on average, were found to be greater than the zEPI scores calculated using codes (Procedures 3 and 2) by a factor of 1.48. This finding, although not ideal in terms of showing the ability of codes and asset rating systems to predict energy performance of buildings, is not surprising. As previously discussed, to account for user behavior in buildings that have used asset rating systems to report their energy use, national average values are used, which have a large uncertainty range compared to actual user behaviors, as shown by previous studies (Turner et al., 2008). In fact, the inconsistency rate found in this study is closely in line with Brown’s study (Brown, 2012) which compared predicted energy

performance of Californian Retrofit projects with their actual performance and found that the predicted energy savings, on average, exceeds actual energy savings by factor of 1.5 (a predicted energy savings of 30%, shows only 20% reduction in actual utility bills) (Brown, 2012).

Consequently, direct comparison of energy consumption of buildings using operational and asset rating systems would be biased, with asset rating systems attributed to higher performance. Theoretically speaking, operational rating systems cannot be a basis for comparison between all building types since these systems are only applicable to common building types for which there are enough CBECS data. Operational rating systems such as Energy Star Portfolio Manager are voluntary programs and could be selective in covering different building types (Eley et al., 2011). On the other hand, while rating systems, such as codes and standards, are more comprehensive in terms of the types of buildings they rate, for buildings that have reported both scores, it would be hard to justify reliance on the less accurate report and award projects based on misrepresentation of their energy consumption. The following strategies are used in this project to lessen the gap between operational and rating systems and allow their comparison with less uncertainty and bias:

1. As discussed in section 7.1.1, one of the most significant sources of difference between operational and asset rating systems are caused by the difference between actual user behavior and the default national values used in rating systems to account for user behavior. On the other hand, one of the significant sources of difference in user behavior is determined by the difference between actual and predicted unregulated energy uses. As for most buildings in the selected database of HP projects, the actual percentage of non-regulated energy uses are available, this percentage is subtracted from the zEPI scores of buildings calculated using Target Finder reports, and replaced with default values as used in asset rating systems using the following equation:

$$\mathbf{nScore=eScore-(eScore* nRegulated/eRulated) + (eScore * nRegulated/dRegulated) \quad (7.2.1)}$$

Where “nScore” represents the new zEPI scores for buildings with operational rating systems calculated based on the national average percentage of non-regulated energy use as opposed to the actual non-regulated energy use; “eScore” represents the calculated zEPI score using Target Finder, “nRegulated” represents actual buildings’ non-regulated energy use; eRegulated represents percentage of the building regulated energy use, and

“dRegulated” represents the default percentage of the building regulated energy based on its type.

2. While applying this equation theoretically lessens the gap between operational and rating systems, it only helped to decrease the gap to the factor of 1.45 (previously being 1.48) within the 15 buildings in the selected database with both operational and asset rating scores. Consequently, for having a fair comparison between the two sets of buildings, the HERS/zEPI scores calculated using codes and asset rating systems, are multiplied by 1.45 to remove this existing bias:

$$\mathbf{fScore} = \mathbf{aScore} * \mathbf{1.45} \quad (7.2.2)$$

Where “fScore” represents the final adjusted energy value considered for buildings with asset rating systems; “aScore” represents the buildings’ adjusted zEPI score as calculated using the equation 7.1.3.1.

3. As the final step in calibrating the “energy consumption” condition, the zEPI/HERS scores calculated using Target Finder and the zEPI/HERS scores adjusted for the bias in comparing the two notions (using equation 7.2.2) were sorted together. The fuzzy set intervals are then drawn using natural breaks in the data.

Table 7-2- Calibrating energy consumption of all buildings

Membership in the set of “[extra-ordinary] energy consumption”	Final HERS/zEPI Scores	Membership score in “Energy consumption” set	Number of Cases
Completely in the set	19-55	1	7
More in than out of the set	58-70	0.67	14
More out than in the set	82-86	0.33	2
Completely out of the set	90-105	0	8

Alternate approaches were considered, including separate calibration of asset ratings and operational rating systems based on natural clusters of data in each system separately, and overwriting the asset rating scores with operational rating scores (rather than multiplying the asset scores by 1.45 and calibrating the two systems together). None of the alternate approaches substantially changed the overall conclusions of the study, while the chosen approach provides the most consistent basis for comparison.

7.3 CALIBRATION OF THE CAUSAL CONDITIONS

One limiting factor of using QCA methods, as discussed in section 4.2.2, is that the number of conditions that can be tested is restricted. In this study, since data was gathered for 33 cases, having 6 conditions would result in at least ($2^6-33=31$) unrepresented configurations while more than 6 conditions would result in a greater number of ($2^7-33=95$) unrepresented configurations, lowering the overall reliability of the research. Therefore, special effort was taken in order to not exceed the maximum number of 6 conditions. The study was started with 4 main conditions (but ended with 6 conditions as will be explained) determined as effective in delivery of HP projects: “IPT practices”, “BIM implementation”, “sustainability objectives”, and “team members’ experience” (as contextual setting), explained in section 4.2.1.

The case study revealed that all HP projects within the study had ambitious environmental goals with owners fully on board with the projects’ sustainability goals. Therefore, the “sustainability objectives” were kept constant within the projects, leaving room for more detailed analysis of other condition.

Next, “IPT practices” condition, was divided into the three identified antecedents: “engagement in others’ activities”, “effective communication”, and “inter-organizational trust”:

- Among the 5 elements captured as being important in “effective communication”, illustrated in Table 6-1- Antecedents of effective communication, and supporting strategies only one contractual element had enough variations to be included in the analysis: “project delivery method”, which was shared among all three antecedents. Other elements had all received a high level of success within their respected HP projects, which indicates the importance of having effective communication in HP projects (although a quantitative method of analysis with a large number of cases is needed to show the significance of this relationship).
- Similarly, within all 13 elements captured in the survey with regards to “engagement in others’ activities”, illustrated in Table 6-2, only 4 elements had enough variation for direct inclusion within fsQCA analysis (other elements had all reported high levels of satisfaction): 1) project delivery method, 2) contract pricing method, 3) team members’ understandings of others’ scope of work, and 4) holding design charrettes, After rounds of

going back and forth between theory and data to construct the typologies of HP projects, the later condition, holding design charrettes, were eliminated from the analysis as it was found to not having a meaningful effect on any of the constructed typologies. This can be justified by the fact that all projects reported having successful inter-organizational meetings and engagement in other activities in general, which can be a good substitutes for teams without having a design charrette.

- Finally, within the 8 contributing elements to “inter-organizational trust”, only two elements had enough variation to be incorporated directly into fsQCA: “contract pricing method”, and “exceeding contractual agreements”. Considering one being a contractual level antecedent and the other organizational level, with different variation themes, combining the two would have resulted in loss of data and could have not helped with constructing the typologies. Therefore, the “contract pricing method” was kept solo within the analysis, while “exceeding contractual agreements” was combined with other elements with low variation within the “inter-organizational trust” category to create a slightly more comprehensive reflection of trust within the HP projects. In other words, the fsQCA study was primarily performed with “exceeding contractual agreements” as the solo construct of the “inter-organizational trust”, which had enough variation to help with creating the typologies. The other three conditions were included in the study as presented within Table 7-3 because of their theoretical relevance, but did not have any effect on the constructed typologies other than a slight change in sufficiency and coverage values.

With regards to incorporating the BIM related elements in the fsQCA, on the other hand, more caution was needed, because of the 8 year time span considered for selecting the population of cases (2005-2013), in which the context and capabilities of BIM technologies has been subject to change, with the rapid growth rate of these technologies (Gu and London, 2010; Underwood and Isikdag, 2011). As an example, supply chain integration of data to achieve more “data inclusivity” in 2005 would have required more organizational change and effort, due to availability of fewer suppliers who had implemented the new technologies. Thus, while the created survey could be used in its’ fullest extent in BIM studies with less time variation, in this study, few basic elements that were less prone to the time difference was used:

- From “representation of data” antecedents, only the “graphical information” construct was used, assessing the 3D+ representation of data during the design phase, eliminating the “format of document exchange” which was more biased towards the newer projects.
- From “reliability of data and processes”, the three antecedents “spatial capability”, “data accuracy”, and “change management” were used, although inclusion of the “data accuracy” was merely for its’ theoretical relevance and did not have any effect on the constructed typologies.
- All conditions with regards to “inclusivity of data” and “convenience of data retrieval” showed a bias with regards to time difference and were eliminated from the analysis.

The four remaining elements were combined under a single condition “reliable BIM technology use” as demonstrated in Table 7-3. Other methods of including these conditions into the analysis, such as using solo conditions, were experimented as well. However, given the limitations of the study in terms of number of conditions, considering more conditions for the BIM implementation required dropping some of the conditions from the IPT practices. While those possibilities were also considered through rounds of experimentation with fsQCA and going back and forth between theory and data to construct the typologies, the six presented final conditions showed the most potential in creating comprehensible typologies.

The implications of this choice for the study is that the “BIM implementation” condition is measured based on having 3D+ representation of that, sharing digital data within organizations, people’s trust in BIM data, and having addressed BIM related liability concerns within contracts. The four construction conditions are combined using Boolean multiplication, meaning that “If a project is given a full membership value in three of the conditions, for instance, and a full non membership value in the remaining condition, the project membership score in “BIM implementation” condition would be considered zero. In other words, within the current presented typologies of HP projects, what makes a difference within a typology is using a liable and reliable BIM technology, and not merely a technology use.

Lastly, the “team member’s experience” condition, originally consisted of two elements of “architecture team experience” and “construction team experience” was recalibrated to

“architecture team experience” and “architecture firm size”, as called for within the data analysis. The construction teams’ lack of experience was found to be overcome by the culture of education and learning available in all successful typologies. Adding the “architecture firm size” condition to “architecture teams experience”, on the other hand, seemed to theoretically help in construction of one of the typologies, due to the considerable effect of availability of slack resources on innovation (Tatum, 1989). The combinatory condition was called “architecture firm’s well-establishment”.

For each contributing elements to the main conditions, theory is used to determine the cross-over point (where maximum ambiguity happens), the threshold for full membership, and the threshold for full non-membership in the sets. In addition, theory and case studies are used to determine what constitute a meaningful variation to build intervals of the fuzzy sets. Table 7-3 shows the final coding scheme for calibrating the six main causal conditions and their contributing elements.

Table 7-3- Coding scheme for calibration of the causal conditions

Conditions	Measurement Unit/ Function	Sub-Conditions (Contributing Elements)	Set Intervals & Membership Score based on responses to the survey (Appendix A)
Architectural Firm’s Well- Establishment (a.establish)	Boolean multiplication function of the two constructs. (a.establish= a.employee* a.age)	a.employee: Architectural firms number of employees.	Architectural firms’ number of employees (based on case studies): 0-10 people: 0 11-20 people:0.33 21-50 people: 0.67 51+ people:1
		a.age: Architectural firms age at the time of project completion.	Project completion date- Architectural firm establishment date (based on case studies) 1-10 years: 0 11-20 years: 0.33 21-30 years: 0.67 31+years:1
Change Allowance in Contract Pricing Method (c.pricing)		c.pricing: The level in which contract pricing method facilitates incorporation of change into the design.	Responses to Question 4: Lump Sum 0 GMP 0.9 Cost Plus 1

Conditions	Measurement Unit/ Function	Sub-Conditions (Contributing Elements)	Set Intervals & Membership Score based on responses to the survey (Appendix A)
Inter- Organizational Scope Understanding (scope.u)		scope.u: Team members' understanding of challenges and obstacles of other organizations' scopes.	Responses to Question 12-C: Always 1 Usually 0.67 Sometimes 0.33 Never-Seldom 0
Inter- Organizational Trust (i.trust)	Boolean multiplication function of the four constructs (i.trust= trust* mutuality* contract.e* t.reliability)	trust: Trusting actions	Response to Question 12-A: Always 1; Usually 0.67; Sometimes 0.33; Never- Seldom 0
		mutuality: Fulfillment of Mutual Obligations	Response to Question 12-D: Always 1; Usually 0.67; Sometimes 0.33; Never- Seldom 0
		contract.e: Exceeding Contractual Obligations	Response to Question 12-F: Always 1; Usually 0.67; Sometimes 0.33; Never- Seldom 0
		t.reliability: Reliability of working team members	Response to Question 10-A: Always 1; Usually 0.67; Sometimes 0.33; Never- Seldom 0
Reliable BIM Technology Use (r.bim)	Boolean multiplication function of the four constructs ⁴ (r.bim=bim.design* spatial.cap* change.manage* data.accuracy)	bim.design: Digital 3D+ representation of data during the Design Development phase.	Response to Question 18: Design Development checked:1 Design Development unchecked: 0
		spatial.cap: Sharing digital information across organizations.	Response to Question 15: Shared across companies:1 In house only:0.33 There was no digital files: 0
		change.manage: Inclusion of liability concerns regarding the exchange of digital files across companies within contractual agreements.	Response to Question 16: Yes:1 Partly: 0.33 No: 0 I don't know:0.33
		data.accuracy: Team members' trust in digital data	Response to Question 20: Always 1; Usually 0.67; Sometimes 0.33; Never- Seldom 0

⁴ Inclusion of bim.sharing and bim.trust conditions in constructing the r.bim condition is solely for their theoretical relevance. This inclusion did not affect the fuzzy set values of any of the projects in the study.

Conditions	Measurement Unit/ Function	Sub-Conditions (Contributing Elements)	Set Intervals & Member-ship Score based on responses to the survey (Appendix A)
Integration of Delivery Method (i.delivery)		i.delivery: The level in which delivery method facilitates integration among core teams (owner, architect and contractor)	Responses to Question 3: Design Bid Build 0 Design Bid Build with a CM and multiple prime contracts: 0.2 Other: Invited Bid 0.30 Other: Federal Government small Business Set Aside- Other: Negotiated Bid 0.4 CM@ Risk 0.7 Design Build 0.9 Other: Modified IPD/ Negotiated Contract 1 IPD 1

7.4 CONSTRUCTION OF THE TRUTH TABLE

The next step after establishing cases, outcome and causal conditions, and their fuzzy values in fsQCA is building the truth table as explained in section 4.1. In this study, after populating the property space with cases of high-performance projects, the projects with the same combination of causal conditions were identified. Next, homogeneity of cases were verified, meaning that if the cases with the same causal recipes were not comparable instances and could not construct a type together, the causal conditions were refined and the property space were reconstructed until the cases produced homogeneous groupings. As suggested by Ragin (2008) the consistency cut-off above 0.9 is considered in this study.

Additionally, the following steps were performed to insure validity and analyzability of the truth table in this study:

1. Ensuring case diversity: In QCA studies, it is important to work with a set of cases that vary both in their causal and outcome conditions. In this study, because a set of chosen cases were all considered successful based on the industry standards, many of the sub-conditions contributing to IPT practices, as discussed, did not have enough variation, representing cases that were more in that out of those set. Consequently, the definition of such sets were refined (to higher-level IPT practices), to create more variation. For instance, to create the “inter-organizational trust” condition, rather than considering the average score for the four contributing factors of “trusting actions”, “fulfillment of mutual obligations”, “exceeding contractual obligations”, and “reliability of working team

members”, the Boolean multiplication function of these sub-conditions are considered (as demonstrated in Table 7-3). The resulted “inter-organizational trust” condition, thus, is highly sensitive to shortcomings in any of the defined conditions.

2. Contradictory configuration test: Resolving contradictory configurations in QCA, is an important and a labor intensive part of the analysis which helps to identify the link between conditions and the outcome as “causation” and gives us a better understanding of the causal mechanism that strike the outcome (Schneider and Rohlfing, 2014). In this step, cases in which all conditions of a given causal recipe were present, but resulted in negation of the outcome condition, were investigated qualitatively. Here, various thought experiments were performed to determine what has caused the contradiction. As an example inclusion of the “architecture firms’ well-establishment” condition, into the study (originally excluded in the study due to having more than 5 conditions, but was brought back in) was a result of solving a contradictory test. Conversion of the initially created “BIM technology use” condition to “reliable BIM technology use” by including the other sub-conditions of “BIM liability” and “BIM trust”, was also a result of solving contradictory configuration cases.

Resolving the contradictory configurations in this study also resulted in elimination of one project from the study. As investigations showed that the project was a remodeling case with a given non-optimal building orientation, which ultimately resulted in having a high-energy consumption despite the team’s effort in optimizing other contributing factors. (The number of cases in this study, thus, was reduced to 32.)

3. Resolving counter-intuitive configurations: Similar to contradictory configuration test, the causal relationship between conditions and the outcome was insured by checking the opposite configurations, where negation of the causal condition should theoretically happen, but did not. Accordingly, in this phase, cases in which all of the causal conditions were absent, but resulted in presence of the outcome, were investigated qualitatively. This examination also created a better understanding of the causal mechanism and led to re-calibration or refining some of the sets, as elements were found that were not contributing to the causal mechanisms but were included in the conditions. For instance, in “reliable BIM technology use” condition, use of BIM technologies in phases other than Design

Development were found unrelated in increasing efficiency of HP projects and thus were eliminated from the constructing sub-conditions.

Rows 1-21 in Table 7-4 shows distribution of cases within the truth table with final conditions and their final calibrated values, after rounds of iterations of resolving contradictory and counter-intuitive cases:

Table 7-4- The study truth table

Configuration ID	a.establish	r.bim	scope.u	c.pricing	int.del	i.trust	number	energy.c	raw consistency	Typology
1	0	1	1	1	1	1	3	1	1.00	Type A
2	1	0	0	0	1	1	3	1	0.97	Type C
3	1	0	1	1	1	1	2	1	0.92	Type B & C
4	1	0	0	0	0	0	2	0	0.51	Type A - Counter intuitive
5	0	1	1	1	0	1	2	1	1.00	Type A
6	0	0	1	1	1	1	2	1	0.92	Type B
7	0	0	1	1	1	0	2	0	0.81	-
8	0	0	1	0	0	1	2	0	0.39	-
9	0	0	1	1	0	0	2	-	0.96	Undetermined
10	1	1	1	1	1	1	1	1	1.00	Type A
11	1	1	0	1	1	0	1	-	1.00	Undetermined
12	1	0	1	1	1	0	1	-	0.91	Undetermined
13	1	0	1	0	1	1	1	1	0.97	Type C
14	1	0	1	0	0	1	1	0	0.60	-
15	0	1	1	0	0	1	1	0	0.67	-
16	0	1	0	0	0	0	1	0	0.45	Type B & C- Counter-intuitive
17	0	0	1	0	1	0	1	0	0.83	-
18	0	0	1	0	0	0	1	0	0.44	Type B- Counter-intuitive
19	0	0	0	1	1	1	1	1	0.91	Type B
20	0	0	0	0	0	1	1	-	-	-
21	1	1	0	0	1	1	0	-	-	-
22	1	1	1	1	1	0	0	-	-	-
23	1	1	1	1	0	1	0	1	-	Type A- Counter-fact
24	1	1	1	1	0	0	0	-	-	-
25	1	1	1	0	1	1	0	-	-	-
26	1	1	1	0	1	0	0	-	-	-
27	1	1	1	0	0	1	0	-	-	-
28	1	1	1	0	0	0	0	0	-	Type B- Counter-intuitive counter-fact

Configuration ID	a.establish	r.bim	scope.u	c.pricing	int.del	i.trust	number	energy.c	raw consistency	Typology
29	1	1	0	1	1	1	0	1	-	Type B counter-fact
30	1	1	0	1	0	1	0	-	-	-
31	1	1	0	1	0	0	0	-	-	-
32	1	1	0	0	1	0	0	-	-	-
33	1	1	0	0	0	1	0	-	-	-
34	1	1	0	0	0	0	0	0	-	Type B- Counter-intuitive counter-fact
35	1	0	1	1	0	1	0	-	-	-
36	1	0	1	1	0	0	0	-	-	-
37	1	0	1	0	1	0	0	-	-	-
38	1	0	1	0	0	0	0	-	-	Type B- Counter-intuitive counter-fact
39	1	0	0	1	1	1	0	1	-	Type C- Counter-fact
40	1	0	0	1	1	0	0	-	-	-
41	1	0	0	1	0	1	0	-	-	-
42	1	0	0	1	0	0	0	-	-	-
43	1	0	0	0	1	0	0	-	-	Type A- Counter-intuitive counter-fact
44	1	0	0	0	0	1	0	-	-	-
45	0	1	1	1	1	0	0	-	-	-
46	0	1	1	1	0	0	0	0	-	Type C – Counter-intuitive counter-fact
47	0	1	1	0	1	1	0	-	-	-
48	0	1	1	0	1	0	0	-	-	-
49	0	1	1	0	0	0	0	-	-	Type B- Counter-intuitive counter-fact
50	0	1	0	1	1	1	0	1	-	Type B- counter-fact
51	0	1	0	1	1	0	0	-	-	-
52	0	1	0	1	0	1	0	-	-	-
53	0	1	0	1	0	0	0	0	-	Type C- Counter-intuitive counter-fact
54	0	1	0	0	1	1	0	-	-	-
55	0	1	0	0	1	0	0	-	-	-
56	0	1	0	0	0	1	0	-	-	-
57	0	0	1	1	0	1	0	-	-	-
58	0	0	1	0	1	1	0	-	-	-
59	0	0	0	1	1	0	0	-	-	-
60	0	0	0	1	0	1	0	-	-	-
61	0	0	0	1	0	0	0	-	-	-
62	0	0	0	0	1	1	0	-	-	-
63	0	0	0	0	1	0	0	0	-	Type C- Counter-intuitive counter-fact
64	0	0	0	0	0	0	0	0	-	Type C- Counter-intuitive counter-fact

In the next phase of the analysis, counter-factual configurations (i.e. configurations that are not observed by any cases) were reviewed to test if the causal recipes can be minimized further. Minimization of a causal recipe is to see if there is theoretically an intelligible basis for dropping an INUS condition from the recipe on the basis that it does not make a difference on the outcome (Schneider and Rohlfing, 2014). The results of engaging in the thought experiment to determine the outcome value of the counter-factual configurations are demonstrated in rows 22-64 of the truth table demonstrated above in Table 7-4.

Chapter 8. TYPOLOGIES OF SUCCESSFUL HIGH-PERFORMANCE BUILDINGS

Performing the above procedures resulted in creating three main typologies of successful HP buildings with regards to having low energy consumption. These typologies, presented in Table 8-1, are also shown within the truth table demonstrated in Table 7-4, along with the representation of their counter-intuitive and counter-factual cases.

Table 8-1- Created causal recipes with coverage and consistency values

<i>Type</i>	Causal Recipes	Raw Coverage	Unique Coverage⁵	Consistency
A	i.trust *c.pricing*r.bim*scope.u	0.301525	0.178430	1.000000
B	i.trust*i.delivery*c.pricing*~r.bim	0.267081	0.076228	0.934783
C	i.trust*i.delivery*a.establish*~r.bim	0.398645	0.188594	0.955345
	Total	0.671937	-	0.973017

An important consideration in interpreting these three typologies is that all projects achieved high energy performance and, therefore, reducing energy consumption was a project goal from the start of the projects, as demonstrated within the case studies. Furthermore, as the results of the surveys and case studies indicate, all the projects have been carried out within an environment of collaborative decision making, where architects, engineers and owner representatives communicated successfully, working closely and early in the design process, and shared similar goals (Survey questions used for this assessment are 8-A, B, C & D; 9-A, B & C; 10- B & C; 11- A, B, D & E). Early involvement of contractors in the design process, however, varies among cases, which has been studied under the “integration of the delivery method” condition. Therefore, all the projects in this study are considered environmentally ambitious and highly-collaborative by industry standard norms, which means these conditions need to be considered as contextual factors in all above recipes, and absence of each condition may result in negation of the outcome.

This section discusses characteristics of the three produced typologies and how firms can strategize for success within each typology.

⁵ Unique coverage is a term used for indicating the ratio of the outcome that is *exclusively* explained by a certain causal recipe.

8.1 TYPE A: INFORMATION DRIVEN PROJECTS

The first typology of successful HP projects with low energy consumption, according to this study, can be described as cases with four INUS conditions: “inter-organizational trust”, “change allowance in contract pricing method”, “inter-organizational scope understanding”, and “reliable BIM technology use” (description and calibration of each condition is presented in Table 7-3). As inferred from raw coverage and consistency values (presented in Table 8-1) respectively, this recipe explains the causal mechanism for achieving success in nearly one third of the studied population, in 100% of those cases the presented recipe has been sufficient for achieving success (HP buildings with low energy consumption). In other words 0% of cases have been contradictory to this recipe.

The projects that follow this causal recipe can be referred to as “Information Driven Projects”, as the working dynamic within such projects is highly affected by reliance of team members on the new information technologies (3D+ representation tools). Following the Information Driven Projects’ recipe for success can free companies from the limitations of traditional delivery methods imposed on project team integration, as well as organizational limitations that exist in small/ or newly founded architectural firms (such as unavailability of slack resources or working with less experienced people). The other conditions identified in this causal recipe as necessary (but not sufficient) include team members’ awareness of the obstacles and challenges of other team members’ scopes of work, working with team members that highly fulfill mutual obligations towards other team members, which creates an environment of trust for collaboration, and finally working with the right contract pricing method that allows design to progress as new ideas emerge throughout the design and construction phase. The causal mechanism that is triggered by presence of these four conditions is described here in more detail.

Presence of “reliable BIM technology use” condition, as demonstrated in Table 7-3, indicates working with at least three dimensional (3D+) design representation documents during the design development phase, sharing digital information across organizations, having trust in digital data (from the perspective of architects working on the project), and having addressed the BIM related liability issues within the contracts. Thus, designers working on projects identified as having

reliable BIM technology use, not only have access, work with, and share 3D+ information cross-organizationally, but also trust and rely on such information.

On the other hand, as described in section 2.1, designing HP projects, requires a design process that allows approaching the building design as a whole by exploring the interrelationships of building elements, environment, and human well-being. While presence of “reliable BIM technology use” facilitates such holistic approach to design, especially when the other two important conditions of having ambitious environmental goals and collaborative decision making environment are present, it is arguably not enough. As the results of this study suggest, “inter-organizational scope understanding” is a complementary element to the “reliable BIM technology use” condition for achieving greater energy efficient buildings in this typology of projects. As the team members’ access to information within the scope of other members increases, so does their potential for gaining a holistic understanding of the project. This holistic understanding, however, cannot be carried out without knowing the obstacles and limitations of other team members’ scope of work, which can be gained by being open to learning from and educating each other. Gaining such an awareness is key for using the liable and reliable information provided by advanced digital technologies.

When team members’ awareness of the project requirement surpasses organizational boundaries, the traditional dynamic among team members from various organizations changes. As this change requires a new social and organizational framework for team members’ interaction, reliance on contractual obligations that team members owe to one another, may not be enough for reaching ambitious environmental goals such as having superior energy performance. Presence of the “inter-organizational trust” condition, therefore, is another complementary element to the previously discussed “reliable BIM technology use” and “inter-organizational scope understanding” conditions for triggering the causal mechanism in this typology that leads to designing buildings with lower energy consumption. Presence of this condition, as presented in Table 7-3, indicates that team members from collaborating organizations, not only are reliable and fulfill the mutual obligations to each other, but also, exceed such obligations as specified within the contracts, collaborating under an environment of reliability and trust.

Finally, the causal mechanism leading to design and construction of HP projects with low energy consumption in “Information Driven Projects” completes with integration of information from the construction team. This integration, however, cannot happen as effectively without having a contract pricing method for the construction process that allows reflection of design changes in building construction. Working with cost plus, or GMP contract pricing method facilitates such integration by eliminating the risks that both design and construction teams bear for changes happening within the design documents after construction contract is awarded.

Although in many types of projects more integrated forms of delivery methods and presence of well-established architectural firms are causally related to achieving greater energy efficiency, as will be discussed within sections 8.2, and 8.3, this study shows that in presence of the described causal mechanism in Information Driven Projects, they are not. This observation can be theoretically justified, first, by addressing the three major benefits of integrated delivery methods such as IPD and Design Build and how they can be substituted within the described casual mechanism.

1. Stipulating the duties that team members owe to one another: In presence of the described causal mechanism, team members exceed contractual obligations on the basis of ambitiousness, integrity and trust, as evident by presence of “inter-organizational trust” condition.
2. Bringing the contractors earlier in the process: Although the design team can benefit from the construction team’s input to resolves issues of constructability, waste management, and value engineering, dealing with these issues could be most helpful in cost management as opposed to dealing with energy efficiency issues.
3. Choosing the construction team based on their qualifications: As case studies in this project show, projects have been able to overcome the problem of working with less qualified teams by having a culture of learning from and educating each other which is a center piece in the described causal mechanism. In the case of Design-Bid-Build projects, this education can happen in pre-bid conferences addressing the sustainability objectives of the project as well as responsibilities of the construction team in achieving them.

Similarly, the described causal mechanism enables firms with any level of development to achieve success. This capacity can be theoretically justified by addressing the two major benefits of working within well-established architectural firms:

1. Availability of slack resources: While well-established architectural firms have more capability for working around innovative ideas because of their available slack resources, innovation can happen within Information Driven Projects because of their holistic approach to design and construction that allows new ideas to emerge from all team members.
2. Organizational experience with various project types: Although this can be a very effective factor in achieving success in most architectural projects, the culture of learning from and educating others existing in Information Driven Projects can help to overcome lack of experience existing in newly established architectural firms.

8.2 TYPE B: PROCESS DRIVEN PROJECTS

The second typology of successful HP projects with low energy consumption that emerged in this study can be described as having four INUS conditions of “inter-organizational trust”, “integrated delivery method”, “change allowance in contract pricing method”, and absence of “reliable BIM technology use”. As inferred from raw coverage and consistency values (presented in Table 8-1) respectively, this recipe is presented in about one quarter of the studied population, in 94% of those cases the presented recipe has been sufficient for achieving HP buildings with greater energy efficiency.

The projects that follow this causal recipe can be referred to as “Process Driven Projects”, as team members’ integration is facilitated mostly by having a process that has a high potential for integration due to contractual agreements and has social and organizational elements required for fulfilling such potentials. As will be explained, this causal recipe liberates team members from relying on BIM technologies, and well-established architectural firms.

The causal mechanism leading to design and construction of higher performance projects in Process Driven Projects starts with having two contractual conditions of “integration of delivery method” and “change allowance in contract pricing method”. Presence of these two conditions

encourages design and construction teams to collaborate more effectively to achieve a holistic view of the project without having the fear of sacrificing their organizations scope and/or facing more risks for sharing information, or making a change in the scope of work.

“Inter-organizational trust”, is another necessary condition in this causal recipe, as lack of trust in this process inhibits team members from fully engaging in the collaboration. Team members’ attributes such as being reliable, fulfilling mutual obligations, and exceeding contractual obligations help to achieve the state of trust in people as well as process.

The final INUS condition in this typology, absence of “reliable BIM technology use” can be justified by the fact that reliance on BIM technology use, in most cases, requires a high level of inter-organizational scope understanding that allows the information to be carried out knowing the obstacles and limitations of other team members’ scope, as it was shown to be the case in Information Driven Projects. Dropping the absence of “reliable BIM technology” use from the causal recipe (i.trust* i.delivery* costaq = enrgy.c), therefore, would allow an interpretation that the described mechanism would work with presence of “reliable BIM technology use” and absence of “inter-organizational scope understanding” (i.trust* i.delivery* costaq *r.bim *~scope.u =enrgy.c) as well, which could be problematic as it was the case in typology A (more data is needed to assess complementarity of the two elements in this typology). Therefore, inclusion of “~r.bim” in the presented causal recipe can be inferred as dividing the Process Driven Projects to two different types of working with and without “reliable BIM technology use”. In the case of working with “reliable BIM technology use”, however, the created typology (i.trust* i.delivery* costaq* r.bim* scope.u) would be a sub-category of typology A: Information Driven Projects (i.trust* costaq* r.bim* scope.u) and does not lead to creating a new typology.

Therefore, a better description for Process Driven Projects would be to say that they are freed from reliance on BIM technologies, rather than being dependent on its absence. This lack of independence can be explained by addressing four main advantages of BIM technologies and how they can be overcome within Process Driven Projects:

1. Inclusiveness of data: Rather than removing physical boundaries between multiple data sources to achieve inclusivity of data in BIM enabled projects, in Process Driven Projects,

removal of organizational boundaries that inhibit information sharing facilitates data inclusivity to some extent.

2. Representation of data: Although representation of data in BIM enabled projects greatly facilitates communication and collaborative problem solving, team members within Process Driven Projects can achieve a fair understanding of the presented scope of work, by having increased collaboration sessions and possessing good communication skills which have been shown to be at the outset of all HP projects in this study.
3. Convenience of data retrieval: Convenience of data retrieval is another major capability of BIM technologies that is irreplaceable by conventional methods of documentation. However, absence of such capability mostly affects the time requirement for retrieving data, which in the presence of ambitiousness and contractual agreements that compensate team members' effort in doing so, ability of the teams to achieve holistic understanding of the project remains intact.
4. Reliability of data: Rather than working with reliable data, in Process Driven Projects, people rely on processes in which data is created and shared. Thus, in the case of discrepancy in data, team members have confidence, that the associated risk is addressed contractually, and the problem would not financially affect the team, to say the least.

Likewise, the described causal mechanism enables firms with any level of development to achieve success. This capacity can be theoretically justified by addressing the two major benefits of working within well-established architectural firms:

1. Availability of slack resources helping with exploration of innovative ideas: Process Driven Projects allow emergence of new ideas within working sessions in which all team members actively participate and brainstorm.
2. Organizational experience: Although this can be a very effective factor for success of the design team, especially for winning a project, once the design team is selected and is dedicated to teamwork and environmental goals, the highly collaborative processes of decision making can help team members in Process Driven Projects to overcome lack of experience existing in newly established architectural firms.

8.3 TYPE C: ORGANIZATIONALLY DRIVEN PROJECTS

The third typology of successful HP projects with low energy consumption as emerged in this study can be described as having four INUS conditions of “inter-organizational trust”, “integrated delivery method”, “architectural firm well-establishment”, and absence of “reliable BIM technology use”. As inferred from raw coverage and consistency values (presented in Table 8-1) respectively, this recipe is presented in 40% of the studied population, in 96% of which the presented recipe has been sufficient for achieving HP buildings with lower energy consumption.

The projects that follow this causal recipe can be referred to as “Organizationally Driven Projects”, since team members’ integration is highly facilitated by having a well-established architectural organization leading the design process. As will be explained, this causal recipe liberates team members from relying on BIM technologies, and selection of contract pricing method.

The causal mechanism leading to design and construction of higher performance projects in Organizationally Driven Projects initiates by well-established architectural firms. A well-established architectural firm, as described in Table 7-3 has more than 20 years of experience at the time of completion of the project, and has more than 20 staff members. Working with a well-established architectural firm, thus, indicates working within an organizational structure that has slack resources available for working on new approaches to sustainability. In addition, such firms typically have established internal teams that work together on long term basis, and have built high level of trust and good working relationships among them.

When a construction team dedicated to the project and environmental goals is brought on board earlier (as indicated by presence of “integration of delivery method”, and “inter-organizational trust”), this momentum for collaboration simply encompass the construction team as well, creating an ultimate environment for inter-organizational collaboration. As all project stakeholders are actively participating in the decision making process early in the design phase, the Organizationally Driven Projects have a high potential for gaining a holistic understanding of the project and emergence of innovative ideas.

The final INUS condition in this typology, absence of “reliable BIM technology use”, can be linked to the great impact that such a change would have on well-established organizational systems.

Although some of the architectural firms in Organizationally Driven Projects in this study have been completely open to adoption of new BIM technologies, especially with regards to energy simulation, they have been mostly using such technologies for internal purposes and relied on traditional contracts for addressing information exchange liability concerns. Therefore, in this typology of successful HP projects, while BIM technologies may or may not be present, the strong organizational structure is the driving force for collaborative decision making. This notion can be theoretically justified by addressing the four major advantages of using BIM technologies and how such advantages can be substituted with a highly collaborative decision making environment as discussed in section 8.2.

Similar to Process Driven Projects, there are no cases in the studied population that exclusively represent presence of “reliable BIM technology use” and “scope understanding” in lieu of absence of “reliable use of BIM technologies” condition (i.trust* i.delivery* a.establish* r.bim* scope.u=energy.c) or any cases that is contradictory to this recipe. However, as indicated by row 9 of the truth table in Table 7-4, the recipe resulted from dropping the absence of “reliable BIM condition” would not pass the counterintuitive test, needing further analysis for resolution. Therefore, an alternative theory would be that presence of “reliable BIM technology use” in this typology could also result in greater energy efficient buildings, but only at the presence of “inter-organizational scope understanding”. Further investigations and data collection, however, is needed for testing this hypothesis.

On the other hand, as it can be inferred from rows 2, 3 and 13 of the truth table in Table 7-4, 67% of cases in Organizationally Driven Projects work with lump sum contract pricing method. 50% of such cases (33% overall), however, are Design Build and IPD contracts, which means the lump sum contract is awarded to the contractors and designers together (i.e. design-build partnership, or IPD partnership). While in those cases the causal mechanism for achieving higher performance buildings are strengthen, in other 33% of cases that are Construction Manager at Risk (CM at Risk) delivery methods with lump sum contract pricing method, the described causal mechanism can work in the absence of change allowance in contract pricing method condition as well. This notion can be theoretically justified by addressing the three major drawbacks of working within lump sum contracts in Organizationally Driven Projects with CM at Risk delivery method:

1. Adversarial relationships between design and construction firms over discrepancies found within the design documents: In CM at Risk delivery method, mitigating approaches can be taken to reduce the adversarial relationships over the design discrepancies and their impacts on schedule and cost. One example is Construction Management at Risk (CMR) assumes the risks associated with the design discrepancies since CMR is involved in the review of the design prior to establishment of the lump sum cost. (CMAA, 2012). The qualification based selection of the construction team also helps with reducing possibilities of adversarial relationships in this delivery type. Presence of the “inter-organizational trust” in this typology indicates the execution of these approaches, securing a cooperative relationship between the design and construction firm.
2. Construction team bearing more risk for unforeseen conditions such as bad weather, acts of nature, price inflation, etc.: Although this is a major disadvantage of lump sum contracts, it does not directly affect collaboration, or energy conservation aspects of the design.
3. Tendency to go with the lowest value construction means and methods that comply with the design specifications: Although this one is also a major drawback of lump sum contracts in general, in the presence of ambitious sustainability goals and team members exceeding contractual obligations (as indicated by presence of inter-organizational trust condition) in this causal mechanism, this characteristic is less likely to happen.

8.4 FUNDAMENTAL DIFFERENCES AMONG THE TYPOLOGIES

As discussed in this chapter, different approaches can be taken to design and construction of HP projects. While practitioners do not need to adhere to a specific causal recipe to reduce their buildings’ energy consumption, three patterns of contractual, organizational and social practices showed superior potentials for achieving greater energy efficiency within HP projects. Understanding the causal mechanism in these typologies and identifying the one that matches the contextual elements of the project can bring competitive advantages to organizations. While previous section discussed specific strategies that help each typology in achieving success, this section aims to highlight the differences among the three approaches on a more conceptual level. The two identified concepts that illustrate the essence of the differences of the work practices among the three typologies are 1) formation of trust, and 2) approaches to learning and innovation. This section discusses the two notions.

8.4.1 **Formation of Trust**

While the survey results show that team members within all three typologies of successful HP projects have developed trust in their work practices and other team members, analyzing the case studies based on the three distinct developed typologies show that the origin and development of trust is different among the three typologies.

Within Information Driven Projects, trust is mostly developed based on team members' trust in the data and related work processes. Maintaining peoples trust in this typology, thus requires especial attention to procedures resulting in data development and transactions. The top strategies to maintain team members trust in the process in Information Driven Projects thus includes tailoring contract clauses to address BIM related liability issues, developing project specific BIM execution plans to address work processes around BIM data, providing technical resources for training staff, and providing back-up services for problem resolution.

Formation of trust in Process Driven Projects, on the other hand, starts from contractual agreements and their comprehensive risk management. Team members within Process Driven Projects have trust in the IPT practices, knowing that the risks they are taking for exposing their organizations and their own intellectual properties are adequately compensated within contractual agreements. The most important strategies for maintaining team members' trust in the process in this typology, therefore, includes adequate selection of contract clauses that addresses risks associated with IPT practices, and educating team members about the new process and how it is different from conventional practices in which team members face conflicting obligations to their scopes, projects and organizations (Dossick and Neff, 2009).

Lastly, trust in Organizationally Driven Projects is initiated by people's trust in an already established successful working relationships within the architectural firm. Based on the architectural firms past achievements, the design team have trust in their team ability of solving complex architectural and sustainability design issues. Similarly, based on their prior relationship and/or the architectural firms' profile, the construction team and other consultants have some initial level of trust in the architectural team, which is maintained thorough frequent inter-organizational meetings and inter-personal and/or inter-disciplinary communications. Accordingly, the architectural firm in this typology has more leverage in maintaining peoples trust

in the process, and can use strategies such as providing a highly interactive roadmap for the team to achieve the project goals, and explaining the process to the teammates to maintain their trust in the newly created work processes.

Furthermore, while all three project types require trust in their partnering organizations, this type of trust is of paramount important in process driven and Organizationally Driven Projects. This is due to the fact that building on prior relationships is one of the main aspects of delivery methods that support integration, which is an inevitable component of these two typologies. Owners and architectural teams working on selecting the construction team, therefore, need to pay significant attention to the trust they have in the construction firm, and strive to maintain this trust by strategies discussed in section 5.2.3 such as proactive communication at interpersonal and inter-firm levels.

8.4.2 Approaches to Learning and Innovation

The other shared element central in the causal mechanisms that lead to achieving greater energy efficiency in all three typologies is the spirit of openness to learning and teaching and embracing innovation. This study, however, shows that the approaches that the three typologies take to learning and innovation are fundamentally different.

Learning in Information Driven Projects mostly initiates from team members' access to a shared repository of information, which pushes team members to know more about the scope of others, followed by inter-organizational meetings where people actively seek to create a shared understanding of the problem at hand. On the other hand, by definition team members within Information Driven Projects know more about the challenges that other team member face within their scope of work, which can be itself a byproduct of having access to more information. This broad inter-disciplinary understanding that are created for key team members within Information Driven Projects, creates the potential of emergence of innovative ideas by all team members.

Learning in Process Driven Projects, on the other hand, is mostly initiated by eco-charrettes or design/sustainability workshops in the beginning of the design phase and continues throughout the design process mostly via design/sustainability workshops that are held frequently throughout the design process (although eco-charrettes and workshops are conducted in other project typologies as well, here they seem to be the driving force for learning and innovation). Because of the great

emphasis that are put on the frequent (mostly bi-weekly) workshops, and because of the construction teams' involvement throughout the process within this typology, Process Driven Projects' teams have shown considerable success in convincing the owners and code agencies to change the design program in favor of the innovative ideas. As an example a process driven project was able to push the public owner to re-evaluate its space standards through multiple presentations and public meetings and were able to pay for green initiatives by constructing less.

Lastly, learning and innovation in Organizationally Driven Projects, mostly initiates from the architectural firm, who tends to take the lead in educating others and providing a roadmap for the team members to follow to achieve the project design and sustainability goals. The design team experience, here is a valuable resource for the project to learn from thorough regular communications and inter-organizational meetings. The on-going learning experience in Organizationally Driven Projects seems to continue even through the post-occupancy phase. The slack resources available in well-established architectural firms in this typology enable them to conduct post-occupancy surveys and in-depth interviews to find out which sustainability strategies have worked well and which one needs improvement, and are used as valuable resources for team members in future projects to learn from.

8.5 STRATEGIZING TO ACHIEVE LOWER ENERGY CONSUMPTION WITHIN HP PROJECTS

While the constructed three typologies create a theoretical framework for studying collaboration behavior, BIM implementation, and contractual agreements, as well as formation of trust and approaches to learning and innovation within HP projects, these typologies can also serve as a guideline for practitioners working on HP projects.

Organizations leaders can determine the typology that best fits their projects conditions from the project inception and strive to adhere to the presented causal recipe. When the design team is rather unexperienced, and the contractual settings are all present for IPT practices, the choice of project typology to pursue depends on availability of liable and reliable BIM technologies. In case of availability of BIM technologies or having the required social, technical, contractual, and cultural support to adopt the new technologies, Information Driven Projects recipe is the one to pursue, otherwise Process Driven Projects have more potential for success. On the other hand, when the

construction delivery method is determined as design bid build and organizations have already adopted BIM technologies, or have the required compatibility to adopt the new technologies, pursuing Information Driven Projects is the wisest strategy. Finally, if the design firm is well-established and the construction delivery method supports IPT practices, once again the choice of project typology depends on the available structure for implementation of liable and reliable BIM technologies. If such a structure exist, Information Driven Projects are the most suitable typology to follow. Otherwise, Organizationally Driven Projects' recipes are the next best recommendation.

Once the typology that best suits the project characteristic is identified, practitioners may strategize accordingly to achieve greater energy efficiency, as presented in this section.

8.5.1 **General Strategies for Achieving Higher Performance Buildings**

The created typologies in this study suggest that achieving success in each project requires different sets of strategies. However, as discussed earlier in this section, several fundamental elements were required for all HP projects. These elements include:

- Having ambitious environmental goals and owners' commitment to peruse these goals;
- Availability of communication lines among team members from different organizations, and effective communication among team members;
- Having successful inter-organizational meetings, in which people from different organizations can brainstorm new ideas and challenges;
- Architects and Engineers working together closely;
- Designers engaging in the construction process;
- Working within an environment of trust and mutual respect.

While the above items were common themes among all HP projects, "inter organizational trust" was found to be a necessary element for achieving higher performance buildings in all three discussed typologies, which represent about two third of the population. In the remaining one third of the population for which no causal recipe was presented, however, "inter-organizational trust" was not a necessary element for achieving higher performance buildings. Thus, the four main

elements contributing in construction of “inter-organizational trust”, are common themes among the three typologies of information driven, process driven and Organizationally Driven Projects:

- High level of trust among organizations;
- Mutual respect among team members;
- Organizations exceeding minimum contractual obligations to each other;
- Working with reliable team members.

Consequently, related strategies for fulfilling all these conditions are shared among the three typologies, although not a necessary factor for design and construction of HP projects.

Practitioners working on HP projects aiming to follow one of the three represented typologies, therefore, can implement the many strategies discussed in sections 5.2 under three categories of effective communication, engagement in others’ activities and inter-organizational trust. This section discusses some of these strategies within the context of HP projects as highlighted within the selected HP projects’ case studies:

Raising Owners’ Awareness on Sustainability Objectives

While all HP projects in this study, more or less, showed the owners commitments to environmental objectives since the project inception, in some of the cases team members were able to build upon this initial commitment and create a stronger sense of ambitiousness in them with regards to sustainability goals. For instance, in some cases, the design and construction team were able to prove to the owner that they can achieve higher sustainability standards by spending a relatively small amount of money, or by adherence to lowering some of the standards of living such as reducing vending machines on site, expanding the thermal comfort range, using non-refrigerated drinking fountains, eliminating desktops for laptops, etc.

User Involvement throughout the Design and Construction Process

In most studied HP projects, various clients’ user groups were involved throughout the design and construction process. The user involvement within the schematic and design phase were mostly to engage them in issues of comfort, operability and maintenance to help with setting sustainability

goals that were compatible with building users. In addition, these meetings informed users about occasional behavioral and institutional changes that were necessary for using the HP buildings. This involvement sometimes was continued during the construction in refining and improving sustainability goals set in the design phase.

Possessing a Sense of Creativity, Exploration, and Discovery

All projects identified as successful HP projects showed a sense of creativity, exploration, and innovation, one way or the other. There were some sustainable systems and products invented in the studied projects that suppliers decided to continue manufacturing. Other innovations happened in the form of architectural design and invention of project specific systems and products. As discussed within each typology causal mechanism, however, the sense of exploration and discovery in different typologies can have different drivers, as discussed in section 8.4.2.

Indicating Key Design Drivers from Early On

Most of the HP projects in this study indicated that key design drivers for their HP buildings were created collaboratively early during the schematic design or design development phase. In some cases this collaboration happened in the form of a design charrette where owner representatives, architects, engineers, sustainability consultants, etc. brainstormed to come up with the guideline that specifies the main forces in creating the building design, shifting the team from having a vague idea of sustainability to targeting state-of-the-art HP project. The first sketches of the building were produced using the guideline, and underwent rigorous testing throughout the design, creating a basis for the final building design.

Frequent Inter-Organizational Meetings

Frequent inter-organizational meetings were important strategies used in all cases studied in this project. These usually bi-weekly meetings helped to transform the traditional linear design process to a “whole system approach”, in which owner representatives, architects, engineers, sustainability consultants (and contractors in more integrated delivery methods) worked in concert from the project inception, evolving the design as a team. This approach proved to be critical to the successful integration of the passive design strategies such as daylighting, ventilation, and cooling

leading to lower building energy consumption. In most projects, the teams were able to achieve desired sustainability goals and a quality work environment within a reasonable budget, demonstrating that whole system approach can achieve efficient, affordable, comfortable and healthy HP buildings.

Early Energy Analysis

Regardless of the project typology (with presence or absence of reliable BIM technology use), in all projects where BIM technologies were implemented (whether reliable and liable or not) energy modeling was performed early in the schematic design or design development process to inform decisions and system selections. The modeled elements in computer simulations included energy, water, airflow, daylighting/shading, materials and wind. Decisions regarding the architectural form, envelope construction, window placement and operability, and mechanical and electrical systems were all driven with the results of the energy simulation analysis.

On-Going Education

Another important project characteristic that were observed to be a theme among all successful HP projects was a sense of on-going education and learning environment among all project participants, mostly around sustainability goals, means and methods. This was particularly common in teams where contractors/sub-contractors did not have previous exposure to sustainable practices. In some projects, all subcontractors were required to have a representative attending a preconstruction meeting to learn about the buildings' sustainability goals and how the systems are designed and function.

Architects' Involvement in Construction

Although not practiced in all HP projects in this study (there was only one exception), in most of the projects architects were actively involved during the construction process to ensure clearer translation between the building design and reality. The contractors were generally shown to share the same commitment to the project goals and welcomed the architects' involvement.

8.5.2 **Information Driven Projects' Exclusive Strategies**

Besides the above strategies that are found to be effective in all project typologies, the results of this study suggest that Information Driven Projects can gain more benefit by focusing on some exclusive strategies. These strategies, as suggested by the causal mechanism evoked in these projects are the ones that can help with successful implementation of BIM technologies, understanding the challenges and obstacles of other team members' scope, and bringing the construction team on board in the case of working with design-bid-build delivery methods. While the strategies for successful implementation of BIM technologies are discussed in detail in section 6.2 under four elements of facilitating data inclusivity, data representation, convenience of data retrieval, and reliability of data and processes, this section discusses the early and extensive use of 3D modeling and energy simulation in the studied projects as well as holding pre-bid conferences for bringing the construction team on board with regards to the projects' sustainability goals.

Early and Extensive Use Of 3D Modeling and Energy Simulation

In addition to having all contractual elements in place for addressing BIM related liability concern, the project identified as information driven had performed whole-building energy and load modeling incorporating all designed elements into the building model. The elements usually incorporated into the simulating software included glazing selection, exterior shading, envelope construction, plug loads, lighting, domestic water heating, and mechanical systems. Energy analyses were always conducted considering efficiency, economy, comfort, aesthetics and long term durability criteria.

Furthermore, as shown in case studies, Information Driven Projects had taken advantage of early integration of all building elements to resolve potential challenges such as constructability issues early on. In cases where structural and/or mechanical systems were exposed in the buildings' design, such early integration was of paramount importance as the systems were considered an integrated part of the architectural aesthetic.

Inter-organizational Scope Understanding

While all HP projects in the study required a high level of engagement in others' activities and collaborative decision making, Information Driven Projects seem to require a higher level of collaboration and engagement in others' activities. A collaboration that can help them gain a better understanding of challenges and obstacles of other people's scope of work. It is through this understanding that high potentials of working with liable and reliable BIM technologies can be realized.

Information Driven Projects in this study reported that use of BIM technologies enabled them to work together to detect potential challenges within the process early on through the virtual environment. When team members showed openness in learning new things and understanding challenges of other team's scope of work, this early detection and understanding of the project challenges were turned into an opportunity for team members to generate innovative ideas to resolve them. As an example, to meet the projects ambitious energy efficiency goals, one of the teams was able to combine the structural piles for geothermal heating and cooling, as well as a phase change thermal storage tank; an innovative idea that required understanding of architectural, mechanical, and structural scopes of work and overcoming all their respective challenges.

Holding Pre-Bid Conferences

In the case of projects with Design-Bid-Build delivery method, as discussed earlier, holding pre-bid conferences addressing environmental goals and construction team's responsibilities for achieving those found to be the key for bringing the construction team on board.

8.5.3 Process Driven Projects' Exclusive Strategies

In addition to the strategies discussed in the beginning of the section, the projects specified as process driven in this study, can also benefit from additional strategies mostly related to having successful integrated project delivery. As discussed in section 5.1 these strategies include provisioning shared incentives, transparency of operations and financial transactions, and limiting litigations. Additional strategies that can be used in Process Driven Projects to achieve buildings with lower energy consumption, as referred to within the case studies, are discussed in this section.

Educating the Construction Team Early On

The early integration of the construction team with the sustainable design process helped to educate the construction team (in cases where the team did not have prior experience with sustainable projects) about the project sustainability goals to make sure the contractors were fully on board. This strategy prevented later value engineering efforts that compromise system efficiencies and performance.

Selection of the Construction Team Based on Sustainability Experiences

In some Process Driven Projects, the owner and the design team decided to work only with contractors and/or subcontractors that had prior exposure to sustainable projects rather than trying to educate members of a traditional construction firm.

Using Construction Teams' Experience in Adjusting Sustainability Milestones

The studied process driven HP projects have been able to take advantage of early involvement of the construction team to integrate cost, schedule, and constructability reviews with the decision making process early in the schematic design and even during the programming phase. Thus, the integrated team were able to set more realistic environmental goals in terms of cost, schedule and constructability early in the design process.

In some Process Driven Projects, being in charge of design, cost and schedule together empowered the integrated team to push sustainability goals further. In one specific projects, the integrated team held numerous presentations and public meetings to win converts. Having data to back up sustainability claims both in terms of cost and schedule helped the team to argue for pursuing sustainability goals.

8.5.4 Organizational Driven Projects' Exclusive Strategies

In addition to the strategies discussed as generally applicable to all typologies of HP projects, the reviewed case studies suggest two strategies can be particularly implemented in Organizationally Driven Projects. These strategies, which are based on working with a well-established architectural firm, are discussed in this section.

Architects Providing Sustainability Milestones for the Team

As discussed previously, the collaborative decision making in this typology is mostly driven by strong architecture firms. Thus, one of the most important strategies in this typology for achieving higher performance projects is with regards to architects taking the lead and providing guidelines for all team members to follow throughout the collaborative process. For instance, in one of the projects in this typology, the architectural team identified key issues in the building design and developed a written guideline for all team members translating the general functionality and sustainability goals to clear project specific milestones. In another case, the architect took the lead in early collaboration with owner, engineers, LEED consultants and contractors via rapid prototyping and feedback, which lead to the preferred design direction, as well as creation of an objective metrics for evaluating design within the context of sustainability goals.

Architects Taking the Lead in Educating Others

Architects leading the collaborative process in Organizationally Driven Projects, also manifested in an on-going education around sustainability goals conducted by the design team. In one particular case, team members stated that several hundred construction workers joined the project being skeptical about the sustainability objectives of the project, while at the end they were all looking forward for the next sustainable project to build. The collaborative process helped them to learn the benefits of the approach and realized the significance of the construction teams' contribution to this process.

Chapter 9. CONCLUSION & FUTURE WORK

HP projects are known for their whole system approach to design and construction, optimizing the building design based on many criteria affecting design and construction of buildings such as sustainability, safety, functionality, and cost-effectiveness. As traditional linear design and construction methods fall short in facilitating such integrated processes, new approaches are emerging to delivery of HP projects. CEM scholars have been able to identify factors facilitating new approaches to design and construction of HP buildings. These factors range from contextual settings such as team members' experience; factors affecting project' environmental goals, such as owners' awareness and demand for sustainability objectives, existing building regulations, and tax structures (Krygiel and Nies, 2008; Nofera and Korkmaz, 2010; Pitt et al., 2009); IPT practices such as early involvement of team members in the design process and conducting regular inter-organizational meetings (Enache-Pommer and Horman, 2009; Lapinski et al., 2006; Reed and 7 Group, 2009); as well as implementation of new BIM technologies (Krygiel and Nies, 2008; Wong and Fan, 2013; Zanni et al., 2013a).

The two factors that can be employed after project inception, IPT practices and BIM implementation are fast growing concepts within the CEM literature. Researchers have been able to identify many elements that play a role in successful IPT practices, categorized under three antecedents of effective communication, engagement in others' activities, and inter-organizational trust (Bechky, 2003a; Dossick and Neff, 2011; Jarvenpaa and Leidner, 1998; Maurer, 2010; Yoo et al., 2006). Similarly, CEM scholars have been able to identify barriers and drivers of adopting the BIM technologies helping to achieve more data inclusivity, advanced representation of data, convenient data retrieval, and reliable data and processes (Azhar, 2011; Dossick and Neff, 2008; Gu and London, 2010).

Although all of these approaches can help with facilitating the whole system approach required for design and construction of HP projects, not every project has the potential of implementing all the techniques together. Moreover, some techniques, if not used within the right context, can have zero or negative effect on the outcome (Greckhamer et al., 2007). Therefore, studying such

strategies within their social and organizational context empowers practitioners in better strategizing, and researchers in gaining a better understanding of the causal complexities embedded in design and construction of HP projects.

To achieve this goal, this study implemented an fsQCA approach to study success factors in achieving HP projects based on the organizational and project related contexts. As the first step, using the literature review, case study field notes and interview transcripts a theoretical framework for categorizing BIM implementation and IPT practices was developed. The created framework was then used to create a questionnaire survey capturing fundamental elements of IPT practices and BIM implementation within the study population. The survey results, available case study reports, and the researcher's substantive knowledge was used to calibrate causal and outcome conditions. Finally, an fsQCA study was performed to analyze the survey results, unfolding some of the discussed causal complexity, based on various social, organizational, contractual, and technical conditions within the design and construction of HP projects. The result of this study suggests three successful typologies for achieving lower energy consumption within HP projects: Information Driven, Process Driven and Organizationally Driven Projects.

The first typology, Information Driven Projects, tend to regulate their work practices around use of the new technologies, relying on the virtual data available early on in the design process to collaborate more effectively and gain a holistic understanding of the project challenges. This understanding has shown to be helpful in producing innovative ideas in overcoming the challenges of reaching the projects' ambitious environmental goals. When carried out within an environment of trust and mutual respect, a non-fixed contract pricing method, and an understanding of other people's scope of work, the spirit of trust, learning and innovation central to Information Driven Projects, liberates team members from the choice of the project delivery method, and overcomes the shortcomings of working with less experienced teams.

The second typology, Process Driven Projects are highly regulated by contractual agreements that facilitate inter-organizational collaboration by aligning the project and organizations' goals. Within Process Driven Projects, team members have a high trust in the process as well as team members and thus fully participate within the decision making process to achieve the project

ambitious environmental goals. These projects are less dependent on team members' experiences and less rely on the new technologies.

Lastly, Organizationally Driven Projects are formed around well-experienced architectural firms with availability of slack resources to explore new potentials with the projects' sustainability goals, and established internal teams that have built high level of trust and good working relationships among them. These projects, when work under an integrated delivery method that allows construction teams to join early in the process, and under an environment of trust, openness, and mutual respect, have the ability to spread their collaboration dynamics into other partner organizations. Organizationally Driven Projects appear to benefit less from the new information technologies, which can be due to the inertia of the team members to rely on the work practices that have been proven successful (although more investigation is needed to test this hypothesis). In addition, these projects have shown to be able to work effectively under all contract pricing methods.

The three constructed typologies collectively explain the causal mechanism for achieving higher performance buildings in about two thirds of the studied population (with 97% consistency), indicating significance of the study in terms of applicability to HP projects. The created typologies lead to accepting several hypotheses, and rejected some general beliefs among practitioners. It showed that the four initial identified elements within the literature for achieving higher performance buildings: having ambitious environmental goals, experienced project teams, successful IPD practices and BIM implementation are sufficient for achieving higher performance buildings. However, not all antecedents of the identified elements are necessary for delivery of HP projects for achieving lower energy consumption. Contractual conditions such as selecting an integrated type of delivery method and non-fixed contract pricing methods, in particular, are perceived by some practitioners as necessary for having a successful collaboration process that can lead to achieving higher performance projects. The study, however, showed that while those elements are necessary in some typologies, others can achieve higher performance projects without joint presence of the aforementioned contractual settings.

The direct future direction for this study would be to increase the population of cases allowing incorporation of more conditions into the study, to explain the causal pathway in remaining one

third of the population. Future work can also address the shortcomings of this project in terms of studying projects within an eight year time span, which prohibited studying the BIM implementation antecedents more comprehensively. This can be achieved by selecting larger databases of HP projects, and putting more effort in recruiting participants in the survey. The study also holds many promises for future research on HP projects. Research studies on IPT practices and BIM implementation, in particular, can use the presented typologies as their framework, and study the effect of the elements under the study, considering the working causal mechanism within its respective typology. This consideration would allow a more comprehensive view of the problem at hand, opening up new opportunities for improving organizational practices. Applications and implications of this study, on the other hand, can be discussed at six conceptual levels:

First, the most general implication of this study is demonstrating the implementation of fsQCA method within CEM domain. The higher level theoretical analyses presented in the methodology section, illustrated the need for fsQCA to address causal complexity embedded in construction projects. Expanding on this notion, future studies can work on many other desired project outcomes such as cost, schedule, and other sustainability goals to find causal mechanisms that are more likely to reach the specified outcomes. Such studies can help bridge the existing gap within CEM domain between quantitative studies on large number of cases and qualitative studies on few cases (Homayouni et al., 2011), attending to the complexity of construction projects.

Second, the survey development phase of the study, which lead to capturing antecedents of successful IPT practices and BIM implementation and showing their interdependencies, provides a framework for researchers to study the two phenomena considering their complementary relationship. This work implies that not only the three main contributing elements to fostering IPT practices: successful communication, engagement in others' activities, and inter-organizational trust are complementary, but they are also interdependent with each of the four antecedents of BIM implementation: data inclusivity, representation of data, convenience of data retrieval, and reliability of data and processes. Accordingly, if a team succeeds in one of the three elements of IPT practices, they are more likely to succeed in all of the other six areas. On the other hand, if a team succeeds in one of the four areas contributing to BIM implementation, they are more likely to succeed in the three areas associated with IPT practices. As a result, implementing BIM

technologies and establishing IPT practices should be pursued in tandem; one cannot cause or lead to the other.

Third, calibrating the outcome condition of the study, energy consumption of HP projects, resulted in creating a methodology for comparing energy performance of buildings that have used different codes, operational and asset rating systems for reporting their energy performance. The created methodology can be used in future research studies involving comparison of various energy report systems.

Forth, studying the three emerged typologies of successful HP projects in terms of their fundamental differences, showed that formation of trust, and approaches to learning and innovation are the core differences among the three typologies. The study proposes that trust in Information Driven Projects is mostly developed around the information technology and the associated work processes, while in Process Driven Projects, contractual agreements and their comprehensive and reliable management of risks are the driving force. On the other hand, trust in Organizationally Driven Projects is mainly developed from the already established successful working relationship within the well-established architectural firms.

Likewise, approaches to learning and innovation are different in the three typologies. In Information Driven Projects, having access to the central repository of information is the driving force for learning, which combined by team members' inter-organizational scope understanding results in emergence of innovative ideas. In Process Driven Projects, on the other hand, learning is mostly driven by the participatory design/sustainability workshops that are held frequently throughout the design process and the project teams in this typology tend to overcome innovation obstacles existing in regulations. Lastly, in Organizationally Driven Projects, architectural firms take the lead in educating others, and their available slack resources, is the driving force for the team members to embrace innovative practices.

The emerged fundamental differences is informative for practitioners in terms of evolving their work practices, and investing on areas with most potential for development and maintaining trust, as well as creating opportunities for learning and embracing innovation. On the other hand, future social and organizational studies on the nature of trust, learning and innovation can shed light on how different approaches to these phenomena can be strengthened and perused.

Fifth, the discovered causal mechanisms explained, provide some insights into the complementary nature of some of the elements. Inter-organizational scope understanding, for instance, appeared to be a complementary element for reliable use of BIM technologies in Information Driven Projects, and counter-intuitively in Process Driven Projects. This complementary relationship shows that team members need to know more about challenges and obstacles of other team members' scope of work while relying on BIM technologies for inter-organizational collaboration. Inter-organizational trust (fulfilling mutual obligations, working with reliable people, and exceeding contractual obligations), on the other hand, appeared to be a necessary element in all three typologies, showing the importance of the strategies to improve social norms that foster collaborative work within organizations in all project types. In addition, the study suggests that having ambitious environmental goals from the project inception and the IPT practices such as conducting regular inter-organizational meetings, effective communication and engaging in others' activities are necessary conditions for all HP projects regardless of their level of energy consumption. This finding calls for a shift in the industry from the emphasis put on contractual and technological settings in general, to social and organizational settings that foster IPT practices.

Sixth, studying the successful HP projects in each typology, provided some guidelines for practitioners on how to strategize for achieving lower energy consumption based on their project specific conditions. Practitioners can determine the typology that best fits their project characteristic from the project inception, based on the projects contractual settings (Choice of the delivery and contract pricing methods as well as contractual supports for BIM liability issues), architectural firms' well-establishment, and cultural, technological, and organizational capabilities for implementing BIM technologies.

Information Driven Projects need investment on implementation of the BIM technologies, and providing the technical as well as contractual support to make the technology reliable and liable. Achieving success within Information Driven Projects also requires team members to be open in learning from and teaching others, to facilitate emergence of innovative ideas and to bring the construction team who may join the process late, up to speed.

Process Driven Projects, on the other hand, need more attention on team building early in the process and to educate all members about the project sustainability goals. Selecting the

construction team based on their experiences is of paramount importance in this typology, as the team tends to rely on the construction teams expertise in pursuing, as well as refining the projects' sustainability goals.

Lastly, the design team within Organizationally Driven Projects need to adhere to the already established mechanisms within their organizations work practices, and embrace other team members within their collaborative decision making dynamic. This is mostly achieved by architectural team developing a roadmap for the teams to follow in achieving the projects sustainability milestones, and providing a trustable environment for them to be open to learn and share their knowledge.

To conclude, different approaches can be taken to design and construction of HP projects with low energy consumption. Practitioners do not need to adhere to a specific roadmap explained here to achieve success. However, configurationally studying 32 HP projects, three patterns of contractual, organizational and social practices emerged as having a high potential for achieving HP buildings with greater energy efficiency. The presented typologies can help researchers in gaining a better understanding of the causal mechanisms leading to delivery of higher performance buildings. At the same time, practitioners can learn from the complementary nature of the BIM implementation and IPD practices explained here and make more informed decisions in terms of strategizing to implement various organizational, technological, and contractual practices.

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APPENDIX A

Question 1

Dear participant,

We would like to thank you in advance for donating your time and experience to this research study. We estimate that completing the survey would take around 20 minutes of your time. This study will increase the understanding of the real-world application of Building Information Modeling, and inter-organizational collaboration. It will also help the AEC industry to realize what social and organizational settings need to provide for better inter-organizational collaboration and implementation of BIM.

The risks of this study entail lack of confidentiality and breach of privacy. However, these risks are minimal. We will not name any particular project in subsequent research articles and general information will be shared in the research articles in a way that inside industry observers would not be able to discern the particular projects being discussed. Yet, we emphasize that participation in this study is voluntary and you can leave any question that you are not comfortable with unanswered.

For gaining more information about this study you may contact Hoda Homayouni via the e-mail address hoda@uw.edu.

I understand the risks and benefits of this study

Question 2


Please select your project from the list.

Select one...

Please answer the following questions about the project that you named above.


Question 3

What was the project's delivery method?

- Design Bid Build
- CM at Risk
- Design Build
- Integrated Project Delivery
- I don't know
-  Other:

Question 4

What was the project's cost acquisition method?

- Cost Plus
- Guaranteed Maximum Price
- Lump Sum
- I don't know
-  Other:

Question 5

The project was delivered....

- early
- on schedule
- late
- I don't know

Question 6

The project was delivered....

- under budget
- on budget
- over budget
- I don't know

Question 7

Compared to other projects you have worked on, this project was....

- One of the best I have ever worked on
- In the top 25% of projects
- Average
- Somewhat below average
- One of the worst projects
- I don't know

Question 8

Comparing this project with others, how successful was the collaboration . . . :

Rows

A-between all project participants

B-between Architects and Owners

C-between Architects and Consultants

D-between Architects and Contractors

- Very successful
- Somewhat successful
- Neutral
- Somewhat unsuccessful
- Very unsuccessful
- I don't know

Question 9

Meetings involving different companies were...

Rows

A-participatory

B- well organized and well run

C- successful

- Always
- Usually
- Sometimes
- Seldom
- Never
- I don't know

Question 10

In teams where I had to work with people from different companies, I found that people in general...:

Rows

A- were reliable

B- were effective at communicating

C- shared similar goals for the project

- Completely agree
- Mostly agree
- Neutral
- Mostly disagree
- Completely disagree
- I don't know

Question 11

Answer the following about collaboration with other companies on this project.

Rows

A-Communication among partner companies was effective

B- People could get easily in touch with others from different companies without any problems

C- There were misunderstandings among people from different companies.

D-Engineers worked closely with the architects

E- Designers were involved in the construction process

- Always
- Usually
- Sometimes
- Seldom
- Never
- I don't know

Question 12

Different companies collaborating on the project....

Rows

A- trusted the actions of other companies

B- took advantage of partner companies' vulnerabilities

C- understood the challenges and obstacles of other companies' scopes

D- fulfilled their mutual obligations to each other

E- felt or expressed a duty to meet their obligations to partner companies


F- exceeded the minimum contractual obligations

- Always
- Usually
- Sometimes
- Seldom
- Never
- I don't know

Now, considering your experience on the same project, please answer the following questions about data, documents and techniques that you used for this project.

Question 13

Which, if any, of the following features of 3D modeling (e.g., 3D Autocad, Sketchup, Revit, Navisworks) were used on this project? Select all that apply.

- Existing Conditions Modeling
- Cost Estimation or Quantity Take-off
- 4D Modeling or Scheduling
- Design Review
- Energy Simulation or Lighting Analysis
- 3D Coordination
- Record Modeling (“as builds”) or Creating an Operations & Maintenance model
- 3D Modeling was not used on this project
-  Other:

Question 14

What kind of data did you have access to in each phase of the project?

Rows

A-Design phase

B- Construction phase

- 2D line drawings
- 3D rudimentary geometry (e.g. CAD- not object oriented 3D models)
- Single object oriented 3D models (e.g. Sketchup, Revit)
- Multiple interdisciplinary models (4D e.g. Navisworks, other databases with building information)
- I don't know

Question 15

How did you use digital files (e.g. CAD, Revit, Navisworks files)?

- In house only
- Shared across companies
- There were no digital files
- I don't know

Question 16

Did contractual agreements address liability concerns regarding the exchange of digital files across companies? (e.g. CAD, Revits, Navisworks files)

- Yes
- Partly
- No
- I don't know

Question 17

In what format were the design and construction documents exchanged? (Check all that applies)

Rows

A- Architectural Design with Consultants

B- Structural Design with Consultants

C- MEP Design with Consultants

D- Architectural Design with Builders

E- Structural Design with Builders

F- MEP Design with Builders

- Paper (including PDF files)
- Digital 2D (e.g. DWG files)
- Digital 3D (e.g. Revit, DWG files)
- I don't know

Question 18

If digital 3D models were used on the project (e.g. Revit, DWG files) which activities did they support? (Check all that you know)

- Schematic Design
- Design Development
- Construction Documents
- Shop Drawings
- Site Conditions
- Turn Over (Inspections+ Punch list)
- Operation and Maintenance
- Don't know
- Not applicable

Question 19

When receiving a document or file, was the data in an immediately usable format (i.e. Excel vs. PDF spreadsheet)

- Always
- Usually
- Sometimes
- Seldom
- Never
- I don't know

Question 20

People trusted information in the model, drawings and other shared electronic documents....

- Always
- Usually
- Sometimes
- Seldom
- Never
- I don't know

Question 21

What was the level of interoperability between software programs? (e.g. If Design models can be imported into the structural engineering model or if structural model can be imported into MEP coordination model)

- The programs were interoperable
- The programs were somewhat interoperable
- There was no interoperability between software programs (information was reloaded for each application)
- I don't know
- Not applicable

VITA

Hoda Homayouni is an Iranian-American researcher in architecture and construction management. She holds a Bachelor of Science degree in Architectural Engineering from University of Tehran, a Master of Science in Design Computing as well as a Doctorate of Philosophy in the Built Environments from University of Washington. Her scholarly work includes studies on computational approaches to architectural design process, organizational approaches to design and construction of High Performance buildings, as well as educational approaches to new technologies and global collaborative practices in schools of architecture and project management.