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THE ROLE OF INTEGRATED PROJECT DELIVERY ELEMENTS IN ADOPTION OF INTEGRAL INNOVATIONS

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ABSTRACT

Product and process innovations in the building sector are continually being developed, yet only innovations that fit within the current industry supply chain diffuse. "Integral" innovations such as radiant heating/cooling cross professional and trade specializations, break industry standards, and redefine how existing modules fit together. These innovations diffuse three times more slowly than innovations that fit within the existing supply chain. Integrated Project Delivery (IPD) offers a collaborative framework with the potential to address the industry fragmentation preventing integral innovation diffusion. This study uses a mix-method research design to understand which elements of IPD play a role in adoption of integral innovations. First, researchers use grounded theory observations and participant interviews from four large IPD projects to uncover the legal, management, and workplace strategies at play during innovation. These elements include owner involvement and vision, early involvement of key participants, team idea generation and support, colocation, fiscal transparency and flexibility, lean construction principles, incentivized contracts with guaranteed cost reimbursement, collaborative decision making, trust and accountability, and virtual design and construction. Second, researchers outline a methodology for using a fuzzy set Qualitative Comparative Analysis (fsQCA) to further understand and refine these propositions for a medium-N population. An exploratory fsQCA of seven IPD cases finds colocation, virtual design and construction, owner involvement and vision, and (for non-renovation projects) lean construction principles are necessary conditions for adoption of integral innovations.

KEYWORDS: IPD, INTEGRAL INNOVATION, FRAGMENTATION, QCA

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INTRODUCTION

Buildings in the United States are currently the single largest contributor to national energy consumption and greenhouse gas (GHG) emissions; annually they account for 41% of total US GHG emissions, 40% of primary energy use, and 74% of national electricity consumption (DOE 2012). Innovative building products like radiant heating/cooling and smart building control systems exist with the potential to improve energy efficiency and reduce GHG emissions. A complete deployment of these green innovations would reduce building energy consumption by 25-30% and save up to $130 billion annually (Choi et al. 2009). With only a 2% premium in upfront project costs to support green innovations, owners receive on average a 20% savings of total construction costs throughout the building's life cycle (Kats et al. 2003).

Yet many energy-saving technologies that require low initial investment and have relatively short payback periods have seen slow market diffusion in the building industry. It seems not all innovations have an equal rate of adoption. Innovations that fit within the existing supply chain tend to diffuse more quickly than innovations that cross traditional discipline boundaries (Sheffer 2011) even when the cross-discipline innovations offer superior system-wide gains in cost, schedule, and energy performance. This is largely due to a construction industry characterized by extreme fragmentation, technological risk aversion, a culture of low cost competitive bidding, and broken agency in decision making (Levitt & Sheffer 2011).

Integrated Project Delivery (IPD) has emerged as a progressive delivery method to address these institutional barriers. IPD promotes a high level of quasi-firm integration on project teams through formal and informal project elements such as colocation, multi-party contracts, early involvement of stakeholders, and liability waivers. This collaborative framework for IPD can be viewed as a virtual horizontal and vertical integration of the fragmented supply chain.

This study uses a mix-method research design to understand which elements of IPD play a role in adoption of integral innovations. First, grounded theory is used to uncover elements present during adoption of innovations at four IPD project sites. When integral innovations are brainstormed, vetted, implemented, or discarded, which formal or informal elements are present? In other words, what are the potential IPD "ingredients" of cross-discipline innovation? Second, the four IPD projects are nested within a seven case data set and analyzed using a fuzzy set Qualitative Comparative Analysis (fsQCA). Which combinations of elements are necessary for high levels of integral innovation adoption on IPD projects? Preliminary results are presented for the seven-case data set. More importantly, researchers lay the groundwork for a future 'medium-N' fsQCA for deeper exploration of the relationship between IPD elements and integral innovations.

POINT OF DEPARTURE

Construction Industry Fragmentation

The construction industry is characterized by three dimensions of fragmentation (Fergusson 1993). Horizontal fragmentation occurs in the trade-by-trade competitive bidding environment of traditional project deliveries. Without cross-subsidization among trades, globally-optimal innovations that offer life cycle project gains cannot compete with traditional solutions that are more cost-effective from the perspective of a particular building element or phase. Vertical fragmentation causes each project phase to have a different set of stakeholders, decision-makers, and values. Broken agency describes the self-interested behavior of parties in one phase passing costs off to stakeholders in a subsequent phase to the detriment of the long-term user (Henisz et al. 2012). Longitudinal fragmentation occurs in North America because project teams disband at the end of projects. Team members lose tacit knowledge about how to effectively work together. It becomes difficult for organizations to build upon performance from project to project, especially for ideas that cross firm boundaries (Dubois & Gadde 2001). This results in a learning disability that slows innovation diffusion (Taylor & Levitt 2004, 2007).

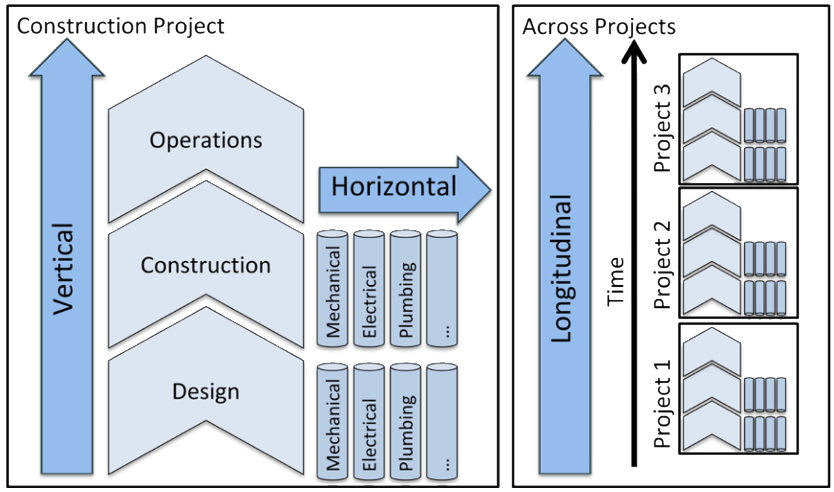


Figure 1 - Three Dimensions of Fragmentation in the AEC industry (Sheffer 2011; adapted from Fergusson 1993)

Integral and Modular Innovations

Innovations can be categorized by their effect on the existing supply chain, the design/construction process, or the participants involved. Extant literature discusses this categorization in terms of autonomous vs. systemic innovations (e.g. Teece 1986, 1996; Taylor & Levitt 2004), bounded vs. unbounded innovations (Harty 2005), and integral vs. modular innovations (Sheffer 2011). According to Teece (1996), an autonomous innovation can be introduced without modifying any other components of equipment whereas a systemic innovation requires significant readjustment to other parts of the system. Therefore, systemic innovations require more coordination in the development and implementation stages of the innovation. Similarly, Taylor and Levitt (2004) define systemic innovations as innovations that reinforce the existing product but require multiple firms in a network to change practices in a coordinated way. As a result, systemic innovations will typically create significant increases in overall productivity but may induce switching or start-up costs for some participants and reduce or even eliminate the role of other participants. Harty (2005) adds another layer to this categorization by introducing the concept of boundedness. Bounded innovations can be contained within an organization's control whereas unbounded innovations cannot.

In this paper, we adopt the terms integral vs. modular innovations proposed by Sheffer (2011). According to Sheffer, innovations that fit within the existing divisions of work and specialization—termed modular innovations—tend to proliferate because they do not cross traditional discipline boundaries. These modular innovations such as energy-efficient light bulbs and water-efficient toilets fit within the existing supply chain and have standardized interfaces. Implementing a modular innovation can be as simple as removing the old component and installing the new one. By contrast, integral innovations - innovations that alter the interfaces between the modules or the overall system architecture are significantly less likely to be adopted in projects even though these innovations offer system wide gains that can vastly surpass those from potential modular improvements. These innovations may introduce a change in the interfaces or design criteria between two or more modules, a change in the process (i.e. schedule, sequencing, etc.) of the overall system, or both. Sheffer's definition of integral innovation refers to architectural and radical innovations at the inter-organizational level. Because these integral innovations cross professional and trade specializations, redefine how work is done in the industry, and break industry standards, they diffuse up to three times slower than modular innovations that fit within the existing supply chain (Levitt & Sheffer 2011). However, projects with high horizontal and vertical integration are two and a half times more likely to adopt integral innovations than standard projects (see figure 2).

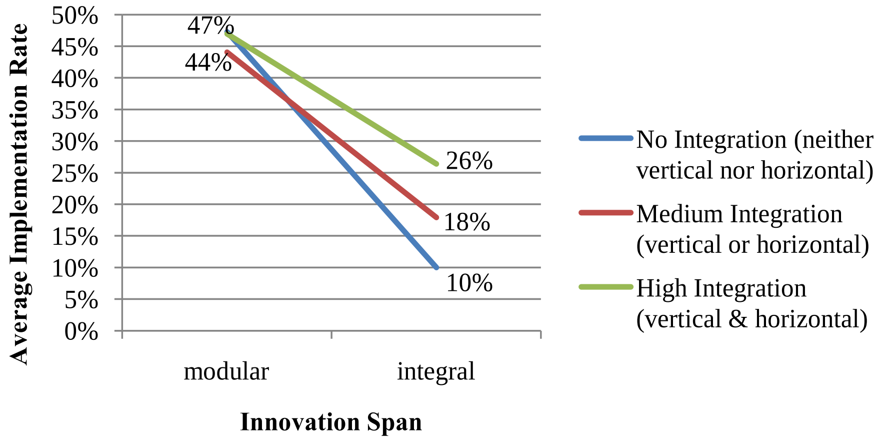


Figure 2 – Average Rate of Implementation of Modular and Integral Innovation by Teams of Varying Degrees of Integration (Sheffer 2011)

Integrated Project Delivery

Various relational project delivery arrangements have been developed to address the fragmentation challenges and inadequate collaboration in the construction industry. An emerging method in North America is Integrated Project Delivery (IPD) (Lahdenperä 2012). IPD is defined as "*a project delivery method that integrates people, systems, business structures and practices into a process that collaboratively harnesses the talents and insights of all participants to reduce waste and optimize efficiency through all phases of design, fabrication and construction*" (AIA 2014). As a method of relational contracting, it encourages collaborative behavior to better handle the uncertainties and risks – including risks of innovating - for large, complex projects, including risks of innovating. It can be viewed as providing "virtual horizontal and vertical integration" of the supply chain.

The IPD approach is built around six characteristics that differentiate it from traditional project delivery; (1) a multi-party contract, (2) early involvement of key participants, (3) collaborative decision making and control, (4) shared risks and rewards, (5) liability waivers among key participants, and (6) jointly developed project goals (Ghassemi & Beceric-Gerber 2011). In addition, there are certain catalysts, such as building information modeling (BIM), Lean Construction methodologies, and team colocation that foster successful IPD projects and are often required in contracts (Kenig et al. 2010). In a sense, IPD re-envisions the concept of "Master Builder" as a collaborative building team of specialists, uniting the key stakeholders (architect, contractor, and owner) under a single contract.

Not all IPD projects, however, employ all of these characteristics. For example, in projects with a public owner, a single multi-party contract may be difficult to realize in practice. IPD can still be applied as a philosophy by implementing other characteristics to support the integration of the project team. Thus, there are different levels of application from "IPD-ish" or "IPD lite" to "full IPD" based on whether the collaboration is contractually required or not (Kenig et al. 2010). Optimally, "full IPD" augments contractual alignment of key participants with lean work processes and shared 3D and 4D BIM to facilitate sharing of information and joint problem solving.

IPD should, in theory, have a significant impact on the adoption rates of integral innovations. It reduces horizontal and vertical fragmentation through shared incentives and creation of a "virtually integrated supply chain." The framework can mitigate longitudinal fragmentation by offering multi-project commitments, thus addressing the issue of learning disability. IPD focuses on the formation of cross-functional, high-performance teams characterized by high levels of creativity, information sharing, and exceptional work output (Ashcraft 2011; Dougherty 1992; Van Der Vegt & Bunderson 2005; Chinowsky, Diekmann, & Galotti 2008). The framework for IPD is informed by theory on team creativity, social exchange, and team cohesion (Hackman, 2011; Homans 1958; Robbins, 2011). IPD facilitates the formation of strong social networks and knowledge sharing – both necessary for integral innovations – through team colocation, shared incentives, and multi-project commitments.

Finally, the US legal system pursues joint and several liability for any failures which means that one provision makes a person liable for errant information that causes damages. While this seems necessary, it causes firms to regulate their communication with others extremely carefully. Essentially, all design data is closely guarded and not shared (AIA 2005; Ashcraft 2011). Liability waivers in IPD reduce inter-team disputes about cross-liability, encouraging free information flow. Thus, the improved legal dynamic could improve team creativity and knowledge sharing leading to increased amount of innovations in projects.

PHASE I: GROUNDED THEORY

Phase I of our research uses case study observations and interviews to uncover the role elements of IPD play during the adoption of integral innovations.

Methodology

Researchers in our team observed four large-scale construction projects over a period of six months. In total, the researchers observed thirty-three meetings and conducted forty interviews with owner representatives, architects, engineers, general contractors, and trade partners. Using constructivist grounded theory, researchers worked towards “a ‘discovered’ reality arising from the interactive process and its temporal, cultural, and structural contexts (Charmaz 2003).” As opposed to traditional grounded theory, constructivist grounded theory does not assume that theories nor data are discovered, but instead are constructed by the researcher through interactions in the field and with interviewees.

Interviewees shared about their specific experiences on the project, whether any innovations were adopted on the project, and whether IPD or other factors contributed to the success of the project. If innovations were adopted, the interviewee described the innovation or technology in detail, including the circumstances and decision points discussed for the adoption. Innovations were later classified as modular or integral. During team meeting observations, the team noted key project issues, collaboration between various project teams, and the overall dynamic of the organizational structure. Interview transcripts and meeting notes were compiled and coded using NVivo software. Key phrases or ideas, either explicit or implicit, were recorded as nodes and sub nodes. Both the frequency a concept was noted and the relationship between two concepts act as a foundation for the theories and key findings discussed in this paper.

Case Descriptions

ID	Case	Contract	Type of project	# Interviews	# Meeting Observations
1	**Suburban MOB**	3 Party IFOA + Trade Joining Agreements	Healthcare *(Medical Office Building)*	5	1
2	**Medical Center**	12 Party IFOA	Healthcare *(Patient Care Pavilion)*	14	5
3	**Coast Hospital**	Design-Build + Umbrella Incentives	Healthcare *(Hospital Complex)*	12	11
4	**Commercial HQ**	3 Party IFOA + Trade Joining Agreements	Commercial *(Campus)*	9	16

Figure 3 – Phase I Case Descriptions

Suburban MOB

Suburban MOB replaces an existing medical office building with a two story, 120,000 square foot building including a 40,000 square foot Community Cancer Care Center. Because of site restrictions, the building is constructed on top of a two-story, 125,000 square foot parking structure. The original logic was to spend fifteen months building out the complete parking structure followed by eighteen months for building construction. Instead, the team decided to construct the top deck of the garage first to reduce total construction time by three months. Although some additional cost was incurred to build the remainder of the garage from the top down, the innovative solution provided a net savings of $300,000.

Medical Center

Medical Center is a 250,000 square foot patient care pavilion with a total of 243 medical/surgical and acute rehabilitation beds. The building consists of two major components, an eleven-story patient care tower with basement and a rooftop central utility plant. The project was built around a fully operational urban hospital campus that introduced additional logistical challenges. The project targets LEED Silver certification. The Medical Center piloted an Auger pile foundation system that was five times faster to build than a traditional system. The Auger pile system cost $300,000 to test and one year for regulatory approval but resulted in a net savings of two million dollars to the project.

Coast Hospital

Coast Hospital is a 900,000 square foot ground-up hospital complex consisting of three integrated buildings. The complex will host operations for children's, women's and cancer hospitals with a total of 289 beds. The project duration is eight years including the design and construction phases. Coast Hospital uses lean construction methodologies, such as target value design and last planner system, and full colocation at a Big Room on site. The project targets LEED Gold certification.

Commercial HQ

The Commercial HQ project delivers several buildings organized to create a large campus headquarters. The IPD contract is a three party agreement between owner, architect, and contractor with subjoining agreements for approximately seven subcontractors. Construction began at 50% design completion, which represents a significant overlap between design and construction phases. The project targets a LEED platinum score.

Project	Innovation	Alternative	Changed Interfaces*	Changed Process**	Use of Prefab
Suburban MOB	Resequence parking structure	Erect Parking Structure, then Erect MOB		x	
Medical Center	Auger Pile Foundation System	Traditional CIDH pile Foundation	x	x	
	Prefabricated X-wall System	Traditional Façade	x	x	x
	Celcrete Foam Concrete Filling	Traditional Soil Filling		x	
Coast Hospital	Prefabricated med-gas pipe systems	Individually Build Pipes On-site		x	x
	Universal wall design for flexibility (doors)	Wall Design based on Predefined Door Locations		x	
	Alternative duct routes for flexibility (equipment)	Predefined Duct Routes		x	
Commercial HQ	ConXtech Structural Steel	Traditional Steel Frame	x	x	
	Horizontal & Vertical MEP racks	Route Each Service Individually		x	x
	Prefab. Restroom Modules	Stick-build Restrooms		x	x
	Radiant Heating/Cooling	Forced Air HVAC	x	x	
	Slotted Architectural/ Structural Deck	Structural Deck w/ Acoustical Ceilings	x	x	

**actual product interfaces, standards, and/or specifications, **timing of design/construction process, trades involved, etc.*

Figure 4 - Integral Innovations by Project

Findings/Results

The four case studies projects produces sixteen integral innovations (see figure 4 above). Some innovations required a changed interface, some used prefabrication strategies, and all of them required a change in the design or construction process.

The Story of One Integral Innovation

One example of an integral innovation is radiant heating/cooling adopted into the Commercial HQ design. Radiant heating/cooling is a HVAC solution driven by radiation rather than convection. It requires an under floor water system integrated with a structural slab. Radiant heating/cooling requires a change in interface (alternative structural and HVAC design decisions) and a change in process (alternative construction schedule sequencing with piping required before structural slab pour) among mechanical, electrical, plumbing, and structural disciplines (Sheffer 2011). A project manager for the mechanical trade partner describes the challenge of implementing radiant heating/cooling, *"radiant tubes never get put in because we never have this kind of cross group coordination. That is a major, major cross group coordination between the structure on the ground floor."*

On the Commercial HQ project, the owner gave high value to indoor air quality and user comfort. In addition, the owner was concerned with life cycle cost and the overall IPD leadership team was concerned with first cost. During conceptual design, a colocated sub team cluster of architects, engineers and trade partners met often to brainstorm possible HVAC systems that would meet these objectives. Once the merits of several potential ideas were considered, the mechanical engineers and trade partners conducted preliminary pricing analyses to narrow the field.

The sub team made the final selection of a radiant system by "choosing-by-advantage" instead of deciding by lowest first cost. The choosing-by-advantage strategy factors life cycle costs and the schedule impact to other trades in order to emphasize selection of a system with the greatest global advantage. Next, team members made reliable promises in design development regarding cost and schedule with the expectation that commitments will be kept during construction. Finally, the team incorporated the radiant floor heating into the building design using multi-trade building information modeling (BIM) sessions and into the project budget by entering the cost into the Target Value Design.

The integral innovation of radiant heating/cooling required the following ten elements: owner involvement and vision, early involvement of key participants, team idea generation and support, colocation, fiscal transparency and flexibility, lean construction principles, incentivized contracts with guaranteed cost reimbursement, collaborative decision making, trust and accountability, and virtual design and construction (VDC) (see figure 5). These same ten elements emerged from observations and participant interviews across all four case studies. The sequence that the elements appeared was not always the same. The following sections describe with further detail each of these ten elements in the context of IPD and integral innovations.

Figure 5 - Radiant Heating/Cooling Implementation Steps

Owner Involvement & Vision

Owner involvement and vision can be an important seed to innovation. An owner's vision and goals on a project will have the largest influence on team decision-making. In addition, the owner's role is more iterative in the IPD process when compared to traditional projects. Instead of designated design review stages, owner feedback is solicited in a more continuous and informal manner. Therefore owner representatives must be bestowed with the authority to provide immediate feedback on ideas as they emerge. Otherwise the owner may emerge as a bottleneck that impedes the momentum of innovative ideas.

Strong owner involvement acts as a support system for idea incubation. The IPD team tends to mirror the owner's enthusiasm and expectations. Trouble arises when owner directives are not clear and consistent. The owner must be comfortable with the speed of the project, and must maintain a helpful but not overbearing presence at meetings.

Early Involvement of Key Participants

Early involvement of key participants provides a decentralized source of innovative ideas. By having *"everyone at the table,"* ideas that are not feasible can be discarded early in the process, allowing teams to focus on good ideas. Trade partners weigh in with immediate feedback on constructability. Accurate pricing centers the discussion on real numbers instead of theoretical savings. Team consensus and "buy-in" from all parties empowers trade partners to take ownership of cost and schedule commitments.

The degree of early involvement varied between projects. On Medical Center and Commercial HQ, the general contractor and trade partners were involved from the beginning of conceptual design. One Commercial HQ interviewee expressed that the builders were possibly involved too early in the process; during the first few weeks they did not have enough work to do. At Coast Hospital, one general contractor thought starting trade partners at the end of schematic design was too late, *"I think the biggest tweak I would make is probably bringing more of the major trades on earlier."*

Colocation

The use of colocation encourages informal collaboration from these key participants. Within a large trailer or open floor plan office commonly referred to as the "Big Room," team members are arranged into interdisciplinary sub team clusters such as Core and Shell, Façade, Interiors, or Services. Colocation encourages iterative and immediate face-to-face communication. As a Suburban MOB trade partner puts it, *"you want to be there. You do not want to go back to the old way of take a snap shot, and PDF it, and email it to somebody, and wait for a reply."* The first few days of an innovative idea can be crucial. Informal information exchange over lunch or coffee with a team member from another discipline can vet out potential obstacles and form an interdisciplinary coalition of support for good ideas. Colocation can lose effectiveness when team members have different levels of engagement. For example, team members from two cases expressed frustration that the architects (whose home firm was located in another state) were only colocated two or three days per week.

Team Idea Generation & Support

Innovation emerges from a culture promoting team idea generation and support. This culture is defined by the presence of strong project stewards, a commitment to social recognition, and creative thinking outside of "traditional silos." The presence of strong leadership and stewardship on the project is indicative of an environment that fosters good ideas. Three such leadership roles emerged during adoption of integral innovations: Champion, Leader, and Facilitator. The Champion takes up the cause for one specific innovation and campaigns its benefits to doubters. The Leader encourages the team to remain true to the overall project vision by promoting a work environment of energy, enthusiasm, teamwork, collaboration, and motivation. The Facilitator collects input and solves challenges from disciplines impacted by the innovation. The Facilitator takes an interdisciplinary vantage point to ensure all team members capture the global benefits of the innovation.

Social recognition actively fosters innovation. The Commercial HQ team awarded a weekly 'Innovation' trophy to different team members. During the resequencing of the parking structure, the Suburban MOB leadership *"emailed the entire team saying thank you for this* *engineering group who created this. This has benefitted the other cluster by this much."* This provided recognition to the innovating sub team. It also reinforced the global benefit of the innovation to sub teams required to redo previously completed work.

IPD team members need to be *'people with the right mindset for collaboration.'* Members need the willingness do things differently. Creativity, adaptability, *'the right personality,'* and *'the ability to think and work outside the box'* are valuable characteristics. According to project manager, IPD is a way to leverage these traits for the overall benefit of the project:

> *"The beauty of IPD, if you do it right, is the only reason you are in this room is because you are able to do that very thing. The only reason you are here is because you are innovative. We brought you here to tap into that innovation. We want to free up that innovation and the costs associated with that innovation, by telling you that you work for us now."* (General contractor, Commercial HQ)

Incentivized Contracts with Guaranteed Cost Reimbursement

Performance-based multi-party IPD contracts – often referred to as shared risk/reward, painshare/gainshare, or "skin in the game" - provide organizations with incentive to consider innovations providing overall project savings even at an increase to their own project costs. Stakeholders are more likely to consider how decisions and actions will impact the work of others. Promises of innovation savings are vetted out among all parties, because as a Commercial HQ electrical trade partner explains, *"there are a lot of interdependencies. Because if I make a decision, how does it affect my trade partner? Do their costs go up because I made a decision for my costs to go down?"* Shared risk/reward creates a "built-in challenge" that invites creativity and incentivizes cross-discipline innovation.

These multi-party contracts provide an innovation safety net for both the individual and the organization. For traditional projects, time spent pursuing an innovative idea will count as billable hours that must be absorbed by an individual's own firm. By contrast, multi-party contracts diffuse an individual's research and coordination overhead across the billable hours of all project participants. In addition, guaranteed cost reimbursement shifts some risk away from organizations. Should a failed innovation cause a project to miss targets, the organization still will be reimbursed for project costs (but not earn profit) instead of taking a loss on the project.

Fiscal Transparency & Flexibility

Multi-party contracts provide IPD teams with transparency for understanding cost decisions. The cost uncertainty of new technologies may discourage builders or owners from innovation, even if these features have potential to save long-term costs in the building's lifetime. Accurate and transparent budgets vetted by multiple trade partners mitigate much of this uncertainty.

Multi-party contracts also provide the flexibility for agile "cost shifting". Cost shifting is the flexibility to quickly allocate costs across traditional horizontal and vertical cost silos. During the re-sequencing of the parking deck that trimmed three months of schedule, the Suburban MOB quickly shifted savings to labor and project management overhead toward additional structural steel design and material costs. A project manager explains the benefit of agile cost shifting:

> *"Imagine yourself as a structural engineer. You have already designed this building. You have done all of the calculation. You have designed the structure already and all of a sudden your contractor is coming in and saying, 'I can save the client time and money,*

> *but it is going to require re-detailing a lot of construction connections.' You are thinking how I am going to get paid for this because it is a lot more work. On a traditional project if you have a lump sum fixed fee contract to your architect, you are going to say it is going to take me x number of hours. I will give you a cost proposal and add services proposal. The architect has to review that and then give that to the owner and say, 'Is this what you want to do?' …. If this process took three weeks to vet out, it would have killed the idea."* (General contractor, Suburban MOB)

Lean Construction Principles

Lean construction principles include target value design (TVD), pull scheduling, reliable promises, daily huddles, last planner, and other methods to promote efficiency in the design and construction stages of a project. Lean construction is not the source of new ideas; instead it provides strategies to better facilitate cross-disciplinary implementation of the innovative concepts. Lean provides additional flexibility to the client, decentralizes decision-making, and squeezes out buffers and inefficiencies from the process. Using the last planner system, Coast Hospital project managers noted increased ownership of the schedule by subcontractors. The participation of subcontractors at Medical Center increased conversation and dialogue about coordination problems. By placing more tasks on the critical path, lean construction surfaces potential cross-discipline coordination problems more quickly.

Collaborative Decision-Making

Collaborative decision-making requires parties to jointly agree on important choices. By leveraging experiences from all parties, collaborative decision-making brings forward innovation implementation and coordination concerns. Projects that promote a collaborative decision-making is reinforced by both organizational strategy and project culture. Project sub teams are created using inter-organizational clusters. These clusters often sit together in the Big Room and work as a team to meet target value design targets. Some clusters participate in team building activities. As opposed to discipline silos, clusters reinforce shared identity and allegiance to the inter-organizational sub team. Collaborative decision-making also requires individuals with a mindset to collaborate. As a Commercial HQ engineer explains, you cannot "*Hit the lights, and just type away, and work in those silos"* but instead must have a willingness to engage and collaborate with your cluster.

Trust & Accountability

Explicit efforts need to be made towards building team trust and accountability. Trust enhances collaboration between parties. Without a strong foundation of trust, it is difficult to reach consensus and information exchange in a meaningful manner. By withholding information, teams can limit innovation possibilities. Trust is necessary to eliminate wasted time and energy in rework, as explained below:

> *"So we're drawing within our database, which matches our fabrication use and cuts out a huge chunk of the fat in the middle of not redrawing things. They're being drawn for the first time but the first pass of them is the finished product, right? So we'll be creating the construction permits for the drawings. Then [the engineers are] going to stamp them so that is a very uncomfortable situation for them at first. They had a hard time kind of letting go of that."* (Mechanical trade partner, Commercial HQ)

The essence of collaboration is to get input from other perspectives. A lack of trust would mean a disregard for their general knowledge in their field. Similarly, using a shared BIM requires trust in the discipline that originally created the model. This factor is especially relevant considering the adversarial relationships that most building professionals are used to working within. In addition, accountability encourages radical out-of-the-box thinking. As a Medical Center mechanical partner describes, accountability enables teams to do their best work by trusting in their team members to be true to their word. *"Now [people] are telling you the true story. This is what I need to do, this is why I need to do it, and it will help us all be successful."*

Virtual Design & Construction (VDC)

Similar to lean construction, using Virtual Design and Construction (VDC) strategies allows for more effective cross-discipline implementation of integral innovations. VDC is the product, work processes, and organization of multi-discipline building information models (BIMs). A BIM allows for concept visualization to communicate innovative products in the context of location. Researchers observed a live modeling session on the Commercial HQ where an interdisciplinary team representing structural, MEP, and the general contractor worked collaboratively to coordinate the placement of the vertical shared utility racks. The team used a BIM to visualize the tolerances and understand the tradeoffs necessary between structural and MEP requirements. In addition, cross-discipline clash detection sessions resolve coordination conflicts and increase confidence in the constructability of innovations. 4D schedule visualization effectively communicates and details a change in the construction sequence that may be required by an integral innovation.

External Barriers to Innovation

Two external barriers to innovation cited by interview participants are regulatory agencies and unions. IPD may provide projects with the ability to navigate these barriers more effectively than other delivery methods. For example, the multi-party contract structure of Medical Center spreads the cost risk of regulatory testing the innovative auger pile system across all stakeholders provides. Should the regulatory testing not be approved, the guaranteed cost reimbursement provides a safety net that in the worst-case scenario, only profit and not hard costs will be risked. To avoid union conflict, Commercial HQ planned multi-trade union teams to prefabricate shared multi-use horizontal and vertical service racks together at an offsite location.

PHASE II: QUALITATIVE COMPARATIVE ANALYSIS

We introduced fuzzy set Qualitative Comparative Analysis (fsQCA) to further understand the relationship between the elements described above and the adoption of integral innovations. If Phase I can be viewed as discovering the ingredients of integral innovations, Phase II can be understood as validating the necessity of each of these ingredients for integral innovations.

Methodology

Qualitative Comparative Analysis (QCA) is a Boolean technique that allows researchers to create theories from a limited number of case studies (i.e. "small-N" or "medium-N" designs) that otherwise is too few to generate statistically significant findings. The use of fuzzy sets extends crisp-set QCA by permitting membership scores in the interval between [0] and [1] (Rihoux & Ragin 2009). Fuzzy membership allows researchers to address the varying degree to which a different case belongs to a set (Ragin 2009).

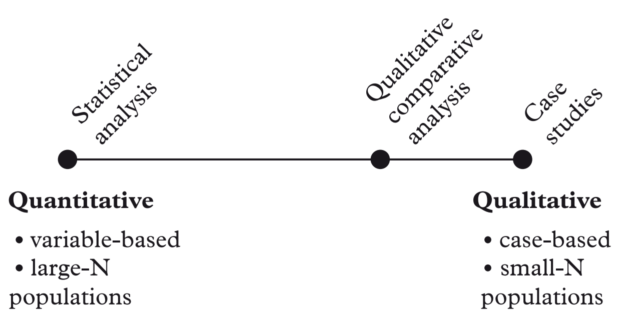


Figure 6 - QCA on the Quantitative/Qualitative spectrum (Jordan et al. 2011; adapted from Gross & Garvin 2011)

By using QCA, the researchers can generate theories about which sets of conditions (independent variables) such colocation or lean construction principles correlate with observed outcomes (dependent variables) such as integral innovations. Because QCA is both systematic and empirical, it is a powerful methodology for researchers to corroborate or falsify a hypothesis (Rihoux & Ragin 2009). Although QCA is a new analytic technique, it is particularly attractive to construction and engineering researchers because the magnitude and expense of large projects often limits the sample size available for study. The frequently complex relationships among the variables of interest make resulting small datasets difficult to investigate using conventional quantitative methods (Jordan et al. 2011).

This paper demonstrates a methodological approach to apply fsQCA to further understand the relationship between IPD elements and integral innovations. This work is an exploratory exercise to evaluate the relationships between our case studies. The fsQCA work intends to suggest preliminary findings and to lay the foundation for future application of fsQCA. This fsQCA work makes early preliminary claims about necessary conditions for innovations in IPD projects, but a larger case set is needed to test and validate this early theory.

Additional Case Descriptions

The original four case studies are nested alongside three additional case studies produced by the American Institute of Architects (AIA) and the University of Minnesota School of Architecture (AIA et al. 2012) to create a data set of seven total cases. A survey distributed to the additional case participants uncovered the degree to which integral innovations were implemented. Some elements such as idea generation or trust rely on the qualitative narratives that arise from meeting observations and participant interviews. While we affirm the importance of these elements in the adoption of integral innovations, these elements are excluded from the fsQCA at this time.

Case ID	Case Name	Cost (millions)	Completion Date	Size	Integral Innovations
5	Cathedral Hill	$1,028.5	Est 2015	858,000	Prefab Bathroom, Shared Utility Racks, Viscous Wall Dampers, Quiet Rock
6	Mercy Remodel	$19.4	2013	94,000	Integrated Headwall System
7	Edith Green Remodel	$123.2	2013	527,000	Radiant Heating & Cooling, Rainwater Harvesting, Elevator Generation,

Figure 7 - Additional IPD Case Studies (AIA et al. 2012)

Fuzzy Set Calibration

Fuzzy membership assesses the varying degrees of membership between full inclusion and full exclusion (Ragin 2009). Conditions are evaluated on a continuous spectrum with three qualitative breakpoints: full membership (1), full non-membership (0), and the cross-over point (.5). The cross-over point demonstrates maximum ambiguity for membership of a condition to be more "in" or more "out" of a set (.5) (Rihoux & Ragin 2007). For example, full membership for early involvement of key participants is defined as conceptual design participation of all key stakeholders, including the owner, architect, engineers, general contractor, and key trade partners. When conceptual design does not include the trade partners, the case is still considered more "in" the set (0.7 score). When involvement of contractor and trades is delayed until design development, the case is considered more "out" of the set (0.4 score). The condition "integral" is scored on a continuous spectrum with 1.0 representing multiple adoptions of significant integral innovations and 0.0 representing no adoption of integral innovation. The condition "New" uses a dichotomous score (score of 0 for retrofit or 1 for new construction); it is the lone exception to continuous fuzzy metrics. Researchers used coded field notes, interviews, and case study literature to construct the fuzzy-set truth table shown below (see figures 8 & 9).

Score	Owner Involvement & Vision
1	Owner has clear directives & goals, a representative colocated on-site, familiarity with IPD, a positive attitude toward IPD, input on selection of subs, quick responses to DMD
0.7	Owner has representative on site and some of the above
0.3	Owner has input on selection of subs and familiarity with IPD
0	Of the above, Owner only has positive attitude towards IPD

Score	Early Involvement of Key Participants
1	Conceptual design participation of all key stakeholders
0.7	Conceptual design participation of OAEC, design development participation of trade partners
0.4	Design development participation of all key stakeholders
0.2	Design development participation of general contractor but not trade partners
0	Traditional involvement of conractor and trade partners (after design stage)

Score	Colocation
1	All teams have daily concurrent work sessions in same space
0.9	All teams have daily concurrent work sessions, instances of islanding by some firms.
0.6	Most teams have daily concurrent work sessions, some key teams have part-time
0.3	Occassional concurrent work sessions such as ICE sessions, no established Big Room.
0	No colocation, majority of cross-disciplinary interaction through formal meetings

Score	Contracts With Incentives & Flexibility
1	IFOA/multi-party contract includes OAEC & trades. Contract is flexible and incentivized.
0.8	IFOA/multi-party contract includes OAC. Contract is flexible and incentivized.
0.6	No multi-party contract. Contracts are flexible & incentivized.
0.3	No multi-party contract. Contracts are incentivized.
0	No multi-party contract. Contracts are not flexible or incentivized.

Score	Lean Construction Principles
1	Successful implementation of TVD, pull scheduling, reliable promises, A3, daily huddles, last planner, JIT Delivery
0.7	Most of the above
0.3	Few of the above
0	No implementation of lean construction

Score	Virtual Design & Construction
1	Project uses BIM execution plan, shared models, a trailer with BIM capability, designated BIM team, live multi-disciplinary modelling sessions, clash detection, high degree of LOD
0.7	Most of the above
0.3	Few of the above
0	None of the above. BIM used only for architectural design.

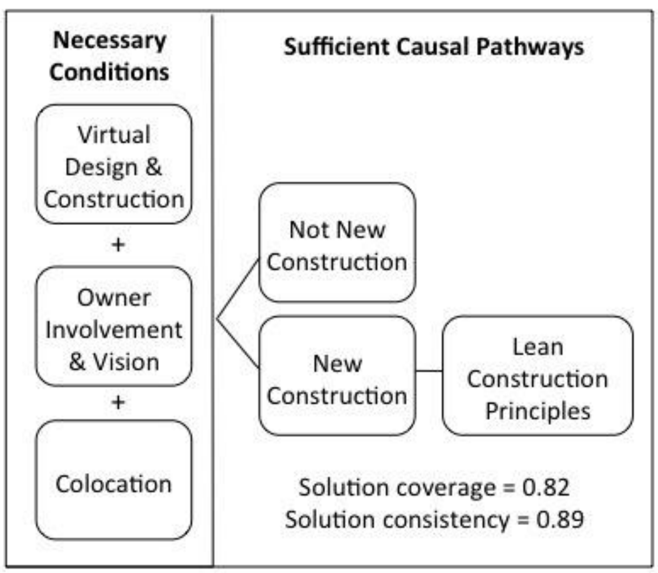
Figure 8 – Fuzzy Set Calibration

Case ID	New	Owner	Early	Colocate	Contract	Lean	VDC	Integral
1	1.0	1.0	1.0	0.9	1.0	1.0	1.0	1.0
2	0.0	0.3	0.4	0.3	0.8	0.7	0.3	0.2
3	0.0	0.7	0.4	0.9	0.0	0.3	0.7	1.0
4	1.0	1.0	0.3	0.9	0.4	1.0	1.0	0.7
5	1.0	0.7	1.0	0.6	0.8	1.0	1.0	1.0
6	1.0	0.7	1.0	0.6	1.0	1.0	0.7	0.7
7	1.0	0.7	1.0	0.6	1.0	0.7	0.7	0.4

Figure 9 - Fuzzy Set QCA Truth Table

fsQCA Results

The complete complex, intermediate, and parsimonious solutions are shown in the appendix. Figure 10 below shows the intermediate solution. VDC, Owner Involvement & Vision, and Colocation are necessary conditions for integral innovations for renovation projects. When a project is new construction (not a renovation or retrofit), lean construction principles are also required. The consistency, which signals whether an empirical connection merits the close attention of the investigator, is given at 0.89. If a hypothesized subset relation is not consistent, then the theory about the inclusion of the element for integral innovations is not supported (Rihoux & Ragin 2007).



Causal Condition	Necessity
VDC	.94
Owner	.88
Colocate	.86
Lean	.86
Early	.80
Contract	.70

Figure 10 - fsQCA results

Authors note: QCA results should be viewed as preliminary and exploratory.
The data set may be expanded to more cases before journal publication.

CONCLUSIONS & DISCUSSION

Interviews and observations from four IPD case studies propose ten elements that play a positive role in the implementation of integral innovations. These elements from Phase I can be organized into three strategies: legal, management, and workplace (see figure 11). Legal strategies are incentivized contracts that guarantee cost reimbursement and provide fiscal transparency and flexibility. Management strategies include owner involvement and vision, early involvement of key participants, team idea generation and support, and lean construction principles. Workplace strategies include colocation, collaborative decision-making, team trust and accountability, and VDC. IPD is better equipped to navigate the innovation barriers created by unions and regulatory agency.

Sheffer (2011) diagrams the relationship between construction product characteristics, the resulting industry structure, and the effect on innovation diffusion (see figure 12). IPD addresses vertical fragmentation by iterating frequently with owners and empowering trade partners. This greater sense of agency is present during collaborative decision-making, colocation, early involvement, and idea generation. IPD addresses horizontal fragmentation through multi-party contracts rewarding actions that benefit the project as a whole. Shared risk/reward contracts hold the entire team accountable for project success. Innovations that do not fit within the existing supply chain can be cross-subsidized not only at bid time but also throughout the project using agile cost shifting.

Legal Strategies

- Incentivized Contracts with Guaranteed Cost Reimbursement
- Fiscal Transparency & Flexibility

Management Strategies

- Owner Involvement & Vision
- Early Involvement of Key Participants
- Team Idea Generation & Support
- Lean Construction Principles

Workplace Strategies

- Colocation
- Collaborative Decision Making
- Team Trust & Accountability
- Virtual Design & Construction

Figure 11 – Legal, Management, and Workplace Elements that Facilitate the Implementation of Integral Innovations

The virtual vertical and horizontal integrations of IPD show potential to overcome learning disability. As a Commercial HQ mechanical trade partner states *"There were systems I had not done before so I did not know about them and I learned a lot. We actually looked at a lot of different types of systems that in order to understand them and how to estimate them…and to understand how to estimate, you have to understand how you are going to build it. So we had to do a lot of research into these different things."* However, at present that learning exists on a project-to-project basis. The vision for IPD is to address longitudinal fragmentation by keeping teams together long term. This may be more difficult in reality. Some interview participants on their second IPD project described a high turnover of personnel between the two projects. IPD's ability to continuously learn and improve from project to project remains to be seen.

The use of prefabrication is a common type of integral innovation. Prefabrication often involves a change in process but not interface. For example, prefabricated bathroom modules cross traditional supply chain boundaries using off-site manufacturing. The interfaces between the plumbing, drywall, and structural system remain unchanged. The relationship between the elements described above and prefabrication of integral innovations on IPD projects is a potential subject of future research.

Surprisingly, interview participants seldom referenced liability waivers in the context of innovation. Perhaps individuals are not aware of the implications of liability waivers on risk aversion. It is also possible that participants have internalized these waivers as a safety net and did not feel the need to bring them up. Future fsQCA work can include liability waivers as a condition of innovation to determine if they are a necessary condition for integral innovations.

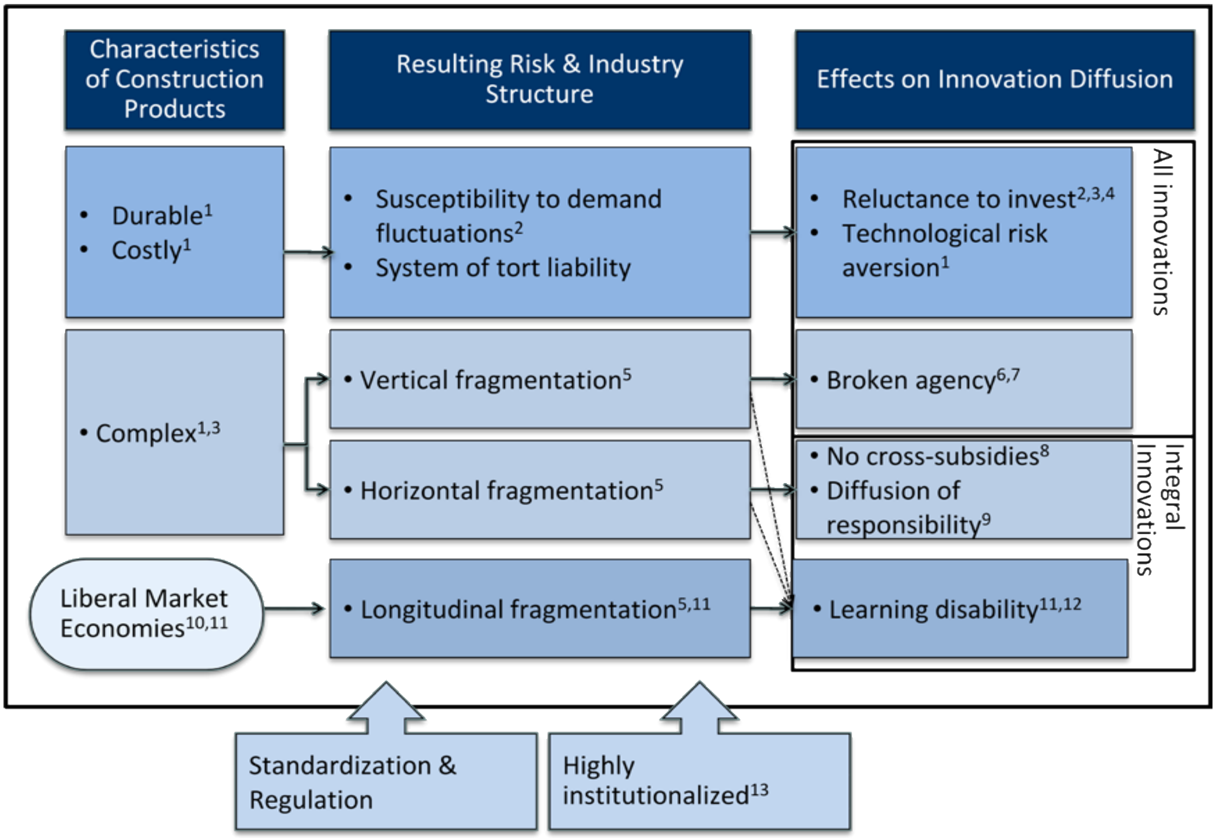


Figure 12 – Barriers to Innovation in Construction (Sheffer 2011)

The preliminary fsQCA of seven cases further emphasizes the importance of VDC, owner involvement and vision, colocation, and (for new construction) lean construction principles. Contracts have the lowest consistency score across the seven projects. Should this be confirmed by a larger data set, future research would show little difference in innovation between IPD and "IPD-lite" projects.

These results are exploratory in nature. More importantly, researchers have developed a methodology for calibrating a fuzzy set truth table and conduction fsQCA that can be expanded to a medium-N data set in future research. For instance, the AIA IPD case study has six additional cases which could be added to the current data set. A fsQCA for a data set of fifteen IPD projects alongside fifteen similar projects using more traditional delivery methods would increase confidence in these early findings.

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APPENDIX

fsQCA Results

--- COMPLEX SOLUTION ---
frequency cutoff: 1.000000
consistency cutoff: 0.933333

	raw coverage	unique coverage	consistency
~New*Owner*~Early*Colocate*~Contract*~Lean*VDC	0.160000	0.160000	1.000000
New*Owner*~Early*Colocate*~Contract*Lean*VDC	0.120000	0.060000	1.000000
New*Owner*Early*Colocate*Contract*Lean*VDC	0.560000	0.500000	0.933333

solution coverage: 0.780000
solution consistency: 0.951220

--- PARSIMONIOUS SOLUTION ---
frequency cutoff: 1.000000
consistency cutoff: 0.933333

	raw coverage	unique coverage	consistency
Owner	0.880000	0.000000	0.862745
Colocate	0.860000	0.040000	0.895833
VDC	0.940000	0.060000	0.870371

solution coverage: 0.980000
solution consistency: 0.875000

--- INTERMEDIATE SOLUTION ---
frequency cutoff: 1.000000
consistency cutoff: 0.933333
Assumptions:
VDC (present)
Lean (present)
Contract (present)
Colocate (present)
Early (present)
Owner (present)

	raw coverage	unique coverage	consistency
VDC*Colocate*Owner*~New	0.180000	0.080000	0.900000
VDC*Lean*Colocate*Owner	0.740000	0.640000	0.880952

solution coverage: 0.820000
solution consistency: 0.891304

Analysis of Necessary Conditions

Outcome variable: Integral

Conditions tested:

	Consistency	Coverage
Owner	0.880000	0.862745
Early	0.800000	0.784314
Colocate	0.860000	0.895833
Contract	0.700000	0.700000
Lean	0.860000	0.754386
VDC	0.940000	0.870370