**DISSERTATION**

# Of Incentive, Bias, and Behaviour: An Empirical Economic Investigation into Project Delivery Constructs Influencing the Adoption of Building Information Modelling

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# Declaration

I, Robert Howard, confirm that the work presented in this dissertation is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

Respectfully Submitted,

[redacted]

Robert W. Howard

# Abstract

Building Information Modelling (BIM) is a collaborative construction platform allowing for digital databases, real-time change management, and a high degree of information reuse catalysing increased quality of work, enhanced productivity, and lower costs. Yet, overall adoption rates within industry remain vexingly low. Integrated Project Delivery (IPD) is currently the only contractual incentive vehicle available for BIM, and indeed the full potential of both are only realised when employed together; even so, uptake rates of IPD exist even lower. In response, this research evaluates hitherto ill-explored factors influencing the adoption of BIM by empirically testing hypotheses related to the impacts of three compounding theories upon the BIM decision calculus. Specifically, the incentive theory, the theory of acceptance and use of technology (UTAUT), and the status quo bias model. The research approaches BIM adoption holistically at the organizational, individual, transactional, and behavioural levels through a mixed design combining five quantitative, cross-sectional, questionnaire-based studies and one interview-based pre-test/post-test case study with sample populations including a Fortune 100 contractor, internationally renowned trade groups, and arguably the most progressive municipal construction client in the world. Data was collected using purposive sampling and analysed quantitatively through Structural Equation Modelling (SEM) and qualitatively with Directed Content Analysis (DCA). Primary conclusions are that BIM decisions are hierarchical; BIM adoption involves a general higher-level decision-making requiring stakeholders' consensus; BIM utilization involves a specific lower-level decision-making with managerial discretion; economic incentives and competitive pressure influence higher-level decisions; non-economic factors influence lower-level decisions but are moderated by organizations' type and size; organizations' size and the degree of managerial discretion are inversely related; strength of the effects vary across and within the three theory-based factors that influence BIM adoption; and the effects of leadership and organizational culture remain unaccounted for and require investigation.

# Impact Statement

This dissertation explores specific constructs responsible for the slow diffusion of collaborative Building Information Modelling (BIM) within the construction industry. Its insights benefit academic research on the topic of BIM specifically and the dissertation's respective theoretical bases more generally. The research is also informative, useful, and deployable for industry practitioners. Impacts further extend to public policy; specifically, in the areas of procurement, contracting, and structuring legislative mandates.

Academically, the empirical analyses herein indicate that it may be more advantageous for researchers to approach the topic of BIM adoption holistically and, to that end, employ mixed-method designs. Through this dissertation, it is clear that excessive emphasis on singular quantitative methods so prevalent within extant literature on BIM implementation cannot provide a complete understanding for the inherent complexities of the BIM decision calculus. The dissertation successfully mitigates this by compounding results across multiple quantitative surveys and a qualitative case study which allowed not only the cross-validation of findings, but their contextualization within a real-world construction environment. This research contributes to the body of knowledge on BIM by systematizing the findings of previous studies and then expanding that knowledge with new analytical insights concerning BIM's bounded rationality, information asymmetry, asset specificity, probity of decision makers, and the reasons underlying stakeholders' opportunistic behaviours. Finally, a novel operationalization for the identification and measurement of status quo bias impacts via survey was proposed and validated within multiple studies, thus significantly extending the research potential of that model.

Construction industry practitioners will benefit from the findings of this research in several ways. First, the conclusions reached suggest that a decision to adopt and fully support BIM is multi-layered and requires a structure that incentivizes higher and lower level decision makers differently. Further, it was found that a sustainable decision for BIM adoption is possible only if the decision is approached as an optimization, rather than maximization, problem and closer attention is paid to biases that divert from the optimal choice. The results of the dissertation also show that absorptive capacity of an organization considering the adoption or expansion of BIM depends significantly upon organizational leadership, which requires further investigation.

Public policy makers will also benefit from the findings of this research through the identification of specific factors that inhibit the full adoption of BIM, even when its use is required by law. Specially, it was found that legal mandates that require BIM for public projects are not sufficient to achieve the level of buy-in necessary from individual stakeholders for the benefits of BIM to be fully realized. This dissertation thus provides hard empirical evidence that can be reliably used in the analysis, formulation, and implementation of regulatory and compliance policies for the construction industry worldwide.

# Dedication

Researching this dissertation significantly altered the course of my life and career. I began my PhD while working as a senior contracts administrator building a natural gas export terminal in Algeria, and then spent years 2-5 as the site contracts department manager on an expansive revitalisation of Iraq's largest oil field. In these roles, I acted as lead negotiator for eight- and nine-figure contract disputes including a variety of extension of time, force majeure and rejected change order claims. Therein, I saw first-hand the massive indirect costs that predictably result from traditional hierarchical construction contracting and follow-on adversarial project delivery environments. Inversely, during this same time, I was studying the extraordinary benefits of early engagement, relational contracting, and shared risk/reward project delivery as I worked through the chapters herein. After completing the project in Iraq and achieving CRS, I returned to Texas for a prominent home office role but was promptly laid off (twice) as petrochemical projects were shelved industry wide. Seeking opportunity in necessity, I founded a now-burgeoning namesake property development company expressly founded upon the principles of incentive alignment and qualification-based procurement that I gleaned from this dissertation. Given submission hereof and an eye towards the future, it seems proper to recognize influences from this unique history. Accordingly, I dedicate this dissertation to the extraordinary co-workers, security forces, subcontractors, and local building crews that I worked with during my years overseas, committed men and women from six continents who pulled long days under arduous conditions and burdensome procedural requirements to construct some of the largest and most complex projects in the world. It was an honour to play my part and hope this effort proves in some small measure equal to that which you displayed in the field every day.

# Acknowledgments

First, I wish to thank Mr. Graham Ive for the chance to attend UCL at all. When interviewing for The Bartlett's *Construction Economics and Management* MSc program in 2009, I was working on a U.S. Department of Defence building and maintenance crew on forward operating bases in *Operations Iraqi Freedom* and *Enduring Freedom*. I flew to my interview on a special pass from Camp Phoenix in the mountains of Kabul, Afghanistan and coming from a conflict zone with a pre-law degree and no formal education in economics or construction, I was not exactly a standard recruit for this elite program. During the interview, Mr. Ive was as interested in my experience as I was in The Bartlett and ultimately said he was willing to take a chance on me. Years later, my PhD supervisor Dr Chen-Yu Chang, who was himself supervised by Mr. Ive as a doctoral candidate, afforded me the honour of assisting with a festschrift published at Mr. Ive's retirement after forty years as one of construction economics' preeminent researchers. Of all the papers I have participated in to-date, I am perhaps most proud of this.

I must also acknowledge the incredible support, guidance, and mentorship of Dr Chen-Yu Chang over eight years of PhD work. As a part-time non-residential student on rotational schedules that were constantly changing, I was not the easiest of candidates to supervise. That said, it worked rather well for Dr Chang and me as we developed a close working relationship and published four papers together along the course of my dissertation. As happens, talent such as Dr Chang's is in high demand and he left the university for private industry just prior to submission hereof.

To wit, I also acknowledge and appreciate Professor Tim Broyd and Associate Professor John Kelsey for stepping in as new supervisors at the eleventh hour. It is a tall order to take in eight years of work in the short time we have worked together but their comments have taken this dissertation to another level. All those named herein, and The Bartlett as a department, represent the world's foremost researchers in the built environment and I am honoured to add this dissertation to such a distinguished body of work.

# Table of Contents

# List of Tables

## List of Figures

# List of Acronyms

| | |
|---|---|
| 3D | 3-Dimensional BIM object (Width, Height, Depth) |
| 4D | 4-Dimensional BIM object (3D + Time) |
| 5D | 5-Dimensional BIM object (4D + Cost) |
| 6D | 6-Dimensional BIM object (5D + As-Built) |
| 7D | 7-Dimensional BIM object (6D + Life-Cycle Management) |
| AEC | Architecture, Engineering, and Construction |
| AECO | Architecture, Engineering, Construction and Owner |
| AIA | American Institute of Architects |
| AMCLOS | Automated Multi-Objective Construction Logistics Optimisation System |
| AMOS | Analysis of Moment Structures (SPSS module for SEM) |
| API | Annual Performance Indicator |
| AR | Augmented Reality |
| ASCE | The American Society of Civil Engineers |
| BE | Behavioral Economics |
| BEA | Building Energy Analysis |
| BIM | Building Information Management |
| BOQ | Bill of Quantity |
| CAD | Computer Aided Design |
| CAVE | Cave Automated Virtual Environment |
| CB | Covariance-Based |
| CBSE | Component-Based Software Engineering |
| CDO | Chief Development Officer |
| CEO | Chief Executive Officer |
| CFA | Confirmatory Factor Analysis |
| CFI | Comparative Fit Index (statistics) |
| CI | Confidence Interval (statistics) |
| CRC | Cyclic Redundancy Check |
| CSI | The Construction Specifications Institute |
| DCA | Directed Content Analysis |
| DES | Discrete-Event Situation |
| DF | Degrees of Freedom (statistics) |
| DIIM | Director of Infrastructure Information Management |
| EGUS | Electronic Give-Up System |
| EPFCM | Engineering, Procurement, Fabrication, Construction & Maintenance |
| EPO | Exceptional Project Outcome |
| EPPD | Exceptional Project Delivery Paradigm |
| FA | Factor Analysis (statistics) |
| FAA | U.S. Federal Aviation Administration |
| FAQ | Frequently Asked Questions |
| FID | First Input Delay |
| FM | Facility Management |

| | |
|---|---|
| FTP | File Transfer Protocol |
| GAO | U.S. Government Accountability Office |
| GC | General Contractor |
| GIS | Geographic Information System |
| GMP | Guaranteed Maximum Price |
| GSA | U.S. General Services Administration |
| HVAC | Heating, ventilation, and air conditioning |
| IDM | Information Delivery Manual |
| IDT | Information Diffusion Theory |
| IFC | Industry Foundation Classes |
| IPD | Integrated Project Delivery |
| IT | Information Technology |
| KPI | Key Performance Indicator |
| LEED | Leadership in Energy and Environmental Design |
| LLC | Limited Liability Company |
| MBA | Master of Business Administration |
| MEP | Mechanical, Electrical and Plumbing |
| MGS | Master Guide Specifications |
| NIBS | The National Institute of Building Sciences |
| NTIS | The National Technical Information Service |
| OCR | Optical Data Recognition |
| PA | Path Analysis (statistics) |
| PC | Personal Computer |
| PLCS | Product Life Cycle Support |
| PLS | Partial Least Squares (statistics) |
| PMBOK | Project Management Body of Knowledge |
| PRC | The People's Republic of China |
| PTCE | Project Target Cost Estimate |
| QDA | Qualitative Data Analysis |
| RA | Regression Analysis (statistics) |
| RFI | Request for Information |
| RFI | Relative Fit Index (statistics) |
| RFID | Radio Frequency Identification Framework |
| RFP | Request for Proposal |
| RMSEA | Root Mean Square Error of Approximation (statistics) |
| ROI | Return on Investment |
| SCP | Structured Collaborative Partnering |
| SCPP | Structured Collaborative Partnering Plan |
| SCPT | Structured Collaborative Partnering Team |
| SEM | Structural Equation Modeling (statistics) |
| SEP | Stakeholder Engagement Process |
| SFO | San Francisco International Airport |
| SPSS | Statistical Package for the Social Sciences |
| TAM | The Technology Acceptance Model |
| TCO | Temporary Certificate of Occupancy |

| | |
|---|---|
| TLI | Tucker-Lewis Index (statistics) |
| TSA | U.S. Transportation Security Administration |
| UASEM | User Activity Simulation and Evaluation Methods |
| UPOEM | User Preoccupancy Evaluation Method |
| UTAUT | Unified Theory of Acceptance and Use of Technology |
| VARIMAX | FA rotation method to maximize the variance of the factor loadings |
| VDC | Virtual Design and Construction |
| VR | Virtual Reality |

# 1. Chapter 1: Introduction

## 1.1. Rationale for the Study

Efficiencies inherent to disruptive technologies typically afford axiomatic incentive structures; that is, the machinations of economy typically guide rational actors towards optimally cost and time efficient methodologies. Building Information Modelling (BIM) is widely considered the most important contemporary advancement within the construction industry worldwide. The findings of past empirical research overwhelmingly support the claim that BIM delivers the same extraordinary benefits as other disruptive technologies. Yet, uptake of BIM within industry remains low. In consulting literature for elucidation, economists note that the adoption of BIM is affected by certain processes and technological barriers, but that BIM's equitably expectant benefits overwhelmingly counterbalance such barriers. Still, diffusion of BIM remains stunted. This raises two important questions: (a) what characteristics unique to BIM may make it ostensibly immune to the effects associated with other disruptive innovations; and (b) how that knowledge might be exploited towards BIM proliferation?

In the most general sense, BIM represents a single process spanning the generation and management of the physical and functional information of a construction project (Kelly & Ilozor, 2019). The output of the process is typically referred to as BIMs or building information models, which are digital files that describe every aspect of the project and support decision-making throughout a construction project cycle. Some researchers and industry analysts argued that BIM is nothing more than advanced 3D modelling (Dainty, Leiringer, & Fernie, 2017), but it involves far more than that. BIM and its subset systems and technologies feature more than just 3D (width, height, and depth) but also include further dimensions such as 4D (time), 5D (cost), and even 6D (as-built operations) (Liu, Al-Hussein, & Lu, 2015).

BIM represents a design as combinations of "objects" – imprecise and undefined, generic, or product-specific, solid shapes or void-space oriented – that carry their geometry, relations, and attributes (Dowsett & Harty, 2019). Among other functionalities, BIM design tools allow the extraction of different views from a model to produce drawings. These different views are automatically consistent because they come from a single definition of each “object instance”. Objects are also defined as parameters in relation to other objects. Thus, if there are changes in an object, related or adjacent ones will automatically change or adjust accordingly in real time. Besides, each element of a BIM model can carry attributes to automatically select and order them where cost estimates and material tracking, and ordering can be provided.

BIM and related technologies provide real benefits for the project but may also pose challenges for the project manager (Ferron & Turkan, 2019). As automation is increasingly used for quantification within the AEC industry, BIM models will need to adapt accordingly to allow for more sophisticated management components that incorporate 4D time and 5D cost modelling and sharing this information with the project team in an integrated project delivery approach (Zhou, Yang, & Yang, 2019).

However, BIM implementation is not solely about new software and technology. Rather, BIM requires an alternative way of thinking and a different approach to project procurement and delivery. In particular, BIM requires that stakeholders move from the traditional approach of project participation with separate information pools and incompatible software technologies to one that is completely integrated with a common platform where participants share and work on the same information (Delhi & Singh, 2019). As such, BIM represents the ultimate tool for such collaboration.

The findings of both industry reports and academic research on this topic indicate that the effects of BIM on the construction industry have been overwhelmingly positive. For example, according to one study that evaluated the advantages and the disadvantages of BIM adoption by surveying various types of construction industry organizations, three-fourth of all companies that have adopted BIM reported positive returns on their investment, shorter lifecycles, and significant savings on paperwork and material costs (Agarwal et al., 2016). Owing to such benefits, governments in various countries now mandate the use of BIM for public infrastructure projects (Nuttens, De Breuck, & Cattoor, 2018; Volk, Stengel, & Schultmann, 2014).

Past research on the topic also concluded that BIM could provide the construction industry with consequential opportunities to raise the quality of the industry to a higher and much more sophisticated level (Migilinskas, Popov, &

Juocevicius, 2013). Because of its advanced capability to simulate a range of data options with real-time cost advice and carry on throughout the detailed design, construction, and operational stages, BIM can surely place the current construction practices at a higher value (Azhar, 2011; Yuan & Yang, 2019). Extant research also shows that BIM is taking off across the world. Currently, many countries have BIM standards in place regarding the BIM level used in projects, but significant differences in BIM adoption and utilization rates worldwide remain (Kelly & Ilozor, 2019).

In the U.S., BIM adoption has been generally slow. Nevertheless, it is expected to grow steadily in the near and medium-term perspectives (Nuttens, De Breuck, & Cattoor, 2018). Wisconsin was the first state to mandate BIM in 2010. The mandate requires that all public projects with a total budget of $5 million or more must be realized using a BIM method. This mandate also applies to all new projects with a total budget of $2.5 billion or more (Nuttens, De Breuck, & Cattoor, 2018). This notwithstanding, in comparison to other countries, the U.S. lags behind in BIM adoption and utilization (Sun, Jiang, & Skibniewski, 2017). Such imbalanced and stunted diffusion of BIM as a transformative technology requires an in-depth investigation of specific reasons and key factors that or substantially inhibit, or prevent altogether, BIM adoption by construction industry organizations. Thus, this discussion begs the following research question.

### 1.2. Research Question

What specific factors unique to the construction project delivery and decision-making environments are influencing the behaviour of industry actors who are largely unwilling to make what appears as an optimal choice regarding the adoption of BIM?

### 1.3. Aim and Objectives

The overarching aim of this dissertation was to investigate empirically the slow speed of technological progress within the construction sector; notably, the reluctance of parts of the AEC sector to adopt Building Information Modelling (BIM). This empirical investigation had the following specific research objectives:

1. To identify the perceived benefits and risks of adoption of the group of digital technologies currently known as Building Information Modelling (BIM).

2. To locate and describe the decision-making process leading to the adoption, or otherwise, of BIM by construction industry organizations.
3. Identify particularly relevant characteristics of construction project management processes and their influence upon the decision to adopt BIM.
4. Based on the preceding, identify sub-optimal practices and the means by which they could be improved.

### 1.4. Theoretical Framework

The decisions to adopt and employ BIM are inherently complex (Hochscheid & Halin, 2019). They involve multiple and usually cascading transactions among key stakeholders (Ayman, Alwan, & McIntyre, 2018; Dowsett & Harty, 2019). These transactions in turn have various conceptual and practical business dimensions (Bosch-Sijtsema & Gluch, 2019). In view of the conceptual complexity of the overarching research problem and a high likelihood that several factors may be interacting to cause the problem, the dissertation relied on the applications of (a) the incentive theory (Baddeley & Chang, 2015; Linderoth, 2010), (b) the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh, 2000; Venkatesh & Davis, 2000; Venkatesh, Morris, Davis, & Davis, 2003; Venkatesh, Thong, & Xu, 2016); and (c) the Status Quo Bias model (Kahneman, 2013; Kahneman, Knetsch, & Thaler, 1991; Kahneman & Lovallo, 1993) to the decisions to adopt and employ BIM in the AEC industry.

The incentive theory posits that for any innovation to be fully adopted by an economic agent, it must be associated with rising productivity as a result of such adoption which should, in turn, lower unit labour costs and increase profits (Baddeley & Chang, 2015). The Incentive theory, drawing on behavioural economics, suggests that economic agents may behave strategically and often opportunistically to maximize benefits (personal, organizational, institutional) for themselves regardless of the costs these might impose on others (Baddeley & Chang, 2015).

The UTAUT postulates that the decision to adopt and use a new technology is influenced by four factors: (a) performance expectancy or perceived usefulness, (b) effort expectancy or perceived ease of use, (c) social influence or subjective norms, and (d) facilitating conditions (Venkatesh et al., 2003). Performance expectancy, effort expectancy, social influence, and facilitating conditions determine the decision and rate of technology acceptance (Samuelson & Björk, 2013), which in turn are affected by decision makers' attitudes towards technology use (Davies & Harty, 2013). The latter are subject to four moderators (i.e., age, gender, experience, and voluntariness) that can be used to predict (a) behavioural intention to use a technology, and (b) actual technology use in organizational contexts (Venkatesh, Thong, & Xu, 2016).

The Status Quo Bias model offers a human behaviour-related perspective and posits that (a) people employ analytical and emotional systems to process and assess risk; (b) the analytical system processes and evaluates risk by consciously considering costs and benefits; (c) the emotional system processes and assesses risk through nonformal and automatic processes; and (d) the systems complement each other but in situations where their outputs differ, the emotional system dominates (Kahneman, 2013; Kahneman, Knetsch, & Thaler, 1991; Kahneman & Lovallo, 1993). When this occurs, decision-makers tend to underestimate the danger of events they have never experienced and overestimate the likelihood of events occurring if they have personally experienced them (Kahneman, 2013).

## 1.5. Background of the Problem

Since the term Building Information Modelling (BIM) was first introduced in the Architecture, Engineering and Construction (AEC) industry, it has progressed from a novel buzzword with a handful of early adopters to the centrepiece of AEC technology encompassing all aspects of design, construction, and operations for the built environment (Jin, 2019). In fact, the share of firms utilizing BIM within the U.S. has risen from just 13 percent in 2007 to 79 percent in 2017 (Dowsett & Harty, 2019).

However, this upsurge comes with a caveat as the degree of utilization varies widely (Eastman, Teicholz, Sacks, & Liston, 2018). Despite an increasing share of companies that adopted BIM, research findings indicated that (a) this is largely confined to low-level adoption with 95% of industry stakeholders still working non-collaboratively based on CAD models; and (b) very few projects are taking part in fully integrated and interoperable Phase 3 BIM systems (Hochscheid & Halin, 2019). This pervasive limited participation is a matter of economics and motivation, as research shows that not all stakeholders are receiving additional compensation for the efficiency and savings created when BIM technology is used, and these participants therefore have less incentive to utilize the system to its full potential (Thomson & Miner, 2006; Nuttens, De Breuck, & Cattoor, 2018). Such asymmetrical rewards for investment make it impossible to realize BIM's exceptional capabilities, revealing an incentive problem which requires that the construction industry undergo a paradigmatic shift in its approach (Ferron & Turkan, 2019; McAdam, 2010).

Contractors will participate in BIM applications in order to be awarded a contract and be technically able to present their design (Eastman et al., 2018), but simple obligatory participation cannot facilitate the information sharing necessary for the creation and use of a high-level interoperable BIM model. Rather, the goal must be to incentivize participation in such a way as to avoid inhibitions or disincentives that discourage stakeholders from fully realizing BIM's potential (Hochscheid & Halin, 2019; Thompson & Miner, 2006). These inhibitions likely include the disclosure of proprietary information (Azhar, 2011) and certainly an increase in the risk and information sharing inherent to a fully developed BIM model (Fountain & Langar, 2018). As such, the advances in IT associated with BIM must be balanced by incentives in order for its full potential to be realized (Ademci & Gundes, 2018).

Currently, Integrated Project Delivery (IPD) is the only broad incentive approach for project owners seeking participation in BIM systems. IPD seeks to improve project outcomes through a collaborative approach of aligning the incentives and goals of the project team through shared risk and reward, early involvement, and a multiparty agreement (Kent & Becerik-Gerber, 2010). Since both BIM and IPD compel a dramatic increase in information sharing, they have become interwoven and represent a clear break away from current linear processes based on exchanges of information through papers (Eastman et al., 2018). In this regard, some claimed that IPD is pivotal to BIM implementation (Yee, Saar, & Yusof, 2017). Yet, IPD is not a singular approach, because (a) multiple IPD methodologies have emerged as the industry experiments with this contracting strategy (Eastman et al., 2018); and (b) different IPD methodologies promote BIM differently (Hall & Scott, 2019). Thus, this chapter sets out a framework for critically examining existing IPD agreements' component incentives, which drive contractor participation in BIM systems.

### *1.5.1 Drivers of BIM Adoption*

In the AEC industry, the concepts of competitive advantage, process problems, technological opportunity, and institutional requirements generally drive the adoption of emergent tools such as BIM (Mitropoulos & Tatum, 2000). However, these drivers are only as effective as their correlation to potential increases in profit (Kassem & Ahmed, 2019), with monetary evidence being a strong driver for any technology adoption (Kent & Becerik-Gerber, 2010). For this reason, several studies have been undertaken that examine the return on investment (ROI) from the use of BIM. These studies, including those conducted by Stanford's Center for Integrated Facility Engineering (CRC Construction Innovation, 2007; Giel, Issa, & Olbina, 2010; McGraw Hill Construction Analytics, 2018, 2019), universally report positive returns. However, the reliability of these results is in question as ROI values are reported without providing the data collection and analysis methodology details needed to validate results (Lee, Park, & Won, 2012). Additionally, while these ROI studies do provide evidence of positive returns, they do so from only a surface-level perspective.

To truly measure the draw of BIM, other drivers must also be considered, including the primary driver of overall efficiency with the ability to reduce material waste, conserve information, and increase productivity (Ngo, 2012). To address these efficiency factors, researchers have utilized key performance indicators other than ROI, including schedule reduction (Khemlani, 2006 & 2007), the incidence of change orders (Cannistrato, 2009) or RFI's (Riese & Peake, 2007). While research shows that these metrics are the most quantifiable (Barlish & Sullivan, 2012), there are many factors outside of BIM to which their variance can be attributed. This means that no standard measure of effectiveness has yet been established. The end result is that despite BIM's high potential, AEC industry and researchers do not recognize a formal methodology to evaluate its benefits (Becerik-Gerber & Rice, 2010).

### *1.5.2 Barriers to BIM Adoption*

There are both real and perceived risks associated with any change in work processes, and the implementation of BIM is no exception. Such barriers generally fall into two categories: process barriers to the business organization and technology barriers related to readiness and implementation (Eastman et al., 2018). Relevant to the current research are process barriers, including contractual issues catalysed by the departure from traditional hierarchies in favour of interrelationships (Tolson, 2012), ownership of the final project model and rights of the creators (Olawumi, Chan, Wong, & Chan, 2018; Udom, 2012), and risk or liability issues resulting from the blurring of input borders within the collaborative environment (Olawumi, Chan, Wong, & Chan, 2018; Oesterreich & Teuteberg, 2019; Sun, Jiang, & Skibniewski, 2017; Ngo, 2012).

The focus on process barriers is supported by a 2012 qualitative study on the AEC industry’s response to the requirement of BIM for public UK projects, which found that none of the construction professionals interviewed expressed technical difficulties in using BIM software. Rather, their concerns were focused on process changes including standards, information and coordination, and changes in culture such as collaborative attitudes, leadership, and education (Ngo, 2012). In a later study, Majrouhi Sardroud, Khorramabadi and Ranjbardar (2018), overall confirmed these findings. Given the widespread acceptance of BIM technology and equally prevalent concern over its follow-on changes to organizational processes, it is argued here that rather than view BIM as a technology, it should be analysed as a project delivery method with novel risks, rewards, and relationships (Ashcraft, 2009).

### *1.5.3 Sources for Conflicts of Interest in Construction Projects*

Extant literature provides that conflicts of interest may arise owing to three causes (Lambert, 2001): agent’s aversion to effort, diversion of resources by the agent for his private consumption or use, or differential time horizons. These cases may be present in three main stages of project procurement: defining project value, dividing project surplus among parties, and maintaining the agreed-upon division with the lowest possible costs.

In the first stage, the owner should seek to best utilize the input from the designer/engineer to clearly scope out the project and specify output requirements in measurable detail (output specifications, design drawings, etc.). The design parameters emerging from this stage will shape the total value that the project creates for the owner, and while the owner hopes to see the design as complete and detailed as possible, the designer will tend to produce the design with the least effort and highest possible fees.

In the second stage, the objective is to select the optimal bidders in terms of capability and price so as to secure a price commitment from the contractor, whereby the project surplus (value net of cost) can be determined. In practice, the commitment could be a fixed amount (lump sum contract) or dependent upon the outturn cost (cost plus contract). The owner would hope to find a contractor capable of producing a requirement-satisfying project with favourable terms of trading such as low price, greater risk transfer, and/or higher protection while the contractor will hope to achieve the opposite. This conflict of interest is normally solved through a tendering system in which competition is properly maintained to keep the winning bidder’s profit margin in line with the market rate while providing enough room for innovation and an in-process monitoring scheme.

In the third stage, the owner is concerned with the enforcement of the contractor’s contractual obligations; namely, how to ensure that the division of project value established in stage two materializes as planned. There are two contractual issues that may hinder this from happening: the contractor exhibits a proclivity to shirk (moral hazard problem) and/or demand a higher profit margin through the pursuit of change orders (holdup problem). For the former, principal-agent theory suggests that the owner should allow the contractor to bear part of the risk to induce his best effort. For the latter, holdup threats become a serious concern when change orders arise (Chang, 2013; Chang & Ive, 2007).

Prior to contract signature, the power rests with the owner as he decides what to purchase, how to govern the project, and who to contract with for services. As a result, once requirements are outlined and the bid basis and payment scheme are determined, the owner faces the major challenge of avoiding being placed at the mercy of the aforementioned problems: at once aiming to ensure contractor performance while simultaneously reducing the magnitude of extra profit that the contractor could potentially bargain away through the negotiation of change orders.

### *1.5.4 Mechanisms of Incentivization in BIM Procurement Systems*

BIM, as a coordination platform, is alleged to have two effects on the mitigation of the contracting problems outlined above. First, digitizing the design into a set of parametric 3D objects could reduce the incidence of misinterpretation of design information arising from human errors in the transfer process between parties. This inherently reduces the incidence of change orders, leaving the owner less exposed to holdup payments.

Second, the use of BIM could make it possible to incorporate the subcontractors' input into design at an earlier stage as well as facilitate the detection of clashes that would result in rework during construction, both of which also reduce the owner's exposure to changes. With this in mind, the fundamental question becomes why general or trade contractors would participate in BIM systems to the extent necessary to achieve the benefits espoused by its proponents?

To answer this question, one must first establish how contractor incentivization works in practice. A review of IPD practices illustrates that no matter what contractual arrangement the owner chooses for achieving integrated project delivery, the driving incentive is based upon a performance-linked payment scheme in which the cost is jointly established by IPD members and used as a benchmark in the determination of bonus pools in which all parties share.

### *1.5.5 Effectiveness of Incentive Mechanisms – Unsolved Questions*

The efficacy of this reward scheme rests on two preconditions: (a) that cost share is an unbiased measure of one non-owner IPD member's contribution and (b) payments are effectively linked to the chosen measure. Either of these two conditions failing to hold will lead to dysfunction of the performance system.

The first condition matters because the according to past studies, incentives actually motivate the wrong behaviour (Lawler, 1990, Kerr, 1975). The choice of performance metrics is therefore a crucial decision for the owner to make. The ensuing theoretical question is whether incentive would work best to induce contractor effort to achieve the owner's objectives. From a principal-agent perspective, the optimal strategy depends upon the observability of the agent's effort (Hölmstrom, 1979).

If allowed full observability, the principal can simply impose a forcing contract upon the agent to induce his best effort. However, in most cases where only the output of the agent is observable and contractible, the principal should tie the agent's pay to performance metrics so that risks can be efficiently shared. Ideally, the choice of metrics should satisfy the condition that "the marginal product of the agent's actions on the performance measure is highly correlated with the marginal product of these actions on the principal's objective" (Baker, 1992). Otherwise, the agent may unduly concentrate attention on the performance areas that pay is linked to at the expense of the areas that are important, but do not result in pay (Hölmstrom & Milgrom, 1991).

This multitasking agency problem would hinder the agent from performing as desired. The informativeness principle suggests that inclusion of a measure that the agent is unable to influence would effectively filter out the interference that may affect the agent's performance (Hölmstrom, 1979). As these principles are not directly applicable, efforts should be made to transform them into decision-making criteria in the form of attributes of the activities to be coordinated through BIM.

The second condition involves three problems. First is what weightings should be given to component metrics to secure the efficient allocation of the agent's effort (Feltham & Xie, 1994; Datar, Kulp, & Lambert, 2001). The second problem involves how to reliably aggregate performance information across different metrics (Banker & Datar, 1989) and avoid "performance padding" where the agent attempts to improve reported measures without increasing real output. The final problem entails how to avoid one party "free riding" on other parties' efforts (Alchian & Demsetz, 1972).

In summary, IPD is currently the only contractual incentive mechanism being utilized for BIM, and the project owner is the primary beneficiary of both practices

(Eastman et al., 2018). While all IPD agreements utilize some shared risk or reward to incentivize contractor participation (Kent & Becerik-Gerber, 2010), the question remains as to which mechanisms are the most effective and to what degree they drive contractor participation in BIM systems specifically. If the AEC industry is to ever realize the full benefits of BIM, the effectiveness of the various IPD arrangements' component incentives must be purposefully addressed and their follow-on effects quantitatively tested. Based on that knowledge, researchers can then recommend IPD methodologies that best incentivize BIM in various environments or establish whether there exist any novel incentive arrangements that could more effectively do so.

### *1.5.6 BIM and Integrated Project Delivery (IPD)*

The interrelationship between BIM and Integrated Project Delivery (IPD) is perhaps best encapsulated by AIA's Integrated Project Delivery Guide, which notes:

> It is understood that integrated project delivery and building information modelling (BIM) are different concepts—the first is a process and the second a tool. Certainly, integrated projects are done without BIM and BIM is used in non-integrated processes. However, the full potential benefits of both IPD and BIM are achieved only when they are used together. (p. 20).

Like BIM, the project owner is the primary beneficiary of IPD (Eastman et al., 2018), and while all IPD agreements utilize some shared risk or reward to incentivize contractor participation (Kent and Becerik-Gerber, 2010), the question remains as to which risk/reward mechanism is the most effective and to what degree they drive participation in BIM systems specifically. In one study, experienced respondents were asked to indicate what compensation method was used to incentivize collaboration on their specific IPD project. Results showed that 45.8% selected "based on value," which incentivizes the project team by offering a bonus linked to adding value to the project; 25.2% selected "incentive pool," which reserves a portion of the project team's fees into a pool that can increase or decrease based on various agreed upon criteria before being divided up and distributed; 17.8% selected "performance bonuses," which provides an award based on quality; 15.9% selected other; 13.1% selected "profit sharing," in which each party's profit is determined collectively rather than individually;

and 7.5% selected “innovation and outstanding performance,” in which the team is rewarded for hard work and creativity (Kent & Becerik-Gerber, 2010).

With the knowledge of what incentive vehicles are currently driving collaboration within IPD arrangements, the next logical step is to establish how each of these inducements fits into the overall IPD incentive to contribute to BIM as a project delivery environment. This chapter seeks to explicate the currently available IPD templates’ component incentives as catalysts for driving contractor participation in BIM systems. It is important to note here that the research does not restrict itself to incentives specifically identifying BIM, but rather addresses the follow-on effects of the broader (and ultimately more effectual) incentive structures inherent to the various IPD approaches. To this end, the three primary IPD strategies currently being utilized in industry are examined below. In keeping with the goals of the current research, the review focuses on the economics of the contracting environment with management processes addressed only insofar as they directly impact stakeholder earnings. Where appropriate, specific contract clauses are referenced in accordance with sample documents provided by the copyright owners. It must also be conceded that the limitations of utilizing existing IPD agreements represent parallel limitations to the dissertation itself since this nascent contracting strategy has few formal templates and their use is geographically disparate. That said, the goal is to study integrated project delivery as a key organizational factor for BIM adoption and implementation so this dissertation must utilize the only contractual forms available despite any inherent limitations resulting therefrom.

### 1.6. AIA A295 (Transitional IPD)

A295 is built on American Institute of Architects’ (AIA) “Construction Management at Risk” platform and is aimed more at the institution of IPD processes than altering risk allocation or creating incentives (O’Conner, 2009). By following traditional models of risk management and compensation, transitional IPD employs collaborative principles in a format that will be more familiar to users. The approach is designed for those stakeholders that may not yet be comfortable engaging in full project integration (AIA FAQ), and aims to provide a smooth transition from traditional design deliveries to a basic form of IPD (Ballobin, 2008). This transitional approach contains separate agreements for the owner/architect and owner/contractor, and is comprised of the following documents:

- A195-2008 – Standard Form of Agreement between Owner and Contractor for Integrate Project Delivery
- B195-2008 – Standard Form of Agreement between Owner and Architect for Integrated Project Delivery
- A295-2008 – General Conditions of the Agreement for Integrated Project Delivery
- E201-2008 – Building Information Modelling Protocol Exhibit

These documents collectively detail the contractor's duties and obligations for each of the six project phases: conceptualization, criteria design, detailed design, implementation documents, construction, and closeout (A295, 1.1), while simultaneously outlining the duties and obligations of the owner and architect and stipulating how they are to work together throughout each project phase (Kenig et al., 2010). During design, the contractor provides "pre-GMP" (guaranteed maximum price) services to include advising the owner/architect on issues such as site use, material selection, building systems and equipment, as well as providing recommendations on constructability and factors related to construction cost (A295, 4.2.1). The contractor also provides increasingly detailed estimating services as the architect progresses in the preparation of the design and implementation documents during the design phases (A295, 4.2.3). These contractor pre-GMP services are compensated through an initial payment upon contract execution and subsequent monthly payments invoiced by the contractor (A195, 5.1). At the conclusion of the detailed design phase, the owner and contractor negotiate a guaranteed maximum price and the contractor is thereafter required to construct the project in accordance with the GMP documents.

One item of note is that because constructability reviews are performed during design, there are likely to be fewer RFI's and change orders (Ballobin, 2008), resulting in the loss of a significant revenue stream for the contractor in traditional procurement models. The contractor's early involvement is furthermore likely to require additional design insurance protection and the contractor inherently loses its protection under the Spearin Doctrine (Ballobin, 2008), a landmark 1918 American Supreme Court decision determining that a contractor is not liable for loss or damage resulting from defective plans or specifications provided by the project owner. Such real and perceived increases in contractor cost/risk should, in theory, be built into its GMP.

The method of formation for the GMP is central to the current research. As noted above, the contractor is responsible for developing a progressively detailed estimate in concert with the architect which is ultimately submitted to the owner at the conclusion of the detailed design phase. If accepted, the contractor then prepares a guaranteed maximum price proposal for the owner's review (A295, 7.6) and incorporation as an amendment to the owner-contractor agreement (A295, 7.10). Once this amendment has been signed, it serves as a guarantee by the contractor that the sum will not exceed the GMP (A295, 1.3.7) with the exception of adjustments resulting from change orders or construction change directives (A295, 9.21). If the cost of work exceeds the GMP, the contractor bears such costs without reimbursement or additional compensation from the owner (A195, 4.2.2).

AIA's transitional IPD does not contain any formal incentive programs. While the GMP amendment does contain a note to insert specific provisions if the contractor is to participate in any savings that occur when the contract sum is less than the GMP (A195, A.1.1.1), this choice would be solely up to the owner and the rest of the project participants would receive no incentive compensation (Ballobin, 2008). With respect to Building Information Modelling, while there is no explicit financial incentive, A295 does require the utilization of BIM to the greatest extent possible (A295, 1.1). In order to facilitate its use, the owner, architect, and contractor are required to meet and delineate the types of software to be used on the project and establish protocols, standards, and tolerances as may be required (A295, 1.5.2). Such determinations are set forth in AIA E201, which establishes the protocols, expected levels of development, and authorized uses of BIM on the project and assigns specific responsibilities for the development of model elements at each project phase (E201, 1.1). Under the transitional IPD agreement, the architect is responsible for the integration and coordination of the models throughout the design and construction of the project (A295, 1.5.1).

In addition to the contract structure and methodologies outlined above, construction bloggers Caldwell and Solomon identify several distinguishing features of transitional IPD pertinent to the current research:

- There is no "all for one and one for all" or "best for project" reward/risk sharing.
- Transitional IPD does not require the establishment of project goals, target costs, reliable commitments, quality plans, project planning system, or construction quality plans.
- By participating in pre-construction, the contractor gives up the implied warranty of fitness of the plans/specs as a basis for increasing its GMP (Collaborative Construction Blog, 2008).

### 1.7. AIA C195 (Full Integration)

C195 is a complete IPD form built on a target cost approach that covers risk sharing, claim suppression and incentive provisions (O’Conner, 2009). Of the three IPD agreements reviewed here, this fully integrated approach will appear the most dissimilar from traditional design and construction contracts. Full integration makes use of a single purpose entity (SPE) agreement in which the owner, architect, construction manager, and other key project participants become members of a limited liability company (LLC) whose sole purpose is to design and construct a project (C195 Instructions). Such an approach allows for the complete sharing of risk and reward in an “all for one and one for all” environment, eschewing the compensation and profit models inherent to the traditional methods of project delivery and substituting them with a wholly unique incentive structure (AIA FAQ).

Under full integration, the SPE does not own any real property, but instead builds a project through construction agreements it enters into directly with general and trade contractors (C195 Instructions). The owner, architect, and construction manager are the initial members of the SPE, referred to as "Company" in contract documents (C195, p. 1), with additional members added to the SPE as necessary. At the conclusion of the project, the members ultimately share in profits or losses in accordance with the target cost and their respective percentage interests in the SPE as outlined in C195 Article 4.1. This fully integrated IPD approach is comprised of the following AIA documents:

- C195-2008 – Standard Form Single Purpose Entity Agreement for Integrated Project Delivery
- C196-2008 – Standard Form of Agreement Between Single Purpose Entity and Owner for Integrated Project Delivery
- C197-2008 - Standard Form of Agreement Between Single Purpose Entity and Non-Owner Member for Integrated Project Delivery
- C199-2010 – Standard Form of Agreement Between Single Purpose Entity and Contractor for Integrated Project Delivery
- E201-2008 – Building Information Modelling Protocol Exhibit

C195 provides the framework for the collaborative environment in which the SPE operates (C195 Instructions), while the remaining agreements establish the contractual relationships of the SPE with its various members. For project funding, the SPE utilizes C196 to enter into an agreement with the owner while entering separate C197 agreements with the architect, construction manager, and other non-owner members, and C199 agreements with non-member consultants and contractors. Each SPE member contributes to the capital of the SPE in an amount detailed in C195 4.1.1, in exchange for which the member receives their respective percentage interests in the company. C195 stipulates that no member may receive any salary or draw with respect to its capital contributions in its capacity as a member of the SPE (C195, 4.2.3). Instead, the architect, construction manager, and other non-owner members are reimbursed only for their direct (C197 6.1.1.1) and indirect costs (C197, 8).

Profits can then be earned in two ways: achievement of goals during the course of the project through “Goal Achievement Compensation” (C197, 6.3) and shared cost savings at the end of the project through “Incentive Compensation” (C197, 6.2). The company pays Goal Achievement Compensation to non-owner members if (and only if) the respective goals outlined in Article CC.2 of the Target Cost Amendment are met. Failure to achieve any particular goal results in the forfeiture of the respective compensation for all non-owner members regardless of who is at fault. Similarly, failure to design and construct the project for a total cost less than the target cost results in forfeiture of any Incentive Compensation for all non-owner members (C195 Instructions). It should also be noted that if the actual costs for the project exceed the target cost, the SPE is not obligated to reimburse members for direct and indirect cost overages; instead, the members must continue to perform the services without reimbursement (C197, 6.1.2).

The process for formulating the target cost begins with the SPE members jointly developing a project definition, which at a minimum includes the program, site information, regulatory information, identification of contractors and consultants, the project criteria, and the project criteria design (C195, 5.2.1). In consultation with the owner and architect, the construction manager is then primarily responsible for developing the target cost proposal to be presented by the conclusion of the criteria design phase (C195, 5.2.1). This proposal must clearly identify all of the fees and contingency amounts necessary for the owner to make a proper evaluation (C195, 5.1.3), and then incorporated as the Target Cost Amendment if accepted by the owner (C195, 5.5). The target cost is then set and cannot be adjusted without the unanimous consent of the SPE members (C195, 5.6).

With regards to BIM, C195 shifts the design work to earlier in the project lifecycle by generally requiring the use of BIM during pre-construction (C195, D.3.1) and specifically requiring the use of BIM models as contract documents in the SPE’s agreements with construction contractors to the fullest extent practicable (C195, D.3.2). Like A295, C195 requires that digital information be exchanged in accordance with AIA E201 (or similar) document to be attached to the Target Cost Amendment (C195, D.3.4). Once again, no explicit BIM incentive program exists, but the researcher contends that there exists within the full integration model a powerful incentive vehicle in making the success of the project’s individual stakeholders dependent upon that of the project as a whole, thus, negating issues of principal-agent relationships and the moral hazards of competing interests in traditional project hierarchies.

### 1.8. ConsensusDOCS 300 Series (Economic Model)

The ConsensusDOCS 300 tri-party agreement was the first IPD standard for construction contracts (Perlberg, 2009). It continues to be used as a method of promoting both collaboration and lean project delivery (300, 3.2). Under this model, the owner, designer, and constructor all sign the same agreement, binding them to collaborate in the planning, design, development, and construction of the project. It is built on a target cost approach (300, 8) with a provision requiring that stakeholders allocate responsibility for costs above the target cost where an adjustment to the target cost is unavailable (300, 11). Savings in the form of actual costs less than the target cost are shared according to agreed-upon percentages (300, 11.4).

When the design is sufficiently complete, the owner, designer, and contractor collaboratively agree on a project target cost estimate (PTCE) (300, 8.3.1). This PTCE represents the sum of the owner's own project design and construction-related costs, the designer’s total costs, and the contractor’s “cost of work” including all contingencies, general conditions, and the contractor’s fee (300, 8.3). Upon agreement of the PTCE, the cost is incorporated as Amendment No. 1 (300, 8.3.6) and can only be increased under very specific circumstances outlined in 8.3.7. Should the actual costs of the project prove less than the incorporated target cost (termed “savings”), the parties share in these funds at pre-determined percentages (300, 11.4).

In the event that actual cost exceeds target cost (termed “losses”), then such costs are either borne by the owner or are also shared by the parties at pre-determined percentages (300, 11.5). If the parties elect to share losses, the agreement calls for the parties to decide whether the designer’s and constructor’s fees are at risk and whether the total amount of each fee represents their respective limit of liability for costs in excess of the target cost (O’Conner, 2009). This structure clearly evidences a target cost platform; however, Article 10.1 identifies additional compensation requirements for the contractor, including: (a) preconstruction services on a lump sum, actual cost or other basis, (b) direct and indirect cost of work in accordance with Article 17, and (c) the contractor's fee less any adjustments for changes, delays, or management of insured or uninsured losses.

CONCENSUSDOCS 300 exists as the only agreement that contemplates true incentives and downside risk sharing in the same agreement for all parties (Collaborative Construction Blog, 2008). However, because the incentive and risk sharing program is based on a target cost estimate set after the completion of all construction documents, the agreement takes a very traditional approach to pricing (Dal Gallo et al., 2009). This contrasts with the C195 approach which sets the target cost early in the project lifecycle, allowing the parties to work collaboratively to design the project to the target cost rather than taking a "wait and see approach" and attempting to bring the project within the owner's budget through value engineering (Dal Gallo et al., 2009). This also means that under CONCENSUSDOCS 300 the PTCE is developed with the input of trade contractors/suppliers, unlike in C195 where the target cost is developed like a baseline budget prior to trade contractor/supplier input (Collaborative Construction Blog, 2008).

Thus, while C195 and CONSENSUSDOCS300 both make use of target cost approaches, there are significant differences between the two strategies incentive-wise. For contractors, the participation in pre-construction also means that it may give up the implied warranty of fitness of the plans/specs (Collaborative Construction Blog, 2008), suffers the loss of its Spearin Doctrine protection, and may require additional design services insurance protection (Ballobin, 2008).

CONCENSUSDOCS 300 provides the option of establishing a BIM approach to design and construction in order to provide "continuous and immediate availability of reliable, integrated and coordinated design, scope, schedule and cost information" (300, 6.4). The processes and technologies necessary to fully utilize BIM are established within a BIM Addendum, which provides relevant BIM definitions (Article 2), responsibilities related to information management (Article 3), a BIM execution plan (Article 4), details of risk allocation (Article 5), and intellectual property rights (Article

6). While it is stipulated that all costs associated with a BIM approach must be approved by the management group (300, 17.2.16) and that all costs for the BIM information manager are to be borne by the owner (BIM Addendum, 3.1), CONSENSUSDOCS is otherwise silent on the economic basis and follow-on effects of BIM use. Under CONCENSUSDOCS 300, the pre-construction phases and duties of the parties (including those related to BIM) are not as detailed as within the AIA IPD agreements, and that the widely accepted project phases form the AIA Project Delivery Guide have not been adopted (Collaborative Construction Blog, 2008).

## 1.9. Awareness of IPD Models

BIM has in recent years been actively promoted by governments worldwide. Indeed, government mandates have been the primary means for diffusion for BIM to date. For instance, the recent outgrowth of BIM in the UK can be largely attributed to the government's target of having Level-2 BIM adopted in all central government sponsored projects (Eadie, Browne, & Odeyinka, 2013). Initially, this "top-down" drive for BIM implementation was built upon the early evidence of BIM benefits including cost savings (e.g., collision detection) or direct return on investment. However, such a drive could lose momentum after a large-scale implementation that lacks further evidential support (Migilinskas, Popov, & Juocevicius, 2013).

For a technology as transformative as BIM, it is necessary to evaluate its benefits from the perspective of the overarching AEC industry's long-term development. This section brings to light a hitherto unexplored benefit from the widespread application of BIM as a result of government mandate: its ability to increase BIM users' awareness of the significance of integrated delivery models which can, in turn, precipitate the acceptance of these models (and BIM) moving forward. This cause-effect relation evinces that the enabling function of BIM does not only result in quantitative changes (e.g., steady improvements in cost) to projects, but also qualitative changes (e.g., greater employment of integrated delivery systems) to the industry at large.

IPD aims to improve project outcomes through a collaborative approach of aligning the incentives and goals of the project team via shared risk and reward, contractor early involvement, and a multiparty agreement. Since both BIM and IPD compel a dramatic increase in information sharing, these concepts have become intertwined (Eastman et al., 2018), with some authors claiming that IPD is pivotal to BIM implementation (Sebastian, Haak, & Vos, 2009). This view provides a central piece of evidence to understand the reinforcement effect of BIM on the evolution of integrated delivery environments. Like the S-curve trajectory in the development of other technologies, the diffusion of BIM has an uphill climb during the early stages.

Without strong driving forces, this “gravity” cannot be easily surmounted, leading to the slow diffusion of BIM. As is well known in physics, the force required to move a still object (static friction) is much higher than that necessary to maintain the speed of a moving object (kinetic friction). This illustrates why a growing number of governments opted for a powerful (and unilateral) tool such as a policy mandate to set in motion large-scale BIM implementation in hopes that its diffusion would be self-sustaining thereafter. Following such mandated implementations, resistance could primarily stem from BIM participants in circumstances where their interests are not aligned. Thus, the application of incentivization measures could help propel BIM participation.

However, these measures could reach a limitation if not embedded within an integrated delivery system. As the implementation of incentivization and delivery systems involve steep learning curves for all parties involved, according to the Technology Acceptance Model, user resistance could become a major hindrance to the realization of BIM’s full potential. The main intellectual contribution lies in the discovery of a set of statistically robust results to demonstrate that the compulsory adoption of BIM could lead to a cycle in which the experience of using BIM translates into the momentum for ushering in a desirable BIM delivery environment (i.e. IPD).

From May 2015, the Chinese government published a series of national standards for utilizing BIM and regulations related to BIM implementation. In July of 2014, PRC’s Department of Housing Construction issued the *Suggestion for Advancing Construction Reform and Development* (as cited in Ni & Wang, 2015), which requires promoting the use of information technology in the entire project lifecycle. This document also indicated that by the end of 2020, the ratio of projects using BIM in medium and large public building projects, public green building projects, and green demonstration housing projects must achieve at least 90 percent. The reason for such policy is that the overall adoption rate of BIM in China has been considerably lower than that of more developed countries (as cited in Cao et al., 2015).

Furthermore, some studies found that the use of BIM in China to date is still limited principally to visualization (Tan, Chen, Xue, & Lu, 2019; Xu & Kong, 2016), although the situation is changing rapidly (Zhou, Yang, & Yang, 2019). With the strong drive from the PRC's central government, it can be expected that BIM will proliferate fast in the Chinese AEC industry. In view of the predominance of the traditional design-bid-build delivery system in China, it is likely that Chinese BIM users will soon come to realize that BIM cannot achieve its full benefit in improving project coordination without introducing collaborative delivery systems.

This reasoning is strongly supported by the findings of the empirical study by Chang, Pan and Howard (2017). In particular, the authors demonstrated that BIM's degree of implementation can have a significant positive effect on the acceptability of IPD in the future via increased perception of the need for supply chain incentivization and improved communication quality enabled by BIM. Using structural equation modelling, Chang et al. analysed survey returns from 145 Chinese BIM-enabled projects and based on the results of statistical analyses found that the acceptance of IPD features actually increases with the use of BIM applications through two channels: (a) via the improved awareness of incentivization being a crucial element in governing BIM-enabled projects; and (b) by improved communication quality affected by BIM.

The researchers also found that the vast majority of projects have reached Level 1 (42.8%) and Level 2 (43.4%) of BIM implementation, while "Level 3 BIM features are not utilized yet" (Chang et al., 2017; p. 04017052). These findings are consistent with the conclusions of Tan et al. (2019), Xu & Kong (2016) and Chang & Howard (2014). The researchers further pointed out that past studies were focused on the examination of immediate, short-term benefits of BIM adoption (e.g., cost savings, streamlining of project life cycle, etc.), which are easily understood by organizational decision-makers. In contrast, Chang et al. drew attention to the fact that their evidence underlined the importance of the long-term qualitative changes BIM could bring about to the AEC industry. Chang et al. (2017) further asserted that their study had demonstrated that “the increasing use of BIM can considerably raise practitioners’ acceptance of the major IPD features, which should then translate into support for implementing this system in the future” (p. 04017053). Another important conclusion is that BIM is an enabling tool but “the realization of BIM’s full potential depends on the readiness of all parties concerned” (p. 04017053). Discussing the long-term benefits of BIM adoption, the researchers further pointed out that “the benefit of BIM can grow exponentially as its application grows broader (more lifecycle stages), deeper (levels of BIM) and more diverse (variety of analysis supported by BIM)” (p. 04017053). As a corollary, Chang et al. concluded that fragmented application of BIM can only realize a small fraction of its potential.

These findings are directly relevant to the topic of this dissertation in two important aspects. First, it has become an official practice that regulatory measures should be subject to a risk-based assessment by weighing up regulatory risks against the attendant benefits (Löfstedt, 2004), but such risk-based assessment should have a long-term rather than immediate perspective, which in turn should be properly accounted for in any integrated models of BIM acceptance and implementation. Second, the results of the study open a new frontier for BIM research as BIM’s spill-over effect onto IPD acceptance could themselves be as significant as the BIM benefits already reported within literature. Addressing this fact can be a first step in developing a comprehensive life-cycle model of BIM diffusion.

### 1.10. Synthesis of Pertinent BIM Issues

The following sections present the summative review of key issues related to the BIM adoption problem by discussing unique characteristics and benefits of BIM as a technological innovation. The summative review also includes the discussion of the broad themes identified in the extant literature on the topic of BIM.

### *1.10.1. BIM as a Technological Innovation*

***Definition***. The most commonly accepted definition of Building Information Modelling is offered by the National Institute of Building Sciences. The NIBS define Building Information Modelling (BIM) as a cutting-edge digital technology tool used to establish a computable representation of all the physical and functional characteristics of a facility and its related project/lifecycle information. BIM is intended to work as a comprehensive repository of all relevant information for the facility owner or operator to use and maintain throughout the lifecycle of a facility.

***History***. BIM has its roots in the early 1980s, when architects started using *PC-based CAD*. By the late 1980s a large proportion of construction documentations and shop drawings were plotted from computers rather than manually. Steadily, CAD began to affect the process. Specifically, DWG files communicated information about a building through their layered structure. Originally designed to store only graphics and drive plotters, they now directly conveyed information about the building that would not appear in the plotted version of the file. The use of CAD evolved toward communicating information about a building in ways that a plotted drawing could not.

This technology further evolved in the early 1990s with the advent of *object-oriented CAD*. In these new systems, in addition to the building graphics, data objects also stored non-graphical data about a building in a logical structure. Object-oriented CAD systems typically supported geometrical modelling of the building in 3D, thereby automating many of the arduous drafting tasks. Forward-looking design firms eagerly embraced these tools, quickly realizing that the data in the object-oriented CAD files, if carefully structured and managed, could be successfully used to automate certain documentation tasks, including schedules and room numbering.

Concurrently, the Internet Revolution of the 1990's ushered a new era of digital data sharing that required digital representation of any information for all communication. This resulted in the transfer of CAD files that had been exchanged on floppy disks within the design team into digital FTP files for e-communication. The same forward-looking design firms who incorporated CAD into their organizational practices started sharing and delivering their documents to clients digitally. They also began investigating the feasibility of developing effective and reliable digital technology tools for web-based project management and team collaboration.

However, *object-oriented CAD* systems were rooted in building graphics, built upon graphics-based CAD foundations, and were therefore not optimized for creating and managing information about a building. Other industries have realized great benefit from non-graphical, parametric information technology tools. This led to the next generation of software solutions: purpose-built, end-user friendly, and fully utilizing the benefits of IT for the AEC industry. *BIM* represents such next generation, information-centric software.

By storing and managing building information as databases, *BIM tools* can capture, manage, and present data in ways that are appropriate for the building team member using that data. Because the information is stored as a database, changes in that data that so occur during design can be logically promulgated and managed by the software throughout the project life cycle.

*BIM tools* move the management of relationships between building components beyond the object-level information in object-oriented CADs, which allows information about design intent to be captured in the design process. The building information model contains not only a list of building components and locations, but also the relationships between those objects. These relationships, implicitly understood by the designer, become explicit when the building is described within a building information model.

Additionally, these relationships can be inferred by the building information modeller as the user works, or explicitly entered as work progresses. These relationships then allow for changes to the building information model to be managed by the software consistent with the design principles and intent for the project. The richness of the relationships embedded within building components themselves, as well as those embedded in the overall model, makes reuse of the data in other applications even more powerful and the design process significantly more efficient.

### *1.10.2. Unique Characteristics of BIM*

As a comprehensive strategy for the application of IT to the AEC industry, all BIM solutions share 3 unique characteristics:

1. They generate and operate on digital databases for collaboration.
2. They manage change throughout those databases so that a change to any part of the database is simultaneously coordinated in all other parts.
3. They retain and preserve information for reuse by other industry-specific applications.

The utilization of BIM solutions by AEC industry organizations results in (1) higher quality work, (2) significantly increased productivity, and (3) substantially lower costs for building industry organizations in the design, construction, and operation of buildings.

**Digital databases**. The distinctive characteristic of BIM solutions is that they create and operate on digital databases/repositories for collaboration. The AEC industry has traditionally illustrated building projects through drawings and added information such as notes and specifications. CAD technology automated that process, and object-oriented CAD extended the idea of adding information to illustrations and graphics into software. The result of earlier manual drafting, graphics CAD systems, and object-oriented CAD systems were identical: the creation of graphic abstractions of the intended building design.

The principles of BIM overhaul this process. BIM applications instead start with the idea of capturing and managing information about the building, and then present that information back as conventional illustrations. A BIM model captures building information at the moment of creation, then promptly stores, manages it within a building information database, and makes it available for use and reuse at every other point in the project. In this approach, drawings become a view into the database that describes the building itself.

In a BIM model, the building information is stored in a database instead of in a presentation format. The BIM model then presents information from the database for editing and review in presentation formats that are suitable and routine for the particular user. Although each user working on the construction project views the building information in the customary way, these presentations of the information (e.g., drawings, schedules, cost estimates, etc.) are all views into the same information model. In other words, while each discipline interacts with familiar and customary views of the information, BIM guarantees that changes made in any of these views are immediately and correctly reflected in all other presentations.

BIM models organize collaboration by the construction team through digital databases. The BIM model can be easily disseminated to individual team members working on a network or sharing files through project collaboration tools. Individual team members work independently on local data sets while the BIM solution manages changes to the model from each of these local databases in a central shared location/repository. In this environment, all team members can compare their work to synchronized work by other team members and dynamically reserve and release portions of the database for use over the entire network. A record of these interactions (e.g., originator of change, date of change, substance of change, etc.) is also available for review immediately, and a historical log of all changes made by all team members is stored in the BIM. Changes can be selectively rolled back to support examinations of options or changes in design.

### *1.10.3. Change Management*

Another unique characteristic of BIM tools is that they manage iterative change through a building’s design, construction, and operation. A change to any part of the database is instantaneously coordinated in all other parts. The process of building design and documentation is inherently iterative because the understanding of a design problem evolves during the design process. Managing this iterative change is an integral part of the design process. Technology tools and work processes that do not allow the design to be refined and reconsidered in an iterative way as the project develops discourage the best possible solutions to the design problem. BIM solutions are unique in this sense because they provide the tools for (a) the management of relationships within the data and (b) for change to that data.

Maintaining an internally consistent representation of the building as a database improves drawing coordination and reduces errors in the documents to the benefit of all building team members. Time and effort that would otherwise be spent in manual document checking and coordination can be redirected instead to the real work of making the building project better. The resulting documents are of higher quality, and as a result, the costs of changes and coordination are reduced. BIM tools enable the design, construction, and occupancy of the building to proceed with less friction and fewer difficulties than conventional tools.

Estimating, procurement, and construction are also iterative processes of definition and elaboration. Specific materials and products are selected from amongst the range of possibilities that meet the project specification. Selection, refinements, and substitutions may result in changes to some aspects of the design. Ambiguities in the design documents are resolved between the design and construction teams before the commencement of construction. The construction and design teams consider changes to improve constructability and value for the client. Each of these decisions requires evaluation and that new information be captured to support later evaluations as well as operation and management of the building. BIM solutions capture and manage this information and make it available to support the collaborative process.

BIM solutions also effectively support the iterative process of building operations post-completion. The conventional design and construction cycle typically end with the first occupancy of a building, but this event also heralds the start of another (far longer) cycle: an evolving occupancy of the building, together with maintenance requirements for the building materials, assemblies, and systems which result in frequent changes throughout the lifecycle of the facility. To address these post-completion needs, BIM supports the building lifecycle with solutions for the design and documentation of the continuing maintenance, renovation, and renewal of the building itself within the BIM model.

#### *1.10.4. Information Reuse*

Yet another exclusive characteristic of BIM solutions is how they approach information reuse. BIM solutions capture and preserve *information for reuse* by additional industry-specific applications. Effective information technology solutions outside the AEC industry are based on one main principle: data is captured once, as close to its point of origin as possible, and stored in a way that it is always easily available and can be presented within context as required. Conventional tools require all this data to be rederived at the point in the project where the information about building size or sections and schedules is required. BIM tools capture such data at the moment of creation, store them, and make them available for representation as information in other documents and artefacts, as needed. In contemporary construction projects, reuse of information is necessary for other applications used for energy analysis, structural analysis, cost reporting, facility management, etc. The persistence of the BIM solutions through the building design, procurement, construction, and operation supports the effective management of workflow and process around this information.

### *1.10.5. The Benefits of BIM*

As mentioned above, the use of BIM in the AEC industry is associated with (a) higher quality work, (b) significantly increased productivity, and (c) substantially lower costs throughout the entire project lifecycle. Although industry reports and extant academic studies overall support these claims, it is important to present a more detailed picture of how these benefits are actually realized.

***Higher quality work***. BIM solutions lead to higher quality work because they allow assessment and changes to the project at any time in the design or documentation process without burdening the design team with protracted re-coordination tasks. They also permit to dedicate more time for design and solving real architectural problems to the design team by minimizing indirect work such as stakeholder coordination and manual checking. By sharing common BIM tools, more experienced team members work alongside the production members of the project team through all phases of the project, providing close control over technical and detailed decisions about the execution of the design. In construction, the consequences of proposed or procured products can be studied and understood easily. The builder can quickly and easily prepare plans showing site utilization or renovation phasing for the owner, communicating and minimizing the impact of construction operations on the owner’s operations and personnel. The building owner uses BIM to improve quality in the management of the building. The BIM provides a digital record of building renovations and improves move planning and management.

***Significantly increased productivity***. With BIM solutions, the design and documentation of the building is performed synchronously instead of sequentially. Design thinking is captured at the point of creation and embedded into the documentation directly as work proceeds. Then, all deliverables for the design team are created dynamically while the design work is underway. When a change is made, all the consequences of that change are automatically coordinated through the project. All of this allows the design team to deliver better work faster as the production of key project deliverables require less time and effort so the project can progress faster. In the construction phase, a builder can use the BIM model to accelerate the quantification of the building for estimating and value engineering purposes. This same model can then be reused for revised estimates and planning. Thus, BIM accelerates the adaptation of standard building prototypes to site conditions for businesses such as retail that require similar buildings in many different locations.

***Substantially lower costs.*** Using BIM, design teams get more work done with fewer people and more cost savings. A smaller design team means lower costs and less chance for miscommunication. Because the documents are coordinated by the computer and are more complete, the cost of changes and coordination in construction administration is reduced drastically. The utilization of BIM makes budgeting and cost estimating easier, and cost information is available earlier and can be updated more frequently than with conventional tools. Utilization of BIM also allows elimination of costs due to changes that occur late in the design process. With better cost information available from BIM these kinds of late changes become less likely.

Likewise, the use of BIM also allows to spend less time and money on process and administration because document quality is higher and construction planning is better. More of the owner’s construction dollar goes into the building instead of administration and overhead in design and construction. BIM is also used to access and manage physical information about the building, as well as financially important data regarding leasable areas and rental income or departmental cost allocations. Access to this information improves both revenue and cost management in the operation of the building.

### *1.10.6. BIM Adoption Issues*

***Scope of BIM adoption***. Since its emergence in the market, BIM has progressed from novelty status to a central focus of Architecture, Engineering, and Construction (AEC) technology that encompasses all aspects of design, construction, and operations for the building environment. Because of its unique characteristics and obvious benefits, the share of AEC industry organizations utilizing BIM in the U.S. has gradually risen. However, the degree of BIM adoption and utilization varies widely.

Available evidence suggests that most of AEC industry organizations are still largely confined to Phase 0 or Phase I of BIM adoption and a large proportion of AEC industry stakeholders still employ CAD models exclusively. Very few construction projects rely on integrated and interoperable Phase 3 BIM systems. This pervasive limited participation may be a matter of economics and motivation. Findings of past research on the topic suggest that not all industry stakeholders were able to benefit from quality, productivity, and efficiency gains and cost savings associated with BIM adoption and use. Therefore, these stakeholders have less incentive to adopt BIM in the first place and then to utilize BIM to its full potential.

***Drivers of BIM adoption***. According to AEC industry reports, considerations of competitive advantage, process improvements, technological opportunity and institutional requirements generally drive the adoption and utilization of BIM. However, as empirical research suggests, these considerations are only as effective as their correlation to potential increases in profit, with monetary evidence being a strong driver for any technology adoption.

To explore this issue, some past studies used ROI as a proxy for the drivers of BIM adoption. They found that AEC industry organizations adopt BIM with the expectation of positive returns and typically realize a healthy ROI as a result of BIM adoption. They further found that when BIM delivers such positive returns, this increases the likelihood of scaling up BIM utilization, i.e. moving up in the range of phases of BIM adoption. However, past research also suggests that profit-maximization, productivity increases, and efficiency gains are not the only drivers of BIM adoption and other non-economic considerations may be at play.

***Barriers to BIM adoption*.** BIM is a complex IT tool that drastically alters the work processes for any AEC industry organization adopting it. Precisely because of this complex nature and the radical changes resulting from BIM adoption, the decision to transition to BIM must overcome serious barriers that reflect real as well as perceived risks. Such barriers generally fall into two broad categories:

1. Process barriers to the business processes; and
2. Technology barriers related to readiness and implementation.

The main process barriers to BIM adoption include: (a) various contractual matters catalysed by the departure from traditional hierarchies in favour of interrelationships, (b) issues of ownership of the final project model, (c) protection of rights of the creators and stakeholders, and finally (d) ambiguity of risk and liability concerns resulting from the blurring of input borders within the collaborative environment created by BIM.

The main technology barriers to BIM adoption include: (i) technology incongruence with specified tasks, (ii) integration issues with legacy technologies, (iii) disruption concerns, (iv) insufficient operational capacity of key personnel and need for training/retraining, (v) IT infrastructure reliability due to glitches and bugs, (vi) issues of interoperability with related IT systems, and finally (vii) vendor product selection/technology suitability.

### 1.11. Closing

With the primary issues, barriers, and benefits for BIM implementation identified within this chapter, the next step for the dissertation is to review the status of existing knowledge on these subjects within existing literature. Consequently, Chapter 2 provides a comprehensive review of literature regarding BIM specifically and the respective theoretical bases more generally.

# 2. Chapter 2: Literature Review

## 2.1. Objectives of the Review

With the introduction providing an overview of the issues at hand, this chapter presents and discusses the results of the comprehensive review of existing literature on these issues. The review was approached as a systematic, objective, evidence-based method for finding, analysing, and synthesizing the existing body of research on the topic of the Building Information Modelling (BIM), especially on its implementation and utilization in the AEC industry. The purpose of this literature review is to provide an exhaustive research synthesis that can give the most reliable cross-section of the newest research findings on the topic of the present study. The review seeks to achieve the following specific objectives:

1. To explore of the recent extant empirical research on BIM.
2. To identify existing knowledge gaps in the current understanding of how and why BIM has been used in the AEC industry, especially when it comes to the barriers and limitations to its adoption and use.
3. To measure the strength of available empirical evidence presented in the extant studies and analyses and the overall quality of the studies that investigated the issues related to the topic of this research.
4. To assess whether findings and conclusions regarding BIM are consistent across various studies and to evaluate possible weaknesses and inconsistencies in the evidence.
5. To provide justifications for the novelty of the current dissertation project.

## 2.2. Approach

The review utilized a comparative-aggregative thematic approach to extant literature on BIM (Booth, Papaioannou, & Sutton, 2016). A scoping exploration was the first step in the literature search sequence. Scoping exploration was a preliminary search that gave an indication of the current quantity and general quality of BIM studies. The exploration was performed on several internet repositories with purposive sampling from a range of areas related to the topic under study. The outcomes of the scoping search led to the identification of key search terms/identifiers for each specific repository and the creation of a list of promising databases for succeeding in-depth inquiry. Boolean logic was used to pool the key search terms for each concept within the search strategy. To isolate the most relevant sources, both adjacency and proximity operators and a boundary function were used, as needed.

The next step in the search sequence was the actual search which utilized stratified multiple terms internet syntax queries for digital peer-reviewed publications available both in user and open-source access using key search words (e.g., IPD, BIM, AEC, construction industry, performance management, visualization, automation, implementation, data management, etc.) and such scientific, engineering, and technology databases as NTIS, Scopus, Synthesis Digital Library of Engineering, ASCE Civil Engineering Database, and Google Scholar. Additional databases and search terms were included or excluded as necessary based on the query output. Several consecutive searches were performed and yielded over 380 relevant sources. Then, based on three exclusion criteria (Dane, 2017): (a) recency, (b) relevance to the research topic, and (c) quality of the empirical evidence, the vast majority of search results were rejected because they did not satisfy all three criteria at the same time.

In addition to the published construction engineering peer-reviewed studies, the search strategy also involved the search for grey literature on BIM. The grey literature contains “the information produced at all levels of government, academia, business, and various industries in electronic and print formats when publishing is not the primary activity of the producing body” (Booth et al., 2016, p. 114). Four relevant sources were identified and included in the current review. Then, all selected peer-reviewed publications and pertinent grey sources were analysed, and research findings were synthesized using critical assessment method.

### 2.3. Definition of BIM

The first step in any literature review on BIM requires specifically defining the term. While many definitions exist within extant literature, the most relevant to the current research comes from the National Institute of Building Sciences (2007), which defines BIM as:

> A Building Information Model utilizes cutting edge digital technology to establish a computable representation of all the physical and functional characteristics of a facility and its related project/lifecycle information and is intended to be a repository of information for the facility owner/operator to use and maintain throughout the life cycle of a facility.

The critical items are BIM's role as a central repository for information, and that it covers the entire lifecycle of a facility from its earliest conception up through its demolition. In this role, a BIM model allows the structure to be built virtually, thereby detecting clashes and informing upon optimal sequencing in a way that is simply not possible using paper-based representations. Where BIM truly shines, however, is in its augmentation of the 3D space with time as a fourth dimension and cost as a fifth. Therefore, BIM covers more than just geometry. It includes quantities and properties of building elements, cost estimates, material inventories and project schedules.

Whereas a traditional CAD drawing illustrates where an electrical contractor should install a light fixture, a fully developed BIM model will provide a reminder of that fixture's upcoming date of replacement, its energy costs per annum and provide a detailed scope of work for its installation. In this role BIM does not just present a new technology; rather, it represents a fundamental shift in how an entire industry interacts with its product and environment.

Predictably, since its emergence as a commercial tool in 2003, BIM has inspired a great deal of research (Autodesk, 2003). This can be explained by the fact that BIM represents both a practical application of information technology and a revolution in the construction process (Demian & Walters, 2014; Eastman et al., 2018; Succar, 2009; Zuppa et al., 2009). Given BIM's proved multi-domain technical and procedural strengths (Barlish & Sullivan, 2012), government and commercial stakeholders around the world have pursued proposals, plans, and protocols to promote the application of BIM to their various interests (Azhar, 2011).

In 2005, the U.S. General Services Administration (GSA) added BIM to the requirements for all of its architecture, engineering, and construction (AEC) projects beginning in 2006 (Silver, 2005, as cited in Goedert and Meadati, 2008). In 2008, the protocols of American Institute of Architects (AIA) Document AIA E202 were established to guide the use of BIM contractually. In 2009, the state of Wisconsin began requiring BIM on all large public projects (Golparvar-Fard, 2011).

In the U.K., with the establishment of the Client BIM Mobilization and Implementation Group in 2011, the government adopted a mandate for full collaborative 3D BIM for all government projects by 2016 (Cabinet Office, 2011). Also, the 2012 Government Construction Strategy plan indicated that collaborative BIM should be integrated into all centrally procured construction contracts by 2016 (Cabinet Office, 2012).

Similarly, in the reciprocal relationship between societal behaviour and theoretical development, the scale of academic research on BIM has shown dramatic growth in recent years. However, while voluminous, there has been criticism on the usefulness and breadth of such studies. The most comprehensive of these reviews was a 2018 *Analysis of Citation Networks in Building Information Modelling Research* published in the *Journal of Construction Engineering and Management* which found that despite the explosion of research interest in BIM, the “cumulative theoretical and practical value of this body of research remains vague” and the “alignment with current industry objectives and relevance to future global challenges remain unclear” (pp. 144). Figure 1 illustrates the number of BIM-related publications from 2003 to 2017 from that study categorized by document type. Upon review, one will note a stark increase in 2012 (coinciding with public BIM mandates) which then gradually plateaus.

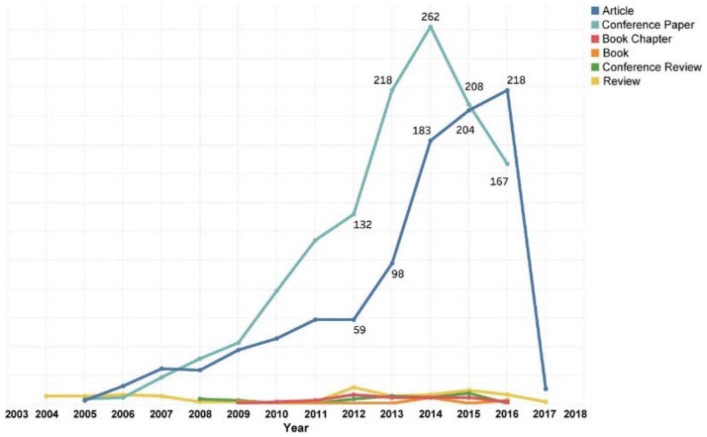


*Figure 1. Variation in the number of BIM Publications (Hosseini et al., 2018)*

### 2.4. Main Themes in the Literature

The review of academic and trade industry-based BIM publications, and examination of the results of comprehensive scientometric analyses of BIM centred research conducted by He, Wang, and Luo (2017) and Jin (2019), allowed to identify five main BIM research focus areas in the extant literature on the topic:

1. Evaluation of BIM conceptions, functions, and value.
2. Integrating BIM into the project life cycle.
3. Using BIM technologies in the visual and real environment.
4. Creating new BIM frameworks through technology improvement.
5. Analysis of BIM implementation issues.

It should also be noted that past BIM-related literature reviews have primarily focused on a single topic, for example, facility management (Rebekka, Julian, & Frank, 2014) or industry foundation classes (Laakso & Kiviniemi, 2012) rather than on the broader field of BIM. In contrast, Whyte's (2012) analysis provided a snapshot of BIM history over a wide range of BIM-related topics. However, Whyte's discussion fell short of being comprehensive because of a time limitation. In seeking to find a reason for the limited diffusion of collaborative BIM, it would be helpful to take a more holistic view of the technology and its various inputs, outputs, and issues. This literature review therefore covers a wide range of BIM studies. Specifically, it defines and reviews five main BIM research areas, discusses gaps in current knowledge, and provides justification for the novelty of this dissertation.

## 2.5. BIM Conceptions, Functions, and Value

Adoption of any new technology predictably raises two critical questions: why should one use it, and how should one use it? A closer look at the extant literature on the topic of BIM suggests that current research primarily focuses on the latter question. Extant research focused on the question of how one should use BIM, the basic conceptions of BIM, its functions, and the value it offers. This stream of scholarly and industry research branches into the following five dominant themes

1. Visualization.
2. Automation.
3. Information and data analysis.
4. Interoperability and collaboration.
5. Functions and value.

Users of BIM recognize its advantages in boosting productivity and achieving long-term benefits. Thus, it makes sense that stakeholders within construction project management would implement BIM to help them to reach their goals (Goedert & Meadati, 2008). The researcher identified approximately 90 academic and industry publications specifically focused on the advanced features of BIM. In these publications, researchers evaluated the character-based benefits of using BIM from both general and specific viewpoints.

Technically, as a revolutionary method to enhance traditional design, BIM's visualization functions include rendering, 3D presentations, and model walk-throughs (Becerik-Gerber & Rice, 2010) that bridge the communication gap between architect and owners (Shen et al., 2013) and decrease project risks with the improvement of design accuracy (Eastman et al., 2018). Automation also can help reduce mistakes and inconsistencies while improving project efficiency (Tang et al., 2011). Together, these advanced technologies result in better quality buildings at lower cost and reduced project duration (Eastman et al., 2018). As a modelling tool, BIM integrates the multidisciplinary participants in project management to optimise the organizational structure and efficiency (Azhar, Khalfan, & Maqsood, 2015; Bansal, 2011).

Hassan Ibrahim (2013) characterised BIM as having five main parts: visualisation, automation, transformation, coordination, and integration. Such typology encompasses the entire process of model creation and utilisation because visualisation occurs through a 3D model enriched with information, and ideally, users can automatically collect and exchange data throughout the project life cycle (Monteiro et al., 2014). Information and value transformation, as the core functions of BIM (Lee et al., 2006), provide the foundation of organizational coordination and process integration. By synthesizing all of the above capacities, BIM has proven useful in coping with the systemic inefficiencies in the AEC industry (Sacks & Pikas, 2013).

### *2.5.1. Visualization*

A significant number of studies of BIM technology have focused on (a) the technical functions of BIM, such as visualization, and (b) BIM-based derivations or integrations, such as geographic information systems (GIS) (Bansal, 2011; Irizarry & Karan, 2012; Paul & Borrmann, 2009). When applied to a construction product or process, computer-aided visualisation can:

1. Reflect project status.
2. Assist decision-makers to understand the workflow intuitively and to enhance the transparency of the project process (Sacks et al., 2009), substantially benefiting lean construction, including flow optimisation (Sacks et al., 2009, 2010) and energy savings (Wu & Chang, 2013).
3. Facilitate efficient defect management for FM, based on knowledge (Motamedi et al., 2014).
4. Enhance 4D modelling inclusive of time parameters (scheduling) to meet fast delivery requirements (Russell et al., 2009) and tackle workspace conflicts (Moon et al., 2014).

Moreover, researchers intend to expand BIM visualisation into other technologies; for instance, by integrating GIS to record geographic information (Elbeltagi & Dawood, 2011) and optimising it in on-site control (Irizarry & Karan, 2012). This integration uses sensor data to support understanding and communication and improve safety management (Arslan et al., 2014). BIM visualisation also introduces a new visual method into education (Yan et al., 2011; Peterson et al., 2011).

Visualisation comprises of virtual reality (VR) and augmented reality (AR). As a simulation tool, users mainly employ VR systems to facilitate communication, thus reducing professional barriers between designers and clients in the early design stage (Shen et al., 2013). For example, Xie et al. (2011) set up a BIM radio frequency identification framework (RFID) based on visual simulation to optimise project processes and support AEC professionals in decision-making during the erection progress. VR also plays a role as an experimental method, as seen with the Cave Automated Virtual Environment (CAVE) (Gurevich & Sacks, 2014).

As a technology to bridge the virtual world and the extant environment, AR can facilitate the performance of BIM and provide a platform allowing on-site managers and subcontractors to interact and share information effectively (Wang et al., 2013). Reflecting the effectiveness and usefulness of AR, Yeh et al. (2012) designed an ideal iHelmet based on AR and BIM to retrieve and share on-site information automatically. Meža et al. (2014) focused on the availability and usability of BIM information in the field in the context of component-based software engineering (CBSE). The AR+BIM prototype was also utilised to control on-site processes in the liquefied natural gas industry, helping to improve communication efficiency, reduce error, and retrieve information (Wang et al., 2014).

In quality management, AR-based defect management systems aid in proactive construction defect management (Park et al., 2013) and defect inspection of reinforced concrete work with image matching (Kwon et al., 2014). In addition to these site-specific activities, Jiao et al. (2013) developed AR+BIM integration into business social networking services to improve collaboration in the AEC field. Further, a multiscreen AR system can support discussions among construction project participants (Lin et al., 2014). Requirements for BIM tools will increase with the application of AR, especially for 4D BIM (Meža et al., 2014). Additional technical supports will be needed to realise fully integrated visualisation.

### *2.5.2. Automation*

Automation generally functions within information processing (Monteiro & Martins, 2013) rather than within information collection, because information collection is time-consuming and error-prone, and thus not well suited to automation (Tang et al., 2011; Vanlande et al., 2008; Welle et al., 2012). Yet, automation is crucial to the overall project life cycle as a control mechanism (El-Omari & Moselhi, 2011). In this regard, Fox and Hietanen (2007) indicated that with increasing automation, shared BIM repositories with concurrent access would eventually take the place of computer or paper file exchanges, which in turn would lead to lower cost and higher efficiency in document and information management. Apart from information extraction (Kim et al., 2013), BIM-based automation also propagates into information conversion, sharing, inspection, synchronisation, and maintenance, which can function in every phase of project management.

Various automated data-acquisition technologies (e.g., barcoding, RFID, 3D laser scanning, photogrammetry, multimedia, and pen-based computers, etc.) can be integrated to support project control and decision-making (El-Omari & Moselhi, 2011). However, these technologies do not possess BIM perceptions. To address the latter issue, Tang et al. (2011) and Xiong et al. (2013) proposed models that can be used to facilitate the information conversion from laser-scanned point clouds to as-built BIM. Fox and Hietanen (2007) explained that transforming data into BIM models automatically, from design to construction, was necessary so that stakeholders could share information contained in the models and bridge professional gaps. This automated data transformation would likely decrease the time wasted in communication and enhance efficiency in cooperation and coordination between multidisciplinary participants (Babič & Rebolj, 2016).

Automation also plays a significant role in design validation (Choi et al., 2013; Eastman et al., 2018; Jiang & Leicht, 2014; Lee et al., 2012; Monteiro & Martins, 2013;

Zhang et al., 2013), logistics management focusing on the integrative data between supply chain and site control (Said & El-Rayes, 2014), and progress measurement to control construction projects (El-Omari & Moselhi, 2011; Gelisen et al., 2014; Kim et al., 2013). Lu and Olofsson (2014) proposed a BIM-discrete event simulation (DES) framework to measure project progress. In addition, BIM can support automated integrated project delivery along with master guide specifications (MGS) and bill of quantity (BOQ) generation protocols (Monteiro et al., 2014). However, considering the decreasing labour demand caused by automation (Fox & Hietanen, 2007), Ibrahim (2013) noted that there may be a conflict between BIM's automation trajectory and the labour-intensive nature of the AEC industry.

As it follows from this stream of literature on BIM, the main functions of BIM technology occur within the reciprocal relationship, especially on the side of automated visualisation. Visual analytics combining automated analysis techniques with interactive visualisation will offer more accurate datasets (Becerik-Gerber & Rice, 2010; Motamedi et al., 2014) and help enhance effective communication to support decision-making to meet project goals more effectively (Kim et al., 2013).

### *2.5.3. Information and Data Analysis*

The AEC industry is evolving into an increasingly interactive information-sharing platform through the integration of digital IS such as BIM (Barlish & Sullivan, 2012). In this industrial environment, BIM can be a central database containing the information of geometry, spatial relationships, geographic information, quantities, and properties of building components (El-Omari & Moselhi, 2011) with various possible information outputs, depending on the users' intentions (Elbeltagi & Dawood, 2011; Goedert & Meadati, 2008; Demian & Walters, 2013).

Nevertheless, the core feature of BIM is the function that produces 3D images of the exterior project environment, including site conditions and the building itself (El-Omari & Moselhi, 2011). In this area, laser scanners are commonly used to collect the point-cloud data (the real on-site or existing data) to build the as-is model (Anil et al., 2013; Bosché, 2012; Bosché et al., 2014; Dore & Murphy, 2014; Lagüela et al., 2013;

Xiong et al., 2013), which is compared with the as-planned model or further used in dimensional control operations (Bosché & Guenet, 2014).

As a smart system, the ‘core enabler’ of BIM should be the capacity to generate valid and useful information consistently based on 3D models and actual information (Lee et al., 2006), for example, jobsite data. Additionally, as a comprehensive accumulation of information to a geometric model (Demian & Walters, 2013), BIM databases store a huge amount of data from different disciplines (El-Omari & Moselhi, 2011), which can be later used in project progress measurement (El-Omari & Moselhi, 2011) or in facilities management of existing buildings (Goedert & Meadati, 2008; Jung et al., 2014; Motamedi et al., 2014; Motawa & Almarshad, 2013).

However, Demian and Walters (2013) indicated that coordination of information exchanges, and in particular organizational collaboration, remains the critical factor needed to improve the efficiency of BIM-based information management. Management concerns include fostering accuracy, timeliness, and reliability (El-Omari & Moselhi, 2011). Thus, researchers have proposed formats such as design patterns based on Web BIM (Isikdag & Underwood, 2010; Isikdag, 2012), central repository (i.e., knowledge-based database) BIM (Fu et al., 2006; Nour, 2009; Motawa & Almarshad, 2013; Motamedi et al., 2014), or cloud BIM to enhance the collaboration of multidisciplinary stakeholders.

Specifically, Nour (2009) developed a central database to demonstrate how the information exchanges in AEC/FM fields, together with the conception of private workbenches, compares with traditional methods of information-sharing.  In turn, Motawa and Almarshad (2013) and Motamedi et al. (2014) mainly focused on knowledge-based BIM in maintenance.  Interestingly, all central database frameworks are established on IFC, a standard information system, which is shown to be deficient because it cannot provide lossless information (Monteiro & Martins, 2013; Redmond et al., 2012; Sacks et al., 2010). In addition, the various applications used in information handling make information-sharing difficult between applications (Jardim-Goncalves & Grilo, 2010).

Cloud BIM, defined as “the binding of heterogeneous applications through a central repository platform” (Redmond et al., 2012, p. 176), which is based on an open standard such as online or IFC, was proposed to boost the information synchronisation and exchange process (Chong et al., 2014; Curry et al., 2013; Du et al., 2014; Grilo & Jardim-Goncalves, 2011; Wu & Issa, 2012). Redmond et al. (2012) illustrated an overall view of cloud BIM in order to develop “an integrated process that would enable faster and cheaper information exchanges and best practices during collaborative work” (p.176). Further, a decision-making model developed by Chong et al. (2014) facilitated selection of appropriate cloud-computing applications to support communication and information flow in the project life cycle.

### *2.5.4. Interoperability and Collaboration*

From a holistic point of view, BIM is an integration of processes and systems developed for participants to use throughout construction projects’ lifecycles (Bryde et al., 2013; Dossick & Neff, 2010; Eastman et al., 2018; Lu et al., 2013; Vanlande et al., 2008). Some authors further posited that such important aspect as interoperability consists of technological and organizational dimensions (e.g., value position at the enterprise level) (Grilo & Jardim-Goncalves, 2010; Ibrahim, 2013).

***Technological interoperation***. As discussed earlier, BIM is a central database for multidisciplinary information creating, sharing, exchanging, reusing, and managing throughout the project life cycle (Goedert & Meadati, 2008; Isikdag et al., 2008; Singh et al., 2011). In this regard, Nederveen and Tolman (1992) contended that heterogeneous participants’ interests are the catalyst for multidisciplinary information integration within projects. BIM can integrate data to assist stakeholders in decision making. Users can integrate object-based data within BIM with time to generate a 4D model (Bansal, 2011; Golparvar-Fard et al., 2011). Such integration can aid progress management, for example, by adding cost parameters into 5D modelling to assist surveyors (Goedert & Meadati, 2008). Martins and Monteiro (2013) indicated that lossless information exchanges among all project participants should be the ideal BIM workflow, thus requiring seamless interoperability. Further, apart from the collaborative information, Grilo and Jardim-Goncalves (2010) stated that heterogeneous BIM applications and software tools should also meet interoperation requirements to reach conformance to some extent.

However, Benghi and Greenwood (2018) noted that as BIM have become more prevalent in the AEC, some of the practical problems of authoring and sharing models also became more evident, specifically, the issue of interoperability (p.27). Benghi and Greenwood (2018) further pointed out that (a) currently there exists a whole range of commercially available BIM software platforms that have specialised to suit the functional needs of their main users but these BIM platforms differ structurally and semantically, (b) the fully collaborative BIM presumes a single model, allowing the full integration of all aspects of the design and further, for the same information to be reused in the delivery and operation of the constructed facility, but (c) to do this effectively, secure and reliable exchange of data is essential, and thus (d) there is an industrywide need to achieve interoperability between multiple models and multiple tools that are used in the whole product lifecycle (p.28-29). To investigate the current degree of interoperability between multiple BIM models, Benghi and Greenwood (2018) focused on the issues of geometric interoperability for reusable BIM components across multiple platforms using IFCs and conducted a longitudinal interoperability test (p.30). The researchers created a simple test model representing significant types of geometry encountered in component libraries, which were then expressed in IFC files. Benghi and Greenwood found that (a) in 2012, 11 commonly used BIM tools showed a dramatic failure to process the geometries as intended, indicating that the authoring tools, whilst technically capable of supporting required component geometric representations, were constrained from doing so by their conversion interfaces with IFC geometries, yet (b) in 2017, improvements were observed though there were still significant processing failures that could result in serious errors; particularly in the case of the BIM library components imported into project design models (pp.49-50).

***Organizational interoperation***. As a facilitation tool, BIM’s core potential is in enhancing collaboration between project stakeholders (Demian & Walters, 2013). Academics and AEC industry practitioners have provided evidence illustrating the low efficiency caused by the fragmented nature of the construction industry (Said & El-Rayes, 2014; Demian & Walters, 2013; Rezgui et al., 2011; Vanlande et al., 2008). As shown in Figure 2, managers evaluate the value of BIM-based interoperation in the construction organization on various levels according to the different degrees of interaction amongst participants (Grilo & Jardim-Goncalves, 2010).

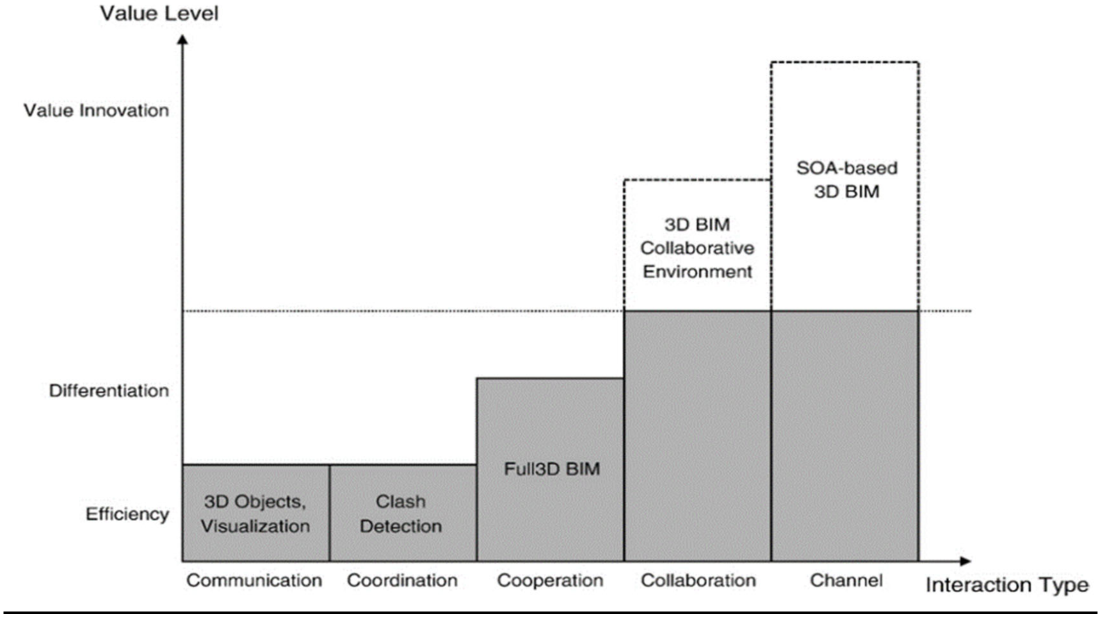


*Figure 2. Value Level of Interoperability for BIM*

Researchers also have evaluated specific BIM-based collaboration relationships and concluded that BIM applications facilitate a revolution in the design team by requiring interdisciplinary teamwork (Moum, 2010) and synchronous collaboration (Isikdag & Underwood, 2010). For example, Lee et al. (2014) compared mechanical, electrical, and plumbing (MEP) coordination strategies of parallel and sequential cascading based on BIM. Ku et al. (2008) identified the collaborative relationship between design and construction from the standpoint of architecture and indicated that this kind of integration can help reduce designers' workloads when sending information downstream.

In addition, through the use of BIM the position of participants in projects also changes. Service-oriented architecture in particular (Isikdag, 2012) can provide information more efficiently when coordinating with other participants in procurement

(Grilo & Jardim-Goncalves, 2011), construction, and facility management (Vanlande et al., 2008). The increasingly important role of project managers is improving collaboration between stakeholders, reducing time wasted, and optimising project outcomes (Bryde et al., 2013).

Fox and Hietanen (2007) suggested that inter-organizational applications of BIM can generally achieve different effects in the construction industry, including “automation effects, informational effects and/or transformational effects” (p.295). However, the different BIM capacities of organizations may lead to divergent outcomes; thus, evaluation of BIM performance remains important (p.297).

### *2.5.5. Functions, Value, and Performance*

Findings of some studies suggested that BIM application can influence the construction project throughout all phases of the construction process (Becerik-Gerber & Rice, 2010; Eadie et al., 2013; Leicht & Messner, 2008). Many studies have focused on evaluating the functions and value of BIM in general or in specific domains, and researchers have looked at aspects of BIM from a wide range of viewpoints.

With reference to the holistic evaluation, Jung and Joo (2011) proposed a framework, stating that “practical BIM implementation effectively incorporates BIM technologies in terms of property, relation, standards, and utilisation across different construction business functions throughout project, organization, and industry perspectives” (p.127). Their conception provided a relatively complete view of the BIM-related issues in the AEC industry. In turn, Barlish and Sullivan (2012) developed a methodology to measure BIM benefits based on cases. Succar et al. (2013) followed up with a study on individual competencies in order to further assess BIM. Bryde et al. (2013) tested the beneficial degree of BIM utilised in construction projects.

Others have conducted further measurement of BIM performance primarily in the contexts of specific regions, economical implementation, and specific functions of BIM. Economically, as an innovative technology in construction, Love et al. (2014) established a framework to help asset owners measure the return on investment of BIM, based on prior research conducted in 2013. Becerik-Gerber and Rice (2010) presented an overview of a BIM implementation cost distribution among users. Love

(2013) justified BIM’s advantages to asset owners, referring to different users with distinct interests in different construction stages.

BIM also performs well for MEP contractors (Hanna et al., 2013; Leite et al., 2011). Becerik-Gerber et al. (2011) explored the beneficial functions of BIM in facility management. BIM also has shown specific value in infrastructure projects (Hassan Ibrahim, 2013) and healthcare facilities (Khanzode et al., 2008; Lucas et al., 2013; Manning & Messner, 2008). Regarding the given activities in construction processes, Suermann and Issa (2009) evaluated BIM performance through data collection. Lu et al. (2013) measured the significant value of BIM as an on-site learning tool. Farr et al. (2014) established the superior function of BIM for construction customisation.

## 2.6. Integrating BIM into the Project Lifecycle

With the proliferation of BIM, its use has expanded into more comprehensive applications (Jung & Joo, 2011), most likely due to the direct influence stemming from its conceptual characters (Chan, Ma, Yi, Zhou, & Xiong, 2018). The utilisation condition of BIM comprises two levels: (a) project process in the project life cycle and (b) path analyses (Eadie, Browne, & Odeyinka, 2013).

### *2.6.1. Project Process*

According to Vanlande et al. (2008), the project life cycle divides roughly into three large areas: design, construction, and maintenance. It is obvious that in the project life cycle, the phases of design and construction apply more BIM processes than do maintenance and facility management (Hassan Ibrahim, 2013; Ma, Xiong, Olawumi, Dong, & Chan, 2018). However, the maintenance has been showing an upward trend in recent years (Rebekka et al., 2014).

### *2.6.2. Project Design*

BIM application in design occurs during two stages: the conceptual stage and the detailed design process. Manning and Messner (2008) and Kaner et al. (2008) identified the advantages of using BIM in the early conceptual stage, including design improvement, simplified communication across project teams, better decision support, and enhancement of labour productivity. Some researchers then grouped these advantages into two clusters: improving communication and offering decision support (Fountain & Langar, 2018), while others developed a user preoccupancy evaluation method (UPOEM) to enable designer–client communication and promote collaborative work at the early design stage (Shen et al., 2013).

To aid decision-making at the conceptual stage, some researchers proposed another schema as an IFC supplement to the process of multidisciplinary information exchanges (Redmond et al., 2012). Developers created more specific applications, including cost estimation and sustainability design, based on BIM-style information. Cheung et al. (2012) introduced a method of early-stage multilevel cost estimation. Lawrence et al. (2014) added flexibility to cost estimation to provide cost data based on the incomplete design. In terms of sustainability. Others produced a prototype to integrate energy assessment into early design (Schlueter & Thesseling, 2009), and life cycle assessment supported early sustainable design (Basbagill et al., 2014).

Second, as a process enriched by a vast amount of specialist knowledge and information (Gray & Hughes, 2001, as cited in Moum, 2010; Thompson & Bank, 2010), BIM has shown a radical change in design process methodology compared to traditional computer-aided design (CAD) (Ma et al., 2011). In terms of information management, BIM can enable the optimisation of multidisciplinary design (Delhi, V., & Singh, 2019). Moum (2010) explored 3D model-based interdisciplinary application in solving real-life problems in architectural design processes, along with others which included specific application of daylight simulation (Kota et al., 2014; Welle et al., 2012). However, to guarantee the efficiency of information delivery and to test the information exchange, it is necessary to standardise the information-sharing model (Berard & Karlshoej, 2012; Jeong et al., 2009; Plume & Mitchell, 2007).

Design validation also represents a significant use of BIM. Lee et al. (2012) analysed the economic effects of design validation. Accurate multidisciplinary information is the foundation of decision-making, together with the knowledge produced from design negotiations (Sidawi & Hamza, 2012). Schade et al. (2011) proposed a performance-based decision-making framework to support the structure design process. With such a framework, collaborative design based on complex information exchanges can be realised through synchronous collaboration (Isikdag & Underwood, 2010) and asynchronous online collaboration (Chen & Hou, 2014).

Because of the complexity of professional information, BIM-based engineering integration is in a critical position. BIM-based engineering integration consists of structural BIM, MEP system design, and evacuation simulation such as fire safety (Isikdag et al., 2008; Li et al., 2014; Rüppel & Schatz, 2011). Research on structural BIM covers high-rise building structures (Lee et al., 2012; Sacks et al., 2010), complex steel structures (Case et al., 2014) and other detailed problems, including precast concrete design produced by midsized structural engineering firms (Kaner et al., 2008), minimisation of the waste rate of structural reinforcement (Porwal & Hewage, 2012), and infrastructure security design (Porter et al., 2014).

Recently, smart-BIM has been introduced to satisfy the requirements of user-centred design (Heidari et al., 2014) generated from multidisciplinary information (Singh et al., 2011); Wikberg et al. (2014) linked customisation with construction industrialisation. Thus, smart-BIM may provide a rich new research direction.

### *2.6.3. Procurement and Construction*

Procurement in the construction industry divides mainly into supply chain-based e-procurement and project delivery procurement (Ajam et al., 2010). The latter includes BIM-related e-procurement challenges in the AEC industry (Fountain & Langar, 2018; Grilo and Jardim-Goncalves, 2011), the status of IFC application in tendering in China (Ma et al., 2011), and public procurement based on BIM partnering (Porwal & Hewage, 2013). Additionally, construction control plays a fundamental role in successful project delivery and goal achievement (Elbeltagi & Dawood, 2011). Topics in this area mainly focus on three BIM application areas: site control (including safety), supply chain, and MEP, all of which integrate closely with design, especially when supported by BIM. The main activities in site control incorporate process flow management and safety management (Zhang, Teizer, & Lee, 2013). For example, site BIM facilitates mobile on-site access to information, including design, quality, and process management, which are further optimised by augmented reality (Kwon et al., 2014; Meža et al., 2014; Wang et al., 2014). Regarding space limitations in the field, BIM-based workspace plans are necessary to rehearse activity execution workspaces (Chavada et al., 2012; Moon et al., 2014). For the spatial features of activities (Choi et al., 2014), BIM can facilitate planning temporary structures such as scaffolding (Kim et al., 2014) and tower cranes (Lee et al., 2012).

Finally, past research demonstrated that BIM can be useful for complete site control as key to safety. Various technologies, including 4D models (Bansal, 2011; Zhang & Hu, 2011), GIS (Bansal, 2011) and sensors such as RFID (Arslan et al., 2014) are integrated with BIM to analyse, plan, check, and manage construction workers' safety. Specifically, BIM-based automatic safety checking is also effective in safety planning and design (Zhang et al., 2013; Melzner et al., 2013).

BIM use in the material supply chain has mainly concentrated on the merging of product data with the BIM system (Nour, 2010). After researchers identified the requirements of the BIM platform for supply chain management, especially for concrete reinforcement (Aram et al., 2013), they developed specific applications, including integration of BIM and GIS to track supply-chain status (Irizarry et al., 2013) and match material names with building energy analysis (BEA; Kim et al., 2013). Said and El-Rayes (2014) proposed an automated multi-objective construction logistics optimisation system (AMCLOS) to assist contractors in managing the supply chain. Additionally, temporary organizational structures based on product information help to optimise BIM performance (Brewer & Gajendram, 2012).

In terms of MEP systems, Khanzode et al. (2008) analysed the pros and cons of BIM application in MEP, and Hanna et al. (2013) introduced the utilisation status of BIM in MEP. MEP is a reference for companies to direct the allocation of resources and adaption to BIM. Dossick and Neff (2010) emphasised the organizational importance of individual leadership in BIM-based MEP coordination; Lee et al. (2014) compared parallel and sequential cascading MEP coordination strategies. In terms of information management, Leite et al. (2011) illustrated BIM-induced advantages of automatic clash detection processes in MEP design coordination, and Bosché et al. (2014) integrated scan-to-BIM and scan-vs-BIM to track construction processes.

### *2.6.4. Maintenance and Facility Management*

Facilities management (FM) comprises multidisciplinary activities involving the processing of large quantities of information (Becerik-Gerber et al., 2011). Thus, document management is one of the main BIM applications in project maintenance, planning, and decision- making (Goedert & Meadati, 2008; Motamedi et al., 2014). Because using BIM alone is not adequate to collect and update complicated data and accommodate the various process documents for existing buildings (Rebekka et al., 2014), Jung et al. (2014) proposed a semiautomatic methodology to enhance productivity of as-built BIM creation, especially for complex indoor structures. Further, knowledge-based BIM systems are effective for enhancing BIM performance (Motawa & Almarshad, 2013) and can be applied to identify failure cause and effect patterns to generate suggestions for preventive maintenance plans (Motamedi et al., 2014). These plans can be enhanced by open BIM integrated with IFC and product life-cycle support (PLCS) for long-term FM strategies (Hallberg & Tarandi, 2011).

### *2.6.5. Cost Control*

The basic utilisation of BIM within cost estimation is the automated quantity take-off and automatic update to cost caused by design changes (Hartmann et al., 2012). Practically, quantity take-offs can be used throughout the project life cycle (Monteiro & Martins, 2013) to support the management team’s decisions (El-Omari & Moselhi, 2011) in virtually every construction process. Specifically, Popov et al. (2010) indicated that integrated 5D models enable the effective comparison of alternatives through calculations of resources demanded in each phase.

With regards to the revenue of contractors, accurate evaluation of project quantity is decisive (Monteiro & Martins, 2013). Thus, detailed estimations based on BIM perform more effectively than traditional tools, especially for complex projects (Shen & Issa, 2010). Lee et al. (2014) proposed an ontology-based approach to cope with the quantity of materials and possible material types obtained during design, as well as with the work items needed to fabricate materials as part of detailed estimation. In addition, a generic approach based on flexible mappings was developed to facilitate real-time changes to optimise the accuracy of cost estimation (Lawrence et al., 2014).

Finally, aiming at cost evaluation, Ma et al. (2011) tested the compatibility of IFC based on a tendering in China.

### *2.6.6. Schedule and Progress Management*

In addition to the research development of BIM-based scheduling, there is a technological combination of BIM and time control consisting of three elements: visualisation, automation, and integration. Specifically, Russell et al. (2009) developed project schedules with visual representations to explore appropriate construction strategies and meet the requirements of quick delivery. Other researchers integrated GIS into the visualised time control system to control on-site construction progress (Elbeltagi & Dawood, 2011). The next stage automatically generates schedules according to BIM data (Kim et al., 2013). Finally, recent advances have shown an interface system to generate project schedules through quantity take-offs established by on-site operations simulations (Wang et al., 2014).

With respect to progress management, following a similar development routine, advanced BIM applications show construction progress through 3D walk-throughs (Roh et al., 2011). However, real BIM-based progress management should compare the as-built model with the as-planned model (Fard & Pena-Mora, 2007). Kim et al. (2013) developed a method to measure construction progress automatically and accurately, and then allied with discrete-event simulation (DES) and BIM-based scheduling to evaluate project progress and aid decision-making (Chen et al., 2013; Lu & Olofsson, 2014). Additionally, in order to ensure on-site safety and efficiency, a schedule-workspace interference management system was proposed to address schedule overlap (Moon et al., 2014). Finally, a 4D model integrated with time and a 5D model integrated with cost were combined to evaluate earned values and enhance progress tracking (Turkan et al., 2013). Based on the researchers' findings, Gelisen et al. (2014) presented a framework to animate project schedules to include the parameter of productivity.

### *2.6.7. Quality Management*

As previously discussed, when integrated with BIM functions, quality management mainly incorporates design checking and on-site defect management based on augmented reality. However, limitations in the research exist (Chen & Luo, 2014; Dainty, Leiringer, & Fernie, 2017). In this regard, Choi et al. (2013) pointed out that because design checking depends upon a series of regulations or rules/codes set according to users' property information, the errors in the original information should be inspected and modified, and criteria for regulation checking should be proposed.

Similarly, with respect to defect management, Kwon et al. (2014) and Park et al. (2013) asserted that specific defect types should be defined to expand the use of the current defect management systems. Also, Chen and Luo (2014) demonstrated that a BIM-based construction quality management model based on 4D BIM can efficiently complement the lack of project life-cycle quality management research.

### *2.6.8. Communication*

BIM visualisation performs well when it comes to narrowing the gap between designers and clients. Because the users of projects are usually inexperienced, BIM-based user activity simulation and evaluation methods (UASEM) (Shen et al., 2012) can help users in understanding spatial factors and the overall design environment. In addition, user preoccupancy evaluation methods (UPOEM) (Shen et al., 2013) can facilitate designers' recording and tracking requirements for changes during design. Both methods are beneficial to designer–user communication, though the constraints of time-consuming training for the users and incomplete information must be properly and efficiently addressed (Shen et al., 2012, 2013).

In terms of information exchange during communication, to prove the benefits of BIM in communication, Demian and Walters (2013) compared the effectiveness of different communication methods, including email, a construction project extranet tool, an enterprise resource planning system, and a new BIM-based system. It was found that the BIM-based system diverted information flow through the building model and away from external systems (i.e. central repository of information) and that the resulting information was considerably more accurate, on-time and appropriate.

### *2.6.9. Decision-Making*

Participants find sub-BIMs helpful for making decisions. Sub-BIMs are combined with specific-function models such as 4D modelling to control project progress. Because of the distinct requirements of information management, various sub-BIMs have been developed to solve particular questions (Schade et al., 2011; Sidawi & Hamza, 2012). Therefore, managers have introduced a system dynamics framework to integrate the separate models with specific functions to assist optimal decision making (Thompson & Bank, 2010). Likewise, Scherer and Schapke (2011) developed a collaborative perspective into a “process-centric, multi-model-based and distributed management information system” (p. 583) to aid both the owner and contractor in making smart decisions.

## 2.7. Using BIM Technologies in Real and Visual Environments

This section of the literature review focuses on BIM-related research that may influence the entire AEC industry. It is related to the use of BIM technologies in real and visual environments. The main themes in this stream of BIM-related research include: (a) green BIM, (b) lean construction, (c) industrialisation and customisation, and (d) education.

### *2.7.1. Green BIM*

Representing the integration of green building and BIM application, green BIM has proven beneficial to both sustainability and waste savings (Krygiel & Nies, 2008; Wu & Chang, 2013; Wu & Issa, 2014). With regards to sustainability, this focus has mainly evolved into design processes that may lead to different decisions. Bynum et al. (2013) suggested that the schematic design, pre-design/program, and design development phases are the most suitable stages for BIM-integrated sustainable design. In turn, Basbagill et al. (2014) posited that sustainable design plays a significant role in the early stages of decision-making through BIM-optimised life-cycle assessment, which was previously used in energy analysis for U.K. housing (Iddon & Firth, 2013). However, the cross-disciplinary nature of design and construction facilitates appropriate modelling based on the non-geometric information stored by BIM (Geyer, 2012) and the simulation of environmental impact of construction

(SimulEICon). Thus, a cross-disciplinary approach aids multiple-objective decision-making (Inyim et al., 2014), all of which support sustainable design phases by providing a holistic BIM-integrated model.

BIM is also useful in recording and analysing energy consumption to evaluate building performance (Schade et al., 2011). Schlueter and Thesseling (2009) proposed a BIM-based tool to calculate energy performance instantaneously supporting flexible design optimisation. Recording the energy consumption of existing buildings is significant for construction sustainability, such as energy rehabilitation, which can occur with a textured as-built model (Lagüela et al., 2013). In the deconstruction phase, BIM works as an information repository and platform for making strategic comparisons based on energy use and carbon footprint da (Akbarnezhad et al., 2014). Aside from the savings-oriented energy consumption calculation, renewable energy modelling can also improve sustainability (Gupta et al., 2014).

As a sustainable building rating system, leadership in energy and environmental design (LEED) was developed to measure the performance of green building (Krygiel & Nies, 2008). The synergy between BIM and LEED has been documented (Azhar et al., 2011), and their integration can be expanded to enhance the functionality of both during project delivery by leveraging cloud BIM for LEED automation (Wu & Issa, 2012). Other standards or tools of construction sustainability assessment have also been developed across the globe, including the Ratio of Equivalent Transparency (REQ) in Taiwan (Wu & Chang, 2013), and the BEAM Plus sustainable building rating system in Hong Kong (Wong & Kuan, 2014). However, it appears that green BIM is still in the developing stages and more research would be necessary to evaluate its full capabilities (Wu & Issa, 2014).

### *2.7.2. Lean Construction*

The synergies between the principles of BIM and lean construction occur through three aspects: (1) a BIM-induced stable process and transparent pull flow to minimise inventory (Sacks et al., 2009); (2) the requirements of integrating BIM with lean construction, i.e. the functions of BIM (Sacks et al., 2010); and (3) a framework for assessing the interactions between BIM and lean construction to help management teams plan lean construction strategies (Sacks et al., 2010). Additionally, researchers assessed and proposed KanBIM, a production management system using BIM and lean construction principles, for its ability to optimise workflows with reduced waste (Sacks et al., 2010; Gurevich & Sacks, 2014). Arayici et al., (2011) demonstrated that managers should adopt BIM technologies from the bottom up through learning by doing in lean construction management. However, recent research has indicated that the full benefits of BIM-based lean construction tools can only occur when employed in real projects (Gurevich & Sacks, 2014; Mesa, Molenaar, & Alarcón, 2019).

### *2.7.3. Industrialization and Customization*

Because construction industrialisation such as off-site prefabrication and on-site assembly require a high level of information-dense automation, BIM integrated with an enterprise resource planning system can perform as an information centralisation platform (Babič et al., 2010; Ferron & Turkan, 2019). Industrialised housing such as rigid “type houses” and open platforms for customisation require object-based BIM integrated to solve flexibility (Wikberg et al., 2014). At least two studies found that BIM is associated with substantial benefits to flexible industrialisation and mass customisation (Farr et al., 2014; Lee & Kim, 2012).

### *2.7.4. Education*

Embedding BIM into education can help educators explain project management theories more precisely and effectively through realistic practice simulations based on the technologies of BIM visualisation (Peterson et al., 2011) and integrated gaming (Yan et al., 2011). With regard to how to teach BIM, some researchers have developed a framework to establish a systematic curriculum of construction, engineering, and management (CEM) education (Pikas et al., 2013) based on the defined requirements of both BIM education and industries that need BIM-skilled students (Wang & Chong, 2015; Sacks & Pikas, 2013).

## 2.8. Creating New BIM Frameworks through Improvement

Beyond the basic BIM functions, further enhancement of the current BIM performance is necessary. This can be done through technology improvements.

Based on a review of the current industry papers and scholarly research in this focus area, three core aspects of BIM technology improvements emerge:

1. BIM performance measurement.
2. Standardization.
3. nD models.

The following sections discuss these three core aspects in more detail.

### *2.8.1. Performance Measurement*

Performance measurement for BIM applications is essential to achieving BIM-induced benefits (Barlish & Sullivan, 2012; Kelly & Ilozor, 2019). First, because the direct users of BIM are individuals within project organizations, managers can benefit from assessing workers' individual competencies to determine BIM performance (Abd Jamil Ahmad & Fathi Mohamad, 2018). Accordingly, Succar et al. (2013) proposed a method to evaluate BIM implementation individually and organizationally, which managers can expand to industry-wide BIM performance measurement framework. When evaluating the performance of BIM in a real business case, it is essential to test performance grounded within the framework of BIM maturity (Barlish & Sullivan, 2012) as illustrated in Figure 3.

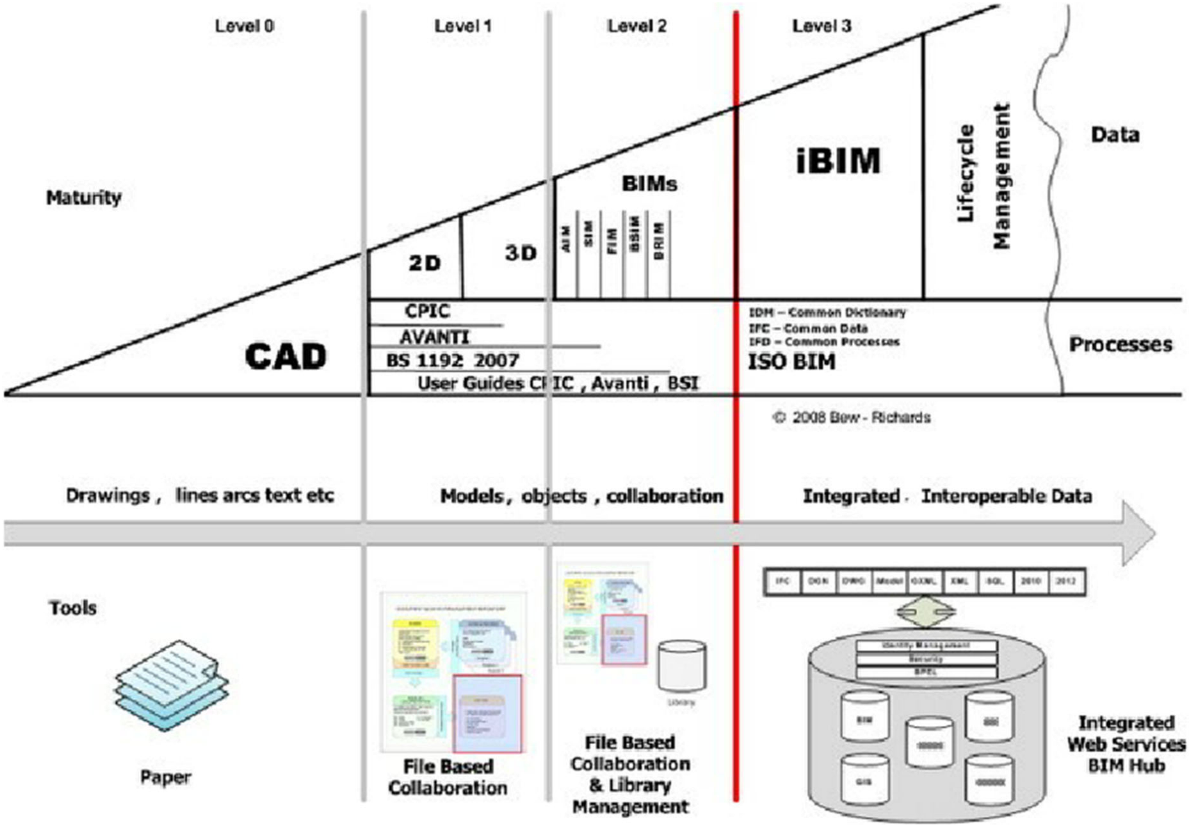
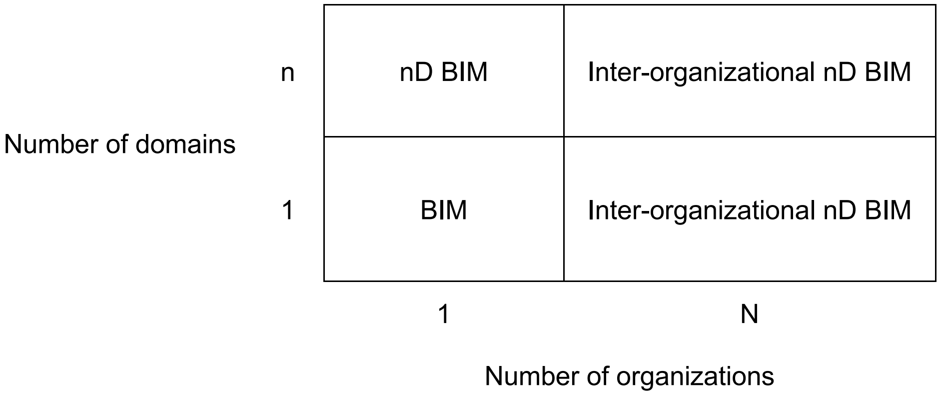


*Figure 3. BIM Maturity Levels*

Aside from maturity, measuring the organizational competency of using BIM is also important as different levels of BIM capacity may result in distinct BIM performance as demonstrated in Figure 4 on the following page (Fox & Hietanen, 2007). Moreover, critical success factors (CSFs) (Won, 2013) and critical risk factors (CRFs) (Chien et al., 2014) are identified and assessed to serve as guidelines for BIM performance optimisation, thus avoiding impairments to BIM value. Document management, as a tool to evaluate BIM performance, is significant, because not only does document management present a suitable measurement tool, but it can also accumulate knowledge gathered across organizations and accepted as standards (Bosch-Sijtsema & Gluch, 2019; Miettinen & Paavola, 2014).



| | 1 | N |
|---|---|---|
| n | nD BIM | Inter-organizational nD BIM |
| 1 | BIM | Inter-organizational nD BIM |

*Figure 4. Scope of BIM Use (Fox & Hietanen, 2007)*

### *2.8.2. Standardization*

Standardization of BIM application is required to systemise and enhance BIM-led interoperability (Rezgui et al., 2011). Interoperability involves the complex multidisciplinary information exchange between participants of construction projects through divergent software applications (Jeong et al., 2009; Sacks et al., 2010). Extensive evidence has shown the effective function of IFC as a non-proprietary open BIM schema (Fox & Hietanen, 2007; Fu et al., 2006; Laakso & Kiviniemi, 2012; Motamedi et al., 2014; Nour, 2009; Pazlar & Turk, 2008). Moreover, research has verified IFC as a supportive public standard for high-quality building information-sharing and management (Doukari & Greenwood, 2020; Jeong et al., 2009; Vanlande et al., 2008). However, the limitations of IFC's ability to satisfy the higher requirements of detailed lossless and errorless information do exist (Jeong et al., 2009). One limitation is associated with information loss during the data exchange process. Because of this issue, inaccurate and incomplete information input can result in incorrect information output, for example, with cost estimation (Ma et al., 2011).

Another limitation is that IFC models are usually incapable of covering all relevant information of every specific process in one schema, such as the information of fabrication-level products (Froese, 2003, as cited in Jeong et al., 2009; Redmond et al., 2012; Sacks et al., 2010). Thus, as an ad-hoc standard (Monteiro & Martins, 2013), IFC cannot help real-time decision-making during construction processes (Laakso & Kiviniemi, 2012), and it cannot define information properties and their corresponding relationships semantically (Venugop et al., 2012).

Aiming to boost compatibility between BIM and IFC, a number of researchers have focused on evolving IFC through integrated frameworks. For instance, Plume and Mitchell (2007) established a shared building model hosted on an IFC server as a design support technology. A semantic indexation method based on IFC was developed to conduct file management and information-sharing throughout the project life cycle using a federate Internet platform (Vanlande et al., 2008). Redmond et al. (2012) listed several improved standards, including CityGML for the geospatial environment based on IFC and open APIs to extract data through open platforms. Open query language was proposed to manage the information embedded in IFC models (Doukari & Greenwood, 2020; Mazairac & Beetz, 2013). In terms of specific features, Lin et al. (2013) advanced a 3D path-planning model based on IFC to contain the semantic information of building components. In addition to IFC, information delivery manuals (IDM) were proposed to solve the AEC industry's lack of effective and valid project processes information (Ademci & Gundes, 2018; Berard & Karlshoej, 2012). Finally, according to Lee et al. (2014), an integrated method can assist in seamless information delivery based on IDM and model view definition (MVD), which is also consistent with the findings of other studies (Ma, Zhang, & Li, 2018; Mesa, Molenaar, & Alarcón, 2019).

In summary of this stream of literature, there is a clear trend in the industry to develop BIM-related standards integrated with other standards, systems, frameworks, or methods to satisfy specific requirements or to realise specific functions in BIM-used construction processes.

### *2.8.3. nD Model*

The application of BIM will eventually expand into nD models grounded upon 3D geometric data (Taylor & Bernstein, 2009; Tse et al., 2005). These models extend the BIM functions from design and construction stages to the entire life cycle management (Lee et al., 2003, as cited in Fu et al., 2006). In this regard, Fu et al. (2006) indicated that IFC models and nD modelling can combine to perform as standardised BIM to assess multidisciplinary interoperability, including information exchanges and decision-making. The trend towards integrating various systems or frameworks into more complex models facilitates a continuously optimised multidimensional model and achieves the ideal nD BIM. In short, the trend is towards establishing a framework containing all realms of project management, all participants of the project, and the whole life cycle (Ding et al., 2014).

## 2.9. Analysis of BIM Implementation Issues

The last stream of extant research on the topic of BIM, and that which is most directly relevant to this dissertation, includes various industry reports and scholarly studies that analysed issues associated with BIM implementation. These sources can be grouped into three large themes: (a) socio-technical issues associated with BIM adoption (Dowsett & Harty, 2019; Elghaish, Abrishami, Hosseini, Abu-Samra, & Gaterell, 2019), (b) analysis of economic benefits of BIM utilization (Ademci & Gundes, 2018; Ahmed, Kawalek, & Kassem, 2017), and finally (c) studies of BIM diffusion (Succar & Kassem, 2015; Yuan & Yang, 2019). The following sections discuss these three themes.

### *2.9.1. Socio-Technical Issues*

Some researchers found that contractors do participate in BIM applications in order to be awarded a contract and be allowed to present their design (Eastman et al., 2018). Yet, simple obligatory participation cannot facilitate the information-sharing necessary for the creation of an interoperable Level 3 model. Rather, the goal must be to incentivise participation in a way that avoids disincentives that can discourage stakeholders from fully realizing BIM’s potential (Thompson & Miner, 2006). These inhibitions usually include the disclosure of proprietary information (Azhar, 2011). They may also be associated with an increased risk due to information-sharing inherent in a fully developed BIM model (Walker & Lloyd-Walker, 2016; Zou, Kiviniemi, & Jones, 2017). As such, the advancements in IT associated with BIM must be balanced by incentives in order for its potential to be realised fully (Oti & Tazani, 2010).

Presently, integrated project delivery (IPD) has been tested as a broad incentive approach for project owners seeking participation in BIM systems (Gomez, Naderpajouh, & Ballard, 2018). IPD facilitates improved project outcomes through a collaborative approach of aligning the incentives and goals of the project team through shared risk and reward (Ma, Zhang, & Li, 2018), early involvement of all parties (Hall & Scott, 2019), and multiparty agreements (Kent & Becerik-Gerber, 2010). Since both BIM and IPD compel a dramatic increase in information sharing (Yee, Saar, C., & Yusof, 2017), these concepts have become intertwined and represent a clear break with the currently utilized linear processes based on exchanges of information through paper representation (Eastman et al., 2018; Elghaish et al., 2019).

In regard to this, some researchers have even claimed that IPD is pivotal to BIM implementation (Sebastian, Haak, & Vos, 2009). However, IPD is not a single approach. It should be noted that multiple IPD methodologies have emerged as the industry experiments with this contracting strategy (Eastman et al., 2018), but not all methodologies promote BIM in the same manner.

### *2.9.2. Economic Benefits of BIM*

Experts generally emphasize the broad industry consensus that BIM has the capacity to influence the construction project throughout all phases of its lifecycle (Eadie et al., 2013). At the same time, a number of researchers have focused on determining the degree to which BIM has influenced the bottom-line results. One such effort involved data analysis on three recent BIM-assisted projects and one similar non-BIM-assisted project, with cost savings measured through reductions in schedule overruns, requests for information (RFIs), and change orders (Giel & Issa, 2013). In all instances, it was found that the BIM projects showed significant benefits, some extraordinarily so, with ROI increased by as much as 1,654 percent, although this measure varied widely (Giel & Issa, 2013). At the same time, RFIs decreased by 34 to 68 percent, whilst change orders dropped by 37 to 48 percent (Giel & Issa, 2013).

Love et al. (2014) reviewed BIM implementation from an ROI perspective and established a framework to help asset owners ensure they can obtain “value” from their BIM investment by observing the cornerstones of governance, performance measurement, change management, and stakeholder management. Love et al. (2014) further pointed out that others stipulated that the process of realizing BIM benefits is not static, and that asset owners must consistently question the implementation process in order to ensure that benefits materialise at the proper time.

Rather than studying individual cases, which remains the standard for BIM research, Bryde, Broquetas, and Volm (2013) explored the extent to which BIM resulted in benefits on a macro scale by collecting data from 35 construction projects that utilised BIM from 2008 to 2010. The data were analysed against a list of success criteria related to project outputs and process management as outlined within the project management body of knowledge (PMBOK) knowledge areas (Bryde, Broquetas, & Volm, 2013). Bryde et al. (2013) reported that cost reduction or cost control were the most frequently noted positive benefits of BIM. This finding is also consistent with the results of Dowsett and Harty (2019) and Elghaish et al. (2019). In a distant second was a tight grouping of time reduction or control, communication and coordination improvement, and quality increase or control. Each element received positive mentions in 34.29 to 37.14 percent of the surveyed projects (Bryde, Broquetas, & Volm, 2013). Won (2013) and Chien et al. (2014) used a similar macro approach to establish critical success factors (CSFs) and critical risk factors (CRFs) assessed in BIM performance optimisation, thus avoiding impairments to BIM value.

In turn, Hanna, Boodai, and Asmar (2013) focused on quantifying the impact of BIM on the labour-intensive trade industries of mechanical and electrical construction. Through a survey of 1,896 mechanical and electrical contractors across North America, these researchers established that the two activities for which BIM generated the most value were clash detection and the visualisation of facility design (Wan Mohammad, Abdullah, Ismail, & Takim, 2018), which had significantly higher mean values than the values found for any other activity (Hanna, Boodai, & Asmar, 2013). Other industry-specific research has shown value for BIM in infrastructure projects (Hassan Ibrahim, 2013; Nuttens, De Breuck, & Cattoor, 2018; Shaaban & Nadeem, 2015) and healthcare facilities (Lucas et al., 2013).

### *2.9.3. Studies of BIM Diffusion*

Using case study reviews of BIM-enabled projects, some recent studies have identified barriers to successful BIM adoption, while others have employed surveys to study the same issue. For instance, Panuwatwanich and Peansupap (2013), applied Everett Rodgers' innovation diffusion theory (IDT) to study factors affecting the diffusion of BIM at the project level. In turn, Gledson and Greenwood (2017), explored how the IDI tenets performed in practice and surveyed 97 construction planning practitioners to measure 4D BIM innovation take-up over time. The researchers found (a) an increasing rate of 4D BIM adoption, and (b) a time lag between awareness and first use that is characteristic of this type of innovation (p.950).

However, IDT's treatment of innovation diffusion using a linear process did not address the fact that innovation inherently changes and evolves over time (Merschbrock & Munkvold, 2014). Kaner et al. (2008), employed case studies to determine obstacles for BIM use by precast concrete contractors, revealing clear improvements in engineering design quality, the incidence of error-free drawings and labour productivity. Merschbrock and Munkvold (2014) also analysed a case study of a healthcare construction project to identify the main problems in applying BIM while Azhar (2011) used online surveys to identify common barriers to BIM implementation throughout the U.S. construction industry. Gu and London (2010) applied information from the Australian construction industry to study the technical and nontechnical issues involved in implementing BIM, Howell and Batcheler (2005) used case studies to point out the main difficulties that early adopters of BIM have faced in implementation, including upfront investment, Standardization, and legal/contractual issues. However, the major problem running through all of these studies is their unidimensional methodology and/or focus; that is, the researchers approached BIM adoption with either a singular theoretical lens or a singular industry focus when the BIM decision-making environment reaches across a wide variety of stakeholders who, in turn, each possess multiple authority levels. The sum of this decision hierarchy is simply too complex to be properly understood through such restrictive study.

## 2.10. Gaps in the Literature

Based on the review of the extant literature discussed above, the researcher concluded that several serious and persistent issues related to BIM adoption and utilization in AEC industry organizations remain either completely unaddressed or underexplored to a significant degree and therefore require further in-depth research.

One such underexplored but exceedingly complex issue is the conflict between industrialisation, automation, and labour intensity. A review of literature suggests that this conflict is obvious and quite ubiquitous in the AEC industry both globally and in the U.S. specifically. Addressing this conflict requires urgency on the part of all involved stakeholders on the one hand and, simultaneously, consistent long-term cooperative effort amongst the AEC industry as a whole with all relevant government agencies on the other. Even more pressing is the urgency for those government agencies mandating the formulation, implementation, and enforcement of regulatory policies in the AEC industry. While the urgency aspect of this problem is manageable through proper application of carefully chosen leadership approaches and tools in either domain of management — private for AEC industry companies or public for government agencies — the cooperation aspect of the conflict is considerably more challenging both substantively and functionally.

From the substantive viewpoint, the challenge to cooperation stems from the fact that businesses and public agencies have multiple lines of accountability to their stakeholders. In fact, organizations are typically accountable to different sets of stakeholders that impose divergent demands with regards to organizational missions. Likewise, from the functional viewpoint, the challenge to cooperation originates in asymmetrical organizational transparency requirements for business organizations as private entities compared to government agencies as public entities. Thus, in this complex environment, in order to address the conflict between industrialisation, automation, and labour intensity, both AEC industry organizations and government agencies need to address these two inherent challenges first.

However, as the analysis of literature on this topic suggests, currently no conceptual framework has been developed either in academia or by AEC industry professionals that would effectively guide the process and the outcomes of addressing the conflict described above. Furthermore, because a conceptual framework is lacking, no empirical tests or valid and reliable field studies of practical applications have been conducted either. Thus, as a corollary, because BIM is a complex tool for adoption and utilization, both of which require cooperation among different stakeholders, it is obvious that proper understanding of why BIM is (or is not) adopted and whether its capabilities are fully utilized depends largely upon appropriate conceptualization. Due to the multifaceted nature of BIM, such conceptualization must blend several theoretical models that simultaneously provide efficient analytical traction while offering a high degree of theoretical consistency.

The review of theoretical explanations for the decision to adopt and utilize BIM in extant studies points to three viable candidates for constituent parts of a theoretical framework – incentive theory (Baddeley & Chang, 2015; Lee, Yu, & Jeong, 2015; Linderoth, 2010); the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh, 2000; Venkatesh & Davis, 2000; Venkatesh, Morris, Davis, & Davis, 2003; Venkatesh, Thong & Xu, 2016); and finally the Status Quo Bias model (Kahneman, 2013; Kahneman, Knetsch, & Thaler, 1991; Kahneman & Lovallo, 1993). The current study addresses this theoretical gap by empirically exploring the specific reasons for, and barriers to, adoption and utilization of BIM within the AEC industry using a conceptual framework that incorporates all three theories. In particular, the studies of this dissertation explored this topic by testing the propositions and predictions of all three theories using both quantitative and qualitative methods.

Another underexplored but critical issue is the serious mismatch between the implementation of technical innovation and satisfaction of specific users' requirements (Ahmed, Kawalek, & Kassem, 2017; Ayman et al., 2018). Extant literature suggests that due to technological constraints, technical innovation frequently falls behind users' requirements. For example, a lack of corresponding software and hardware, which is a common problem in BIM systems' development. At the same time, integrative BIM-based technologies for project management, such as the flexible mappings between BIM and cost information (Lawrence et al. 2014), often require model testing through real-case application or theoretically through advanced algorithms (Dainty, Leiringer & Fernie, 2017).

Given the immense potential for BIM and its measured diffusion, what stands out most is the dearth of research concerning incentives to adopt and utilize BIM, particularly, incentives that act on the organizational level. For instance, O’Connor (2009), Dal Gallo, O’Leary, and Louridas (2010), and Ballobin (2008) have conducted their respective studies on incentives for IPD. Yet, despite the well-documented correlation between these project management practices, none of these researchers have taken the next logical step and examined how the incentive vehicles inherent to IPD may or may not affect the uptake of BIM.

While a powerful technology, BIM cannot drive itself so in order to harness its full potential it is imperative that BIM-enabled projects be effectively incentivised. This seems obvious but BIM incentivization remains surprisingly, and significantly, understudied. Therefore, a much more detailed empirical exploration of the role the incentives play in the adoption and subsequent utilization of BIM by AEC industry organizations is warranted. Such detailed exploration would provide an empirical affirmation of the main tenets of incentive theory and as a result increase explanatory power, descriptive ability, and predictive capacity for the conceptual framework of the current study. To address this particular gap in the current understanding of the role the incentives play in the adoption and utilization of BIM, an exploratory study was conducted which evaluated the most general issues related to the BIM incentivization process. In turn, building upon the findings of the exploratory study, the follow-on in-depth analysis of the incentive questions therein explored AEC industry practitioners’ perception of existing BIM incentive problems.

The results of the exploratory study allowed the researcher to evaluate two key predictions of incentive theory. Specifically, whether indeed (a) any innovation, to be fully adopted by an economic agent, must be associated with rising productivity that lowers unit labour costs and increases profits, and (b) that economic agents behave strategically and opportunistically to maximize benefits (personal, organizational, institutional) for themselves regardless of the costs these might impose on others. The results of the exploratory study and the analysis of incentive questions are presented and discussed in subsequent chapters.

Next, while some empirical studies reviewed above investigated the end result of the decision to adopt and utilize BIM, few studies actually explored specifically how such important decisions are made. It is clear from the analysis of extant research that virtually no researcher looked into the actual calculus that underlies such a complex decision. The decision to adopt and use BIM is, in fact, incredibly complex and necessarily involves the evaluation of several critical factors. The conceptual framework used within this dissertation not only includes the theory that explains the economic incentives rationale behind the decision to adopt and utilize BIM, but also relies on the tenets of the Unified Theory of Acceptance and Use of Technology (UTAUT) to generate more usable knowledge on the underlying cumulative decision-making processes employed; specifically:

1. If the tenets of the UTAUT are applied to BIM, then the higher-level finite decision to adopt and use BIM is actually viewed as composed of several interrelated lower-level decisions: Decision on performance expectancy of BIM, i.e., the degree to which an individual decision-maker believes that using BIM would help to achieve measurable improvements in job performance; Judgement on effort expectancy, i.e., the degree of ease linked with the use of BIM.

2. Evaluation of social influence, i.e., the degree to which an individual decision-maker perceives that others believe he or she should use BIM.

3. Assessment of relevant facilitating conditions, i.e., the degree to which an individual decision-maker believes that organizational and technical infrastructure does exist and is capable of supporting the use of BIM.

Thus, according to the precepts of the UTAUT, performance expectancy, effort expectancy, social influence, and facilitating conditions together determine the decision to adopt BIM and the rate of its acceptance in an organization or set of organizations. UTAUT is subject to key decision-makers’ attitudes towards BIM utility.

To address the gap in the current understanding of how specifically a decision to adopt and utilize BIM is made, an in-depth empirical exploration of individual perceptions of key decision-makers from a selected number of leading construction companies that adopted and utilized BIM was conducted. Specifically, this second survey for the dissertation tested the application of the UTAUT to the decision to adopt and utilize BIM. The study was conducted to moderate the obvious explanatory deficiency of incentive theory. Furthermore, the study empirically tested the accuracy of the UTAUT predictions that (a) decision-makers who do not fully accept BIM may delay, obstruct, underutilize, or even disrupt its implementation and that (b) individual perceptions of key decision-makers influence behaviour (i.e., acceptance of BIM), so that the aggregate benefits of project-level acceptance can be realized. The results of the analysis of individual perceptions are discussed in the respective section and overall provide credence to the theoretical claim that users' perceptions towards collaborative BIM play a pivotal role in its current low rate of adoption. The results of the analysis of individual perceptions then necessitated taking a closer look at unique human behaviour-related explanations of why the pace of full BIM adoption within the AEC industry has been stunted. Existing literature has not fully explored this issue in practical terms and very few past empirical studies delved into this topic comprehensively within the context of the AEC industry. Thus, this is another important gap the current research aims to address.

The third component of the conceptual framework that guided this dissertation is the Status Quo Bias model. This model was used to complement the predictions of the incentive theory and the UTAUT and permitted to account for unique and potentially illogical individual differences in decision-making processes. Prior literature on the effects of the Status Quo Bias draws upon, and blends together, insights from decision-making and cognitive theories (Kahneman, 2013; Kahneman, Knetsch, & Thaler, 1991; Kahneman & Lovallo, 1993). The literature posits that (a) decision makers rely on both analytical and emotional systems to process and assess risk; (b) the analytical system allows to process and evaluate risk by consciously considering costs and benefits; (c) in contrast, the emotional system evaluates risk through nonformal and automatic processes that are expressed in instinctive feeling or gut reaction; and finally (d) the systems generally complement each other, but the emotional system becomes dominant in situations where their outputs differ.

To fill in the gap in the current theoretical and practical knowledge of individual differences in decision-making processes, an empirical study was conducted that tested the four propositions of the Status Quo Bias model within the context of AEC industry organizations and when a decision to adopt and utilize BIM is considered. The Status Quo Bias study was conducted (a) to complement the main findings of the exploratory study, the analysis of incentive questions and the UTAUT study and (b) to test the predictions of the Status Quo Bias model. The overall research purpose in this case was to identify specific factors in BIM adoption that act not on organizational or project levels, but on personal levels.

Finally, held together, these studies offered only partial and thus unsatisfactory explanation of BIM acceptance decisions. While each successfully addressed a specific gap in the extant literature, in isolation, they were not enough to fill in probably the largest lacunae in the current theoretical and practical knowledge: namely, how to account in a meaningful and consistent way for all relevant aspects of the complexity associated with the decision to adopt and utilize BIM in the AEC industry.

This realization justified the next logical step, i.e., to assess the analytical and explanatory performance of the entire conceptual model used in this dissertation research, not merely its individual theoretical parts. To this end, a Synthesized Secondary Survey was conducted (a) to empirically explore the predictions of the entire conceptual model and (b) to achieve a higher degree of explanatory consistency and exhaustiveness. In addition to filling in the gaps discussed above, this also allowed to broaden the scope of empirical affirmation for the entire dissertation study.

Then, because all previous studies of the dissertation utilized quantitative methodologies and relied upon advanced statistical analytical methods, it was necessary to appropriately contextualize the results of the quantitative analyses using a different methodological approach. Further, given that the results of the quantitative analyses identified several key trends and critical perceptions that inform how project delivery environments affect BIM adoption, a case study was conducted to better frame the latter through qualitative analyses based on data collected from interviews with key leaders from a nationally renowned construction organization. The qualitative case study allowed to achieve a reliable cross-validation of conclusions of the four quantitative studies. Also, because the results of quantitative analyses revealed similar trends, it was necessary to evaluate whether these trends do in fact exist and can be reliably confirmed by experienced AEC industry professionals using interview techniques.

In summary, the analysis of the extant literature identified the following gaps in the extant empirical research and current knowledge:

1. The conflict between industrialisation, automation, and labour intensity in the AEC industry, especially in the decisions to adopt and utilize BIM.
2. A mismatch between the implementation of technical innovation and satisfaction of specific users' requirements, particularly as far as BIM is concerned.
3. An in-depth understanding of specific processes involved in a decision to adopt and utilize BIM such as individual perceptions of key decision-makers.
4. A reliable explanation of unique human behaviour-related factors directly and indirectly responsible for the observed slow pace of BIM adoption in the AEC industry.
5. How to account in a meaningful and consistent way for all relevant aspects of the complexity associated with the decision to adopt and utilize BIM in the AEC industry.

With these gaps identified and overall research approach justified, the following chapter provides the detailed methodology for the dissertation.

# 3. Chapter 3: Methodology

## 3.1. Research Design

Based on the results of the literature review, the dissertation employed a mixed method, multiple-study methodology to address the research question. Five empirical analyses were quantitative utilizing cross-sectional questionnaire-based surveys to collect data. The sixth empirical analysis, the case study, was qualitative and utilized multiple interviews of key informants with a standard set of open-ended questions. The case study relied upon a pre-test/post-test design to measure the consistency and strength of reported perceptions during, and immediately after, the implementation of large-scale BIM-enabled construction projects at the San Francisco International Airport.

The dissertation relied upon multiple studies combined in one mixed method design because BIM has not seen widespread adoption. Hence, after the initial feasibility assessment of possible data collection options, the researcher concluded that it would be exceedingly difficult to obtain a large enough sample for a single comprehensive survey covering all theoretical constructs of the study. Furthermore, the researcher had concerns that attempting to collect participants' responses on all theoretical constructs in a single survey would make it too long. Therefore, given the scope of this dissertation research, the decision was made to have multiple quantitative analyses, each of smaller analytical scope. This measure proved to be expedient as it allowed to have more focused data collection and analyses in each case. Also, because quantitative studies were implemented in a sequence, this allowed to adjust the data collection instruments accordingly.

The samples of all six empirical analyses were drawn using purposive sampling. Purposive sampling was utilized because it is an informant selection instrument frequently employed in management and organizational studies, especially when there is a research need "to evaluate a certain management aspect, specific administrative process, certain decision-making approach or a particular domain of organizational culture within a business organization with highly knowledgeable experts within" (Ray, 2012; p. 39). Because of reliance on purposive sampling, the researcher exercised a significant degree of investigative discretion so was able to identify participants who "were capable and willing to provide key information primarily by virtue of expert knowledge or professional experience" (Ray, 2012; p. 44).

Overall, the selected research design aimed to approach the issue of BIM adoption holistically, meaning, at the organizational, individual, and behavioural levels through four complementary studies, a confirmatory Synthetized Secondary Survey, and a case study. The Synthesized Secondary Survey and case study cross-validated and properly contextualized the findings of the four first quantitative studies. Thus, the researcher adhered as closely as possible to scientific methodologies, while allowing enough progressive elaboration of the research design so as not to force a preconceived acceptance model but rather be guided by sound theory and confirmatory analyses. More specifically, given that BIM is a novel technology and the inherent complexities of studying a phenomenon that is not happening rather than one that is, at its outset this research presents even more unknowns than normal. To wit, the methodology was developed through a process of progressive elaboration of the research plan.

### 3.2. Data Analyses

Because individual studies within the mixed methods model collected different types of data, the data analyses were conducted using two different approaches. Specifically, structural equation modelling (SEM) was used to analyse data collected in the five quantitative studies. SEM is a general statistical modelling approach that combines factor analysis (FA), regression analysis (RA) and/or path analysis (PA) techniques (Kline, 2016). The use of SEM made it possible to explore empirically the theoretical constructs of the study. All SEM analyses were performed using IBM SPSS AMOS 27 – a software package for conducting SEM analyses (Byrne, 2016).

In turn, directed content analysis (DCA) was used to analyse qualitative data collected in the case study (Krippendorf, 2018). The DCA in this dissertation included the following analytical procedures: (a) development of analytical constructs, (b) coding of textual data, and (c) thematic analysis. The analytical constructs reflected the key elements of the theoretical framework, i.e., the incentive theory, the UTAUT and the Status Quo Bias model. The coding procedure used sentence as a unit of analysis and the coding scheme again mirrored the analytical constructs. The directed content analysis was performed using NVivo 19.0 qualitative data analysis software.

## 3.3. Quantitative Studies

### *3.3.1. Exploratory Study*

***Questionnaire design***. As Level 3 BIM application remains in the nascent stage, the design of the questionnaire should elicit experienced BIM users' perceptions of the importance of incentivization for the extent of effort they could exert. The questionnaire therefore consists of three parts: Part I gathers respondents' base information; Part II aims to explore if the six key issues in incentive design are perceived to be significant by experienced BIM users; and Part III considers the seriousness of inhibitors in resolving these issues (Appendix B). Given that BIM practitioners would necessarily be technically inclined, it was determined that a web-based survey presented the best option for distribution. Popular survey hosting site www.surveymonkey.com was chosen due to its ability to utilize skip logic formatting and its ease of use. It was further determined that the most straightforward method of distribution would be to create a unique website for the questionnaire and distribute it to the sample population as a hyperlink.

***Survey design***. Since BIM has not yet seen widespread global implementation, it was determined that a sample population of general construction practitioners would be unlikely to return sufficient BIM data. Instead, the researcher sought out a BIM-specific trade group to act as the sample population for the survey. After a great deal of research into various BIM-related groups and societies, the researcher chose to partner with the largest BIM-related group on professional networking site LinkedIn.com to act as the sample population. The group had a membership of 23,041 at the time of survey distribution. Topics posted to the group's "Discussions" page at the time of distribution included:

1. Australian BIM vs. the UK BIM, aka the global BIM leaders.
2. BIM case study of 100-bed hospital: How to measure, cost, and track literally any building product in real-time.

3. 3D Models for the Real Estate Industry.
4. Which BIM software do you prefer to use and why?

It is the researcher's position that the benefit of utilizing this membership data was not only that it presented a knowledgeable group, but also that its members purposefully sought out the group and made the conscious decision to join. Thus, they may be more receptive to opening a survey link sent to them from the group itself. As such, rather than post the link to the "Discussions" page, the researcher arranged to have an invitation and link distributed from the group itself as a message from the group's manager (Appendices A, B). This message was received as a LinkedIn message by the group members, and generally then forwarded on automatically by the website to members' email address depending on individual communication settings. The survey was distributed and went live on 13 December 2013.

### *3.3.2 Analysis of Individual Perceptions*

**Questionnaire.** The next step in the methodology was to design a questionnaire that tests the adapted UTAUT variant while using the original UTAUT model construct as a foundation for the decision-making context. Each variable is measured within the survey by a set of questions that, when combined, provide an accurate measure of that variable. The wording and format for the questions were based largely upon the seminal UTAUT questionnaire distributed by Venkatesh et al. (2003), providing inbuilt validity without the need for a pilot study.

After the questions were drafted, but prior to the full implementation of survey, interviews were held with two leading BIM experts. Both had extensive experience in the AECO industry and over seven years of experience with BIM. One is a BIM leader within an engineering consultancy firm and the other a senior project manager from a construction management firm. The purpose of the interviews was twofold: first, to examine the clarity and appropriateness of wording and the answerability of questions; second, to ensure that the questions are understood by the respondent as intended. Throughout the interviews, the constructs for all questions were validated within the context of BIM and individual technology acceptance. The inclusion of Attitude was one of the central topics, with the interviewees ultimately validating Attitude as an appropriate construct for BIM through the following comments:

1. Personally, I think that Attitude plays a big role in how individuals learn and use BIM. However, the Attitude is formed differently in each individual depending on a wide range of circumstances. I think it is a good idea to include it in the model. I think that measuring independently Attitude is not a problem for the model because you are just measuring a different variable and if it proves not to directly affect User Behaviour then all the other results from the original model still work. In conclusion, yes, I think you should include Attitude.
2. The feelings that employees have about working with BIM can be particularly important because we want them to be as motivated as possible and we know that having a good motivation will result in better job performance. In this sense, yes, I think that the variable should be included in the model.

Thus, the questionnaire-based survey was implemented. In order to improve response percentages from the exploratory study issued via LinkedIn, the survey was distributed via direct email to 364 professionals from various sectors of the AECO industry identified through extensive networking. In the survey, respondents were first asked to provide some basic information about their experience with BIM and the subsector of the industry in which they work. Respondents were then asked to rate the extent to which they agreed with a set of statements within each category according to a seven-point Likert scale. From the sample population of 364, a total of 84 respondents completed the survey for a response rate of 23 percent. The aim was to conduct the survey at the individual level, which is why the survey targeted not only senior BIM users but also more general participants within the U.K.'s AECO industry. The criteria for selecting these individuals were as follows:

1. Employees of companies in the AECO industry.
2. Excluding general management and sales employees.

3. U.K.-based organizations only.

It should be noted that the restriction to UK-based organizations was a matter of operational necessity as interviewees were solicited through university channels. During this time, the researcher was splitting time between London and a construction project in Iraq so it was agreed with supervisors that restricting to the UK was both appropriate and necessary as a practical matter. Further, it was hoped that the approach would increase response rate from the exploratory study, which was issued more broadly. Any surveys that were incomplete were discarded due to no-response.

### *3.3.3 Analysis of the Status Quo Bias*

**Survey**. In seeking the largest audience for general construction, and in building upon previous distribution methodologies, a unique survey link and invitation was posted on the “Conversations” board of Linking Construction, the largest construction-based trade group on professional networking website LinkedIn.com. This group was chosen because they represent a wide base of general construction practitioners across an equally wide range of geography and roles within the AEC industry. The questionnaire consisted of control questions related to the professional background of the participants, their experience with IPD and their reaction to BIM-based status quo questions.

### *3.3.4 Synthesized Secondary Survey*

**Sample**. The sample population of the Synthesized Secondary Survey was determined through purposive sampling. Purposive sampling is an informant selection instrument frequently used in management and organizational studies, especially when there is a research need “to evaluate a certain management aspect, specific administrative process, certain decision-making approach or a particular domain of organizational culture within a business organization with highly knowledgeable experts within” (Ray, 2012, p. 39). The purposive sampling technique is the deliberate choice of a group of key informants because of their knowledge, advanced professional qualifications, or exclusive expertise, i.e., their unique qualities (Edmonds & Kennedy, 2017, pp. 20-21). Purposive sampling is a non-random sampling technique that does not require the use of underlying theories or a statistically determined number of informants (Arnab, 2017). In case of purposive sampling, the researcher exercises a significant degree of investigative discretion on the specific purpose of sampling and determines to identify participants who are able to provide key information and are willing to provide such information primarily by virtue of expert knowledge or professional experience (Levy & Lemeshow, 2009).

Key informant technique is one of the most frequently used purposive sampling solutions, wherein key informants are solicited to participate in research and to provide their unique perspectives directly related to the management problem under investigation (Ray, 2012). Key informants are “experienced, objective members of the professional community of interest who possess immediate pertinent knowledge and are both able and willing to share that knowledge with the researcher” (Ray, 2012, p. 41). In management studies, key informant technique of purposive sampling is commonly used either (a) to study specific management or business skills, knowledge, or practices, or (b) to make relevant and justified comparisons between management practices or processes in different organizations (Arnab, 2017).

In the Synthesized Secondary Survey, purposive sampling was used for two main reasons. First, ongoing and persistent systemic issues with universal acceptance of BIM by construction industry organizations, both globally and in the U.S., rendered a probability-based sample of construction practitioners unlikely to provide valid “across the board” comparisons. Second, as the results of preceding analyses of this dissertation suggest, members of specific trade groups tend to be much more familiar, both conceptually and practically, with BIM per se and various organizational and institutional issues related to the adoption and utilization decision. Given these considerations, the purposive sample of key informants was drawn from the following two construction industry groups:

Group 1—The Texas, USA home office of a Fortune 100 general contractor that for business reasons wished not to be named. This organization was selected because they (1) employ highly diversified staff of construction industry managers and other specialists who can serve as key informants on the problem under research, and (2) rely on highly integrated processes and systems for high-quality and timely execution of projects, i.e., possess necessary expertise and experience with BIM/IPD. The key informants from this group received an invitation to participate within their monthly corporate update letter. This construction company is one of the world's largest engineering, procurement, fabrication, construction, and maintenance (EPFCM) companies and offers integrated solutions that bring greater capital efficiency with improved project costs and schedule certainty. This construction industry group employs 56,000 employees worldwide, with 21,000 in the U.S. and 1,200 in their Houston office employs. In total, 73 key informants from this group participated in the survey and 41 were included in the final analytical sample after all inclusion criteria were applied.

Group 2—FIA Technology Services, Inc. (FIA Tech), a large U.S. trade group with explicit focus on innovative construction technologies. FIA Tech was purposefully selected because they (1) provide a wide range of project integration and delivery services to improve operational efficiency for their clients via integrated cloud-based systems, and (2) possess unique knowledge of key financial services and processes directly relevant to the execution of complex construction projects including management of legal agreements, meeting and enforcing contract compliance requirements, and reconciliation. A wide range of key informants from FIA Tech received an invitation to participate in the survey via monthly membership "Fiatech Happenings" email. FIA Tech is one of the leading providers of financial and project integration and delivery services to construction companies in the U.S. In particular, its core applications and services include Docs (EGUS agreements), Fees (brokerage settlement), Integrated Recs (reconciliation), OCR data service (regulatory compliance), MiFID lockbox, and the FIA Tech Databank with its suite of position limits and exchanges fees data. This makes FIA Tech key informants uniquely positioned to provide valuable insights on the topic of this study. In total, 80 key informants from FIA Tech participated in the survey and 43 were included in the final analytical sample after all inclusion criteria were applied.

The main assumption of key informant technique of purposive sampling was that there is a clear research benefit of utilizing membership data from the two groups of key informants because (a) not only are both groups comprised of highly knowledgeable construction industry experts with unique knowledge, but also that (b) professional members of such groups made the conscious decision to join. Therefore, they were more receptive to opening a survey link sent to them from the group itself. The use of purposive sampling with the key informant criterion allowed to collect responses from 153 highly qualified and experienced construction industry professionals from leading construction industry groups.

**Instrumentation**. To collect data for the Synthesized Secondary Survey, a questionnaire-based survey was created (Appendix E). The general structure and the content of this survey overall mirrored those of the surveys used in the previous studies of this dissertation. The survey contained 9 questions that reflected the constructs of the joint model that blended the incentive theory, the UTAUT, and the Status Quo Bias models. In particular, Q1 collected data on whether BIM is being utilized in the project. The response was measured using a dichotomous (yes/no) measure. Q2 collected data on the best classification of the BIM system used in the respondent’s project and was measured by a multiple-choice logic corresponding to BIM adoption Level 1, Level 2, and Level 3, respectively.

Q3 was used to collect data on the type of respondent’s company through a multiple-choice logic corresponding to specific types of companies (architectural company, engineering consultancy, project management company, main contractor, trade contractor, construction client/owner, material supplier, BIM consultant, other). Next, Q4 collected data on the type of project delivery method that was utilized on the construction project in question (Design-Bid-Build, Design-Build, Integrated Project Delivery, Other). Q5 collected data on which form of Integrated Project Delivery was employed through a 5-item multiple-choice logic (AIA Form 295 Transitional IPD, AIA Form C195 Full Integration, ConsensusDocs 300, unknown, other). Q6-Q9 collected data on respondents’ attitudes regarding a number of statements directly related to the decision to adopt and use BIM. The attitudes in these questions were measured using a 5-item Likert scale (i.e., strongly disagree, disagree, undecided, agree, and strongly agree). Then, a SurveyMonkey link was created and circulated to participants.

Because the Synthesized Secondary Survey was conducted with a dual purpose of empirically exploring the predictions of the joint model and achieving a higher degree of explanatory consistency and exhaustiveness, the primary attention in the data analyses was focused on correctly identifying and closely examining new relationships and interactions. Therefore, only those results will be discussed in the following pages that add new insights to the problem under investigation.

## 3.4. Qualitative Study (Case Study)

### *3.4.1. Purpose*

The purpose of the case study was twofold. First, it was necessary to appropriately contextualize the results of the quantitative analyses. Because the results of the quantitative analyses have revealed a number of key trends and critical perceptions that inform how project delivery environments affect BIM adoption, the case study sought to better frame the latter through qualitative analyses based on data from a real-world construction environment. Second, a reliable cross-validation of previous conclusions was also required. Because the results of the four quantitative studies of this dissertation in many respects revealed similar trends, it was necessary (a) to evaluate whether these trends do in fact exist, and (b) can be reliably confirmed by experienced AEC industry professional serving as key decision makers.

### *3.4.2. Research question*

The following overarching research question guided the case study: What specific factors in the opinion of the key decision makers affect adoption of BIM, and does the use of Exceptional Project Delivery Paradigm at San Francisco International Airport serve as a moderator in the process?

### *3.4.3. Qualitative paradigm*

Researchers typically can rely on qualitative, quantitative, or mixed methods in their research (Perri & Bellamy, 2012). However, the selected research method should always be appropriate for the investigative purpose of the study (Dane, 2017).

Quantitative and mixed methods are subject to existing knowledge and are used to test hypotheses and for studying relationships between variables (Knowlton & Phillips, 2013). In contrast, qualitative research investigates various social and economic phenomena relying on non-statistical methods (Howell, 2014). Qualitative methodology relies on direct and detailed narratives from the perspective of the research participants (Letherby & Williams, 2013). Qualitative approach also serves as a means of exploring unique problems and social and organizational issues in their natural contexts (Ravich & Riggan, 2016).

Qualitative approach to the exploration of business problems offers a number of advantages compared to quantitative instruments. In particular, (a) qualitative research generates much more comprehensive information about the phenomenon under study (Marshall & Rossman, 2015); (b) it allows to treat the phenomenon holistically (i.e., without dissecting it into separate parts); (c) it permits observing research participants and collects data in natural settings. The process of qualitative data collection can proceed for prolonged periods of time allowing to investigate at the phenomenon through the prism of longitudinal analysis (Aneshensel, 2013).

Creswell suggests that qualitative research can be especially helpful if there is a genuine need to gain a comprehensive understanding of a social or business problem about which there is either limited, inconsistent, or controversial information (Creswell, 2018). Thus qualitative method enables researchers to gain new insights on issues and problems already known, or to obtain more in-depth information, which may be problematic to present quantitatively (Creswell & Poth, 2017).

Another intrinsic characteristic of qualitative method is that it is emergent in design. It does not have already programmed outcomes. Such unique quality of qualitative method allows the researcher to concentrate on the result and the outcome of a study concurrently (Knowlton & Phillips, 2013). The emergent design of qualitative research offers an additional advantage over quantitative methods. It does not suffer from research path dependency (Letherby & Williams, 2013). It is dynamic, and provides an opportunity for any skilful investigator to dig deeper into the subject matter of the research with an intent to uncover as much valuable information as possible to explain various aspects of the phenomenon studied (Dane, 2017). Due to the nature of the overarching research problem of this dissertation and the type of data that were already collected, and analysed, quantitative, and mixed methods approaches for this case study were not justified. Instead, a qualitative approach was chosen.

### *3.4.4. Research design*

Several qualitative designs such as phenomenology, ethnography, content analysis, and case study are available for qualitative research (Simmons, Mukhopadhyay, Conlon, & Yang, 2011). Researchers relying on phenomenology investigate the lived experiences of various psychological phenomena (van Manen, 2014). Those who utilize ethnography explore social customs, networks, and practices, i.e. culture (Lune & Berg, 2016). Finally, researchers use content analysis to comprehensively examine large amounts of textual information (Marshall & Rossman, 2015). Given these options and for the reasons mentioned in the previous section, an explorative multiple case study research design with pretest/post-test questionnaire-based interviews was viewed as the most appropriate research design for the following reasons.

First, using this design will allow the close exploration of the IPD and BIM use for the delivery of SFO's construction projects, because a multiple case study design is a comprehensive strategy of qualitative inquiry to derive the information about a specific clearly defined issue from relevant key informants (Yin, 2015; 2017).

Second, by relying on the case study design it will be possible to explore the direct experiences of individuals who have unique and immediate knowledge of an issue or a process and serve as key decision makers (Barratt, Choi, & Li; 2011). Third, such design is the most applicable in the context of exploring the localized experiences of a focused group of people (Stake, 2005) – the research population of this study. Lastly, such design is most appropriate when the research intent is exploratory (Hancock & Algozzine, 2011), and the results of the qualitative analyses will serve to complement findings from previously conducted quantitative studies.

In the most general sense, a case study design involves investigating perspectives of a phenomenon or event. A qualitative multiple case study will enable the research to gain a deeper understanding of the topic. Since this study will involve collecting data through interviews, the issue of data saturation must be addressed. As methodology texts suggest, interviews must continue until the data reaches the point of saturation (Letherby & Williams, 2013; Maxwell, 2013). Some suggested that in interviews the point of saturation occurs with 8-10 individuals (Yin, 2017), while others contended that larger number would be required to achieve redundancy. However, because the data needed for this case study can be obtained only from a very small group of executives tasked with project delivery at SFO, data were collected from only two informants, but those informants were the #1 and #2 decision makers within the construction organization under study. To address the issue of data saturation, the key informants were allowed to elaborate on the questions as much as they so choose.

### *3.4.5. Sample*

The population of the study included all possible key informants who are currently key decision makers within the SFO construction team. The participants in this case study were selected from the population using purposive sampling and they all meet the following research sample inclusion criteria: (a) they manage delivery of large-scale construction processes at SFO; (b) they have close familiarity with issues directly relevant to the IPD and BIM utilization; and finally, (c) they were willing to provide detailed insights into the subject matter of the current case study.

### *3.4.6. Purposive sampling*

Purposive sampling helps to gain specific information from the population most likely to have the information (Ray, 2012). In this case study, the information was related to the utilization of IPD and BIM in construction projects at SFO. Methodology texts recommend selecting key informants based on the study criteria and the ability of research participants to answer the research questions (Radley & Chamberlain, 2012), while others argued that a strength of purposive sampling is in the selection of individuals who can provide perspective on the research topic and closely align it with the overarching research question (Marshall & Rossman, 2015). Given these considerations, purposive sampling was used to draw participants from the candidate pool of individuals meeting the participation criteria.

### *3.4.7. Participants*

After careful consideration, two high-level key decision makers were selected to participate in this case study. They were selected because they:

1. Currently work at SFO.
2. Were/are actively involved in the delivery of the two construction projects (Air Traffic Control Tower and Terminal 1 Redevelopment), and
3. Are familiar with the Exceptional Project Delivery Paradigm.

***Participant 1.*** For the purposes of this case study and to protect the personal identity of the participant, the participant is referred to as the Chief Development Officer (CDO). Participant CDO earned a bachelor's degree in architectural engineering and is a registered licensed Civil & Structural Engineer. Participant CDO had at the time of the interviews nearly 30 years of direct experience in the design and construction industry. Participant CDO has been in the current executive position for over six years, has extensive expertise in BIM and IPD and actively participates in SFO knowledge development, management, and transfer. Specifically, Participant CDO was part of the team that developed the Exceptional Project Delivery Paradigm for SFO. This participant also sits on various professional committees and is an active member of several construction industry professional associations. Highly advanced expertise in the delivery of construction projects of various scales and the current scope of decision-making responsibilities at SFO makes Participant CDO an especially valuable key informant who can provide high-quality information.

***Participant 2*.** For the same reasons as above, this research participant is referred to as the Director of Infrastructure Information Management (DIIM). Participant DIIM has received an MBA degree and also recently an Advanced Certificate in Visual Design and Construction. Participant has been with SFO for 18 years and occupied progressively more responsible decision-making positions in the SFO management team. This participant established and is presently overseeing Geographic Information System (GIS) at SFO. Most importantly, Participant DIIM in the last several years has been spearheading an enterprise implementation of BIM through the use of Virtual Design and Construction (VDC) principles. Also, since 2015, this participant has been directing SFO's Design and Construction Division's Technology Visioning Program, focusing on research, development, and deployment of practice technologies. The educational qualifications and extensive decision-making experience with the two SFO construction projects as well as close familiarity with BIM make this participant a high-quality informant.

### *3.4.8. Principles*

Two main principles guided collection of qualitative data in this case study. The first principle was clear identification of both the sources and the chain of evidence to use within the study (Yin, 2017). The second principle was proper contextualization of all sources of evidence as understanding of specific meanings and contexts is important in qualitative research (Lune & Berg, 2016). Adhering to these two principles and following an established research sequence ensured collection of reliable and valid data (Howell, 2014).

### *3.4.9. Instrumentation*

The instruments that were used to collect qualitative data in the current case study included:

4. The researcher,
5. Semi-structured interviews,
6. A tape recorder,
7. Relevant documentation.

The primary data collection instrument was the researcher, and the semi-structured interviews were the secondary instrument of the case study. Some authors suggested that the researcher and interviews represent the most important sources of evidence in qualitative research (Miles, Huberman, & Saldaña, 2013). To engage in a face-to-face, semi-structured interview technique, key decision makers were asked questions based on the theoretical expectations or results (depending on pre-test/post-test) developed based on the extant literature and the findings of quantitative studies discussed earlier in this dissertation.

Interviews were the secondary data collection instrument in this case study. The interviews were used to collect data from key decision makers who have specific knowledge and information on IPD and BIM utilization at SFO that could not have been available for the researcher through other means (Barratt et al., 2011). Interviews in qualitative research are used to identify and correctly describe meanings of central themes and problems associated with specific organizational and business processes (Miles et al., 2013). Interviews are particularly valuable in obtaining in-depth information about a problem from a participant's personal experience (Seidman, 2013). Interviews also allow to establish a direct rapport with research participants, and enable trust creation to acquire important information the research participant would not normally reveal by any other method of data collection (Rubin, 2011).

### *3.4.10. Process*

All interviews in the current case study were semi-structured and relied on open-ended questions allowing for the opportunity to speak as long as necessary (Rubin, 2011). The semi-structured interviews with open-ended questions are the most efficient of the qualitative interviewing techniques because they significantly reduce the researcher's bias and indirectly contribute to reductions in the overall level of subjectivity because the data collected can be cross-validated (Letherby & Williams, 2013). In addition, such an approach to interviewing increases the overall reliability of the interview and eliminates the opportunity of significant differences in the interview process as the research participants are not restricted to answer choices provided by the researcher and will have the opportunity to provide answers using their own words (GAO, 1991; Rubin, 2011).

### *3.4.11. Data organization*

Qualitative data are the written records and notes, audio-video recordings and transcripts, observations, and gestures recorded in journals before coding (Miles et al., 2013). A credible qualitative research typically generates relatively large amounts of data that align with the study's conceptual framework, answer the research question, and address the research problem (Miles et al., 2013). However, such data should be correctly structured because based on sufficiently structured data provided, other researchers can replicate the study utilizing the same methodology to either substantiate or dispute the research claims (Marshall & Rossman, 2015). Also, a transparent and structured organization of qualitative data suggests research rigor (Merriam, 2015). In view of these issues, all qualitative data collected in this case study were organized as clearly and consistently as possible.

### *3.4.12. Data analysis*

The analysis of qualitative data is the systematic process of examining, organizing, and transforming the collected primary data into a form suitable for explorations, sensemaking, and interpretation of the studied phenomenon or problem (Miles et al., 2013). The analysis of qualitative data is challenging, and requires a high degree of consistency and veracity (Lune & Berg, 2016). An appropriate method of analysis of qualitative data is critical for the correct identification of the main themes that address the research question (Miles et al., 2013). In the qualitative approach, the main source of themes is interviews (Miles et al., 2013), although themes can also be extracted from the extant literature on the topic of research (Cooper, 2020). Given the large amount of qualitative data generated by the interviews, the data were analysed using NVivo qualitative data analysis (QDA) computer software. NVivo was designed for qualitative researchers working with very rich text-based and/or multimedia information, where deep levels of analysis on small or large volumes of data are required (Bazeley & Jackson, 2013).

***Reliability*.** Reliability is broadly defined as a measure of the consistency of results over time and the replicability of results using similar research methods (Letherby & Williams, 2013). Reliability also measures how well the sample results reflect the characteristics of the population (Merriam, 2015). These criteria are integral requirements to comply with the research community guidelines. According to NVivo software designers, the results of all data analysis conducted using the software ensure replicability of this study by other researchers (Bazeley & Jackson, 2013). To assure that the research sample reflected the characteristics of the entire research population, purposive sampling of key informants closely familiar with IPD and BIM use at SFO was used. Purposive sampling is a reliable sampling method for multiple case studies (Ray, 2012). Dependability of the collected data was achieved by asking each research participant to review the transcript of the interview and confirm that all answers were recorded correctly.

***Validity.*** Validity is usually defined as “the degree to which a result of a study is likely to be true and free of bias, i.e. systematic errors” (Booth, Papaioannou, & Sutton, 2016, p. 137). All validity requirements were fully satisfied in this case study. In a qualitative case study that uses interviews as a data collection instrument, consistent application of the interview protocol and documenting the validation procedure increase internal validity. Therefore, the same interview protocol for all research participants was used. The research participants validated the interview transcripts and the interpretation through transcript review and member checking, ultimately ensuring a correct report and accurate interpretation of the information.

### *3.5 Closing*

Following the tenets of progressive elaboration, the preceding outlined the literature review and how it guided the choice of methods. Moreover, each of those methods were themselves guided by the results of the successive studies. In this way, the quantitative and qualitative results outlined in the following chapter act as both guides and explanatory tools for the unique economic phenomena surrounding the BIM decision calculus.

# 4. Chapter 4: Results

## 4.1. Exploratory Study

### *4.1.1. Background*

In seeking to understand why the industry continues to experience pervasive limited application of collaborative BIM despite extensive research evidencing its benefits, it must first be recognized that a fully developed BIM model requires that a great deal more information be provided by contractors, subcontractors, and suppliers at a much earlier stage in the project lifecycle. In an industry where power is based largely on information asymmetry, this creates a significant impediment.

Further, while BIM is clearly a boon to the project as a closed system, for the individual stakeholder (particularly main and trade contractors), it increases work, largely eliminates high profit change orders, as well as decreases bargaining position. Contractors are participating in BIM applications in order to be awarded a contract and be technically able to present their design, but simple obligatory participation cannot facilitate the information-sharing necessary for the creation of a collaborative model. Rather, the goal must be to incentivize participation in such a way as to overcome the inhibitions that discourage stakeholders from fully realizing BIM's potential.

### *4.1.2. Aims*

As a coordination-facilitating information technology, BIM entails a well-conceived incentive system to reap its full potential based on schedule and cost reductions. However, incentive problems seem to have been considerably under-addressed in both theory and practice. As noted in the literature review, despite voluminous published academic research on BIM, extant studies focusing on incentives driving BIM uptake are severely limited. That which has been conducted generally take a macro-holistic approach including the incentive impacts of government regulatory bodies, educational institutions, and insurance companies, but no empirical research whatsoever was found on the efficacy of direct incentive strategies for participation in BIM systems. As a first step in an effort to establish practical strategies for incentivizing BIM, the purpose of this survey is to explore practitioners' awareness of potential incentive problems and associated possible solutions in order to signpost the direction of further BIM incentive research within this dissertation. More specifically, this chapter aims to address the following two aims:

*Aim 1: Establish the current state of BIM application*

1. The frequency of the three levels of BIM application being used in the surveyed projects.
2. The frequency of Integrated Project Delivery (IPD) being used in BIM-enabled projects.
3. The frequency of different IPD contract forms being used in BIM-enabled projects.

*Aim 2: The testing of hypotheses in respect to incentive design in BIM systems*

*Part I:* Importance of issues involved in the design of a BIM incentive scheme.

1. Experience: The effect of experience on one's perception of the incentive problems in BIM systems in terms of the average score from respondents of different disciplines.
2. Respondent's position on the supply chain: The effect of respondents' discipline on their perception of the incentive problems in BIM systems.

*Part II:* Identifying factors facilitating or inhibiting the implementation of incentive schemes in BIM systems.

1. To comment on the desirability of providing monetary rewards in incentivizing contractors.
2. To comment on the desirability of a group-based reward scheme.
3. To comment on the necessity of including subjective metrics in measuring the contractor's contribution.
4. To comment on the desirability of assigning different weightings to performance metrics.

5. To comment on the desirability of adopting a linear compensation scheme.
6. To comment on the difficulty in choosing a right bonus pool for motivating contractors.

Part III: Identifying the most effective incentive measures.

### *4.1.3. Results*

The survey saw a return rate of 1.6% from the 23,041 membership at the time of distribution over a survey duration of three weeks. It should be noted that there were 190 responses to the Likert scale and ranking questions 9 – 11, which represents just 50% of those respondents who completed Questions 1 – 7. Based on feedback from the sample population, it is understood that this is due to the fact that Likert scale questions are difficult to read on mobile device screens as opposed to desktops and laptops. Whereas the answers for questions 1 through 7 were presented vertically and are therefore optimized for any screen, Likert scale answer options are presented horizontally. This means that for mobile devices, the typeface would be zoomed out to such a degree as to make it illegible. The question can still be answered by zooming in and scrolling from left to right for every question, but it is assumed that respondents simply abandoned the survey rather than put forth the additional effort. As noted earlier, users would have generally received the link via email, and research has shown that mobile devices accounted for 51% of email opens in December 2013 (Litmus, 2014). The correlation is clear, and while this unforeseeable technical issue did preclude a number of responses, there was still more than sufficient data collected to draw valid conclusions. It should be noted moving forward that the trend towards mobile devices over computers is an important factor to consider for any follow-up questionnaires, as well as research methodology in general.

**Question 1:** *How would you characterize your level of experience with BIM?*

*Table 1. Individual Level of BIM Experience*

| **Answer Options** | **1 no experience** | **2 some experience** | **3 moderately experienced** | **4 highly experienced** | **5 subject matter expert** | **Rating Average** | **Response Count** |
|---|---|---|---|---|---|---|---|
| Response Percent | 1.85% | 10.80% | 31.17% | 36.42% | 19.75% | 3.61 | 324 |
| Response Count | 6 | 35 | 101 | 118 | 64 | | |
| | | | | | *answered question* | | 324 |
| | | | | | | *skipped question* | 48 |

Given the group composition, it was assumed that the majority of the survey population would self-identify as moderately experienced or higher. This was generally true, although since BIM is a topic of interest for novices and students, the group also included a few individuals not as highly experienced. Table 1 illustrates the results of this first control question. The average of the 324 respondents was between "moderately experienced" and "highly experienced", trending towards the latter. This is in line with expectations. Those who described themselves as having no experience identified their work roles as: project management consultant (1), architect (1), owner's internal project management team (2), engineer (1), and tender manager (1). Those who identified themselves as subject matter experts were mostly architects (18), project management consultants (11), or identified as other (16). These open-ended responses were almost universally variations of BIM Manager or BIM Consultant. Future research should include these as options on subsequent surveys.

**Question 2:** *What is the best classification for the BIM system used in the latest project you were involved in?*

*Table 2. BIM Classification Systems*

| **Answer Options** | **Response Percent** | **Response Count** |
|---|---|---|
| *Level 0:* Unmanaged CAD, in 2D, with paper or electronic paper data exchanges. | 6.3% | 23 |
| *Level 1:* Managed CAD in 2D or 3D format with a collaborative tool providing a common data environment and standardized approach to data structure format. Commercial data managed by standalone finance and cost management packages with no integration. | 36.5% | 134 |
| *Level 2:* A managed 3D environment held in separate discipline BIM tools with data attached. Commercial data managed by enterprise resource planning software and integrated by proprietary interfaces or bespoke middleware. This level of BIM may utilize 4Dc. | 47.7% | 175 |
| *Level 3:* Characterized by a fully integrated and collaborative process enabled by web services, and incorporating 4D construction sequencing, 5D cost information and 6D project lifecycle management information. | 9.5% | 35 |
| *Answered Question* | 367 | |
| *Skipped Question* | 5 | |

Because BIM literature generally describes collaborative BIM (Level 2 or above) as being in the nascent stages of proliferation, it was hypothesized that the majority of BIM classifications would be identified as Level 1. However, it was found that over half of all respondents reported having worked with Level 2 BIM or higher on their latest BIM-enabled project. Respondents reporting having utilized Level 3 BIM were slightly less than 10%, which, while higher than expected, evidences the drastic underutilization of this readily available technology.

It should also be noted that the phraseology of Question 2 is loosely based on the Bew-Richards BIM Maturity Model (Bew & Richards, 2008), but makes use of modified language compiled from a variety of sources.

**Question 3:** *In what role were you involved in BIM-enabled projects most of the time?*

*Table 3. Roles in BIM-Enabled Projects*

| **Answer Options** | **Response Percent** | **Response Count** |
|---|---|---|
| Owner’s internal project management team | 5.7% | 21 |
| Architect | 30.7% | 113 |
| Engineer | 13.6% | 50 |
| Quantity surveyor | 3.0% | 11 |
| Project management consultant | 8.7% | 32 |
| Main contractor | 9.2% | 34 |
| Trade contractor | 6.0% | 22 |
| Material supplier | 0.3% | 1 |
| Equipment supplier | 0.5% | 2 |
| Never involved | 0.5% | 2 |
| Other (please specify) | 21.7% | 80 |
| *answered question* | | 368 |
| *skipped question* | | 4 |

As could be expected from a BIM-related trade group, the largest percentage of respondents’ job role was architects. Interestingly, the second largest group was “other”. These others included mostly variations of BIM Manager and BIM Consultant, with four coming from academia and a selection of other roles with a single response. For the purposes of its applicability as a control question, having no more than 1/3 of the sample population in any one job role should provide enough diversity to derive valid conclusions across the built environment.

**Question 4:** *What type of company do you work for?*

*Table 4. Type of Company*

| Answer Options | Response Percent | Response Count |
|---|---|---|
| Architectural company | 32.8% | 120 |
| Engineering consultancy | 21.0% | 77 |
| Project management company | 8.7% | 32 |
| Main contractor | 9.8% | 36 |
| Trade contractor | 5.5% | 20 |
| Material supplier | 0.3% | 1 |
| Equipment supplier | 0.5% | 2 |
| Other (please specify) | 21.3% | 78 |
|  | *answered question* | 366 |
|  | *skipped question* | 6 |

As expected, the results of question 4 closely mirrored those of question 3, with architects (30.7%) working for architectural companies (32.8%), main contractor job roles (9.2%) working at main contracting companies (9.8%), etc. While similar in format and content, the two questions do serve distinct roles as variables in further study.

**Question 5:** *How many years have you worked in the construction industry?*

*Table 5. Construction Industry Seniority*

| Unit of Measure | Response Average | Response Total |
|---|---|---|
| Years | 15.6 | 5,677 |
| Answered Question | | 364 |
| Skipped Question | | 8 |
| **Statistics** | | |
| Range | | 0 - 50 |
| Lower 1/4 | | 0 - 8 |
| Upper 1/4 | | 22 - 50 |
| Median | | 14 |
| Mode | | 10 |

Overall, the sample population provided a highly experienced group of construction professionals, with a range of 0 – 50 years of experience. For the purposes of calculating responses for inexperienced vs. experienced respondents, lower and upper quarters were established of 0 – 8 and 22 – 50, respectively. The mode for the entire population was 10 years (31), followed closely by 15 years (30) and 20 years (29). This middle half of the population provides the journeyman level of experience that makes up most of the construction industry.

**Question 6:** *Where is your current or most recent project located?*

*Table 6. Project Location*

| Answer Options | Response Percent | Response Count |
|---|---|---|
| United States | 36.1% | 132 |

| | | |
|---|---|---|
| United Kingdom | 18.0% | 66 |
| China | 0.5% | 2 |
| Japan | 0.5% | 2 |
| European Union | 11.7% | 43 |
| Australia | 3.6% | 13 |
| Other (please specify) | 29.5% | 108 |
| | *answered question* | 366 |
| | *skipped question* | 6 |

What was surprising was the number of “other” responses, as the list of available countries included the three consistently noted for leading in commercial construction: USA, China, and Japan. However, it is observed that LinkedIn.com is blocked in China as a social networking site, and it has only recently (2011) reached Japan with reports showing minimal adoption in that country. Of the “other” responses, the most common were Canada (15) and India (10).

**Question 7:** *Did you utilize Integrated Project Delivery (IPD) on any BIM-enabled projects?*

*Table 7. IPD Utilization on BIM-Enabled Projects*

| **Answer Options** | **Response Percent** | **Response Count** |
|---|---|---|
| Yes | 29.1% | 106 |
| No | 70.9% | 258 |
| | *answered question* | 364 |
| | *skipped question* | 8 |

Whereas no secondary data exists detailing the number of projects currently utilizing IPD, it is generally accepted that while highly regarded in theory, this contracting strategy has seen low uptake in practice. It was therefore expected that a sample population specific to BIM would have a higher percentage of IPD experience, but even with this caveat the affirmative response rate of 29% was surprisingly high. This higher-than-expected percentage provides some interesting research opportunities on the viability and effectiveness of the respective IPD formats and their component incentive vehicles.

**Question 8:** *Which form of IPD was employed? (If multiple IPD formats have been used, please specify that which was utilized most recently).*

*Table 8. IPD Form*

| **Answer Options** | **Response Percent** | **Response Count** |
|---|---|---|
| AIA Form A295 - Transitional IPD | 31.8% | 14 |
| AIA Form C195 - Full Integration | 11.4% | 5 |
| Consensus Docs 300 | 20.5% | 9 |
| Other (please specify) | 36.4% | 16 |
| | *answered question* | 44 |
| | *skipped question* | 328 |

Question 8 was presented in a skip logic format that appeared only if Question 7 was answered in the affirmative. However, as the second part of the skip logic question, it appeared on a new screen with the Likert scale questions 9 – 10, and as such suffered from the aforementioned formatting issue, thus leading to the lower answer total of only 44 out of the 106 respondents that received the question. Those that did respond provided a novel view of what contract forms are currently being employed for the small segment of the industry that has adopted this forward-thinking contract strategy.

Expectedly, AIA Form *A295 - Transitional IPD* had the largest percentage response of the answer options provided. By following traditional models of risk management and compensation, transitional IPD employs collaborative principles in a format more familiar to users and is thus likely to be the most palatable to stakeholders. Likewise, AIA Form *C195 – Full Integration* is the most dissimilar from traditional design and construction contracts, and thus has seen the least percentage use. The amount of “other” responses was unexpected, with the most common answer being that a custom format was created (6). The second most common answer was some form of “unknown” (5), so the value of these responses remains unclear. For the purposes of Aim 1-C, the variety of answers is certainly least interesting enough to warrant further study.

**Question 9:** *To what extent do you agree with the following statements?*

*Table 9. Rewards and Incentives*

| Answer Options | 1 strongly disagree |  | 2 Disagree |  | 3 neither agree nor |  | 4 agree |  | 5 strongly agree |  | Rating | Response |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | Response Percent | Response Count | Response Percent | Response Count | Response Percent | Response Count | Response Percent | Response Count | Response Percent | Response Count | Average | Count |
| Monetary rewards can improve the effectiveness of BIM considerably better than non-monetary rewards | 3.17% | 6 | 8.47% | 16 | 22.75% | 43 | 49.21% | 93 | 16.40% | 31 | 3.67 | 189 |
| Group based rewards will work considerably better than individual rewards in incentivizing contractor participation in BIM systems | 2.12% | 4 | 7.41% | 14 | 30.69% | 58 | 42.86% | 81 | 16.93% | 32 | 3.65 | 189 |
| Objective metrics are considerably better than subjective ones as the | 2.12% | 4 | 4.23% | 8 | 31.22% | 59 | 48.15% | 91 | 14.29% | 27 | 3.68 | 189 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| basis for determining incentive rewards for BIM participants | | | | | | | | | | | |
| It is absolutely necessary to assign different weightings to performance metrics in the determination of incentive rewards for BIM participants | 1.06% | 2 | 7.45% | 14 | 35.11% | 66 | 42.02% | 79 | 14.36% | 27 | 3.61 | 188 |
| A simple linear reward sharing rule (e.g., reward linked to a fixed percentage of cost savings) will work considerably better than a more complicated non-linear reward sharing rule in incentivizing contractors to contribute to BIM | 4.76% | 9 | 15.87% | 30 | 31.22% | 59 | 40.74 | 77 | 7.41% | 14 | 3.30 | 189 |
| There is a minimum amount of incentive reward that can motivate contractors' full participation in BIM | 2.65% | 5 | 20.63% | 39 | 29.63% | 56 | 33.86% | 64 | 13.23% | 25 | 3.34 | 189 |

*answered question* 190

*skipped question* 182

Table 9 illustrates the overall response averages across all disciplines and experience levels. One can see that some level of agreement occurred for all questions, albeit to varying degrees. Each question is reviewed on the following pages in the context of Aim 2 and their respective hypotheses:

*Aim 2, Part 1.1 – Experience.*

**Monetary rewards can improve the effectiveness of BIM considerably better than non-monetary rewards.**

*Hypothesis: Experienced respondents > Inexperienced respondents*

*Results:*

Lower ¼ of respondents: 3.67

Middle half: 3.75

Upper ¼ of respondents: 3.89

As expected, the average score increased to coincide with a higher level of experience.

**Group-based rewards will work considerably better than individual rewards in incentivizing contractor participation in BIM systems.**

*Hypothesis: Experienced respondents > Inexperienced respondents*

*Results:*

Lower ¼ of respondents: 3.65

Middle half: 3.65

Upper ¼ of respondents: 3.67

Given an overall variance of just .02, the researcher considers the difference between the experience levels for this question to be negligible. This will be an important distinction in the design of any future incentive strategy, as it can be used as a cornerstone upon which all parties already agree.

**Objective metrics are considerably better than subjective ones as the basis for determining the incentive reward of BIM participants.**

*Hypothesis: Both groups will equally (and strongly) agree with this statement.*

*Results:*

Lower ¼ of respondents: 3.64

Middle half: 3.72

Upper ¼ of respondents: 3.91

While both groups did in fact agree, the more experienced respondents did so to a much higher degree.

**It is absolutely necessary to assign different weightings to performance metrics in the determination of incentive reward to IM participants.**

*Hypothesis: Experienced respondents > Inexperienced respondents*

*Results:*

Lower ¼ of respondents: 3.61

Middle half: 3.62

Upper ¼ of respondents: 3.71

Again, the average score increased to coincide with a higher level of experience but not until it reached the upper ¼ of respondents.

**A simple linear reward sharing rule (e.g., reward linked to a fixed percentage of cost savings) will work considerably better than a more complicated non-linear reward sharing rule in incentivizing contractors to contribute to BIM.**

*Hypothesis: Inexperienced respondents > Experienced respondents*

*Results:*

Lower ¼ of respondents: 3.30

Middle half: 3.29

Upper ¼ of respondents: 3.42

Surprisingly, the trend favouring experienced respondents continued in this question. It was anticipated that more highly experienced individuals would favour a more robust and complex reward scheme, but this does not seem to be the case. This should be welcome news for owners looking to design such a scheme.

**There is a minimum amount of incentive reward that can motivate the full participation of contractors in BIM.**

*Hypothesis: Average score in the middle with no difference across groups.*

*Results:*

Lower ¼ of respondents: 3.34

Middle half: 3.27

Upper ¼ of respondents: 3.96

Unexpectedly, this question saw the highest variance between the upper and lower ¼'s, with experienced respondents almost universally agreeing with the statement and inexperienced ones just barely doing so. This should spur further research efforts towards establishing how owners can identify that minimum reward amount or percentage to motivate participation without over-sharing their profit.

*Aim 2, Part 1.2 – Position on the Supply Chain:*

It should first be noted that the following job roles are not included due to lack of responses: Material Supplier (0), Equipment Supplier (0), and Never involved (2). Quantity Survey is included but may present a statistical outlier having received only four responses. All tables are presented in descending order of agreement.

**Monetary rewards can improve the effectiveness of BIM considerably better than non-monetary rewards.**

*Hypothesis: Project Management Consultant > Architect ≈ Engineer > Main contractor > Trade Contractor > Quantity Surveyor > Owner's Management Team > Material Supplier ≈ Equipment Supplier*

*Table 10. Rewards and BIM Effectiveness*

| **Job Role** | **Response Average** |
|---|---|
| Project Management Consultant | 3.88 |
| Engineer | 3.76 |
| Other (please specify) | 3.76 |
| Trade Contractor | 3.73 |
| Architect | 3.68 |

| | |
|---|---|
| Main Contractor | 3.62 |
| Owner's Internal Project Management Team | 3.11 |
| Quantity Surveyor | 3.00 |

The results generally mirrored expectations, with the major differences being that architects and main contractors agreed to a slightly lower degree than expected.

**Group-based rewards will work considerably better than individual rewards in incentivizing contractor participation in BIM systems.**

*Hypothesis: Project Management Consultant ≈ Architect ≈ Engineer > Main Contractor > Trade Contractor > Quantity Surveyor > Owner's Management Team > Equipment Supplier ≈ Material Supplier*

*Table 11. Group vs. Individual Rewards*

| Job Role | Response Average |
|---|---|
| Project Management Consultant | 3.76 |
| Engineer | 3.73 |
| Other (please specify) | 3.70 |
| Trade Contractor | 3.59 |
| Architect | 3.56 |
| Main Contractor | 3.50 |
| Owner's Internal Project Management Team | 3.45 |
| Quantity Surveyor | 3.44 |

The key item of note here is the high degree of agreement from Main Contractors. This tendency towards group-based rewards will be central to the creation of any incentive based contracting strategy.

**Objective metrics are considerably better than subjective ones as the basis for determining the incentive reward of BIM participants.**

*Hypothesis: Project Management Consultant ≈ Architect ≈ Engineer > Quantity Surveyor > Main Contractor > Trade Contractor > Owner's Management Team > Equipment Supplier ≈ Material Supplier*

*Table 12. Objective vs. Subjective Metrics*

| Job Role | Response Average |
|---|---|
| Architect | 3.86 |
| Engineer | 3.73 |
| Other (please specify) | 3.68 |
| Owner's Internal Management Team | 3.67 |
| Main Contractor | 3.67 |
| Project Management Consultant | 3.44 |
| Trade Contractor | 3.36 |
| Quantity Surveyor | 3.00 |

The fact that quantity surveyors did not have a high degree of agreement for the implementation of objective metrics was surprising but is likely to have little effect on contracting strategy, while the low agreement of project management consultants is worthy of further study.

**It is absolutely necessary to assign different weightings to performance metrics in the determination of incentive reward to BIM participants.**

*Hypothesis: Project Management Consultant ≈ Architect ≈ Engineer > Owner's Management Team > Main Contractor > Trade Contractor > Quantity Surveyors > Equipment Supplier ≈ Material Supplier*

*Table 13. Weightings of Performance Metrics*

| Job Role | Response Average |
|---|---|
| Engineer | 3.96 |
| Project Management Consultant | 3.75 |

| | |
|---|---|
| Other (please specify) | 3.68 |
| Architect | 3.55 |
| Owner’s Internal Project Management team | 3.44 |
| Trade Contractor | 3.40 |
| Main Contractor | 3.33 |
| Quantity Surveyor | 3.25 |

Weighting for performance metrics was expected to be an item of particular import for project owners, so their comparatively low degree of agreement was surprising. Conversely, the fact that main contractors had the lowest degree of agreement was anticipated given that such weightings are likely to favour the owner and complicate invoicing.

**A simple linear reward sharing rule (e.g., reward linked to a fixed percentage of cost savings) will work considerably better than a more complicated non-linear reward sharing rule in incentivizing contractors to contribute to BIM.**

*Hypothesis: No difference across groups and a linear reward sharing rule would be favoured.*

*Table 14. Linear vs. Non-Linear Reward Sharing Rule*

| **Job Role** | **Response Average** |
|---|---|
| Main Contractor | 3.71 |
| Engineer | 3.54 |
| Owner’s Internal Project Management team | 3.44 |
| Quantity Surveyor | 3.25 |
| Other (please, specify) | 3.23 |
| Trade Contractor | 3.18 |
| Architect | 3.16 |
| Project Management Consultant | 3.06 |

The responses were significantly more variable than expected, although it could be understood why main contractors favour a more simplified approach in light of the results of the previous question.

**There is a minimum amount of incentive reward that can motivate the full participation of contractors in BIM.**

*Hypothesis: The average score is around in the middle, and no difference is expected across groups*

*Table 15. Amount of Incentive Reward*

| **Job Role** | **Response Average** |
|---|---|
| Project Management Consultant | 3.75 |
| Other (Please, specify) | 3.52 |
| Engineer | 3.35 |
| Main Contractor | 3.33 |
| Architect | 3.25 |
| Owner’s Internal Project Management Team | 3.00 |
| Trade Contractor | 2.91 |
| Quantity Surveyor | 2.75 |

Again, the responses were significantly more variable than expected. Given that project management consultants’ fees are ordinarily not dependent upon project profit, it could be argued that they are the most objective stakeholder for this particular question. Their high degree of agreement is therefore quite interesting and should be investigated further.

**Question 10:** *Based on your perception, to what extent do you agree with the following statements?*

*Table 16. Incentive Schemes*

| | 1 | | 2 | | 3 | | 4 | | 5 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | strongly disagree | | Disagree | | neither agree nor | | agree | | strongly agree | | Rating | Response |
| | Percent | Count | Percent | Count | Percent | Count | Percent | Count | Percent | Count | | |
| Provision of monetary rewards will actually harm cooperation between parties in the BIM system | 5.85% | 11 | 38.83% | 73 | 28.72% | 54 | 21.28% | 40 | 5.32% | 10 | 2.81 | 188 |
| Group based rewards would likely result in one party freeriding on another's effort | 2.65% | 5 | 26.46% | 50 | 25.93% | 49 | 35.98% | 68 | 8.99% | 17 | 3.22 | 189 |
| There are no objective metrics sufficient to measure contractors' contributions to BIM systems | 2.69% | 5 | 35.48% | 66 | 28.49% | 53 | 29.57% | 55 | 3.76% | 7 | 2.96 | 186 |
| It would be difficult for the owner to establish appropriate weightings for performance metrics used in a reward scheme | 1.60% | 3 | 26.20% | 49 | 19.79% | 37 | 44.39% | 83 | 8.02% | 15 | 3.31 | 187 |
| A linear reward sharing rule is too simple to reliably reflect the contribution of BIM participants | 3.23% | 6 | 19.89% | 37 | 36.02% | 67 | 34.41% | 64 | 6.45% | 12 | 3.21 | 186 |
| It would be difficult for the owner to determine the size of bonus pools that could effectively induce contractor participation in BIM | 3.19% | 6 | 23.40% | 44 | 25.00% | 47 | 43.62% | 82 | 4.79% | 9 | 3.23 | 188 |
| | | | | | | | | | | | *answered question* | 189 |
| | | | | | | | | | | | *skipped question* | 183 |

The results contained in Table 16 are reviewed in Part II below alongside the stated aims of the survey.

*<u>Part II:</u>* Identifying factors facilitating or inhibiting the implementation of incentive schemes in BIM systems

**Provision of monetary rewards will actually harm cooperation between parties in the BIM system.**

*Aim: To comment on the desirability of providing monetary rewards in incentivizing contractors.*

*Table 17. Monetary Rewards and Cooperation*

| **Job Role** | **Response Average** |
|---|---|
| Owner’s Internal Project Management Team | 3.44 |
| Engineer | 2.96 |
| Architect | 2.95 |
| Trade Contractor | 2.82 |
| Quantity Surveyor | 2.75 |
| Other (Please, specify) | 2.61 |
| Main Contractor | 2.60 |
| Project Management Consultant | 2.50 |

Only the owner agreed that monetary rewards presented a potential harm, with all other stakeholders disagreeing. Given that an affirmative response would be of benefit to owners’ bottom line, this is not surprising.

**Group-based rewards would likely result in one party free-riding on another's effort.**

*Aim: To comment on the desirability of a group-based reward scheme.*

*Table 18. Desirability of a Group-Based Reward Scheme*

| Job Role | Response Average |
|---|---|
| Trade Contractor | 3.36 |
| Owner's Internal Project Management Team | 3.33 |
| Engineer | 3.31 |
| Project Management Consultant | 3.25 |
| Architect | 3.23 |
| Main Contractor | 3.14 |
| Other (Please, specify) | 3.14 |
| Quantity Surveyor | 3.00 |

It was expected that free riding would be a larger concern to main contractors, but trade contractors' response makes sense given their position in the project environment.

**There are no objective metrics sufficient to measure contractors' contributions to BIM systems.**

*Aim: To comment on the necessity of including subjective metrics in measuring the contractor's contribution.*

*Table 19. Objective Metrics*

| Job Role | Response Average |
|---|---|
| Quantity Surveyor | 3.50 |
| Owner's Internal Project Management Team | 3.22 |
| Other (Please, specify) | 3.09 |

| | |
|---|---|
| Engineer | 3.00 |
| Main Contractor | 3.00 |
| Architect | 2.86 |
| Trade Contractor | 2.82 |
| Project Management Consultant | 2.63 |

It was expected that main contractors would have strongly disagreed with this statement, as the establishment of objective metrics seems the most likely to allow for remuneration for their BIM contributions. Their noncommittal average of 3.0 is therefore quite surprising and worthy of further review.

**It is hard for the owner to decide the weightings appropriate for performance metrics used in the reward scheme.**

*Aim: To comment on the desirability of assigning different weightings to performance metrics*

*Table 20. Metrics Desirability*

| **Job Role** | **Response Average** |
|---|---|
| Quantity Surveyor | 3.75 |
| Owner’s Internal Project Management Team | 3.56 |
| Main Contractor | 3.50 |
| Architect | 3.40 |
| Other (Please, specify) | 3.39 |
| Trade Contractor | 3.18 |
| Engineer | 3.12 |
| Project Management Consultant | 2.69 |

With the exception of project management consultants, it was generally agreed that establishing weightings would be difficult for the owner.

**A linear reward sharing rule is too simple to reliably reflect the contribution of BIM participants.**

*Aim: To comment on the desirability of adopting a linear compensation scheme.*

*Table 21. Desirability of Linear Compensation Scheme*

| **Job Role** | **Response Average** |
|---|---|
| Quantity Surveyor | 3.75 |
| Owner's Internal Project Management Team | 3.33 |
| Other (Please, specify) | 3.33 |
| Architect | 3.30 |
| Main Contractor | 3.11 |
| Trade Contractor | 3.09 |
| Engineer | 3.04 |
| Project Management Consultant | 2.88 |

It was generally agreed (to a small degree) that a linear-based scheme would be too simple, with the sole exception of project management consultants.

**It is difficult for the owner to determine the size of bonus pools that can effectively induce contractor participation in BIM.**

*Aim: To comment on the difficulty in choosing a right bonus pool for motivating contractors.*

*Table 22. Choice of Bonus*

| **Job Role** | **Response Average** |
|---|---|
| Owner's Internal Project Management Team | 4.00 |
| Quantity Surveyor | 4.00 |
| Engineer | 3.27 |
| Other (Please, specify) | 3.23 |

| | |
|---|---|
| Main Contractor | 3.20 |
| Architect | 3.18 |
| Project Management Consultant | 3.06 |
| Trade Contractor | 2.91 |

This was strongly agreed by owners, and to a lesser degree main contractors. Trade contractors disagreed, suggesting that they favour a bonus pool-based reward scheme.

**Question 11:** *Please rank the following incentive methods in their likelihood to promote participation in BIM systems (1 being the most effective, 7 being the least).*

*Table 23. Incentive Methods Likelihood*

| **Answer Options** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **Rating Average** |
|---|---|---|---|---|---|---|---|---|
| Based on value: Incentivizes the project team by offering a bonus linked to adding value to the project | 31 | 32 | 33 | 28 | 22 | 28 | 16 | 3.66 |
| Innovation and outstanding performance: The team is awarded for hard work and creativity | 26 | 35 | 29 | 40 | 22 | 26 | 12 | 3.65 |
| Performance bonuses: An award based on quality | 29 | 27 | 40 | 37 | 29 | 15 | 13 | 3.56 |
| Profit sharing: Each party's profit is determined collectively rather than individually | 21 | 30 | 26 | 33 | 39 | 25 | 16 | 3.94 |
| Subjective measurement: Bonuses depend on the owner's subjective measurement | 22 | 8 | 13 | 3 | 28 | 28 | 88 | 5.33 |
| Key performance indicators: | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Reserves a portion of the project team’s fees into a pool that can increase or decrease based on key performance indicators | 18 | 33 | 29 | 22 | 28 | 39 | 21 | 4.11 |
| Cost savings: Each party retains a share of cost savings resulting from early clash detection and other Efficiencies | 43 | 25 | 20 | 27 | 22 | 29 | 24 | 3.75 |

*answered question* *190*

*skipped question* *182*

While Table 23 provides an order of performance measures in terms of their effectiveness in promoting contractor participation in BIM according to the respondents’ perceptions, the real value of Question 11 lies in revealing the divergent preference of respondents across different disciplines over the relative advantage of a measure to the others. As such, the responses are presented below by discipline. It should be noted again that Material Supplier (0), Equipment Supplier (0) and never involved (2) were removed due to lack of responses and that Quantity Surveyor may present a statistical outlier with only four responses. Since 1 is the highest affirmative rating for these questions (7 being the lowest), the responses are presented by stakeholder in ascending order:

*Table 24. Architect*

| **Answer Options** | **Response Average** |
|---|---|
| Based on Value | 3.63 |
| Innovation and outstanding performance | 3.68 |
| Cost savings | 3.75 |
| Performance bonuses | 3.96 |
| Key performance indicators | 3.96 |
| Profit sharing | 4.02 |

| | |
|---|---|
| Subjective measurement | 5.00 |

Architects showed a tendency towards value and innovation while eschewing subjective measurement. While these results are not surprising given the inherent nature of design work, they should nonetheless play a pivotal role in the design of an incentive arrangement.

*Table 25. Engineer*

| **Answer Options** | **Response Average** |
|---|---|
| Performance bonuses | 2.96 |
| Based on value | 3.15 |
| Profit sharing | 3.38 |
| Innovation and outstanding performance | 3.85 |
| Cost savings | 4.19 |
| Key performance indicators | 4.62 |
| Subjective measurement | 5.85 |

Engineers significantly favoured performance bonuses, which could be a result of the objective (measurable) nature of their work. Again, subjective measurement was ranked lowest among the choices.

*Table 26. Main Contractor*

| **Answer Options** | **Response Average** |
|---|---|
| Innovation and outstanding performance | 3.24 |
| Key performance indicators | 3.33 |
| Based on value | 3.86 |
| Performance bonuses | 3.90 |
| Profit sharing | 3.90 |
| Cost savings | 4.19 |
| Subjective measurement | 5.57 |

Main contractors preferred performance-based incentives, followed closely by key performance indicators. The researcher was surprised how low contractors ranked cost savings, as this is an objective measurement over which the contractor has a high degree of control.

*Table 27. Other*

| Answer Options | Response Average |
|---|---|
| Cost savings | 3.51 |
| Innovation and outstanding performance | 3.71 |
| Performance bonuses | 3.73 |
| Profit sharing | 3.87 |
| Key performance indicators | 4.02 |
| Based on value | 4.33 |
| Subjective measurement | 4.82 |

Keeping in mind that the vast majority of “other” responses were either BIM managers or BIM consultants, the cost savings associated with BIM are ranked understandably high. Such savings are the primary evidence of the value of BIM, and by extension these stakeholders.

*Table 28. Owner’s Internal Project Management Team*

| Answer Options | Response Average |
|---|---|
| Key performance indicators | 2.56 |
| Cost savings | 3.22 |
| Innovation and outstanding performance | 3.56 |
| Performance bonuses | 3.78 |
| Profit sharing | 4.56 |
| Based on value | 4.89 |
| Subjective measurement | 5.44 |

Owners justifiably favoured key performance indicators and cost savings, two objective measures that allow the owner to track overall performance (and eventually, profit). Likewise, owners' tendency to shy aware from profit sharing and subject measurement were in line with expectations.

*Table 29. Project Management Consultant*

| Answer Options | Response Average |
|---|---|
| Based on value | 2.69 |
| Performance bonuses | 2.81 |
| Innovation and outstanding performance | 3.25 |
| Profit sharing | 3.94 |
| Cost savings | 4.06 |
| Key performance indicators | 5.00 |
| Subjective measurement | 6.25 |

The entire premise of bringing in a project management consultant is one of added value, which aligns with the results of the survey. It was surprising how low "key performance indicators" was ranked, given that project management practices make use of such indicators on a regular basis. It would be worth further study to investigate why this was ranked so low.

*Table 30. Trade Contractor*

| Answer Options | Response Average |
|---|---|
| Cost savings | 2.64 |
| Performance bonuses | 2.73 |
| Based on value | 3.18 |
| Innovation and outstanding performance | 3.82 |
| Profit sharing | 4.82 |
| Key performance indicators | 4.91 |
| Subjective measurement | 5.91 |

It is interesting to note how different the responses are for trade contractors and main contractors. While the latter favoured innovation and key performance indicators, the former ranked both of these rather low in favour of cost savings and performance bonuses. The rationale for this divergence is worth further review.

### *4.1.4. Conclusions*

Three important considerations provided the rationale for the exploratory study: (a) as a coordination-facilitating IT technology, BIM involves a well-conceived incentive system to reap its full efficiency increasing potential; (b) incentive problems have been considerably under-addressed in both extant theory and current construction industry practice; and (c) field studies focusing on incentives driving BIM adoption and utilization decisions are either severely limited in scope or generally take a macro-holistic approach, but no empirical research whatsoever had been conducted on the efficacy of direct incentive strategies for participation in BIM systems.

The exploratory study was conducted to address existing gaps in theoretical and practical knowledge stemming from these three important considerations. Specifically, relying on a questionnaire-based survey methodology, the exploratory study explored AEC industry practitioners' awareness of potential incentive problems and possible solutions to these problems in order to signpost the direction of further incentive research for BIM. In particular, the exploratory study had the following two aims:

1. *Aim 1: Establish the current state of BIM application* – i.e., (a) the frequency of the three levels of BIM application being used in the surveyed projects; (b) the frequency of Integrated Project Delivery (IPD) being used in BIM-enabled projects; and (c) the frequency of different IPD contract forms being used in BIM-enabled projects.
2. *Aim 2: Test several hypotheses in respect to incentive design in BIM systems* – i.e. (a) to assess importance of issues involved in the design of a BIM incentive scheme; (b) to identify specific factors mediating or moderating the implementation of incentive schemes in BIM systems; (c) to identify the most effective incentive measures.

The exploratory study empirically assessed practitioners' awareness of potential incentive problems and possible solutions to such problems, particularly with regards to the differing goals and perspectives of the various classes of stakeholders involved in the decision-making. The results of the exploratory study allowed to make the following conclusions:

1. As the results suggest, IPD is accounting for a significant portion of BIM contracting arrangements, thus this confirms that IPD serves as an enabler of BIM adoption by construction industry organizations.
2. Experience is a key determining factor in how respondents viewed incentive strategies, as was stakeholders' position within the supply chain.
3. With regards to the ranking of incentive methodologies by main contractors and owners, no two stakeholders presented identical or even highly similar responses to the Likert scale and ranking questions, providing a wealth of data to be used in follow-on research.

In addition to these conclusions, several potential research avenues were identified regarding degrees of stakeholder experience with incentives and integrated project delivery methods. The results of the exploratory study also underscore the critical need for further in-depth exploration of AEC industry practitioners' perception of existing problems associated with incentives to adopt and utilize BIM.

Overall, the results of the exploratory study provide partial confirmation to the predictions of the incentive theory. Specifically, that the decision to adopt BIM as an innovative coordination tool is associated with the need to increase internal organizational productivity as well as efficiency of internal management processes. The decision to adopt BIM is associated with lower labour costs and profit increases for all organizations and stakeholders involved. On the other hand, the results also suggest that the scope of BIM utilization after the initial adoption decision appears to be dependent upon the existence of a strategic opportunity for key decision-makers to maximize personal, organizational, and institutional benefits within the larger context of BIM. This finding is also consistent with the main tenets of incentive theory.

The results of the exploratory study also indicated that in practice decision to select and adopt BIM is moderated by at least two significant factors. First, the decision is moderated by high specificity of BIM itself as an asset, which in turn is further influenced by relatively low absorptive capacity of some construction industry organizations. The analyses of this study indicated that a substantial number of construction industry organizations may be lacking an underlying corporate-level IT capability and associated IT infrastructure to adopt BIM beyond Level 0 and Level 1. This may explain that almost half or 42.8% of all respondents indicated that their organizations adopted BIM on Level 0 and Level 1.

Second, the decision to adopt BIM and use it beyond the low levels of adoption may be concurrently moderated by the bounded rationality of decision makers. So, decision makers adopt BIM through a satisficing approach (Simon, 1955) and accept a specific alternative as a satisfactory, serving the current needs of their organization. This moderating logic explains the findings that (a) experience is a key determining factor in how respondents viewed incentive strategies, and (b) stakeholders' position within the supply chain in they viewed them.

## 4.2. Analysis of Incentive Questions

### *4.2.1 Background*

A central tenet of the research premise is that stakeholders within the construction supply chain require differing intensities of incentives to drive their BIM participation. At its core, a BIM system is analogous to a water supply system. The farther that users are located from the water source, the greater pressure needed to pump water to them. In a similar vein, the later one party participates in the project traditionally, the stronger incentives they will require for cooperative participation. Generally, the owner reaps most of the BIM benefit while contractors bear most of the risk and costs arising from BIM participation. This source of conflicting interests poses a significant hindrance to the efficient working of BIM and should thus be systematically investigated.

Since the differential demand for incentivization amongst a project's BIM contributors is not addressed within the literature, an instrumental first step is to explore the perceptions of BIM professionals on the usefulness of including incentive schemes in BIM-enabled projects based on their level of experience and position within the supply chain. To this end, this chapter further investigates the incentive questions from the exploratory questionnaire to establish major inhibitors/facilitators to the implementation of BIM incentives and the perceived most effective performance measures for incentive plans.

In the discussion of strategy for propelling the adoption of fully collaborative BIM, a popular view is held among BIM researchers that as long as technical problems (e.g., inoperability of data) are resolved, the desirability of switching to Level 3 BIM should be innately appreciated by practitioners. The exploratory survey results showed the contrary, as the majority of respondents acknowledge the value of incentives in improving BIM participation. This empirical evidence echoes the theoretical view that in the analysis of organizations, it is essential to make the distinction between consummate and perfunctory performance (Simon, 1955). Only when incentives are correctly formulated can the former be induced. The current research contends that the low adoption rate of Level 3 BIM is largely ascribed to the lack of understanding of the incentive problems inherent to advanced BIM systems.

### *4.2.2 Hypotheses*

In stark contrast to its prominence within social sciences (e.g., economics, accounting, psychology), the vast literature on incentives remains obscure to construction project management researchers. The current authoritative publication on the subject is a literature review paper (Chang, 2014) which outlines that the design of BIM incentivization involves six choices.

The first such choice is one of motivation and monetization. When it comes to incentives, monetary rewards are generally regarded as the most powerful instrument in aligning conflicting interests in commercial transactions (Gibbons, 2005). In agency relationships, the major barrier to contracting stems from informational asymmetry. The unobservability of the agent's effort prevents the principal from relying upon a forcing contract to assure the outcome (Holmstrom, 1979). Linking the agent's reward to the outcome of his effort through a risk-sharing arrangement would provide a solution to this so-called moral hazard problem (Roberts, 2007). However, using money as a motivator has limitations.

On the one hand, it would destroy intrinsic motivation (Deci et al., 1999), resulting in the crowding out effect (Frey & Jegen, 2001). On the other hand, strong monetary incentives could motivate the wrong behaviour (Kerr, 1975), particularly when the agent has to work in a multitasking environment (Holmstrom & Milgrom, 1991). The former would become problematic if the activity is originally driven by altruistic motives, as in the case of blood donation. Research shows that paying donors actually does more harm than good (Titmuss, 1970) as the altruistic motivation of blood donation is lessened by the existence of monetary incentives.

Incentivization type becomes an issue when there are several ends competing for the agent's attention. On both accounts, the context of BIM incentivization is of a commercial nature, so the perverse effect of monetary rewards on intrinsic motivation is less a concern than failure to induce desirable behaviour owing to the multi-objectives of the client. As multitask Principal-Agent problems can be remedied through a careful choice of performance indicators, it is expected that monetary incentives can help improve genuine participation.

Additionally, it is postulated that the powerfulness of incentives in facilitating coordination can be better appreciated by more experienced practitioners. Lastly, clients and agents would hold a divided view on the necessity of providing incentives in BIM. Perhaps, the client's ex ante bargaining advantage would force the contractor to participate in BIM by setting it as a tender requirement, but it cannot guarantee the consummate participation of non-client members, meaning there is a client-agent divide. As a result, this section hypothesizes:

**$H_1$**: *Monetary rewards can improve the effectiveness of BIM considerably better than non-monetary rewards.*

**$H_{1a}$**: *Experienced construction professionals more highly value the importance of monetary rewards than less experienced ones.*

**$H_{1b}$**: *Non-client members have a stronger demand for incentives than the client.*

The second choice is associated with the basis upon which team participants are rewarded. Teamwork is ubiquitous in a modern economy, and working as a team has an advantage in terms of efficiency when team members possess complementary resources or competencies (Alchian & Demsetz, 1972). However, if all members take an equal share of the group output, shirking may become a pervasive strategy. To curb this problem, an effective solution is to impose a group penalty should the group output fall below the target (Holmstrom, 1982). By its nature, BIM is meant to facilitate coordination among parties who participate in the project at different stages. Thus, the engineering ingenuity and innovation each party injects into the project would not be evaluated individually.

The inseparability of individual output from the project's overall outcome can limit the use of individual reward schemes in BIM. Whilst output inseparability would vary project to project, it is generally the case for BIM-enabled projects. It then follows that group-based rewards should be more feasible than individual rewards. Also, BIM users' perception of the desirability of group-based compensation would vary according to their role within a BIM system. The parties involved in coordination tasks would show stronger preference over group-based compensation than the parties (e.g., trade contractors) whose input could result in direct cost savings through, say, detection of collisions. This is also the group of parties who should worry most about freeriding in group-based compensation.

***$H_2$:*** *Group-based compensation is more desirable than individual compensation.*

***$H_{2a}$:*** *Contractors and designers have a stronger inclination to work under a group-based compensation plan than trade contractors.*

***$H_{2b}$:*** *Compared to other parties, trade contractors are more worrisome about the freeriding problem in a group-based reward scheme.*

The third issue in the design of incentive schemes concerns how to choose between objective and subjective performance indicators. In a multi-task Principal-Agent framework, the agent's attention must spread amongst several tasks. The optimal result is that the agent allocates efforts to the tasks in line with the principal's priority. To ensure this occurs, two preconditions must be satisfied (Feltham & Xie, 1994): (a) the effect of the agent's action on performance indicators must be highly correlated with its effect on the principal's objectives (congruence); and (b) the indicators can be reliably measured (precision).

In circumstances where objective measures are deficient, the principal's subjective evaluation can be used as a remedial measure to capture the aspects of performance that are either not measured or measured with bias. However, subjective evaluation is subject to serious limitations (Roberts, 2007): first, the principal may renege on the promise to discretionary rewards once the agent completes the task; second, the determination of evaluation results would contain ambiguity and arbitrariness; third, subject evaluation is susceptible to favouritism and influence activity (Milgrom & Roberts, 1990). Reputation can serve as a solution to these problems (Baker et al., 1994). As objective performance indicators (e.g., KPIs) have been popularly utilized in construction for decades, subjective evaluation could be received with suspicion. The parties that can make "concrete" contributions to BIM will prefer to see performance evaluated by objective rules rather than by discretion and will likely concern themselves with the availability of adequate subjective performance metrics.

***$H_3$:*** *Objective evaluation is more desirable than subjective evaluation in motivating contractor participation in BIM.*

***$H_{3a}$:*** *Trade contractors have a stronger preference over differential weightings than designers and contractors.*

***$H_{3b}$:*** *Trade contractors are least worried about the availability of objective performance indicators.*

The fourth choice is concerned with contract type. While linear contracts are the dominant form in practice, one must not ignore the power of non-linear contracts as more flexible functional forms for capturing the relationships between cost and price. Since most practitioners undertake linear contracts as the default choice, it is expected that this contract type retains a perceived level of preference in applications, and that this view does not vary according to the party's position on the supply chain.

***$H_4$*: Linear contracts are perceived to be more suitable than non-linear contracts.***

***$H_{4a}$*: Trade contractors have a stronger preference over objective evaluation than designers and contractors.***

The fifth question of interest is the weighting of performance indicators. Principal-agent theory suggests that a performance indicator's weighting should be lower if it varies in a wider range, and higher if it would result in a sensitive response from the agent (Banker & Datar, 1989; Holmstrom, 1979). When the value of one party's output perceived by the owner is more sensitive to the choice of weighting, the party will be more concerned with this issue. Generally, trade contractors only provide specialist services to the project, so they are more concerned with how their specific contributions are evaluated by the owner, which in turn depends on the weight given to their output by the owner. As a result, this research hypothesizes:

*$H_5$: Trade contractors are more concerned with the choice of weightings than main contractors and designers.*

The sixth and final question is whether the owner sets a threshold for the performance level at which participants are rewarded with a performance payment.

### *4.2.3 Results*

Significance of Six Decisions in Incentive Design. This in-depth theoretical analysis of the exploratory survey results relevant to incentive theory explores three overarching themes. The first is associated with the respondents' judgment on the relative desirability of key decisions involved in the design of a BIM incentivization system. The respondents were requested to comment on six affirmative statements to elicit the extent to which they agree on a 5-point scale (1: strongly disagree; 5: strongly agree). It is hypothesized that the respondents tend to concur with these propositions, i.e.:

$$H_0: \mu = 3$$

$$H_1: \mu \geq 3$$

Table 31 in Appendix F illustrates the overall average and statistical test for the six questions relevant to incentive theory. The results for all questions was that the mean of response was significantly larger than 3 at a 99% level of confidence. They indicated that: financial rewards are perceived to be of benefit to BIM collaboration; the provision of incentives should be based on group performance instead of individual contribution; objective performance indicators are expected to work more effectively than subjective ones; that owners should weight performance indicators differently in the determination of group compensation and must pay enough to yield the motivational effect of financial incentives.

Whereas the answers to the six importance questions for incentive design are consensual, the strength of parties agreeing to the propositions could be different owing to their positions within the supply chain. For ease of exposition, parties are grouped into four types according to their interest. The owner’s internal team and the owner’s consultants and designers are of the same type given the assumption that the business of architects, engineers, quantity surveyors and project management consultants are all heavily influenced by reputation, which is effective enough to drive them to act in the interest of the owner (Winch, 2001). The other three types are main contractors, trade contractors, and IT professionals. The data further reveals that groups of BIM participants hold differing views on incentives:

1. Main contractors show a stronger preference for group-based rewards than trade contractors and BIM IT experts (90% confidence level). A possible reason is associated with the nature of their contribution to the project. The primary task of the main contractor is to coordinate inputs across the supply chain, and thus its performance inherently depends upon the joint performance of teamwork. However, for trade contractors and information system infrastructure builders, the value they create for the project is relatively more discernible and would thus desire that their reward be directly tied to their contribution.
2. The importance of objective measures is rated low as the basis of incentive reward by trade contractors.
3. A marked difference in opinion appears between the owner and main contractor, where the former thinks more highly of the necessity of differentiating the relative importance of performance metrics. In theory, within a multi-task environment,

weightings provide the principal an effective means of directing the agent's effort towards the performance area most valuable to her. However, for main contractors, this strategy could increase the complexity of management.

4. Main contractors appreciate the linear reward system to a much higher degree than other groups of parties, particularly compared to trade contractors and IT experts. This result aligns with the previous point that main contractors favour a simple reward system.

**Perception of potential impediments to incentive measures**. The researcher also explored major impediments to the efficient working of incentives. The results suggested that the view of financial incentives harming intrinsic motivation is not perceived to be significant by the surveyed respondents. However, freeriding problems may occur in the team production of BIM. The possible reasons for this could be associated with (a) the difficulty in setting and maintaining reliable objective performance standards, (b) the over-simplicity of the common linear sharing rule in reflecting one party's contribution, and finally (c) the difficulty in choosing a suitable size of incentive pool.

In the survey, the highest percentage of disagreement, both overall and between disciplines, related to whether the provision of monetary rewards would actually harm cooperation within the BIM system. This result closely aligns with expectations, as well as with prior research illustrating that monetary rewards are a strong driver for any technology adoption. The proportion of respondents either agreeing or strongly agreeing with this statement was a surprising 26.6%. However, the results also indicated that the stakeholder classification with the highest degree of agreement was Owner and Consultants. This aligns with Hypothesis 1b, which foresaw that non-client members would have a stronger demand for incentives than the client owing to owners preferring to provide non-monetary incentives to contractors/suppliers. This is reinforced by main contactors providing the lowest degree of agreement outside of the "others" category, as well as this response possessing the highest disparity between disciplines. Of notable import was that the highest level of agreement related to the difficulty in establishing appropriate weighting for performance metrics.

This aligns closely with Hypothesis 3, as does the fact that of those in agreement, main contractors did so to the greatest measure. Hypothesis 3a predicted this, stating that trade contractors would have a stronger preference over differential weightings than designers and contractors. This may indicate a suspicion on the part of general contractors on the ability of the owner to provide fairness in a more complex weighted incentive scheme. This is reinforced by main contractors having the highest degree of agreement that there are no objective metrics sufficient to measure contractors' contributions to BIM systems. It would seem, based on the above, that main contractors should prefer a simple linear reward sharing rule, but this is not necessarily the case as their response indicates a belief that such a rule is too simple to reliably reflect BIM contribution (in opposition to hypothesis 4a). This begs the question that if main contractors do not significantly support objective metrics, performance weightings or simple linear sharing rules, what incentive structure would they support?

The second highest degree of agreement overall confirmed the perception that group-based rewards would likely result in one party freeriding on another's effort. In contrast to Hypothesis 2b, which foresaw main contactors being more worrisome over freeriding than other disciplines, there was not a high degree of difference between disciplines on this question, leading the researcher to believe that each stakeholder sees itself as the primary party at risk to free-riders rather as a potential free-rider themselves.

**Relative importance of performance measurement basis**. The study also measured the relative importance of performance measurement bases by asking respondents to rank a number of incentive vehicles in their likelihood to promote participation in BIM systems (1 being the most effective, 7 being the least). It was found overall that the lower numbers were associated with higher perceived effectiveness of that methodology. In line with findings discussed in the previous section, the most unpopular methodology was subjective measurement. This option was ranked lowest by trade contractors, but all classifications ranked it in the bottom quarter. The second lowest ranking option was based upon key performance indicators (KPI), which would reserve a portion of the project team's fees into a pool that increases or decreases based on KPI metrics. This was a somewhat surprising finding, as KPIs provide a level of objectivity to performance measurement. The exception to this ranking was with main contractors, who ranked this option significantly higher (3.33) than the mean of 4.11 at a 99% confidence level.

The overall highest ranked option was "Bonus: Performance bonuses: An award based on quality." This incentive method was favoured heavily by Trade and Main Contractors (2.83 and 2.90, respectively) over owners who ranked it at 3.53. Conversely, there seems to be general opposition to each party's profit being determined collectively rather than individually, a situation likely due to the previously noted fear of freeriding by other stakeholders. Trade contractors had the lowest favourability rating of this method at 4.86, preferring instead that each party retain a share of cost savings resulting from early clash detection and other efficiencies (the highest ranked option for this classification at 2.50). Value added bonuses and awards for innovations were tightly grouped with ranking averages of 3.65 and 3.63, respectively. With little disparity between classifications, these moderately favoured options could provide some measure of agreement between stakeholders in the formation of a mutually agreeable incentive solution.

### *4.2.4 Conclusions*

The research purposes for further analysis of the exploratory study incentive questions were: (a) to explore construction industry practitioners' actual level of situational awareness of potential incentive problems associated with BIM, and (b) to identify possible solutions in order to determine the future direction of incentive research for BIM. Both research purposes were accomplished, particularly with regards to the differing goals and perspectives of the various stakeholder classes. The analysis of incentive questions was conducted to address existing gaps in theoretical and current practical knowledge directly related to the purposes of the study. Specifically, the analysis of incentive questions yielded the following findings:

1. Position within the supply chain is a critical factor for the perception of the importance of incentivization issues. It was found that the largest percentage of respondents' job role was architects, and it appears that in the majority of cases,

architects are not only the most cognizant about BIM incentivization issues, but they may actively incentivize others to adopt BIM.

2. In terms of specific incentives, financial rewards are generally perceived to be of benefit to BIM collaboration; however, to be effective, the provision of incentives should be based on group performance instead of individual contribution.
3. Objective performance indicators and related incentives appear to work more effectively than subjective ones.
4. Owners appear to weight performance indicators differently in the determination of group compensation but achieve the motivational effect of financial incentives only when they use sufficient monetary remuneration.
5. BIM participants hold differing views on incentives in four respects: (a) main contractors display a stronger preference for group-based rewards and incentives than trade contractors and BIM IT experts; however, for trade contractors and information system infrastructure builders, the value they create for the project is relatively more discernible and they prefer that their reward be directly tied to their contribution; (b) the importance of objective measures is rated low as the basis of incentive reward by trade contractors; (c) a marked difference in opinion appears between the owner and main contractor, where the former thinks more highly of the necessity of differentiating the relative importance of performance metrics and incentivization; and lastly (d) main contractors appreciate the linear reward and incentives system to a much higher degree than other groups of parties, particularly compared to trade contractors and IT experts, which is consistent with the finding that main contractors favour a simple reward system.

Overall, these findings are highly consistent with the predictions of incentive theory. In particular, taken together, they suggest that (a) the possibility of increasing internal productivity appears to be the most important driver for the adoption of BIM by construction industry organizations; (b) in some instances, at least as far as the data allows to generalize, benefit maximization by some stakeholders may impose costs on other stakeholders involved; but (c) because BIM as a decision-making tool requires a substantially higher degree of information transparency, its use may create a disincentive for unscrupulous economic agents to become involved in the project.

The findings also strongly suggest that BIM does in fact require that different stakeholders fully recognize and actively internalize the advantages of collaborative processes inherent to BIM as a tool. This change in behaviour due to incentivization leads to opportunism and short-term orientation throughout the supply-chain. It must be conceded, though, that these incentive theory constructs exist primarily at the organizational level and do not sufficiently account for those stakeholders actually performing the work associated with BIM. Put plainly, just because an organization determines to accept BIM does not presage that its individual members will do the same. It has already been established that simple obligatory participation is not sufficient to bring about the deep collaboration BIM and IPD seek to achieve. Thus, a more detailed evaluation of individual decision-making constructs is required.

## 4.3. Analysis of Individual Perceptions

### *4.3.1. Background*

The hitherto focus of this dissertation, and indeed the bulk of existing research into BIM adoption, have focused solely on the aggregate (industry, company, or project) level. In such studies, several impediments to BIM adoption have been identified, including low awareness, lack of training, fragmentation of the industry, difficulties in changing traditional work processes, nebulous roles, and responsibilities in deploying BIM within organizations, and software interoperability issues. From the perspective of technology diffusion, there is one type of inhibitor that has not been investigated: the perception of BIM by users. This neglect is despite a 2004 survey of 375 organizations indicating that individual user resistance is the top-ranked challenge for the implementation of large-scale information technologies (ITtoolbox, 2004). Since BIM is at its core an information technology, it would stand to reason that it be impacted by the same forces; namely, the perceptions of individual users. The research problem for this section thus became how BIM is perceived by individual users and how those perceptions influence BIM's application on a project.

It is recognized that people who do not fully accept an innovation could delay, hinder, underutilize, or even disrupt its implementation (Brown et al., 2002). Since acceptance is an individual act based on personal perceptions, philosophically the current section is guided by the need to identify what perceptions influence behaviour (i.e., acceptance) so that the aggregate benefits of project-level adoption can be realized. In short, this research contends that users' perceptions towards collaborative BIM play a pivotal role in its current low rate of adoption.

The significance of this factor for the case of BIM adoption remains an empirical issue, in response to which this section aims to provide an opposite empirical analysis. The empirical model is based on the Unified Theory of Acceptance and Use of Technology (UTAUT) developed by Venkatesh et al. (2003). Built upon the highly influential TAM model (Davis, 1989), Venkatesh et al. (2003) refines, integrates, and validates the constructs of eight previous technology acceptance methodologies into a single model, making UTAUT a robust basis for exploring a wide range of technology diffusion issues (Wu et al., 2007; Keong et al., 2012; Oh & Yoon, 2014). Seven hypotheses were derived through the modification of UTAUT and tested through a survey employing structural equation modelling (SEM).

These findings should be of special interest to policymakers, companies, and organizations interested in the diffusion of BIM with important insights on policies, incentives, work strategies, and role structuring potentially stemming from the research. The study also investigates the UTAUT model and its robustness for predicting the diffusion of BIM, enhancing academic research on technology, and innovation acceptance.

This study commenced with a comprehensive literature review revealing that the UTAUT model provides a powerful and flexible theoretical framework for probing the perception of BIM at the individual level. Some issues with the model were addressed in order to suit the research purpose; specifically, the UTAUT model was adapted to reflect the limitations and suggestions made by the literature.

First, Attitude was included as an independent variable affecting User Behaviour. Second, moderators were adjusted to tailor the model to the context of

BIM and the scope of the research itself with the removal of age and gender. Age was removed because the moderator of experience addresses this construct with respect to BIM use. Given the fact that BIM is a specialized information technology and not in general use, and also considering the sample size of the research, the moderator of gender was not seen to fit with the model and was therefore removed.

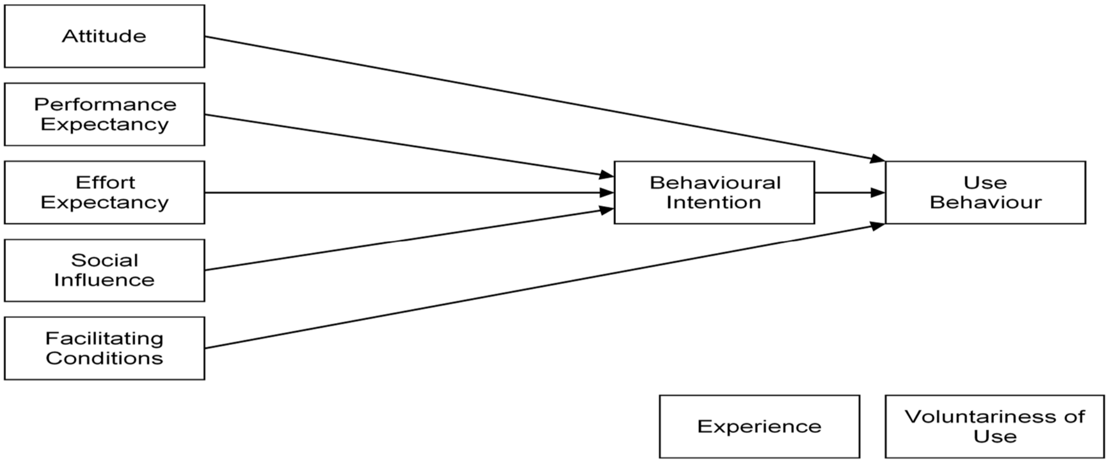


*Figure 5. Proposed Framework for UTAUT Model as Applied to BIM*

Within UTAUT and TAM literature, a Likert scale survey is normally employed for collating data in respect of the perceptions of IT system users which is then examined statistically through the use of structural equation modelling (SEM). As such, a close-ended, seven-point Likert scale survey was chosen with 1 meaning *strongly disagree* and 7 *strongly agree* and the data subsequently analysed using an econometric model (Appendix C). The primary analysis methodology of cross-sectional data econometric analysis is expounded upon below, as is the data collection strategy.

### *4.3.2. Hypotheses*

Overall, the hypotheses were drafted to correspond with the path relationships theorized by the established UTAUT model. The model contains nine variables in total: two dependent, five independent, and two moderating. The first dependent variable, Behavioural Intention, refers to the intention of the person to use the technology, and the model predicts that Performance Expectancy, Effort Expectancy, and Social influence could all affect this variable. Based on this composition, the following hypotheses were developed:

***$H_1$:*** *Performance Expectancy can strengthen individuals' Behavioural Intention to use BIM.*

***$H_2$:*** *Effort Expectancy has a positive effect on individuals' Behavioural Intention to use BIM.*

***$H_3$:*** *Social Influence will exert a positive influence on the individual's Behavioural Intention to use BIM.*

The second dependent variable, User Behaviour, measures the actual involvement of the individual with BIM. As such, the model predicts that this variable could be influenced by three factors: Attitude, Facilitating Conditions, and Behavioural Intention. Hence, the following hypotheses are developed:

***$H_4$:*** *Attitude has a positive effect on one individual's usage of BIM.*

***$H_5$:*** *Facilitating Conditions have a positive correlation with one individual's usage of BIM.*

***$H_6$:*** *Behavioural Intention can increase one individuals' usage of BIM.*

Last, the model also predicts the effect of Attitude on individuals' Behavioural Intention to use BIM:

***$H_7$:*** *Attitude will have an influence with the individual's Behavioural Intention.*

It should be noted that with Hypothesis 7, the theoretical prediction does not align with the data that SEM provides. The model predicts that Attitude will influence User Behaviour but not Behavioural Intention. However, in the interest of uniformity for hypotheses direction (null vs. alternative/test), Hypothesis 7 is phrased as written. If theory holds, the level of significance for Attitude's influence on Behavioural Intention will be less than 95% (i.e., insignificant).

The model is moderated by two variables to achieve robust conclusions. The variable of Voluntariness moderates the relationships according to the degree of freedom individuals had in choosing whether to utilize BIM, while the variable Experience measures how much practice the individual had in working with BIM. The respondents have four choices for this variable: none, less than two years, two to five years, and more than five years.

### *4.3.3. Data Analysis Using SEM*

As noted previously, UTAUT traditionally utilizes SEM for statistical analysis. Accordingly, after the data from the surveys was collected SEM was employed for data analysis utilizing the AMOS II program. Aside from its established use within UTAUT research, SEM was also chosen due to its capacity to use latent variables with the maximum likelihood method applied to run the model. It was further determined to utilize Covariance-based SEM (CB-SEM) over Partial Least Square SEM (PLS-SEM). This choice was based on Hair et al. (2011) who note that if one's research objective is theory-testing and confirmation, then the most appropriate method is CB-SEM. In contrast, if the research objective is prediction and theory development, then the appropriate method is PLS-SEM" (p. 140). In this instance the questionnaire was designed to confirm that the data fits the UTAUT model, so CB-SEM was the optimal choice. If the goal had rather been to predict outcomes using the model, then PLS-SEM would have been employed.

Figure 6 in Appendix E illustrates the complete model constructed using SEM. The squared box variables are observed variables and represent the questions asked in the survey. The circled variables represent the latent or unobserved variables. Likewise, the circled variables labelled with "e" represent the error term of each construct. Lastly, the arrows indicate the path relationships between the different variables. SEM shows the reliability of the measurement in the model, which theoretically leads to an accurate estimation of the relationships between latent variables.

### *4.3.4. Results*

**Goodness of Fit**. The optimal model specification is discovered through confirmatory factor analysis (CFA). In this process, constructs are dropped from the model if they add no predictive power. The new model is then re-estimated and compared to the old model until no improvement can be made. The acceptance of the optimal model is judged by the Chi-squared to degrees of freedom ($X^2/DF$). A rule of thumb is that $X^2/DF<3$ for accepting the general specification of the model (Kline, 2016). In term of this index (2.659), the model can be deemed satisfactory. Another index, the Comparative Fit Index (CFI), measures the degree of incremental improvement when comparing the fit of two models (Bentler, 1990; Bentler & Bonett, 1980). CFI is a good measure for an exploratory study where the causal relationships between variables are ill-understood and the number of samples is small (Rigdon, 1996). The current research is of this nature as the question of interest is this: compared to the baseline model in which no paths are estimated, is the model presented in Figure 6 a better model? A concern of SEM is that goodness of fit can be easily achieved if the parsimony issue (i.e., including unnecessary variables to improve goodness of fit) is ignored (Iacobucci, 2010). As a result, an adjustment should be made using Mulaik et al. (1989) formula. The model of this research has the value of 0.774 in the adjusted CFI, which is over the threshold value of 0.75 (Rigdon, 1996), and thus can be accepted as a good fit. Tables 32 and 33 on the following page summarize the values of the model fit measures.

*Table 31. Chi-Squared to Degrees of Freedom Ratio*

| Model | NPAR | CMIN | DF | P | $X^2$/DF |
|---|---|---|---|---|---|
| Default model | 64 | 763,017 | 287 | .000 | 2,659 |
| Saturated model | 351 | .000 | 0 | | |
| Independence model | 26 | 2,432,476 | 325 | .000 | 7,485 |

*Table 32. Model Fit Measures*

| Model | $X^2$/DF | RMSEA | GFI | CFI |
|---|---|---|---|---|
| Default model | 2,659 | .148 | .585 | .774 |

**Path Analysis.** A path analysis for the structural model was conducted to examine the hypothesized relationships that assist in predicting individuals' Behavioural Intention and actual User Behaviour towards BIM. Figure 7 in Appendix F illustrates the structural model with the results of the assessed path coefficient and the adjusted coefficient of determination ($R^2$) scores:

In order to cross-validate the predictive validity of the regression and direct the model, one question related to each latent variable was assigned a weight of one (Pace 2014). As a result, the statistical significance of the questions used in the survey is fit to measure the latent variables.

**Results for variables theorized to affect behavioural intention**. As shown in Table 34, the first hypothesis reveals that the path from Performance Expectancy to Behavioural Intention exhibits an exceedingly weak relationship in terms of coefficient (0.015) and p-value (0.921), meaning that Performance Expectancy does not significantly affect Behavioural Intention to use BIM. The hypothesis was thus rejected. This result appears at odds with what has been found in other applications of UTAUT, begging the question as to what particular characteristics make BIM unique amongst information systems?

*Table 33. Model Outcomes*

| Hypothesis | Dependent variable | Path | Independent variable | Estimate | S.E. | C.R. | P. | Label |
|---|---|---|---|---|---|---|---|---|
| $H_1$ | Behavioural Intention | ← | Performance Expectancy | 0.015 | 0.154 | -.099 | .921 | W18 |
| $H_1$ | Behavioural Intention | ← | Performance Expectancy | 0.218 | 0.171 | 1,276 | .202 | W18 |
| $H_2$ | Behavioural Intention | ← | Effort Expectancy | 0.407 | 0.114 | 3.569 | 0 | W19 |
| $H_3$ | Behavioural Intention | ← | Social Influence | 0.700 | 0.143 | 4.914 | 0 | W20 |
| $H_4$ | User Behaviour | ← | Attitude | 0.127 | 0.086 | 1.477 | 0.14 | W24 |
| $H_5$ | User Behaviour | ← | Facilitating Conditions | 0.543 | 0.161 | 3.371 | 0 | W25 |
| $H_6$ | User Behaviour | ← | Behavioural Intention | 0.218 | 0.062 | 3.507 | 0 | W23 |
| $H_7$ | Behavioural Intention | ← | Attitude | -.159 | .207 | -.766 | .444 | W24 |

The second hypothesis indicated that Effort Expectancy has a direct effect on individuals' Behavioural Intentions to use BIM, which is consistent with theory. The hypothesis was accepted based on the statistical indication that there is a strong effect (0.407) of Effort Expectancy on Behavioural Intention with $p$-value < 0.05. This effect on the individual's Behavioural Intention to use BIM implies that potential and actual users' value how easy it is to work with the technology.

The third hypothesis indicated that there is a significant relationship between Social Influence and the individual's Behavioural Intention to use BIM. The statistical result reveals that Social Influence has the greatest influence on Behavioural Intention (0.70) with the estimate remaining within the 95% CI. Hence, Hypothesis 3 was accepted. This finding suggests that of all the variables affecting Behavioural Intention, the general opinion held by BIM users has the strongest influence on individuals' Behavioural Intentions towards BIM. In addition, the relationship between Social Influence and Behavioural Intention is moderated by voluntariness, in accordance with theory, where this relationship is strengthened, especially under mandatory settings (Brown, et al., 2002; Venkatesh, et al., 2003; Koh, et al., 2010).

**Results for variables theorized to affect user behaviour**. Attitude is found to significantly affect User Behaviour. This additional construct, which Venkatesh et al. (2003) theorize to be covered by Performance Expectancy and Effort Expectancy proves to work differently in the case of BIM. In accordance with Brown et al., (2002), Yousafzai et al., (2007), and Koh et al., (2010), in which Attitude is predicted to be a separate construct affecting User Behaviour and considerably so within mandatory environments, Hypothesis 4 is accepted with a positive coefficient of 0.127 and a p-value just outside the 90 percent confidence interval. As a result, the positive or negative feelings about working with BIM led to an effect on User Behaviour. On the other hand, Hypothesis 5 indicated that Facilitating Conditions has a significant effect on User Behaviour. This hypothesis was accepted since the statistical result reveals a strong relationship (0.543) which is consistent with theory.

Hypothesis 6 indicated that Behavioural Intention has a substantial relationship with User Behaviour, which was accepted since the estimate accounted for 0.218 and was within the confidence interval. In accordance with theory, the model predicts that Behavioural Intention affects the actual User Behaviour with regards to BIM.

Finally, Hypothesis 7 stated that Attitude would influence Behavioural Intention. The results showed a negative path coefficient and a very high *p*-value (0.444), which evidences a weak statistical significance for this relationship. In the rejection of this hypothesis the theoretical prediction of the model is confirmed. The results thus predict four important correlations between variables as shown in Table 35 on the following page:

*Table 34. Correlations*

| Variable | Path | Variable | Estimate |
|---|---|---|---|
| Performance Expectancy | ←→ | Facilitating Conditions | 0.284 |
| Performance Expectancy | ←→ | Attitude | 0.648 |
| Performance Expectancy | ←→ | Social Influence | 0.306 |
| Effort Expectancy | ←→ | Facilitating Conditions | 0.609 |

Performance Expectancy has significant correlations with Facilitating Conditions of 0.284, with Attitude of 0.648, and with Social Influence of 0.306. These correlations demonstrate that the Performance Expectancy in individuals has profound effects within the model. The correlation with Social Influence is explained as the more that individuals perceive that important people think they should use BIM, the higher expectancy they will have regarding their job performance with BIM. Under this reasoning, increasing Social Influence correlates to higher expectancy in the job, and vice versa. Effort Expectancy and Facilitating Conditions likewise possess a significant correlation of 0.609, which explains how the conditions given to individuals affect the effort they expect to put into working with BIM, and vice versa.

As a result, this study revealed that five of the seven proposed hypotheses are accepted. A summary of the results for the hypotheses is shown in Table 36, and the revised model based on the SEM results shown in Figure 8.

*Table 35. Hypothesis Testing Results*

| No. | Study Assumption | Verified Result |
|---|---|---|
| **$H_1$** | Performance Expectancy will have a positive influence with the individual's Behavioural Intention to use BIM. | Rejected |
| **$H_2$** | Effort Expectancy will have a positive influence with the individual's Behavioural Intention to use BIM. | Accepted |

| **No.** | **Study Assumption** | **Verified Result** |
|---|---|---|
| **H3** | Social Influence will have a positive influence with the individual's Behavioural Intention to use BIM. | Accepted |
| **H4** | Attitude will have a positive influence with the individual's User Behaviour of BIM. | Accepted |
| **H5** | Facilitating Conditions will have a positive influence with the individual's User Behaviour of BIM. | Accepted |
| **H6** | Behavioural Intention will have a positive influence with the individual's User Behaviour of BIM. | Accepted |
| **H7** | Attitude will have an influence with the individual's Behavioural Intention. | Rejected |

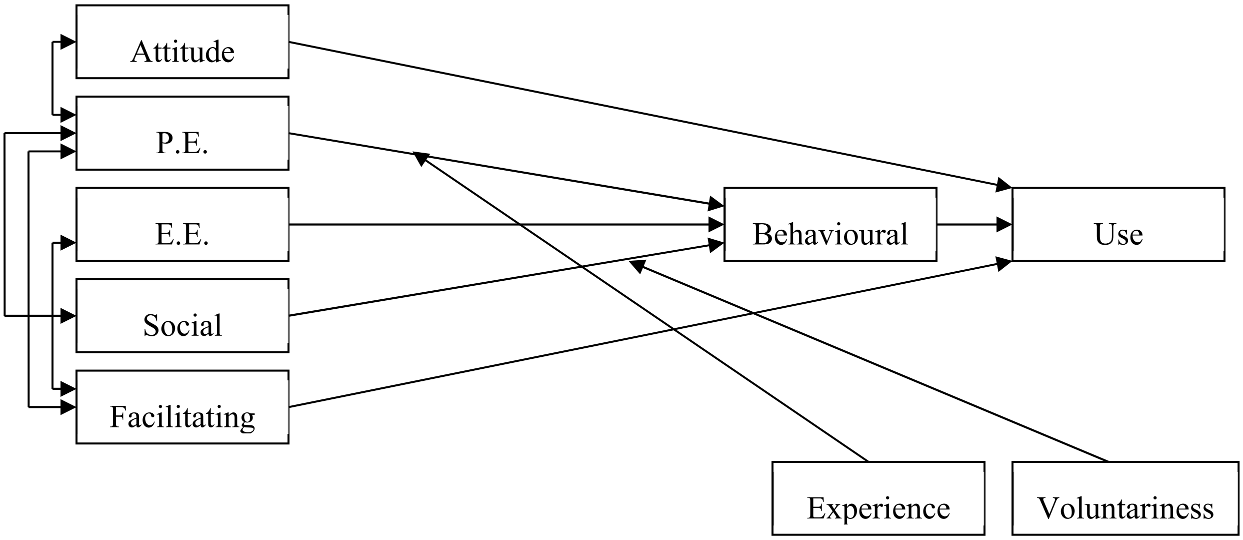


*Figure 6.* Revised Model Based on SEM Results

#### *4.3.5. Implications*

The results of this study have several implications. In the model, four independent variables (Social Influence, Effort Expectancy, Attitude, and Facilitating Conditions) are proven to have a significant effect on the Behavioural Intention and actual User Behaviour in working with BIM. By contrast, Performance Expectancy had a low effect on Behavioural Intention, which is contrary to existing theory. Accordingly, the moderator of experience proved to have a strong effect on the relationship between Performance Expectancy and Behavioural Intention.

**Attitude as a new construct.** The new variable incorporated in the model, Attitude (AT), had a significant effect on User Behaviour. Thus, the proposed variation increased the model's predictability by adding a further construct that affects User Behaviour. This suggests that compared to the original UTAUT model, the proposed variation provides a better fit to explain BIM acceptance at the individual level. Since a high proportion of the individuals use BIM under mandatory environments, the variable of Attitude did imply a significant effect on User Behaviour and not on Behavioural Intention. This finding matches previous research performed on the mandatory use of technology (Brown, et al., 2002; Yousafzai, et al., 2007; Koh, et al., 2010). On the contrary, it contrasts with the findings of Venkatesh et al. (2003), which theorized that Attitude affects Behavioural Intention and is covered by the variables of Performance Expectancy and Effort Expectancy. However, the correlation found between Attitude and Performance Expectancy does suggest that these variables are related. As such, this research contends that Attitude should be included as a separate variable within the context of BIM acceptance.

**Performance expectancy**. As previously noted, Performance Expectancy is composed of measures of perceived usefulness, extrinsic motivation, job-fit, relative advantage, and outcome expectations. These measures are theorized by existing literature to affect Behavioural Intention, but the low effect of Performance Expectancy towards Behavioural Intention suggests that perhaps individuals do not regard BIM as an instrument to enhance their performance at work. This is the most significant departure from existing theory and indicates that there may be other forces influencing how individuals perceive BIM's impact on job performance. It would appear that BIM is perceived more as a hurdle to completing tasks or as a required additional imposition that does not improve overall job performance. In short, working with BIM is seen as an additional unrewarded task for individuals that is not creating Performance Expectancy at the individual level — perceptions which certainly impede the diffusion of BIM. This crucial implication requires further research within each sector and role within AECO in order to consider the industry's high fragmentation.

The strong moderating effect that experience has on relationships underlines the perception that working with BIM does not create expectancy at the individual level. As experience accumulates with BIM, individuals would (in theory) expect this knowledge to be rewarded by either an increase in salary or increased job performance. On the contrary, what is actually occurring is that the more experience one has with BIM, the less the Performance Expectancy. As a result, working with BIM evolves into a routine unrewarded task for individuals rather than representing a performance-enhancing tool. BIM enthusiasts should focus on developing strategies to link BIM usage to individual job performance to overcome this perception.

**Other relationships and correlations**. It is noted that other variables in the model also play a crucial role. First, the results of the model illustrate that experience has a significant effect on voluntariness. Specifically, the more experience one has with BIM the less mandatory one's decision is to use BIM. As people accumulate experience and progress in their careers, they are placed in decision-making positions and can eventually choose whether or not to use BIM. Second, Social Influence has the strongest influence on Behavioural Intention. Thus far, positive communication and effective transmission of influential people's positive opinions of BIM are the strongest contributors to individuals' intentions towards BIM. Efforts to increase Behavioural Intention may include efficient communication and improved interaction of influential people in the industry.

Third, Effort Expectancy and Facilitating Conditions are two variables that influence the diffusion of BIM. There is a strong correlation between the two, and although one affects Behavioural Intention and the other User Behaviour, the more effort individuals perceive they have to exert in order to use BIM the poorer they regard the work tools for the system, and vice versa. This implies that the better the work tools (including training, software, hardware, etc.) the easier it will be for individuals to work with BIM, and the more intention and subsequent use there will be. Also, the more user-friendly BIM becomes, the better the perception of the Facilitating Conditions. Performance Expectancy's correlation with Attitude, Social Influence, and Facilitating Conditions highlight the need for understanding how improving one of these constructs will lead to an improvement in the correlated variables.

**Policy implications**. This study provides a path for BIM enthusiasts to improve the acceptance of BIM in the AECO industry. Understanding the influence of the measured variables upon individual acceptance of BIM supports a reconsideration of current strategies for BIM incentivization. Further, the lack of Performance Expectancy suggests that the benefits generated by using BIM are not reaching front-line users. Benefits appear at the industry, company, or project but not on individual levels. A revision of current policies should consider channelling part of these benefits towards the individual level. Incentives, raises, promotions, etc., may have a positive effect on accelerating the acceptance of BIM if they can be adequately integrated into current policy. This shift in expectancy may also help industry organizations redefine work processes and create a collaborative environment faster.

As mentioned previously, the U.K. Government is a vocal supporter of establishing BIM in the AEC industry. However, their strategy of requiring the use of BIM for public projects is focused primarily at the company level, leaving the individuals' involvement subject to each firm's interpretation. This policy could be refined in order to incentivize the individual level. An example would be a scheme in which employee certifications in BIM add points to the overall score of a company's bid for a Government project. This could feasibly create Performance Expectancy in practitioners as companies reward employees for progressing their skills in BIM in order to make their firm more competitive in public bids. Consequently, this should improve collaboration within the fragmented AEC industry as it would be in individuals' best interest to accept BIM. The results of this research suggest that there exists the potential to accelerate the diffusion of BIM by complementing current policies to develop Performance Expectancy within front-line practitioners.

### *4.3.6. Conclusions*

To address the gap in the current understanding of how specifically a decision to adopt and utilize BIM is made, this study of the dissertation tested the application of the UTAUT to the decision to adopt and utilize BIM. The study was conducted to mitigate the obvious explanatory deficiency of the incentive theory, which was tested by the exploratory study and the analysis of the incentive questions. As noted previously, the decision to adopt and use BIM is multifaceted and involves evaluation of several critical factors that may be partially explained by the UTAUT.

If the tenets of the UTAUT are applied to BIM, then the higher-level finite decision to adopt and use BIM is actually composed of several interrelated lower-level decisions: (a) decision on Performance Expectancy of BIM, i.e. the degree to which an individual decision-maker believes that using BIM would help to achieve measurable improvements in job performance; (b) judgement on Effort Expectancy, i.e., the degree of ease linked with the use of BIM; (c) evaluation of Social Influence, i.e., the degree to which an individual decision-maker perceives that others believe he or she should use BIM; and lastly (d) assessment of relevant facilitating conditions, i.e., the degree to which an individual decision-maker believes that organizational and technical infrastructure do exist and are capable of supporting the use of BIM. Then, according to the UTAUT, performance expectancy, effort expectancy, social influence and facilitating conditions all in-combination determine the decision to adopt BIM and the rate of its acceptance within a specific organization or national economy.

This section utilizes a questionnaire-based survey methodology and relies upon statistical analysis using Structural Equation Modelling (SEM) to test several propositions reflecting the constructs of the UTAUT. The results of the study allow the researcher to make the following conclusions:

1. Effort Expectancy does have a positive influence upon individuals’ Behavioural Intention to use BIM.

2. Amongst all constructs, Social Influence has the single greatest positive influence upon individuals' Behavioural Intention to use BIM.
3. Attitude will have a positive influence with the individual's User Behaviour of BIM.
4. Facilitating Conditions will have a positive influence with the individual's User Behaviour of BIM.
5. Behavioural Intention will have a positive influence with the individual's User Behaviour of BIM.

These conclusions and findings regarding individual correlations of lower-level decisions that lead to the ultimate decision to adopt and utilize BIM are highly consistent with the predictions of the UTAUT. Taken as a whole, they provide an additional empirical affirmation to the precepts of the UTAUT and thus increase its predictive capacity and its explanatory power in relation to the decision to adopt BIM, specifically. However, these conclusions should be further evaluated within the larger conceptual context of this dissertation. The satisfactory results that were obtained in the exploratory study and further analysis of incentive questions are highly consistent with the predictions of incentive theory. The current study also provided empirical evidence for the claims supported by the UTAUT, thus covering the BIM uptake decision at the organizational and individual levels. Yet, both of these perspectives require that decision-makers rationally consider the various inputs influencing their decision. As nearly any construction practitioner will confirm, this is not always the case. Construction as an industry is historically resistant to change, and a revolutionary technology such as BIM is likely to elicit opposition from long-time practitioners of existing tools and processes. Industry participants inherently know this, but in order to overcome it, the theoretical basis must first be established to understand it. Thus, the next chapter applies a behavioural economics model known as the Status Quo Bias to explicate this curious phenomenon impacting BIM diffusion.

## 4.4. Analysis of the Status Quo Bias

### *4.4.1. Background*

Even after considering the impediments arising from incentive theory at the organizational level and UTAUT and the individual, the literature review clearly shows that BIM's benefits disproportionally outweigh the process barrier risks claimed by collaborative opponents. This observation, in combination with the construction industry's widely recognized resistance to change, led to the realisation that if objections are not wholly rational, they must necessarily be (at least partially) behavioural. Accordingly, an investigation into the application of behavioural economics to the BIM-decision calculus was undertaken.

Neoclassical economic theorists describe how people should choose in certain situations, but they also claim to describe how people do choose (Thaler, 1979). Such theory is built on the premise that actors maximise utility, have rational economic preferences among identifiable outcomes, and act independently based on complete and relevant information (Conforth, 2009). However, there are times when people act in ways that are incompatible with neoclassical theory (Kahneman & Tversky, 1986; Thaler, 1979). Specifically, Thaler (1979) posited that in these situations, "neoclassical economic theory makes 'systemic errors in predicting behaviour" (p. 39). This is especially true when making choices involving significant risk.

For the reasons outlined above, it should be expected that an industry full of rational actors would adopt BIM more rapidly than has occurred. Thus, this research contends that some measure of irrationality must exist preventing the uptake of BIM. This position is further buttressed by the results of the previous UTAUT study whose greatest departure from existing theory (presumably as a result of characteristics unique to BIM as an information technology) was the low effect of Performance Expectancy towards Behavioural Intention to use BIM. That is to say, individuals within the AECO industry have a unique and measurable predisposition to reject BIM as an instrument to enhance their performance despite voluminous evidence to the contrary. This appears to confirm some level of irrationality in the acceptance/adoption decision. Within economics, the only explanation for irrationality is a bias. A thorough review was therefore performed of all biases identified within the literature of behavioural economics and industrial psychology. Given that the subject involves decision-making, biases affecting belief formation, economic decisions, and human behaviour were considered, while attributional (social) and memory biases were not.

The review found that concerns dealing with the Status Quo Bias most closely resemble the issues related to BIM adoption. Status Quo Bias represents a preference for the current state of affairs wherein the current baseline (or status quo) is taken as a reference point and any deviation from that baseline is perceived as a loss. Adversarial contracting certainly exists as the construction industry’s status quo, and it is indeed the information asymmetry inherent to its constructs that stakeholders view as the source of leverage (and by extension, profit). Therefore, actors may see any deviation from this current state of affairs as a loss regardless of what benefits the deviation could provide. Although technologies have advanced, the traditional design-bid-build contracting strategy has evolved little in the past century, leading the processes and practices within it to become ingrained into many stakeholders’ understanding of the construction industry itself. The Status Quo Bias may therefore explain why the contradictory tenets of collaborative construction (i.e., BIM and IPD) are being rejected in spite of the overwhelming evidence for their economic benefit.

**Status quo bias**. According to past studies, people employ two systems to process and assess risk: analytical and emotional (Gertner, 2009; Sunstein & Thaler, 2008; Swim et al., 2009). When one experiences risk through the analytical system, there is an opportunity to consider costs and benefits consciously (Conforth, 2009). However, when one experiences risk through the emotional system, the process is nonformal and automatic, experienced as an instinctive feeling or gut reaction (Weber, 2006). These processing systems generally reinforce one another, but in situations where their outputs differ, the emotional system generally dominates (Conforth, 2009).

When this occurs, people tend to underestimate the danger of events they have never experienced and overestimate the likelihood of events occurring if they have personally experienced them (Gertner, 2009; Weber, 2006). For the current research, this maxim could account for stakeholders’ assigning an undue level of risk to the novel processes within BIM and IPD while underestimating the risks associated with familiar adversarial contracting. Past research has also shown that people often take large risks to avoid losses while avoiding small risks to make gains (Kahneman & Tversky, 1986; Thaler, 1992; Dawnay & Shah, 2005). Termed loss aversion, this tendency is associated with inertia, i.e., when people may be resistant to changes to the status quo (Thaler, 1992). Thaler (1992) described this as the Status Quo Bias and defined it as a preference for the current state that biases people against change. It is this preference that provides the conceptual lens for the current study.

Most published experiments related to the Status Quo Bias have focused only on showing that the bias exists rather than proving its application to a given context. This research focus is best exemplified by Samuelson and Zeckhauser’s (1988) seminal study in which a questionnaire was distributed requiring that respondents choose from a fixed number of alternatives. While controlling for preferences and holding constant the set of choice alternatives, the experimental design varied only the framing of those alternatives (Samuelson & Zeckhauser, 1988). Under neutral framing, respondents received a number of potential alternatives with no specific labels attached; thus, all options were on equal footing. Under status quo framing, one of the choice alternatives was placed in a status quo position, and the others became alternatives to the status quo (Samuelson & Zeckhauser, 1988).

In some of the experiments, Samuelson and Zeckhauser (1988), manipulated the status quo condition. In the remainder, which involved sequential decisions, the subject’s initial choice self-selected the status quo option for a subsequent choice (Samuelson & Zeckhauser, 1988). In both parts of the experiment, status quo framing had predictable and significant effects on subjects’ decision-making. Respondents exhibited a significant Status Quo Bias across a range of decisions (Samuelson & Zeckhauser, 1988; Figure 9). The researchers described Status Quo Bias explanations in terms of three main categories: (a) rational decision making, (b) cognitive misperceptions, and (c) psychological commitment. While the current study is concerned mostly with psychological commitment, a brief review of all three causes of bias are provided herein for context.

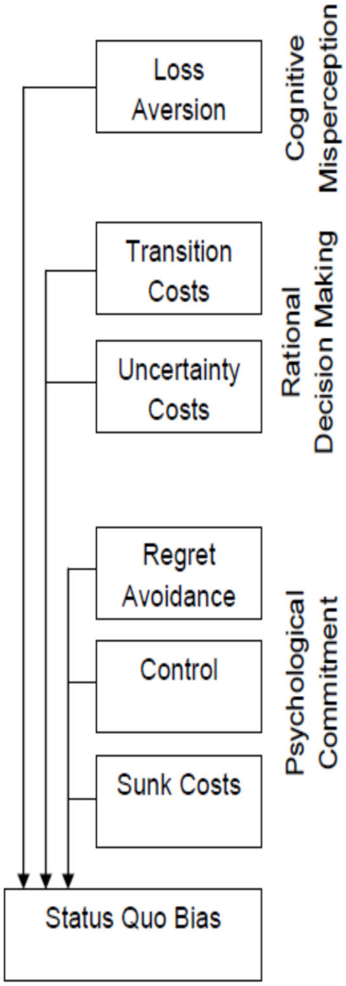


*Figure 7. Novel Model Based on study by Samuelson and Zeckhauser (1988)*

**Cognitive misperception**. The cognitive misperception of loss aversion also clarifies the Status Quo Bias (Samuelson & Zeckhauser, 1988). Loss aversion implies that people will often take large risks to avoid losses while avoiding small risks to make gains. For an objective observer, this position presents an obviously specious proposition. For an economic actor with his/her business at risk, however, cognitive misperception may dominate. It will be essential to this study to establish at what point in the BIM acceptance timeline actors experience this phenomenon.

**Rational decision-making**. By definition, rational decision-making relies upon the idea that an actor weighs the relative costs and benefits of a change before choosing an alternative. Higher costs than benefits within the context of a departure from established norms or principles can lead to Status Quo Bias. From a rational decision-making viewpoint, two types of costs are identified: (a) transition costs and (b) uncertainty costs. Samuelson and Zeckhauser (1988) noted that transition costs are those incurred when adapting to the new situation, which may include both transient costs that occur during the change and permanent costs that result from the change. Within the context of the current study, transition costs may include the IT costs, the training of existing employees, and costs associated with the need to hire new or additional employees.

Uncertainty costs, which represent the psychological uncertainty or perception of risk, are associated with the new alternative, and can also cause Status Quo Bias (Kim & Kankanhalli, 2009). Consequently, fundamentally altering a construction stakeholder's business model to allow for increased collaboration through BIM certainly presents the perception of risk, as does investing significant time and money in an emergent technology no matter how extraordinary the purported benefits.

**Psychological commitment**. Three main factors contribute to psychological commitment: (a) sunk cost, (b) regret avoidance, and (c) efforts to feel in control (Samuelson & Zeckhauser, 1988). Garland (1990) aptly described the sunk cost effect as "throwing good money after bad" (p. 728); once funds have been "sunk" into a project or plan, the actor believes the only way to avoid wasting them is to sink more. From the perspective of BIM, builders have sunk significant time and resources into their existing business processes. Thus, this may partially explain resistance to investing elsewhere. The fallacy, however, is that such decisions are based on the past rather than on their future consequences.

Samuelson and Zeckhauser (1988) in this regard note that the experience of regretting outcomes of past decisions teaches them to avoid, if possible, regrettable consequences. This can influence individuals to remain within their status quo routine since the outcome of that routine is known and, presumably, not something the actor regrets doing. However, when viewed objectively, this line of reasoning is implausible, at best. To illustrate this critical point, Samuelson and Zeckhauser (1988) proffer an example of leaving a child home alone. Most parents would never consider leaving a baby at home alone while they run errands. If they did so and the baby died in a fire, they would feel inexorable guilt. However, that same parent thinks nothing of driving the child to the store with them, which is arguably a much more dangerous proposition than being left home alone. This example specifically illustrates that the change for feeling regret would be less for driving the child than for leaving him or her home alone, despite the former being the higher risk activity. Efforts to feel in control stem from individuals' desires to determine their own situations (Samuelson & Zeckhauser, 1988), i.e., a desire that can lead to Status Quo Bias – actors do not wish to lose control by switching to an unknown system or unfamiliar way of working (Kim & Kankanhalli, 2009). Within the construction industry, loss of control would be especially prevalent in moving away from a contracting approach based on information asymmetry to one that is inherently open to information sharing and cooperation.

**Reversal test**. In order to distinguish between valid criticisms of increased collaboration and those merely motivated by resistance to change, a reversal test may be introduced (Samuelson & Zeckhauser, 1988). When decision-makers believe a proposal to change a certain parameter will have negative overall consequences, they should consider a change to the same parameter to move it in the opposite direction. If this change could also have negative overall consequences, then the onus is on the decision-makers to explain why the position cannot be improved through changes to this parameter. If decision-makers are unable to do so, then one has a reason to suspect that they suffer from Status Quo Bias (Samuelson & Zeckhauser, 1988).

**Status quo and technology**. As is evident from the literature review, studies that applied behavioural economics and the Status Quo Bias model towards the analysis of decisions related to complex technology adoption are scarce and typically limited in their research scope. For instance, an empirical study by Kim and Kankanhalli (2009) provides the only directly relevant analysis of user resistance to IT systems implementation from a status quo perspective. The authors found that switching costs represent a key determinant of user resistance and identified colleague opinion and self-efficacy for change as antecedents that reduce switching costs (Kim & Kankanhalli, 2009).

### *4.4.2. Hypothesis*

Past empirical studies investigating the performance of the Status Quo Bias model under specific management conditions relied on experimental research designs—a methodological solution that does not lend itself to the overall design of this dissertation. In view of this methodological issue, and in keeping with the preceding surveys, a questionnaire-based survey design was employed to investigate the effects of the Status Quo Bias on the decision to adopt and utilize BIM. In particular, a multiple-item questionnaire operationalized the constructs of (a) regret avoidance, (b) control, and (c) sunk cost. The current section therefore undertakes a novel research approach to the study of the Status Quo Bias, potentially broadening the theoretical understanding and operationalization of its constructs while also acting as a pilot study for status quo questions within the follow-on Synthesized Secondary Survey. Appendix D provides the full questionnaire.

### *4.4.3. Results*

The resulting dataset included 56 respondents but eventually 4 were excluded from the sample due to incompleteness of their answers. The final sample consisted of 52 participants. Analysis began with observing the distributions of participants by different control characteristics for which Table 37 in Appendix F presents frequency and percentage distributions. It was seen that almost half (N = 23, 45.1%) of the participants have used Level 2 BIM system. This means that advanced BIM usage is well represented in the sample. Then, about one-fourth (N = 12, 23.5%) of participants never have used BIM, while 13 respondents (25.5%) have only utilized Level 1 BIM. As expected, very few participants (N = 3, 5.9%) have used the most advanced Level 3 BIM systems.

The largest stakeholder category for respondents was that of main contractors (N = 17, 32.7%), followed by project management companies (N = 10, 19.2%), engineering consultancies (N = 6, 11.5%), client/owners (N = 4, 7.7%), and trade contractors (N = 4, 7.7%). Nearly half of respondents (N = 24, 46.2%) were positioned in middle management in their company, while 22 (42.3%) self-identified as executives. Only a few (N = 6, 11.5%) participants were frontline employees.

With regards to BIM experience, over a third of participants (N = 19, 37.3%) claimed to have significant levels of investment in BIM, while 16 (31.4%) had moderate investments. Nearly one-fourth (N = 11, 21.6%) had zero investment, which was larger than expected. Project delivery methods used were evenly distributed between design-bid-build (N = 16, 30.8%), design-build (N = 15, 28.8%), and IPD (14, 26.9%). Only 13 participants answered the question on which form of IPD was used and the answers were dominated by AIA form C195 full integration (N = 5, 38.5%), AIA form A295 transitional IPD (N = 3, 23.1%) and other IPD (N = 3, 23.1%).

**Reliability analysis**. As noted previously, the overwhelming majority of extant studies concerning the effects of Status Quo Bias on management decisions were conducted through behavioural experiments, but such an approach is not feasible for the current study. To that end, various constructs of Status Quo Bias model were operationalized into survey questions for data collection. Given the novelty of such an approach, it was necessary to perform a reliability analysis of the results. For that purpose, several reliability measures were employed, including (a) Cronbach's alpha, (b) split-half reliability measure, and (c) parallel forms reliability measure. The Cronbach's alpha coefficient represents a scale's internal consistency, while the split-half approach of measuring reliability aims to correlate scores on one random half of the items on the test with the scores on the other random half. If there exist two or more forms of a test, the analysis looks to ensure that the two forms are equivalent (on means, standard deviations) and highly correlated. The correlation between alternate forms can be used as an estimate of the tests' reliability. In a reliable solution, these measures range between zero and one—the larger the value, the more stable the factors. A high value implies that the observed variables account for substantial variance in the construct scores, while a low value indicates that the factors are poorly defined by the observed variables. Generally, the value of 0.70 is accepted as the minimum desired value of reliability (Aneshensel, 2013). Table 38 presents the pilot study constructs, the items used in their construction, and the corresponding reliability measures. It was found that all the constructs/scales except "sunk cost" have reliability well above the desired level. The construct with highest reliability was

Regret Avoidance' and this was followed by 'Control' and 'Sunk Cost'. The items under each construct were averaged to obtain the construct values.

*Table 36. Study Constructs*

| **Constructs & Items** | **Cronbach's Alpha** | **Split-half** | **Parallel** |
|---|---|---|---|
| ***Regret Avoidance*** | 0.883 | 0.890 | 0.883 |
| RA1: My company or I may come to regret the decision to participate in a BIM-enabled project. | | | |
| RA2: My company or I may come to regret investing the time and money necessary to become proficient in the use of BIM. | | | |
| ***Control*** | 0.853 | 0.865 | 0.858 |
| CO1: Participating in BIM decreases the control I have to complete my job. | | | |
| CO2: BIM decreases the control my company has in the success of the project. | | | |
| ***Sunk Cost*** | 0.599 | 0.599 | 0.615 |
| SC1: Investing in BIM technology would waste my investment in standard non-BIM construction practices (AutocCad, etc.). | | | |
| SC2: Investing additional time or money into other non-BIM construction practices represents a better use of resources. | | | |

The analysis further reviewed individual questionnaire items to see if any required additional attention from a reliability perspective. In this regard, the researcher computed the pairwise correlations between the items under a construct and the revised reliability measures after opting out one item at a time from the constructs. Table 39 in Appendix F presents the computed pairwise correlations and the revised reliability estimates. The construct "Regret Avoidance" had two items and the reasonably high correlation (0.803) between the items, which indicates good agreement between them towards measuring the same underlying concept. The poorest inter-item association (0.427) was found between the two items under the construct “Sunk Cost”. The two items under “Sunk Cost” are not presenting similar underlying concepts to the respondents and require further attention. The two items under “Control” also have strong association (0.761) as well as high reliability.

***Structural Equation Modelling (SEM).*** The ultimate objective of this study was to examine not just the existence of the Status Quo Bias but also a measurement of its effect upon BIM adoption. As with the UTAUT survey, the best statistical method for investigating such issues is Structural Equation Modelling (SEM). Fitting an SEM model requires a measurement model which confirms the validity of constructs/scales being built for use in SEM. In the current study, a Confirmatory Factor Analysis (CFA) was used to fit a measurement model and thus examine the validity of the scales being built. Figure 10 shows the CFA model. Table 40 summarizes the goodness of fit statistics for the CFA model. The CFA model satisfies most of the goodness of fit statistics except Tucker-Lewis Index (TLI), Relative Fit Index (RFI), and Root Mean Square Error of Approximation (RMSEA). It can be inferred that with increasing sample size, the constructs built can gain better goodness of fit characteristics.

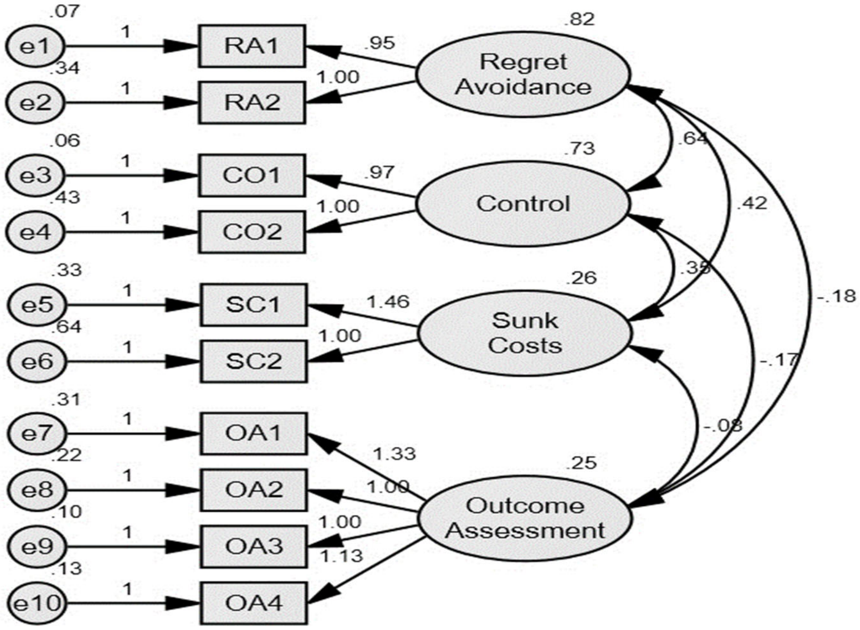


*Figure 8. Fitted Measurement (CFA) Model with Unstandardized Coefficients.*

*Table 37. Goodness of Fit Statistics for Measurement Model (CFA)*

| **Goodness of fit index** | **Recommended level** | **Measurement model** |
|---|---|---|
| CMIN/DF | ≤ 3.00 (Byrne, 2016) | 2.01 |
| Comparative Fit Index (CFI) | ≥ 0.90 (Kline, 2016) | 0.91 |
| Normed fit index (NFI) | ≥ 0.80 (Ullman, 2001) | 0.84 |
| Incremental fit index (IFI) | ≥ 0.80 (Garson, 2006) | 0.91 |
| The Tucker-Lewis Index (TLI) | ≥ 0.90 (Kline, 2016) | 0.86 |
| Relative fit index (RFI) | ≥ 0.80 (Garson, 2006) | 0.75 |
| Root Mean Square Error of Approximation (RMSEA) | ≤ 0.10 (Tabachnick & Fidell, 2007) | 0.14 |

*Observations farthest from the centroid (Mahalanobis distance) (Group 1)

The following SEM model was finally fitted finally (Figure 11). Table 41 presents the goodness of fit statistics.

*Figure 9. Fitted SEM with Unstandardized Coefficients*

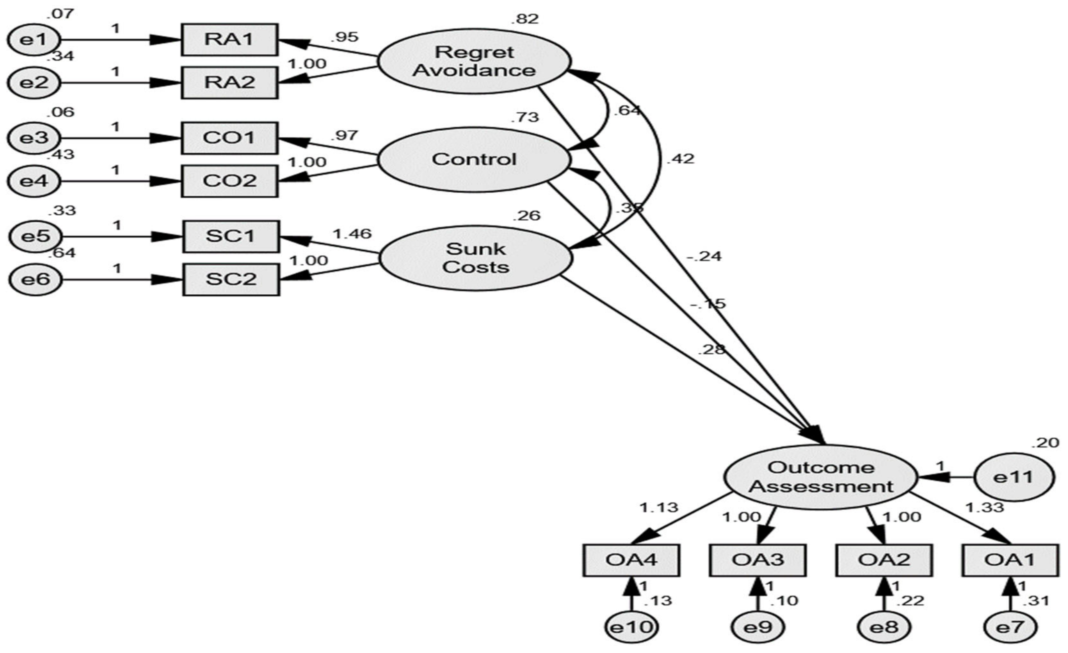


*Table 38. Goodness of Fit Statistics for SEM*

| Goodness of fit index | Recommended level | Measurement model |
|---|---|---|
| CMIN/DF | ≤ 3.00 (Byrne, 2016) | 2.01 |
| Comparative Fit Index (CFI) | ≥ 0.90 (Kline, 2015) | 0.91 |
| Normed Fit Index (NFI) | ≥ 0.80 (Ullman, 2001) | 0.84 |
| Incremental Fit Index (IFI) | ≥ 0.80 (Garson, 2006) | 0.91 |
| The Tucker-Lewis Index (TLI) | ≥ 0.90 (Kline, 2016) | 0.86 |
| Relative Fit Index (RFI) | ≥ 0.80 (Garson, 2006) | 0.75 |
| Root Mean Square Error of Approximation (RMSEA) | ≤ 0.10 (Tabachnick & Fidell, 2007) | 0.14 |

*Observations farthest from the centroid (Mahalanobis distance) (Group 1)

Like the CFA, all the goodness of fit statistics except the three–Tucker-Lewis Index (TLI), Relative Fit Index (RFI), and Root Mean Square Error of Approximation (RMSEA)—were acceptable and satisfactory. A higher sample size and higher reliability in constructs could overcome this limitation.

### *4.4.4. Conclusions*

The third component of the conceptual framework for this dissertation is the Status Quo Bias model. Functionally, the Status Quo Bias model was used to complement the predictions of the Incentive Theory and the UTAUT regarding decision-making involved in BIM adoption. Reliance on the Status Quo Bias model allowed to account for unique individual differences in decision-making processes.

Substantively, the Status Quo Bias model draws on and fuses important insights from decision-making and behavioural cognitive theories and specifically posits that (a) decision-makers rely on both analytical and emotional systems to process and assess risk; (b) the analytical system allows to process and evaluate risk by consciously considering costs and benefits; (c) in contrast, the emotional system processes and evaluates risk through nonformal and automatic processes that are expressed in intuitive feelings; and finally (d) the two systems generally complement each other but in situations where their outputs differ, the emotional system dominates (Kahneman, Knetsch, & Thaler, 1991; Kahneman & Lovallo, 1993).

To fill in the gap in the current theoretical and practical knowledge of unique individual differences in decision-making processes, the researcher designed and conducted an empirical study that tested the propositions of the Status Quo Bias model in the context of construction industry organizations and, in particular, when a decision to adopt and utilize BIM is considered. The Status Quo Bias study was conducted (a) to complement the main findings of the exploratory study, the analysis of incentive questions and the UTAUT study, and (b) to test the predictions of the Status Quo Bias model in a specific management context. The overall research purpose in this case was to identify specific factors in BIM adoption that act not on organizational or project levels but on personal levels.

Using SEM statistical tools, the current study empirically tested the global hypothesis that there exists a measurable Status Quo Bias that exerts negative effects on the adoption of BIM. Past empirical studies of this topic relied on experimental research designs, which was unfeasible for the research purposes of both this study and the entire dissertation research project. In this study, a questionnaire-based survey design was employed in which a multiple-item questionnaire operationalized the constructs of regret avoidance, control, and sunk cost. The key findings of the analysis of the participants' responses are the following:

1. The respondents indicated a relatively high level of investment in BIM, which is consistent with past research finding and partially with conclusions of the three preceding studies of this dissertation.
2. However, a relatively high level of investment in BIM technology appears to be moderated by either significant or moderate levels of investment in standard non-BIM construction. These account for over 70% of the responses and imply that despite the observed level of advanced BIM usage, respondents' decisions to embrace BIM more may be counteracted

by the sunk costs associated with more traditional technologies. This finding is highly consistent with the predictions of the Status Quo Bias model.

Also, in the current study, three constructs of Status Quo Bias model (i.e., regret avoidance, control, and sunk cost) were operationalized into survey questions and then statistically analysed using Structural Equation Modelling (SEM) techniques. The reliability analysis suggested that all the constructs except *sunk cost* had sufficient reliability. Then a pairwise correlation analysis was conducted, and the effects of the constructs evaluated. The results of these analyses are the following:

1. Regret Avoidance and Control appear to have negative effects on the decision to adopt and utilize BIM.
2. Sunk Cost exerts positive effects on the decision to adopt and utilize BIM.
3. However, because none of the effects of the three constructs of the Status Quo Bias model were statistically significant, this suggests that there is a need to conduct a more comprehensive statistical investigation of the effects of the Status Quo Bias on the decision in question. Thus, this survey also acts as a pilot study for the Status Quo Bias questions in the follow-on Synthesized Secondary Survey and in the operationalization of Status Quo Bias investigations more generally.

Taken together, the results of the analysis of the participants’ responses to the survey questions and the outcomes of the SEM analyses serve at least a partial empirical confirmation of the predictions of the Status Quo Bias model. In turn, these results contribute to further increase the overall validity, explanatory power, and predictive capacity of the conceptual framework underpinning this dissertation overall. At the same time, because none of the assessed Status Quo Bias effects were found to be statistically significant, this justifies the need to explore the effects of the Status Quo Bias constructs within a comprehensive statistical model that would incorporate all relevant constructs from the incentive theory, the UTAUT, and the Status Quo Bias model. Also, to cross-validate and properly contextualize the findings of all quantitative studies, a qualitative assessment of the reasons behind the low rate of BIM adoption and utilization in the construction industry is also feasible.

## 4.5. Synthesized Secondary Survey

### *4.5.1. Background*

Several internally consistent conceptual explanations have been offered by industry researchers to clarify the observed mismatch between the obvious design, operational, management, economic and other benefits for adopting BIM and its slow pace of adoption. Specifically, according to the dominant economic explanation (the incentive theory), to be fully adopted by an economic agent (e.g., a construction company or subcontractor) any innovation must be associated with rising productivity as a result of such adoption which should in turn lower unit labour costs and increase profits (Baddeley & Chang, 2015).

However, the incentive theory simultaneously posits that economic agents typically behave strategically and opportunistically to maximize benefits (personal, organizational, institutional) for themselves regardless of the costs these might impose on others (Baddeley & Chang, 2015). For example, suppliers and subcontractors' incentives to save on project costs will be affected by whether they are on a cost-plus or a fixed price contract. Then, in the process of tendering, contractors may have an incentive to underbid to get a job, but then recover their profits through change orders.

Precisely because BIM (as a decision-making tool) operates on a substantially higher degree of information transparency, the use of BIM may de facto create a disincentive for a range of economic agents to be involved in a construction project (Lee, Yu, & Jeong, 2015). The latter may occur due to suppliers and subcontractors' realization that they may no longer be able to capitalize on poor information and opportunistic use of information and inflate costs, particularly at lower tiers of supply chain. Furthermore, the adoption of BIM requires that suppliers and subcontractors fully recognize and actively internalize the advantages of collaborative process inherent to BIM as a tool (Linderoth, 2010). Given the requirements BIM imposes and due to the fact that BIM utilization leads to price and other information equalization across the board, many economic agents in the construction industry may not be willing to reduce their usual opportunism and short-term orientation throughout the supply-chain. This, in turn, creates serious barriers to BIM adoption.

Others contended that acceptance to adopt BIM is not a simple dichotomous case of either approval or rejection, and that a multitude of various interrelated factors can influence technology adoption and acceptance (Chan, 2014; He et al., 2012; Migilinskas, Popov, & Juocevicius, 2013). To address the issue of multiple factors that may affect the BIM adoption decision, drawing on several technology acceptance and behavioural psychology theories and past empirical results, Venkatesh et al. proposed the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh, 2000; Venkatesh & Davis, 2000; Venkatesh, Morris, Davis, & Davis, 2003).

According to the UTAUT, acceptance to adopt BIM is a combination of several factors: (a) performance expectancy (perceived usefulness) – the degree to which an individual believes that using the technology will help to achieve improvements in job performance; (b) effort expectancy (perceived ease of use) – the degree of ease linked with the use of the technology; (c) social influence or subjective norms – the degree to which an individual perceives that others believe they should use the new technology; and (d) facilitating conditions, the degree to which an individual believes that an organizational and technical infrastructure exists to support the use of the technology (Venkatesh et al., 2003). According to the UTAUT model, performance expectancy, effort expectancy, social influence, and facilitating conditions determine the decision and rate of BIM acceptance (Samuelson & Björk, 2013), which are further subject to people’s attitudes towards technology use (Davies & Harty, 2013).

The third, also human behaviour-related, explanation of why the pace of BIM adoption in construction industry has been slow is offered by the Status Quo Bias. This explanation draws on and blends the theoretical and empirical advances of decision-making theory and cognitive theory. In particular, the Status Quo Bias explanation posits that (a) people employ two different systems to process and assess risk—analytical and emotional; (b) the analytical system offers an opportunity to process and evaluate risk by consciously considering costs and benefits; (c) in contrast, the emotional system processes and assesses risk through nonformal and automatic processes that are manifested in instinctive feeling or gut reaction; and (d) the systems generally complement each other, but in situations where their outputs differ, the emotional system becomes dominant (Kahneman, 2013; Kahneman, Knetsch, & Thaler, 1991; Kahneman & Lovallo, 1993).

When the latter occurs, decision-makers tend to underestimate the danger of events they have never experienced and overestimate the likelihood of personally experienced events (Kahneman, 2013). This explains why and how stakeholders' assign an undue level of risk to the novel processes within collaborative construction (i.e., BIM), while concurrently underestimating the risks and technological limitations associated with familiar adversarial contracting (Rogers, Chong, & Preece, 2015).

***Past empirical findings.*** The predictions of three complimentary conceptual explanations of BIM acceptance have been empirically explored in this dissertation. The design of all studies and their results were discussed but there is a need to revisit, at least briefly, the major findings of the previous studies to contextualize appropriately the findings of the Synthesized Secondary Survey.

The aims of the Exploratory Study were: (a) to establish the current state of BIM adoption and use in construction industry, and (b) to empirically test the predictions of the incentives theory in regard to BIM adoption in construction industry. The key findings of the Exploratory Study are the following: (a) Level 2 BIM is being utilized more frequently than previously thought; (b) IPD accounts for a significant portion of BIM contracting arrangements; (c) experience is the key determinant in how incentive strategies are viewed by various stakeholders; and (d) stakeholders' position within the supply chain has direct effects on BIM adoption.

Working within the same analytical paradigm of the incentive theory, the results of the Exploratory Study were further boosted through further in-depth analysis of the Incentive Questions. The main theoretical premise of this analysis was that because the differential demand for incentivization among a project's BIM contributors has not been properly addressed in the extant literature, there is a need to explore further the perceptions of BIM professionals on the usefulness of including incentive schemes in BIM-enabled projects. Further, such exploration should be based on professionals' level of experience and position within the supply chain.

To achieve this research objective, a questionnaire-based survey was designed to explore three issues: (1) the current state of BIM application (percentage of Levels 1, 2, and 3); (2) major inhibitors or facilitators to the implementation of BIM incentives; and finally, (3) the perceived most effective performance measures for incentive plans. The ultimate purpose of the survey was to collect data to conduct a reliable BIM incentivization analysis.

Overall, the further analysis of the incentive questions found that (a) Level 2 BIM is being utilized more often; (b) IPD accounts for a significant portion of BIM contracting arrangements. Experience was shown to be a key determining factor in how respondents view incentive strategies, as was stakeholders' position within the supply chain; (c) experience is the key determinant in how incentive strategies are viewed by various stakeholders; and (d) stakeholders' position within the supply chain has direct effects on BIM adoption. As it becomes clear, while these findings on the one hand reinforce the key findings of the Exploratory Study, on the other hand, they offer no new insights on specific factors that may affect the decision to adopt BIM and the degree of BIM utilization by construction organizations.

Thus, the study of individual perceptions was conducted to address the obvious explanatory deficiency of the analysis of the incentive questions. As it follows from the review of extant literature, people who do not fully accept an innovation could delay, hinder, underutilize, or even disrupt its implementation (Chan, 2014; Chen & Lu, 2017; He et al., 2012; S. Liu et al., 2015; Rogers et al., 2015). Furthermore, technology acceptance is an individual act based on personal perceptions according to the main tenets of the UTAUT model (Venkatesh, 2000; Venkatesh & Davis, 2000; Venkatesh et al., 2003). Thus, the study of individual perceptions was guided by the general investigative need to identify what perceptions influence behaviour (i.e., acceptance) so that the aggregate benefits of project-level acceptance can be realized. All analyses reflect the literature's contention that users' perceptions towards collaborative BIM plays a pivotal role in its current low rate of adoption (Eadie, Browne, & Odeyinka, 2013; Singh et al., 2011) and were conducted using SEM analyses.

The results of SEM analyses of Individual Perceptions suggest that (a) social influence, effort expectancy, attitude, and facilitating conditions do in fact exert a significant effect on the behavioural intention and actual user behaviour in working with BIM. At the same time, contrary to UTAUT model predictions, (b) performance expectancy has a low effect on behavioural intention, and (c) the moderator of experience proved to have a strong effect on the relationship between performance expectancy and behavioural intention. The Status Quo Bias Study was conducted, on the one hand, to complement the key findings of the three studies discussed above, and, on the other hand, to test the predictions of a complementary theory. The overall research purpose of the Status Quo Bias Study was to identify factors in BIM adoption that act not on organizational or project levels but specifically on personal level as according to past research, the decision-makers who decide whether to invest resources into BIM are unlikely to be those inputting data under a mandatory setting (Gu & London, 2010; Kassem & Succar, 2017; Linderoth, 2010).

The data for the Status Quo Bias Study were collected using online survey and analysed using SEM. In general, the results of the Status Quo Bias Study suggest that (a) regret avoidance and control as decision-making factors exert overall negative effect on the assessment of outcomes of BIM adoption decision, while at the same time (b) evaluation of sunk costs as a decision-making factor has a positive effect on the assessment of outcomes of BIM adoption decision. The findings are overall consistent with the predictions of the Status Quo Bias model.

In summary, if the results of all four studies discussed above are collated, the following general conclusions can be reached:

1. The results of the exploratory study overall suggest that the incentive theory questions provided the most interesting but not exhaustive explanations of BIM adoption decisions.
2. The further analysis of the incentive questions, while overall reiterating the findings of the exploratory study, could not completely or satisfactorily explain the low adoption rates of BIM.

3. While the UTAUT model allowed for useful conclusions regarding BIM adoption decision-making processes and vectors in the Study of Individual Perceptions, it offered no exhaustive explanations either.
4. Although the results of the Status Quo Bias Study allowed to account for a number of factors that act on the individual rather than on organizational or project levels, the Status Quo Bias model in essence explains how decision-making actually works during the process of BIM adoption

However, if assessed in their entirety as a set, what these general conclusions imply is that each of the three theoretical explanations – the incentive theory, the UTAUT, and the Status Quo Bias model – that underpinned the studies conducted in this dissertation can offer only partial and therefore insufficient explanation of BIM adoption decision. This raises the need for the next logical step: to fuse all three theoretical models into a single study and explore the issue of low BIM adoption through a synthetic model. To this end, the Synthesized Secondary Survey was conducted (a) to empirically explore the predictions of the joint model and (b) to achieve higher degree of explanatory consistency and exhaustiveness.

### *4.5.2. Hypotheses*

The synthesized secondary survey was guided by the need to test in a combined model the five hypotheses of the overarching dissertation that have not been proven by the four preceding studies:

***$H_1$**: Trade contractors are more concerned with the choice of weightings than main contractors and designers.*

***$H_2$**: Social Influence will exert a positive effect on the individual's Behavioural Intention to use BIM.*

***$H_3$**: Facilitating Conditions have a positive correlation with one's individual usage of BIM.*

***$H_4$**: Attitude will have an influence with the individual's Behavioural Intention.*

***$H_5$**: Company type determines manifestation of the Status Quo Bias (i.e., sunk cost vs. regret avoidance).*

In this set of hypotheses, $H_1$ was specifically formulated to test the predictions of the incentive theory regarding BIM adoption. $H_2$, $H_3$, $H_4$ were formulated to empirically test the effects of constructs of the UTAUT. Finally, $H_5$ will be used to test the predictions of the Status Quo Bias model. These five hypotheses were not proved in the three preceding studies of the dissertation either because: (a) not enough data were collected by the previous surveys to run SEM appropriately, or (b) previous surveys did not utilize all constructs necessary to test these hypotheses, or (c) both. This survey is also meant as a first attempt at operationalizing a comprehensive survey instrument that allows for deeper analyses of constructs not just within theories, but between them. As noted in the first chapter, concerns exist that including all constructs under study within a single survey could make the instrument too long and responses would suffer as a result. This synthesized secondary survey was thus also constructed to pilot a comprehensive instrument for a planned successive larger (and better funded) research effort than is possible within the confines of this dissertation. To ameliorate the issue of length, particular care was taken to establish the highest quality sample populations possible.

### *4.5.3. Results*

In total, 153 respondents participated in the survey. However, because some of the responses were incomplete or contained missing or inconsistent answers, respondents with such responses were excluded from subsequent statistical analyses. Consequently, the final analytical sample contained 84 participants in total. Table 42 presents key descriptive statistics characterizing respondents’ organization by whether BIM is used or not and by type of construction industry organization they work for.

*Table 39. BIM Adoption and Types of Organizations (Q1, Q3)*

| Question | Response |
|---|---|
| **Q$_1$**: Have you ever utilized Building Information Modelling on a project? | Yes – 40 (48%)<br>No – 44 (52%)<br>**Total: 84 (100%)** |
| **Q$_3$**What type of company do you work for? | Engineering Consultancy – 25 (29.3%)<br>Project Management Company – 11 (13.1%)<br>Main Contractor – 17 (20.2%)<br>Architectural Company – 5 (6.0%)<br>Construction Client/Owner – 9 (11.0%)<br>BIM Consultant – 3 (3.6%)<br>Trade Contractor – 3 (3.6%)<br>Material Supplier – 1 (1.2%)<br>Other – 10 (12%)<br>**Total: 84 (100%)** |

***Confirmatory factor analysis***. The first step in the analysis was to obtain the optimal SEM specification through the confirmatory factor analysis (CFA) (Krzanowski, 2014). To achieve optimal SEM specification and parsimony, a jack-knifing procedure was employed (van Etten, 2005), in which constructs were sequentially removed from the model if these constructs contributed no further predictive power. The new SEM was then re-estimated and compared to the old SEM until no improvement in its parsimony and optimality can be made.

The optimality of the SEM was determined using the ratio Chi-squared to degrees of freedom (X2/df) as a measure and the criterion X2/df < 3 for accepting the general specification of the model (Kline, 2016). Because X2/df = 1.353 < 3, the researcher concluded the SEM was in good fit and therefore that optimality was attained. Table 43 presents the SEM goodness of fit measures. Figure 12 presents the final SEM.

*Table 40. SEM Goodness of Fit Assessment*

| | $X^2$/df | *p* | RMSEA | PGFI | GFI | CFI |
|---|---|---|---|---|---|---|
| Default model | 1.353 | 0.007 | 0.065 | 0.627 | 0.842 | 0.947 |
| Criteria of good fit | Not significant | P>0.05 | <0.08 | >0.5 | >0.90 | >0.90 |

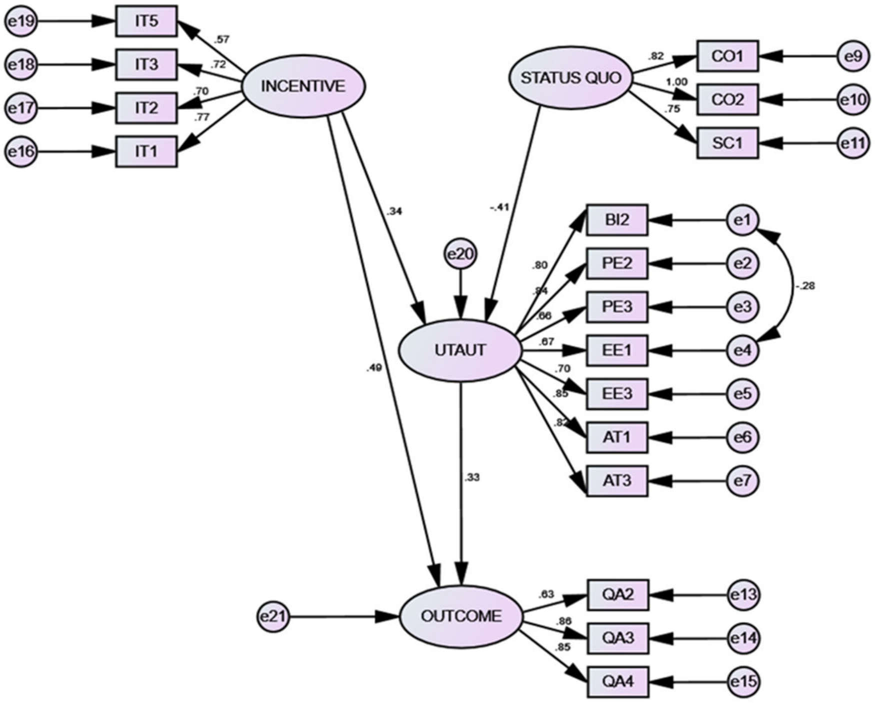


*Figure 10. Final SEM*

***SEM performance***. The next step in the analysis was to compare SEM performance in terms of its stability, predictive ability, and consistency when it is applied to two groups in the sample – Group A (BIM in use) vs. Group B (BIM not in use). This step was required because BIM use/non-use appears to be the main demarcating factor in the sample (Group An = 40, Group Bn = 44, N = 84), which may completely overshadow the effects of other variables in the SEM used as these effects are expected to be somewhat weaker (Kline, 2016). Also, a number of past studies of BIM adoption decision found that once BIM is in use, its users are more likely to move up from lower to higher levels of BIM classification (Arayici et al., 2011; Gu & London, 2010; Poirier, Staub-French, & Forgues, 2015; Succar & Kassem, 2015). For example, once BIM is adopted at Level 1 and its benefits are realized, BIM users will be more inclined to move to Level 2 and Level 3 of BIM integration. This also may distort the effects of constructs of the incentive theory, the UTAUT, and the Status Quo Bias.

The performance of SEM (Group A *vs.* Group B) was evaluated as a test of differences between groups who either use or not use BIM in their construction industry organizations. Specifically, SEM performance in each group was evaluated comparing (a) unstandardized and standardized estimates for each group, and then (b) by making pairwise comparisons between the two groups using unconstrained measures of structural weights (Kline, 2016). The assumptions of unconstrained model were met satisfactorily (Krzanowski, 2014). Then, the researcher determined whether the differences between groups were statistically significant by comparing the *p*-value to the significance level $\alpha = 0.05$. Because (a) the assumptions of unconstrained model were properly satisfied and (b) because $p = 0.208 > \alpha$, it was concluded that there is no statistically significant difference in SEM performance between Group A and Group B. This implies that whether participants work in construction industry organizations where BIM is in use or not in use does not affect the current SEM stability, predictive ability, and consistency. This paves the way to apply the current SEM to test the differences between different groups of stakeholders in next analyses. Table 44 in Appendix F presents the results of SEM performance assessment.

***Multigroup analysis.*** The next step in the analysis involved using SEM to predict the effects of constructs associated with variables Incentive, UTAUT, Status Quo (i.e., joined model variables) using all groups of stakeholders. Initially, the researcher attempted to run the tests on all 9 groups identified using Q2 of the survey (Table 45 – Q2). However, the construction of multigroup model failed due to (1) insufficient sample size, (2) substantial degree of collinearity among the variables, and finally (3) considerably different group sizes, which raised the possibility of assigning disproportionate weights purely on the basis of group size.

Given the impossibility to increase the sample size, dimensionality was reduced of the sample under analysis using a Factor Analysis (FA) procedure (Brown, 2015; Kim & Mueller, 1978), with VARIMAX rotation (Kaiser, 1958) as a remedial measure. Based on the analysis of eigenvector and eigenvalues (Cooperstein, 2008), the dimensionality on this parameter was reduced by ≈ 66% from 9 groups to only 3 groups. Moreover, the comparative size of the groups was also improved; they do not differ in number of respondents as much as the original 9 groups. Table 45 presents the groups that were created as a result of FA to be used for subsequent analyses.

*Table 41. Groups of Stakeholders*

| **Initial Groups** | **Final Groups** | **Number of Respondents** |
|---|---|---|
| Main Contractor – 17<br>Trade Contractor – 3<br>Material Supplier - 1 | G1 – Contractor/Supplier | 21 |
| Engineering Consultancy – 25<br>BIM Consultancy – 3<br>Architectural Company - 5 | G2 – Consultants | 33 |
| Project Management Company – 11<br>Construction Client/Owner – 9<br>Other – 10 | G3 – Management Owner | 30 |

With these improvements the researcher was able to examine whether any differences in SEM performance do exist between the three groups of stakeholders on the three variables that are part of the Synthesized Secondary Data Model, i.e., Incentive, UTAUT, and Status Quo Bias. The performance of SEM was evaluated sequentially on variables Incentive, UTAUT, and Status Quo Bias. Akin to the procedures described earlier in this section, the performance of SEM was evaluated as a test of differences between the three groups of stakeholders (G1 vs. G2 vs. G3). Specifically, SEM performance in each group was evaluated comparing (1) unstandardized and standardized estimates for each of the three groups and then (2) by making pairwise comparisons between the three groups using unconstrained measures of structural weights (Kline, 2016).

***Incentive***. The first variable in the evaluative sequence was Incentive. Because (a) the assumptions of unconstrained model were properly satisfied in each instance of between-groups comparisons and (b) because all relevant *p* values were > α, it was concluded that there is no statistically significant difference in SEM performance between the three groups on the variable Incentive. This conclusion allowed us to reject $H_0$ and accept $H_1$. The logic behind this decision is relatively straightforward.

$H_1$ states that trade contractors are more concerned with the choice of weightings than main contractors and designers. $H_1$ specifically tested the predictions of incentive theory that predicts that different stakeholders assign different perceived values to weightings. If this were true, then the differences in SEM performance on variable Incentive between the three groups of stakeholders would have been observed. Contrary to the prediction of incentives theory, no such between-groups difference on variable Incentive was observed. Therefore, $H_1$ was accepted as valid. Table 46 presents the results of SEM performance comparison.

*Table 42. SEM Performance Assessment on Variable Incentive*

| **Model** | **DF** | **CMIN** | **p** | **NFI Δ-1** | **IFI Δ-2** | **RFI ρ-1** | **TLI ρ2** |
|---|---|---|---|---|---|---|---|
| Measurement weights | 6 | 14.693 | .061 | .122 | .128 | .092 | .108 |
| Measurement intercepts | 14 | 21.303 | .094 | .177 | .186 | .031 | .037 |
| Structural covariances | 16 | 21.393 | .164 | .178 | .187 | .012 | .014 |
| Measurement residuals | 24 | 38.277 | .032 | .318 | .335 | .044 | .052 |

***UTAUT**.* Then, following the same procedure, SEM performance was evaluated between the three groups on the variable UTAUT. Because (a) the assumptions of unconstrained model were properly satisfied in each instance of between-groups comparisons and (b) because at least one $p = 0.043 < \alpha$, it was concluded that there is a statistically significant difference in SEM performance between the three groups on the variable UTAUT.

*Table 43. SEM Performance Assessment on Variable UTAUT*

| **Model** | **DF** | **CMIN** | **P** | **NFI Δ-1** | **IFI Δ-2** | **RFI ρ-1** | **TLI ρ2** |
|---|---|---|---|---|---|---|---|
| Measurement weights | 12 | 21.577 | .043 | .054 | .060 | .016 | .018 |
| Measurement intercepts | 26 | 34.404 | .125 | .087 | .096 | -.004 | -.004 |
| Structural covariances | 28 | 35.527 | .155 | .089 | .099 | -.007 | -.009 |
| Measurement residuals | 44 | 52.279 | .183 | .132 | .146 | -.016 | -.019 |

This conclusion prompted the examination of specific SEM outcomes on variable UTAUT (Table 48).

*Table 44. Specific SEM Outcomes on UTAUT*

| **Hypothesis** | **Dependent variable** | **Path** | **Independent variable** | **Estimate** | **S.E.** | **C.R.** | ***p*** | **Label** |
|---|---|---|---|---|---|---|---|---|
| $H_8$ | Behavioural Intention | ← | Social Influence | 0.011 | 0.143 | -.087 | .003 | K65 |
| $H_{10}$ | BIM Usage | ← | Facilitating Conditions | 0.109 | 0.132 | 1,071 | .164 | K66 |
| $H_{12}$ | Behavioural Intention | ← | Attitude | 0.117 | 0.101 | 3.241 | .000 | W19 |

The examination of specific SEM outcomes on variable UTAUT allows one to reach the following conclusions: First, Social Influence appears to exert a positive effect on individual's Behavioural Intention to use BIM, given $p = 0.003 < \alpha$. However, the size of this positive effect is negligible. Nonetheless, this allowed the rejection of $H_0$ and accept $H_2$ of the Synthesized Secondary Survey. Second, according to the predictions of the UTAUT, Facilitating Conditions may be positively correlated with individual BIM usage. However, because $p = 0.164 > \alpha$, the research failed to reject $H_0$ and accept $H_3$ in this case. However, it is quite likely $H_3$ can be proven if a substantially larger sample is used to examine the relationship between Facilitating Conditions and BIM Usage as constructs of the UTAUT. Third, Attitude appears to have a positive effect on individual Behavioural Intention, given $p = 0.000 < \alpha$. This allowed the rejection of $H_0$ and acceptance of $H_4$.

***Status quo bias***. Finally, the last variable in the evaluative sequence was Status Quo Bias. Because (a) the assumptions of unconstrained model were properly satisfied in each instance of between-groups comparisons and (b) because all relevant *p* values were > α, it was concluded that there is no statistically significant difference in SEM performance between the three groups on the variable Status Quo Bias. This conclusion allowed the rejection of $H_0$ and acceptance of $H_5$. In this decision, the same logic was applied as in the case of the variable Incentive. $H_5$ states that company type determines manifestation of the Status Quo Bias. $H_5$ specifically tested the predictions of the Status Quo Bias model which predicts that decision-makers tend to underestimate the danger of events they have never experienced and overestimate the likelihood of events occurring if they have personally experienced them. This bias becomes especially pronounced when value judgements are based solely on unique information associated with the type of organization where such decision-makers work. If this were true, then the differences in SEM performance on variable Status Quo Bias between the three groups of stakeholders would have been observed because the three groups represent different company types. Contrary to the prediction of the Status Quo Bias model, no such between-the-groups difference on variable Status Quo Bias was observed. Therefore, $H_5$ has been accepted as valid. Table 49 on the following page presents the results of SEM performance comparison.

*Table 45. SEM Performance Assessment on Variable Status Quo Bias*

| **Model** | **DF** | **CMIN** | ***p*** | **NFI Δ-1** | **IFI Δ-2** | **RFI ρ-1** | **TLI ρ2** |
|---|---|---|---|---|---|---|---|
| Measurement weights | 4 | 3.219 | .522 | .017 | .017 | | |
| Measurement intercepts | 10 | 6.009 | .815 | .032 | .032 | | |
| Structural covariances | 12 | 6.415 | .894 | .034 | .034 | | |
| Measurement residuals | 18 | 34.477 | .011 | .185 | .185 | | |

### *4.5.4. Conclusions*

As discussed in the beginning of this study, adoption of BIM by construction industry organizations faces barriers. These barriers can be classified into (a) process barriers to the business organization (Chen & Lu, 2017; S. Liu et al., 2015), and (b) technology barriers related to readiness and implementation (Chan, 2014; He et al., 2012). However, each of the four studies presented in the previous chapters of this dissertation failed to provide exhaustive explanations of BIM acceptance decision. To address this explanatory deficiency, the Synthesized Secondary Survey combined the three theoretical models (incentives theory, the UTAUT, and the Status Quo Bias model) and explored the issue of low BIM adoption in a blended model. To this effect, the Synthesized Secondary Survey study empirically explored the predictions of the joint model in an effort to attain better explanatory consistency and exhaustiveness.

Additional data related to the constructs of the incentive theory, the UTAUT, and the Status Quo Bias model were collected through purposeful sampling from a sample of professionals working in various types of construction industry organizations. The sample was divided into groups and then SEM was used to explore the differences between the groups on the variables of Incentive, UTAUT, and Status

Quo Bias. The outcomes of SEM analyses allowed to test 5 hypotheses related to the variables. Table 50 presents the summary of hypotheses testing.

*Table 46. Hypotheses Testing Results*

| No. | Study Assumption | Result |
|---|---|---|
| **$H_1$** | Trade contractors are more concerned with the choice of weightings than main contractors and designers. | Accepted |
| **$H_2$** | Social Influence will exert a positive effect on the individual's Behavioural Intention to use BIM. | Accepted |
| **$H_3$** | Facilitating Conditions have a positive correlation with one's individual usage of BIM. | Rejected |
| **$H_4$** | Attitude will have an influence with the individual's Behavioural Intention. | Accepted |
| **$H_5$** | Company type determines manifestation of the Status Quo Bias (i.e., sunk cost *vs.* regret avoidance). | Accepted |

Taken as whole, the results of the Synthesized Secondary Survey study allowed to accept 4 out of 5 remaining hypotheses that operationalized the reasons for low rates of BIM adoption in the construction industry. This clearly increases general explanatory consistency and exhaustiveness of the entire dissertation, and reliance on the joint model further provides more robust analytical traction.

## 4.6. Case Study: San Francisco International Airport

### *4.6.1. Background*

This dissertation pulls together three streams of literature to study the diffusion of BIM and its interdependence with project delivery constructs: the incentive theory (Baddeley & Chang, 2015; Linderoth, 2010), the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh, 2000; Venkatesh & Davis, 2000; Venkatesh, Morris, Davis, & Davis, 2003), and the Status Quo Bias model (Kahneman, 2013; Kahneman, Knetsch, & Thaler, 1991; Kahneman & Lovallo, 1993; Rogers, Chong, &

Preece, 2015). The quantitative data were collected through three separate surveys and the Synthesized Secondary Survey revealed a number of key trends and perceptions that inform how project delivery environments affect BIM adoption.

To better frame the results in a real-world construction environment, a case study subject was sought. Since both IPD and advanced levels of BIM adoption remain rare in the AEC industry practice, a substantial effort was expended to find an appropriate research subject. Eventually, two projects at the San Francisco International Airport were chosen due to their use of an advanced form of IPD and their implementation of 7D BIM (Neumayr, 2017). To the best of the researcher's knowledge, this represents the most advanced collaborative environment for a major construction project in the U.S., and possibly in the world (Nuttens, De Breuck, & Cattoor, 2018). Specifically, two projects were reviewed along with the overall project delivery platform utilized by the airport. The first project is the *Air Traffic Control Tower*, which was completed in October 2016. The second the *Terminal 1 Redevelopment Project*, which commenced in October 2016 with a planned completion in 2024 (SFO, 2016). The Terminal 1 Redevelopment Project is seen as a more collaborative and technologically advanced construction environment than was utilized for the Air Traffic Control Tower. Thus, while still in the engineering phase, the approach used for the former is key to understanding the results of the quantitative analyses performed, presented, and discussed in the preceding chapters of this dissertation.

***SFO contracting approach***. The San Francisco International Airport (SFO) has developed a unique approach to delivering projects known as the Exceptional Project Delivery Paradigm (SFO, 2017, p. 14). This approach guides the planning, design, and execution of airport projects through Structured Collaborative Partnering (SCP) and a Stakeholder Engagement Process (SEP).

The principal aim of the SCP is to create an integrated, high performing project team from multiple parties with explicit commitments to "teamwork, communication, trust, transparency, respect, and fairness" (SFO, 2017, p. 12). In essence, the SCP is used to cultivate solid external and internal working relationships before any problems and serious performance issues arise. From the perspective of organizational objectives and outcomes, SCP serves as a management tool to redefine expectations of how all parties in a construction project work together, thereby minimizing negative results such as financial losses, dysfunctional relationships, and unresolved claims. This is accomplished through multi-party agreements referred to as “super IPD” by the SFO team (SFO, 2017). Within this approach, the contracts are based on a Guaranteed Maximum Price (GMP) with the parties sharing in any cost savings. This base approach is analogous to AIA Integrated Project Delivery methodologies (Lind, 2012). However, SFO takes this a step further with each stakeholder rating and commenting on the collaboration efforts of other stakeholders throughout the project.

Partnering started at SFO under a previous master plan when SFO’s arts director was a founding member of the National Partner Institute. Like many in the industry, projects sporadically were negatively affected by adversarial relationships. To address this challenge, SFO had brought people together to collaborate and on a mutually beneficial basis. This approach was then furthered by the current Director of Construction who promoted a qualification-based contracting methodology rather than a standard bid cycle. Here, the goal was to facilitate early involvement, one of the central goals of the IPD approach. The market-driven pricing is ensured through trust-building grounded in a thorough qualification-based selection process after which the contractor is not motivated to seek an unfair price. According to available documents, SFO takes it as their obligation to develop that trust (SFO, 2017).

While partnering had a long history at SFO, it wasn’t until 2008 that they began to formalize the approach and developed what they call a “structured collaborative process”—a structured way to build a high-performing team through issue identification, commitments, and then assessment of success at meeting those commitments (Neumayr, 2017). Then, SFO leadership began to refine the progressive design-build model. Specifically, this refinement was accomplished by fine-tuning the mechanisms of how the stakeholders work together through a programming phase, complete the basis of design, and then negotiate a target budget that everybody works towards. It should be noted that the development of that particular process remains ongoing, as SFO continues to improve their business processes.

Across the construction industry, the vast majority of issues can be traced back to a misalignment of expectations as related to scope, cost, and schedule. In contrast, reliance on the structured collaborative allows to co-create these items from the start of any project, assign clearly defined project responsibilities based on objective facts and cost projections, and as a result achieve a common purpose in a much more efficient and mutually beneficial way. In case of SFO, partnering is intended to achieve both integration and collaboration (SFO, 2015).

***Air Traffic Control Tower project***. As a joint venture between SFO and the Federal Aviation Administration (FAA), the airport built a new air traffic control tower with the latest in technology and design. Standing 221 feet tall, the new tower features a modern, flared design clad in curved metal panelling. The project also includes a new three-story integrated facility building for the FAA and other personnel, and two connector walkways and improvements to the Terminal 1 boarding area C entrance (SFO, 2015). Construction began in the summer of 2012 and the project became fully operational in October 2016. The new tower was built to satisfy specific technical and site requirements as well as stringent seismic, safety, and security design standards required for the Bay Area, while simultaneously achieving LEED Gold status (SFO, 2015). SFO provided full access to the researcher of all contract documents, budgetary information, and tracking metrics for the project, which were reviewed against the results of the quantitative analyses.

***Terminal 1 redevelopment project***. Currently, SFO is also redeveloping Terminal 1, one of its oldest terminals built in the 1960s, to meet the needs of modern travellers and revolutionize the guest experience for all passengers arriving at the airport. When fully completed in 2024, Terminal 1 is expected to meet or exceed the award-winning standards of Terminal 2, and, at minimum, receive LEED Gold certification (SFO, 2016). This $2.4 billion project includes design and construction of north, south, and central areas, a new boarding area, new passenger loading bridges, concessions, a renovated space for passenger check-in, a consolidated security checkpoint, a re-composure area, baggage handling system and baggage claims, and a new mezzanine with connections to the Air Train and Central Parking Garage (SFO, 2016). Like in the case of the air traffic control tower, SFO has provided the researcher full access to all contract documentation and relevant budgetary information to be reviewed against the results of the quantitative analyses.

***SFO project delivery paradigm***. In a comprehensive effort to improve organizational productivity, increase overall efficiency of business processes, and eliminate various processes and resources redundancies, in 2014 SFO adopted an Exceptional Project Delivery Paradigm (SFO, 2017). The Paradigm governs the daily organization and interaction of project teams working at SFO. All project participants are expected to understand, fully accept, and actively implement the elements of the Paradigm wherever possible (SFO, 2017). The main impetus for this strategic decision was a clearly articulated SFO organizational vision with realistic, scalable, and achievable goals and orientation to become one of the global leaders in airport services with top customer ranking. Then, reflective of this long-term-organizational vision of SFO, the Exceptional Project Delivery Paradigm serves as a wide-ranging management tool that can be used to achieve this vision in the most effective and efficient way possible (SFO, 2017).

***Structured Collaborative Partnering***. As mentioned above, the Exceptional Project Delivery Paradigm (EPDP) rests on two pillars – Structured Collaborative Partnering (SCP) and Stakeholder Engagement Process (SEP) (SFO, 2017, p. 15). SCP is the core of SFO's Exceptional Project Delivery Paradigm. It provides a trusted leadership framework that supports an integrated, high-performing team. The Project Team is appointed for every project under design and implementation at SFO. The Project Team typically is comprised of two or more organizations with precise project responsibilities. The performance of the Project Team is guided by two core values:

1. A promise to embrace cooperative teamwork, direct communication, mutual trust, transparency, complete respect, and fairness, and

2. A promise to establish a collaborative environment that sets achievable goals and objectives. The combination of the two core values should lead to Exceptional project Outcomes (SFO, 2017, p. 15).

The main underlying principle of the SCP is mutual benefit. SCP also explicitly emphasizes that a “zero sum” approach to project design and implementation, no matter how small or large the specific project is, runs contrary to the spirit of collaboration. As a result, participants in any project team are encouraged and expected to fully engage challenges “in the spirit of what is best for everyone” with the end result being an Exceptional Project Outcome. In this project environment, every member of the Project Team is responsible for examining the relationship of issues to the overall project vision at all times at all stages of the project. (SFO, 2017, p. 15).

Productivity in the design and construction industry has come under serious scrutiny and severe criticism over the past several decades both from industry practitioners and academics (Arditi & Mochtar, 2000; Dubois & Gadde, 2002; Sveikauskas, Rowe, Mildenberger, Price, & Young, 2016). In particular, according to various empirical studies, construction projects across the U.S. incur annual extra costs in the range of tens of billions of dollars if not more (Kranker, Qiping, Munch, & Ditlev, 2016; Odeck, 2004; Touran & Lopez, 2006). These preventable expenses typically result from claims avoidance, incorrect claims documentation, high legal costs for claims, potential claims that go unresolved, long project delays due to unsettled project issues, and other project activities that add nothing to the successful completion of the project (Mulla & Waghmare, 2015). This epitomizes wasted organizational resources that could have been used instead to enhance project outcomes related to its scope and schedule (Fulford & Standing, 2014; Kenley, 2014).

However, beyond the quantifiable monetary and time costs, the greater damage emerges in the bad attitudes and poor working interactions created by adversarial relationships among stakeholders, project/construction managers, designers, and builders (Humphreys, Matthews, & Kumaraswamy, 2003). Past empirical studies of construction industry projects that involved several implementing partners found that adversarial relationships between project partners are closely associated with poor communication and a breakdown of trust and cooperation, and ultimately result in lost productivity (Laan, Noorderhaven, Voordijk, & Dewulf, 2011;

Li, Cheng, Love, & Irani, 2001). When these problems remain unaddressed through the project lifecycle, achieving project outcomes becomes a serious problem.

With these project implementation issues in mind, SCP was created as a consistently reliable management tool intended to minimize the negative consequences such as financial loss, damaged relationships, and unresolved claims by replacing antagonistic relationships between project partners with a cooperative, high-performing team model. In essence, Structured Collaborative Partnering fundamentally redefines the project implementation dynamics and policies and rules on how all parties involved are expected to work together (SFO, 2017).

Under the SCP model, Project Teams are established before planning and design begin, i.e., well in advance of potential problems and issue conflicts. By working together from the very start of the design phase of a project, SFO project teams develop solid working relationships and prepare for the challenge of resolving project issues through a productive and collaborative approach. In practice, selected members of the Project Team may be responsible for identifying and resolving any problem before it grows to involve other project partners. In this context, resolution must occur among those closest to a problem to prevent issues from escalating into a project-threatening crises (SFO, 2017).

***SEP model components***. Conceptually, the SCP model consists of seven closely interrelated components (SFO, 2017, pp. 19-20):

1. *Encouragement of Trust*—team leaders and team members will encourage and expect complete trust among themselves.
2. *Open Communication*—all team members will engage in completely open and transparent communication.
3. *Identification and Resolution of Problems*—team leaders and members will identify and resolve problems and issues at the lowest responsible level to reduce significant impacts on project budget, schedule, and quality; invoking issue resolution at the lowest responsible level should result in a

more effective allocation of time and financial resources and supports the overall team in achieving an Exceptional Project Outcome.

4. *Establishment of Common Goals*—all project members will identify common goals for an integrated, high-performing team while maintaining awareness of and respect for each other's individual goals and values.

5. *Collaboration*—by actively seeking input from all interested stakeholders, the Project Team will develop collaborative solutions that respect the needs of everyone involved; this fosters cooperation and improves the productivity of the Project Team members who are encouraged to pursue creativity and innovation.

6. *Risks Identification*—team leaders and members understand that it is everyone's responsibility to identify project risks early, share these concerns with all relevant team members, and develop mitigation measures that manage the risk to the satisfaction of all involved.

7. *Goals Development*—project goals are jointly developed and subsequently evaluated by all Project Team members to ensure goals are met.

***Locus of the SCP Model.*** The locus of all project related activities in the SCP model is the Structured Collaborative Partnering Team (SCPT) (SFO, 2017, p. 21). The logic behind this entity is straightforward. SFO is responsible for the formulation of the vision of the project and for setting the general expectations for SCP. Then, in this context, any project that is being implemented in the SCP requires a driving force that defines all implementation roles and responsibilities, establishes acceptable implementation schedules, and monitors and objectively evaluates both overall project performance and specific contribution of all implementation parties involved. This is the role of the Structured Collaborative Partnering Team (SFO, 2017).

Structurally, the SCPT consists of: (a) executive committee, (b) core team, and last but not least (c) stakeholders. The Executive Committee usually consists of the executive-level leaders and Senior Managers of SFO, Construction Manager, Contractor, and Designer. The Executive Committee defines specific program or project goals and sets immediate objectives, provides direction, is mandated with the responsibility of addressing all high-level issues, and resolves conflicts, as they arise. Most importantly, the Executive Committee is directly responsible for ensuring that all participants routinely apply the SCP practices (SFO, 2017).

The Core Team comprises Airport, Designer, and Builder leaders responsible for the management, implementation, and execution of the project. Normally, the Core Team includes all parties involved with project delivery, including but not limited to the Project/Construction Managers and their sub-consultant(s), the Designer and sub-consultant(s), the Contractor and subcontractor(s), and other key stakeholders (e.g., federal, state, and local government agencies, airline representatives, tenants, concessionaires, third parties, etc.). Depending on the progress of certain scopes of work, key subcontractor/sub-consultant personnel may be included in the Core Team. The Core Team typically meets as frequently as required to ensure that the Project Team is compliant with the SCP principles of transparency, teamwork, and accountability. Members of the Core Team are expected to actively participate in discovery of problematic issues and ensuring timely decision-making and issue resolution (SFO, 2017, p. 21).

Finally, the SCPT includes various stakeholders. For project implementation purposes, a stakeholder is operationally defined as any person or entity that: (a) has a stake in the outcome of the project; (b) is not employed to specifically deliver the project; and (c) is not part of SFO’s project management staff. In most instances stakeholders include end users, neighbours, vendors, special interest groups, facility maintenance personnel, vendors, project funders, and those who own one or more of the systems. Depending on specific needs, this group could also include SFO personnel (other than Project Management staff), airline representatives, retail tenants, TSA, FAA, Fire, Police, etc. (SFO, 2017, p. 22). Stakeholders have the following particular responsibilities as members of the SCPT (SFO, 2017, p. 23):

1. Meeting frequently (no less than quarterly), in turn, the Core Team is required to ensure all stakeholders are properly informed and engaged at all stages of a project, all requirements are being properly met, and that issues are being promptly resolved;

2. Contributing to the discovery of problematic issues and ensuring timely decision-making and amicable and mutually beneficial issue resolution;

3. Contributing in SEP efforts to deliver specific technical requirements and participating in the Structured Collaborative Partnering workshops.

***Workshops.*** The productive cohesion between the Executive Committee, the Core Team and the Stakeholders is ensured through Structured Collaborative Partnering Workshops. Each project specification contains provisions that define the guidelines for (SFO, 2017, p. 24):

4. *Planning Workshop* occurs prior to all other meetings and establishes the vision and goals for the programming phase. The planning workshop should result in a complete Structured Collaborative Partnering Plan (SCPP) and should involve as many stakeholders as possible; typically, the Design Builder/Contractor is not involved at this phase and SFO leads this effort. The goals for the Planning workshop are the following: (1) develop goals for the initial visioning of the project, (2) develop goals for the pre-programming phase of the project, and finally (3) develop a Structured Collaborative Partnering Plan.

5. *Kick-off Workshop* is the official beginning of a project for many partners and stakeholders. It defines the SCP commitments and begins to establish a cohesive SCPT. The goals of the Kick-off Workshop are the following: (a) develop a structured collaborative partnering charter, (b) establish issue resolution plan, and also (c) design an SCP Maintenance Plan.

6. *Ongoing Workshops* that recur throughout the project to evaluate and realign team progress toward an Exceptional Project Outcome. Ongoing

workshops usually include separate Executive Committee Workshops, Core Team Workshops, and Stakeholder Workshops. The goals of the Ongoing Workshops are the following: (a) review core project goals status, (b) review of specific project goals status, (c) review of project outcomes progress, (d) review of current monthly project scorecard, (e) highlight any new key or risk issues that have been identified, (f) develop viable risk mitigation measures to address the issues.

7. *Closeout Workshop* during which the team must focus on ensuring that the project closeout process goes smoothly. This workshop is an opportunity for reviewing lessons learned to help future projects run more smoothly. Before the Closeout Workshop, project leaders usually prepare a Final Project Scorecard to share with the Project Team. The Final Project Scorecard measures the Project Team's performance regarding the Core, Project, and EPO goals. Then, the Executive Committee usually receives a briefing on the results of the Final Project Scorecard before the Closeout Workshop and presents the results to the entire Project Team at the workshop. Normally, the Project Team is encouraged to lead a deliberative, truthful discussion on the results of the project delivery and project successes, challenges, bottlenecks, and most important, lessons learnt.

In Exceptional Project Delivery Paradigm, stakeholders are the ultimate owners and operators of all SFO facilities and systems. Therefore, their active participation and constructive input are vital in delivering exceptional projects. Furthermore, stakeholder engagement provides an open forum for them as members of the Structured Collaborative Partnering Team to have their voice and opinions heard and incorporated in the calculus of the project decision-making. For this reason, the Stakeholder Engagement Process (SEP) represents the second pillar of the Exceptional Project Delivery Paradigm.

***Stakeholder Engagement Process***. The SEP concept is focal to the Exceptional Project Delivery Paradigm on all SFO capital projects. Whilst SCP serves as the mechanism for fostering cooperation among all project participants, SEP integrates all project participants into a collaborative unit, which specifically includes stakeholders as an integral part of the project team (SFO, 2017, p. 27). In essence, the SEP provides a framework for increased stakeholder participation and their meaningful integration into the project. SEP creates the shared leadership structure of SFO's internal resources that are critical to delivering an Exceptional Project Outcome (EPO). Because the primary focus is the best interest of the project relative to SFO's long-term goals, team members' individual interests are also satisfied because their successes are central to these goals. This focus on collaborative success builds upon itself to promote even greater creativity and innovation because parties that may have felt themselves in conflict with one another now find the common ground that supports group success (SFO, 2017, p. 27).

Stakeholder Engagement facilitates EPO by creating a team-based environment where a shared understanding of project objectives and requirements combines with common knowledge and ideas. The SEP may focus on a general subject area or on a more special issue that requires resolution. An SEP Team may remain active throughout an entire project, or it may dissolve once its focus issue has been properly addressed. In either case, membership in the SEP Team will be based upon subject matter expertise and/or the relevance of an issue to specific partner organizations (SFO, 2017).

***SEP Roles and Responsibilities*** may be assigned differently depending on the needs of specific projects. In most case, staffing for these roles is scalable based on the size of the project. Team members may assume multiple SEP roles or lead multiple SEP Teams. The SEP Manager may combine positions based upon the size and scope of the project. In particular, under the SEP model, the roles and responsibilities can be assigned as follows (SFO, 2017, pp. 29-31):

1. *SEP Team*—is an integration of stakeholders and partners, it provides the project owner with insight into the issues and resolution of the work of the SEP Group Leader and the SEP Manager.

2. *SEP Manager*—responsible for managing the overall SEP process through all phases of a project. The SEP Manager assists in implementation of SEP activities, including the assigning of SEP Group Leaders, monitoring the progress of Group Leaders and Groups, and most importantly, ensuring that stakeholder input is recognized by the partners. A design background is typically strongly encouraged when choosing an SEP Manager.

3. *SEP Group*—is an assembly of stakeholders with a common focus and mission to provide input through all phases of project development; it enables more efficient information sharing and issue resolution and also plays an important role in resolving budget, schedule, and technical issues; the critical factor for each SEP Group is to understand and align their goals, communicate in an ongoing manner, and fully participate in the process from providing input, to reviewing designs, to making decisions. In most instances, the SEP Group is led by a SEP Group Leader.

4. *SEP Group Leader*—is a partner directly responsible for managing a group of related, project-specific SEP Subgroups. The SEP Group Leader is responsible for: (a) assembling, reviewing, modifying, and validating SEP Design Narrative standards and criteria for the SEP Subgroup area of focus; (b) preparing, reviewing, approving, and distributing meeting minutes for a SEP Subgroup; (c) facilitating resolution of issues submitted to the SEP Group; (d) ensuring documents are reviewed by the SEP Group and SEP Subgroups; (e) reporting findings to the SEP Owner; and (f) collecting and disseminating information to the SEP Group and SEP Subgroups.

5. *SEP Subgroup*—is a collection of Subgroups assembled by the SEP Manager. The SEP Subgroup has the knowledge and experience to define airport standards, so it can quickly and precisely address issues, questions, or tasks that arise during any phase of project development. Each Subgroup is overseen by an SEP Owner, who is the technical lead of each Group. The number of SEP Subgroups on a project depends upon the scope of work.

6. *SEP Owner*—is SFO representative responsible for managing the area, system, or operation that constitutes the focus of an SEP Subgroup. The SEP Owner also ensures the completeness and accuracy of the SEP Design Narratives, including: (a) approving SEP Design Narrative standards and criteria for the area of focus, and (b) providing final decisions on SEP issues submitted to the SEP Group.

7. *SEP Group Member*—is SFO representative working with the area, system, or operation that constitutes the focus of the particular SEP Subgroup. These members are part of the larger group of stakeholders whose input is important for the project success.

***Stakeholder Engagement Meetings***. Similarly to how the productive cohesion is ensured through Structured Collaborative Partnering Workshops in the SCP model, in the SEP cohesion is achieved through Stakeholder Engagement Meetings that proceed in the following phases (SFO, 2017, pp. 31-33):

1. *Programming Phase*—during which SFO defines the programmatic requirements in the Pre-Programming Phase. Once the Design/Builder has been selected, the Programming Phase aims to vet and confirm the Project Program. The Programming Phase SEP Groups are responsible for clarifying the program and confirming expectations, cost, and schedule. In this phase, the Project Team joins the SEP Team. The Design/Builder’s Design Manager facilitates the Stakeholder Engagement Process by connecting with project stakeholders and by guiding programming decisions. Participants review and expand upon the Project Definition Report (the programmatic requirements defined during Pre-Programming) to develop the Basis of Design, Conceptual Drawings, a Cost Model, and Proposed Schedule. Upon completion of this phase, the Design/Build Team transitions into the Design Phase, with the SEP Team's role shifting to design review. Specific stakeholder engagement activities during this phase include: (a) data gathering and confirmation of Pre-programming Phase data; (b) quantitative and qualitative information about the function and use

of the space; (c) needs assessment via observation and/or interviews; and finally, (d) current and future space inventory. The goals of Programming Phase SEP meetings include assessment of facility or system needs, identification and integration of interfaces to existing facilities/systems, and development of a conceptual design that addresses the needs and interfaces for each facility/system. In turn, the objectives of Programming Phase SEP meetings include establishing the Basis of Design based upon the Project Vision, assessment of functionality and ease of maintenance, and finally, optimization of long-term value for SFO.

2. *Design Phase*—is where the team with substantial input from the Design/Builder develops an integrated design plan that supports these project standards. This phase includes production of Schematic, Design Development, and Construction Drawings. The Project Management Support Team and the Design/Builder verifies that the drawings and specifications follow the Project Program requirements and note any exceptions prior to issuing the drawings to stakeholders. The goals of Design Phase SEP meetings include: (a) review for alignment with the Project Program represented in the Design Drawings and Specifications; (b) review of additions to the Project Program represented in the Design Drawings and Specifications; (c) recommending solutions for Design, Cost, and Schedule Issues. In turn, the objectives of Design Phase SEP meetings include: (a) completion of the Design Documents in order to secure bids for the project (D/B/B) or begin issuing Construction Bid Trade Packages (D/B); (b) resolution of issues to maintain the Cost Model; and finally, (c) resolution of issues to maintain the Schedule objectives.

3. *Construction Phase*—starts upon completion of the Design Phase in traditional Design-Bid-Build project delivery scenarios. However, there are variations to the progression of construction activities due to the collaborative and fast-track nature of the Design/Build project delivery process, where the Construction Phase begins with the completion of fully

designed Issued for Bid Documents or fully-designed Trade Bid Packages. The goals of Construction Phase SEP meetings include: resolving design/construction issues as a team; assisting with review of product and material submittals and shop drawings; recommending solutions for construction, cost, and schedule issues. In turn, the objectives of Construction Phase SEP meetings include: (a) ensuring consistency with the approved Project Program; (b) resolution of issues to maintain the forecasted project cost; (c) resolution of issues to maintain the Schedule.

4. *Activation Phase*—during this phase participants prepare the facility or system for occupancy and beneficial use by the user groups' community, frequently through a simulation event that tests systems readiness. The Activation Phase focuses primarily on Airport Operational tasks to ensure smooth operation of the facility or system on opening day. Simulation Test Plans addressing all probable operational scenarios provide an opportunity to discover operational issues and develop corrective actions during simulation activities. The goals of this phase are to have a seamless activation and minimize unforeseen issues and resolve operational, construction, and customer service issues discovered during activation, simulation, and testing. The objectives of Activation Phase SEP meetings are the following: (a) to prepare facility for opening and beneficial use, and (b) to support contractors' efforts to obtain Temporary Certificate of Occupancy (TCO).

5. *Close-Out Phase*—completes the project lifecycle. Development and resolution of all punch list items occur during this phase, as does completion of Testing and Commissioning in accordance with the contract requirements. This phase also includes completion of closeout submittals, including the preparation of Operations and Maintenance (O&M) Manuals, as-built drawings, and all required training. The goals of SEP meetings during the Close-Out Phase include completion of punch list, approval of closeout submittals, completing testing and commissioning, and completion

> of personnel training. The only objective of Close-Out Phase SEP meetings is to complete the project and turn over to user group/maintenance.

Every major construction effort can expect challenges that threaten the project's success. Whether it is balancing design, constructability, and regulatory requirements, or whether it is tensions that arise among different personality types, conflicts are inevitable. Coordinating a variety of design goals and needs of building occupants with schedule and budget is a challenge SFO met through the creation of the Exceptional Project Delivery Paradigm. This Exceptional Project Delivery Paradigm was born of SFO's recognition that there must be a better way to deliver construction projects. Prior to the adoption of the Exceptional Project Delivery Paradigm, project teams often had adversarial relationships among themselves, causing untimely and expensive resolution of issues. Stakeholders were not always well integrated into the project teams, so feedback often came too late in the process, if at all, for issues to be addressed in a meaningful way. Air Traffic Control Tower and Terminal 1 Redevelopment projects were among the first major construction projects at SFO since the International Terminal Building was constructed, and this hiatus presented a unique opportunity for SFO leadership to rethink the traditional process of implementing construction projects.

At the core of the Exceptional Project Delivery Paradigm, SCP and SEP foster a working relationship where trust and transparency are the norm. On these two projects, each partner was able to identify project challenges exceedingly early, work proactively, and share concerns openly with other project delivery team members. The collaborative issue resolution process considered budget, schedule, and the needs of building occupants to resolve issues with the primary goal being the success of the project and every participant. The conflicts common among traditional project relationships were easily overcome because all partners put trust in each other and the success of everyone at the table was of equal importance (SFO, 2017, p. 37).

### *4.6.2. Results*

***Qualitative data collection***. In total, three interviews were conducted in this case study. Two interviews prior to the Synthesized Secondary Survey were conducted in sequence on December 8th, 2016. The last interview post-Synthesized Secondary Surveys was conducted on April 6th, 2018. All interviews were conducted in the SFO offices of the two key decision makers with the researcher travelling to San Francisco to conduct the interviews in-person. All interviews were recorded using a digital recorder and then transcribed using a transcription service. Both decision makers consented to participate in the interviews, collaborated fully by providing as much information related to their respective areas of professional expertise as possible, and displayed enthusiastic attitudes throughout both pre-survey and post-survey interviews. The participants were not remunerated in any way for their time and information; they provided all opinions on a purely voluntary and free basis.

Once the interviews were transcribed, their contents were reviewed by the researcher for consistency and correctness of transcription. Then, member checking was conducted with participants via email to ensure reliability and validity of the collected data (Kuckartz, 2015). Table 54 in Appendix F presents the description of the textual files generated by the interviews after the transcription process. In total, approximately 201 minutes of interviews or 34,138 words were analysed.

*Table 47. Coding Scheme*

| **Nodes** | **Codes** | **Codes Number** |
|---|---|---|
| **INCENTIVE THEORY** | Collaborative process<br>Contract variations<br>Cost efficiency<br>Information transparency<br>Long-term orientation<br>Price equalization<br>Productivity<br>Profit maximization<br>Streamlined tendering | **10** |

| | | |
|---|---|---|
| **UTAUT** | Effort expectancy<br>Facilitating conditions<br>Performance expectancy<br>Social influence<br>*Organizational inertia*<br>*Organizational isomorphism* | **7** |
| **STATUS QUO BIAS** | Cost-benefit analysis<br>*Hyperbolic discounting*<br>Risk assessment<br>*Analytical*<br>*Availability heuristic*<br>*Emotional*<br>*Recency bias* | **8** |
| **ORGANIZATIONAL CULTURE** | | **1** |
| **LEADERSHIP** | | 1 |
| **Total Number of Nodes/Codes** | | **5/27** |

The developed codes and the coding scheme were tested on a sample of a text (Pre-survey DIIM1) through a pilot coding exercise. DIIM1 file was selected because it was the shortest, yet it had a well-developed structure, and based on an exploratory assessment of the textual file, a wide range of thematic content items allowed to test the internal consistency of the codes and the external consistency of the coding scheme. The results were satisfactory as they allowed to code the three main nodes of the analysis with coherence and consistency.

The remaining interviews were coded using the codes and the coding scheme that were developed and tested in a pilot coding exercise. In this step the coding scheme was applied based on the contextual meaning of a specific sentence (as a unit of analysis). Because many sentences under analysis frequently contained direct and indirect references to several analytical constructs, multiple codes and associated nodes were assigned in such instances as necessary to reflect the richness of the content. Tables 52 – 54 in Appendix F present the results of Step Three and Step Four of the coding procedure.

***Thematic analysis***. Thematic analysis was the last procedure performed in the directed content analysis. It was governed by the deductive-theoretical paradigm to identify themes. Themes were coded based on whether they match the analytical constructs of the case study (Schreier, 2012; Vaismoradi et al., 2013). The same is applicable to the identification of sub-themes. Such bottom-down approach was justified given the purpose of the case study. Epistemologically, thematic analysis was conducted within an essentialist-realist domain and a unidirectional relationship was assumed between experience, meaning, and corresponding language (Howell, 2014). Because an essentialist-realist perspective was selected, motivations, experiences, and meanings expressed in the interviews were analysed in a straight-forward, semantic way. Exploration of latent ideas, assumptions, and conceptualizations was not performed as it would have exceeded the scope of the current case study.

Then, once the themes were identified, they were interpreted using a semantic approach (Krippendorff, 2018) in which: (a) themes were identified within the explicit or surface meanings of the textual data, and (b) the researcher was not looking for anything beyond what a participant has said or what has been transcribed. Using a semantic approach allowed to progress from (a) descriptions, where the data have simply been organized and summarized to show patterns in semantic content, to (b) interpretation, where the significance of the patterns and their broader meanings and implications were analysed. The following criteria were used for thematic analysis (Krippendorff, 2018, pp. 97-98):

1. Internal homogeneity
2. External homogeneity
3. Incidence frequency
4. Relative weight of sources of evidence.

*Table 48. Thematic Homogeneity Matrix*

| ANALYTICAL CONSTRUCTS | CDO1 | CDO2 | DIIM1 | DIIM2 |
|---|---|---|---|---|
| **Incentive theory** | Yes | Yes | Yes | No |
| **UTAUT** | Yes | Yes | Yes | Yes |
| **Status Quo Bias** | Yes | Yes | Yes | Yes |
| **Organizational culture** | Yes | Yes | Yes | Yes |
| **Leadership** | Yes | Yes | No | No |

On the criterion of internal homogeneity, data within each textual file cohere together meaningfully, while clear and identifiable distinctions between separate themes do exist in virtually all textual files (Table 58). In particular, interviews CDO1 and CDO2 were the files with the highest internal homogeneity of 100%. In these two interviews, it was possible to establish clear distinctions between all three pre-selected theory-based analytical constructs (i.e., incentive theory, the UTAUT, and the Status Quo Bias) and the two emergent analytical constructs (i.e., leadership and organizational culture).

Internal homogeneity of interview DIIM1 was approximately 20% lower because its thematic analysis resulted in identification of only four analytical constructs (incentive theory, the UTAUT, Status Quo Bias, and Organizational culture). Finally, internal homogeneity of interview DIIM2 was 40% lower because its thematic analysis resulted in identification of only three analytical constructs – two pre-selected theory-based analytical constructs (the UTAUT and the Status Quo Bias) and only one emergent analytical construct (Organizational culture).

On the criterion of external homogeneity, data across all textual files also cohere together meaningfully, and clear and identifiable distinctions between separate themes can be reliably drawn throughout all four textual files (Table 58). Specifically, the UTAUT, Status Quo Bias, and Organizational culture were the three analytical constructs with the highest (100%) level of external homogeneity, i.e., these analytical constructs were identified in all four interviews. These three were followed by the analytical construct Incentive theory. Its external homogeneity was 75% and was affected by its absence in interview DIIM2. Finally, the emergent analytical construct

"Leadership" was associated with the lowest (50%) external homogeneity as codes relevant to this analytical construct were absent in interviews DIIM1 and DIIM2.

The criterion of incidence frequency was assessed using two measures: (1) number of coding references, and (2) number of words coded. On the first measure of incidence frequency, interviews CDO1 and DIIM2 were the two dominant sources of coding references with 99 and 53 coding references, respectively (Table 59). They were followed by CDO2 with 44 coding references and DIIM1 with 9 coding references. When the measure of the number of coding references was applied to analytical constructs, all three pre-selected theory-based analytical constructs received the highest number of coding references: incentive theory – 72, the UTAU – 57, and the Status Quo Bias – 49. They were followed by the two emergent analytical constructs: Organizational culture – 19 and Leadership – 8.

*Table 49. Incidence Frequency by Number of Coding References*

| **Analytical Constructs** | **CDO1** | **CDO2** | **DIIM1** | **DIIM2** | **Total** |
|---|---|---|---|---|---|
| **Incentive theory** | 46 | 21 | 5 | 0 | **72** |
| **UTAUT** | 17 | 12 | 2 | 26 | **57** |
| **Status Quo Bias** | 26 | 5 | 1 | 17 | **49** |
| **Organizational culture** | 7 | 1 | 1 | 10 | **19** |
| **Leadership** | 3 | 5 | 0 | 0 | **8** |
| **Total** | **99** | **44** | **9** | **53** | |

On the second measure of incidence frequency, interviews CDO1 and CDO2 contained the vast majority of coded words, 6,294 and 4,308 words, respectively (Table 64). They were followed by interview DIIM2 with 1,517 coded words and DIIM1 with 596 words. When the measure of number of words coded was applied to analytical constructs, then similarly to the first measure, all three pre-selected theory-based analytical constructs received the highest number of coded words: incentive theory – 4,673; the UTAUT – 4,288; Status Quo Bias – 2,964. Likewise, they were followed by the two emergent analytical constructs: Organizational culture – 479 and Leadership – 411.

*Table 50. Incidence frequency by number of words coded*

| Analytical Constructs | CDO1 | CDO2 | DIIM1 | DIIM2 | Total |
|---|---|---|---|---|---|
| **Incentive theory** | 2545 | 1885 | 243 | 0 | **4673** |
| **UTAUT** | 1387 | 1800 | 236 | 865 | **4288** |
| **Status Quo Bias** | 1864 | 457 | 37 | 506 | **2864** |
| **Organizational culture** | 246 | 7 | 80 | 146 | **479** |
| **Leadership** | 252 | 159 | 0 | 0 | **411** |
| **Total** | **6294** | **4308** | **596** | **1517** | |

The criterion of relative weight of the sources of evidence was assessed using three measures: (a) contribution to thematic content by codes, (b) contribution to the incidence of analytical constructs, and (c) combined relative weight—weighted average of the first two measures.

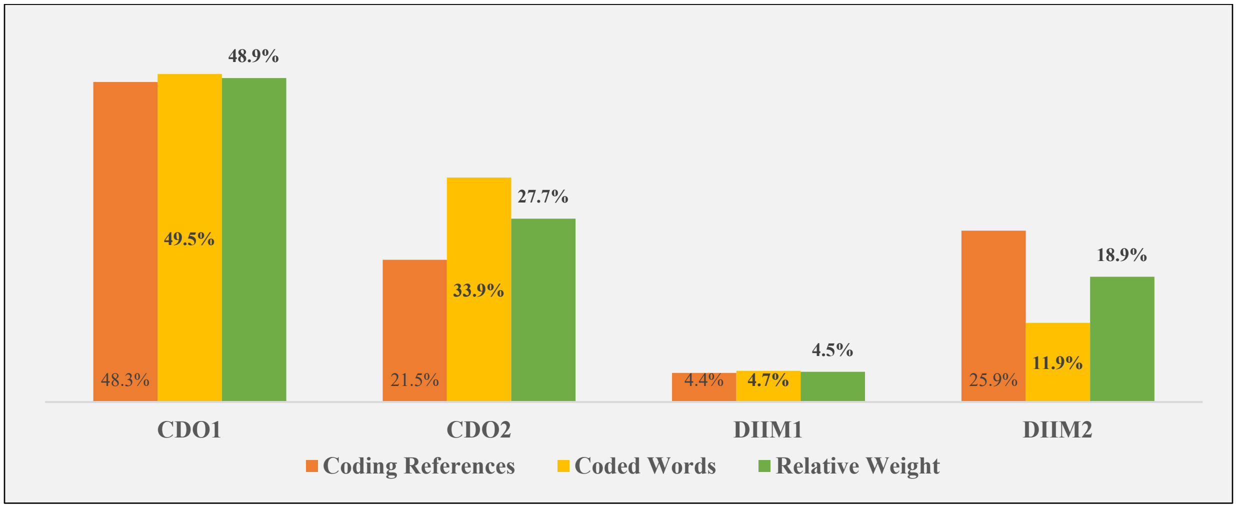


*Figure 113. Relative Weight of Sources of Evidence*

As Figure 13 shows, interviews CDO1 and CDO2 contributed the most as the sources of evidence to the overall thematic content, with the combined relative weights of 48.9% and 27.7%, respectively. DIIM2 was the third contributor to the overall thematic content of the interviews with its combined relative weight of 18.9%. Interview DIIM1 contributed the least as the source of evidence. Its relative insignificance can be explained by its comparatively small size in relation to the other three interviews.

### *4.6.3. Conclusions*

This case study utilized a directed content analysis and a detailed examination of key quotes (a) to systematically consolidate and (b) consistently make reliable inferences from the entirety of qualitative evidence collected during interviews with informants and then followed with discussion of key quotations to further contextualize the overarching research. The key decision makers who were interviewed possess extensive knowledge, highly advanced level of professional expertise, and multi-year experience in implementation of large-scale construction projects. Therefore, they are reliable sources of high-quality evidence about the processes and management tools used in the delivery of large-scale infrastructure construction projects such as, for example, the SFO's Air Traffic Control Tower and Terminal 1 Redevelopment projects.

Also, a directed content analysis relied on theory-driven deductive inferences as discrete analytical categories. This allowed to evaluate directly whether the same factors that were found by the preceding quantitative analyses to affect the adoption of BIM, can be identified by the qualitative analyses (conceptualized as analytical constructs) as exerting similar or at least comparable effects on the adoption of BIM. Furthermore, using the instrument of thematic analysis, the researcher also attempted to assess the nature of these effects – mediating or moderating. Taken as a whole, the results of qualitative analyses support the following general conclusions.

First, the qualitative analyses exhaustively confirmed the presence of exactly the same principal factors that were identified in prior quantitative analyses. This provides further support for the choice of the three key factors which the respective extant theoretical literature supported but which had largely never been applied to the adoption of BIM, specifically. These factors are those related to the incentive theory, the UTAUT, and the Status Quo Bias model. Moreover, the identification of the same factors by the qualitative analyses (a) cross-validates the findings of the qualitative analyses of the dissertation, and (b) provides further basis to claim that the factors used in both quantitative and qualitative sections of this dissertation research have adequate predictive validity and discriminant validity and can consequently be reliably used as analytical constructs in future studies.

Second, similar to the findings of quantitative studies of this dissertation, the results of the qualitative analyses performed in this case study strongly suggest overall that different factors that affect the adoption of BIM in construction industry have differential effects on (a) the scope of BIM adoption, (b) the decision to adopt BIM, and (c) the scale of BIM utilization for project delivery.

Third, variation in the strength of the effects does exist not only across the three theory-driven factors but also within factors. The qualitative analyses found that not only do factors differ in the vectors and the strengths of their effects on decision-making regarding adoption of BIM, but also that a significant variation appears to exist within these three factors. In other words, it was found that not only do the incentive theory, the UTAUT, and the Status Quo Bias have differential effects compared to each other, but their internal structural constructs possess different weights that may determine the strength and the vector of each factor’s effect.

Given the frequency of incidence of descriptors related to specific constructs within the three factors, these constructs play unequal roles in the process. The results of the thematic analysis point to the following diverse picture. If the constructs related to the incentive theory are considered, then the adoption and the utilization of BIM is differentially affected by specific constructs (Figure 14). The realization that adoption of BIM leads to a more collaborative process between all stakeholders contributes the most (29.7%) to the effects of incentive theory as a BIM adoption factor.

Then, reductions in adverse effects of contract variations and increases in cost-efficiency of construction projects contribute approximately equally with 11.8% and 11.24% respectively. The fourth strongest construct appears to be the ability of all stakeholders to adopt long-term orientation (8.43%). Four constructs—price equalization (7.87%), increases in overall productivity (7.3%), profit maximization (7.3%) and streamlined tendering process (6.74%)—contribute approximately equally.

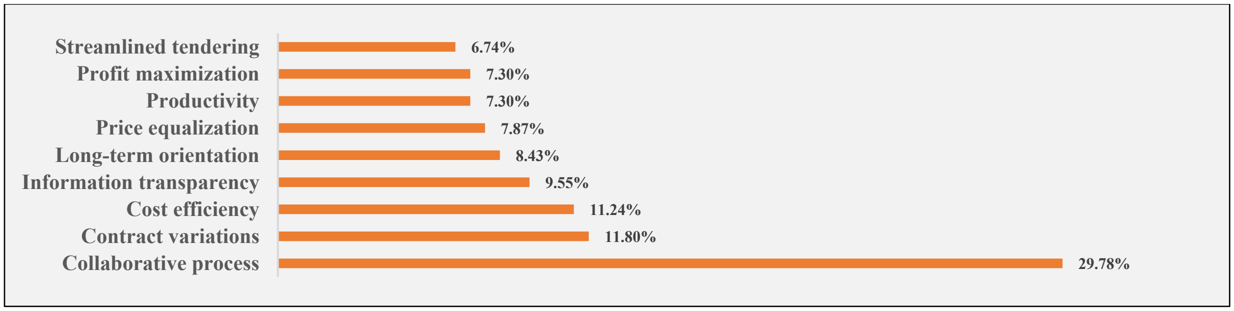


*Figure 14. Contribution of Incentive Theory Constructs*

If the constructs related to the UTAUT are considered, then the adoption and the utilization of BIM is differentially affected as shown in Figure 15. Performance expectancy contributes the most (29.59%) to the effects of the UTAUT as a factor in BIM adoption. In turn, facilitating conditions (28.57%) and effort expectancy (19.39%) are the second and third most important contributing constructs. They are followed by social influence (13.27%). What is interesting about the UTAUT constructs is that the key informants identified organizational inertia (8.16%) as a significant contributing construct. One interview identified organizational isomorphism, especially in its memetic form, as one of the significant constructs within the UTAUT factor, although its relative weight appears to be low compared to other social influence's constructs.

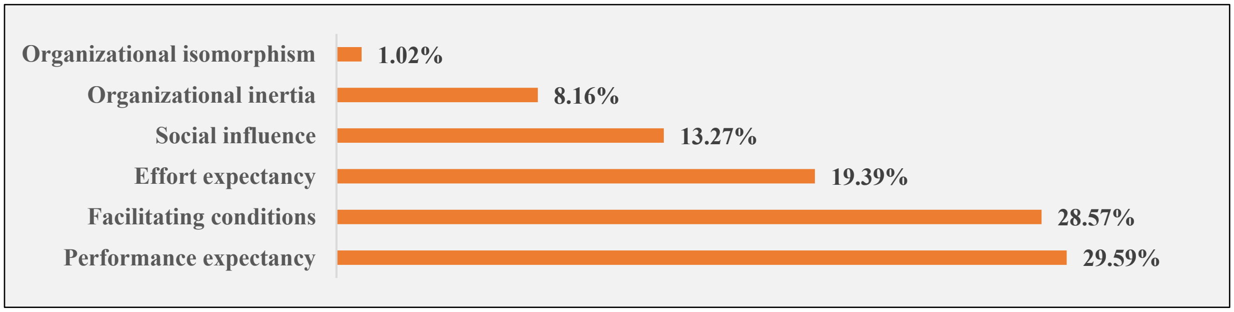


*Figure 15. Contribution of the UTAUT Constructs*

Finally, if the constructs related to the Status Quo Bias are considered, then the adoption and the utilization of BIM is differentially affected in the following way (Figure 15). Risk assessment contributes the most (40.4%) to the effects of the Status Quo Bias as a factor in BIM adoption. Analytical component (19.19%) of risk assessment tends to dominate emotional component (16.16%), while cost-benefit analysis as an instrument of risk-assessment contributes 13.13% to the effects of Status Quo Bias.

Interestingly, the thematic analysis also found that (a) hyperbolic discounting (tendency of decision-makers to increasingly choose a smaller-sooner reward over a larger-later reward as the delay occurs sooner rather than later) also plays a significant role (6.06%) in this factor, and so do (b) availability heuristic (dependence on mental shortcuts that relies on immediate examples when evaluating a specific topic, idea, or a course of action), and (c) recency bias (decisions made under the influence of recent events) with 3.03% and 2.02% contribution respectively. The influence of these constructs needs to be further investigated in future studies of BIM adoption.

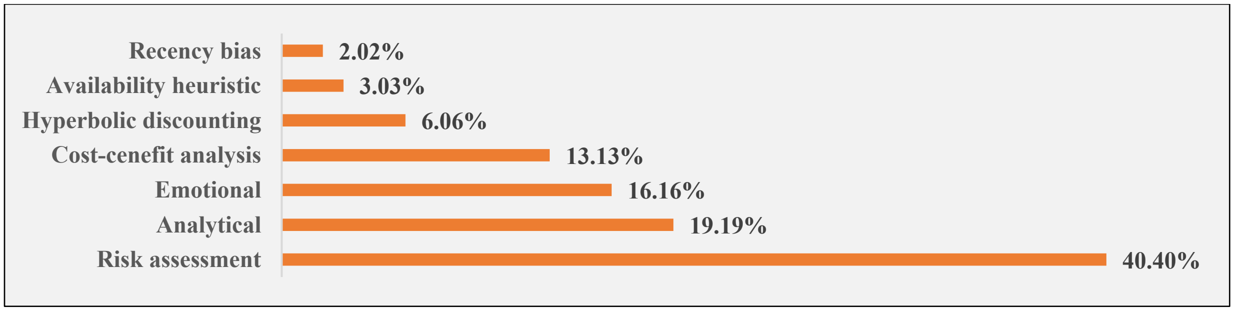


*Figure 16. Contribution of the Status Quo Bias Constructs*

Fourth, in the analysis, organizational culture and leadership emerged as two additional factors affecting the adoption and utilization of BIM. Organizational culture accounted for 9.3% of coded references and 3.4% of coded words. Leadership accounted for 3.9% of coded references and 3.2% of coded words. In the opinion of the key decision makers, both factors were significant in the adoption of the Exceptional Project Delivery Paradigm at SFO, and by extension they were also important in the process of BIM and IPD adoption and utilization. Although these two factors were not present in all four sources of qualitative evidence analysed, the fact that they were present in the two sources that contributed the most to the entirety of qualitative evidence evaluated in this case study suggest that organizational culture and leadership are important contributing factors. Therefore, both organizational culture and leadership should be properly accounted in future empirical models of BIM adoption, with investigation and more in-depth analyses of their effects.

Fifth, SFO's Exceptional Project Delivery Paradigm (EPDP) served as a strong mediator of BIM adoption and provided a wider context for the qualitative analysis and its findings. What is clear from the interviews is that in the opinion of the key decision makers, EPDP's structure and pragmatic purpose as a complex management tool for generic projects reflect the general best practices of BIM and IPD as project management tools utilized industry wide. Then, he collaborative process as a construct contributes the most to incentive theory as a factor within BIM adoption.

Thus, because EPDP rests on both (a) Structured Collaborative Partnering (SCP), and (b) Stakeholder Engagement Process (SEP), if EDPD is transferred to other institutional and organizational settings elsewhere in the U.S. construction industry, it can be effectively and efficiently used as a scaffolding for the adoption and utilization of both BIM and IPD. Also, because EPDP aims to change organizational culture through innovative leadership and active stakeholder engagement, and since both organizational culture and leadership emerged as important factors in BIM adoption, the former may, at least plausibly, play mediating roles in BIM adoption and use if EPDP is present. Finally, reliance on active stakeholder engagement in EDPD may also serve as a positive factor in BIM utilization.

***Theoretical implications*.** The findings of this case study have two theoretical implications. First and foremost, they are consistent across the board with theoretical predictions. The incentive theory makes two predictions directly relevant to the adoption of BIM. Specifically, that (a) a rational economic agent adopts any innovation only when it is associated with rising productivity, lower costs, and increase in profits due to higher information transparency, and need for better cooperation among stakeholders (Baddeley & Chang, 2015); and (b) due to push for increased cooperation, stakeholders face a set of economic disincentives to behave opportunistically for the sake of profit-maximization (Lee, Yu, & Jeong, 2015). In turn, this stimulates trust-building (Laan et al., 2011) and long-term strategic orientation (He, Qian, & Duan, 2012). The results of the qualitative analyses suggest exactly that. Because BIM allows to increase cooperation among stakeholders drastically, this mediates trust-building among them and encourages long-termism with all associated benefits—streamlined tendering, reductions in contract variations, and most importantly, increases in productivity and profitability due to reductions in costs.

Likewise, according to the predictions of the UTAUT model, performance expectancy, effort expectancy, social influence, and facilitating conditions all in combined but with varying degree of contribution, determine the decision and rate of BIM acceptance (Samuelson & Björk, 2013). These factors are further subject to people's attitudes towards technology use (Davies & Harty, 2013). The conclusions of the qualitative analyses demonstrated that (a) not only are performance expectancy, facilitating conditions, effort expectancy and social influence co-dependent in their influence on BIM acceptance and use, but (b) they are also moderated by such subjective factors as organizational inertia and organizational isomorphism.

Lastly, the Status Quo Bias explanation posits that (a) people concurrently employ analytical and emotional systems to process and assess risk; (b) the analytical system relies on rational value judgements evident, for example, in cost-benefit analysis; (c) in contrast, the emotional system processes and assesses risk through mostly subjective determinations; and (d) the systems are generally complementary but in situations where their outputs differ, the emotional system becomes dominant (Kahneman, 2013; Kahneman et al., 1991; Kahneman & Lovallo, 1993).

The evidence obtained from the interviews (a) not only generally confirms the concurrent reliance on both analytical and emotional systems of risk processing and assessment by relevant decision-makers tasked with complex decisions with far-reaching financial ramifications, but also (b) this evidence strongly suggests that even rational decision makers with highly specialized expertise and long and diverse professional experience (like the participants of this case study) exhibit a clearly identifiable tendency to rely on subjective mental decision-making patterns (e.g., hyperbolic discounting, recency bias) and shortcuts (e.g., availability heuristic).

Another important theoretical implication of these qualitative findings is that taken as a whole, they provided further empirical affirmation of the theoretical constructs and models used elsewhere in this dissertation and in other extant studies. This, in turn, (a) contributes to some gains in explanatory power of theoretical models employed across various empirical studies on the topic of BIM adoption and use, and

(b) further enhances their general and specific descriptive ability, and finally (c) expands the scope and scale of their predictive capacity.

Considered as a whole, the new evidence, especially because it allowed to cross-validate findings of preceding quantitative studies of this dissertation through an entirely different data collection and data analysis apparatus, may also be useful for improving theoretical parsimony of the current models of BIM adoption and use in future studies. Thus, this may result in theoretical concepts that fit the reality of construction project management much better and provide superior analytical traction.

***Practical implications*.** Findings of this case study also have two practical implications for the construction industry. First, they underscore the critical importance of timely knowledge management and proper knowledge transfer when it comes to critical innovations that may benefit specific companies and potentially revolutionize the entire construction industry. Precisely because SFO's experience with Exceptional Project Delivery Paradigm as a general organizational management tool was overwhelmingly positive, this allowed the SFO team to focus on achieving consistent results in other spheres. In other words, SFO designed and implemented Exceptional Project Delivery Paradigm as a means, not an end. Thus, perhaps BIM and IPD also ought to be approached as such – as a means to achieve better management outcomes in the delivery of construction projects, not the end in itself.

Second, because organizational culture and leadership emerged as plausible factors that also contribute to the process of adoption and use of BIM, both organizational culture and leadership should be considered as potential influences when a business organization embarks on the journey to adopt and use BIM or expand the scope of its current use. Both concepts are complex and subject to substantial internal variation. For example, organizational culture can be functional, dysfunctional, traditional, innovative, etc. (Barney, 1986; Hofstede, Neuijen, Ohayv, & Sanders, 1990; Ouchi & Wilkins, 1985; Pettigrew, 1979; Schein, 1996a; Schein, 1996b), while leadership can be transformational (Bass & Avolio, 1993), transactional and laissez-faire (Eagly, Johannesen-Schmidt, & van Engen, 2003), servant (Graham, 1991), etc.

In this context, as the decision to adopt and use BIM is multifactorial, and since the effects are differential both across and within factors that affect such decision, a combination of a specific organizational culture and a leadership style may skew the entire decision-making in the wrong direction with dire consequences for BIM. For this reason, construction industry managers must be, at minimum, aware of these influences. At maximum, they must have a realistic plan to either take advantage of the positive interaction between organizational culture and leadership or introduce effective measures to ameliorate the negative interactions between the two.

***Assumptions.*** Assumptions are “acknowledged causal relationships or estimations of the existence of a fact from the known presence of other fact(s) or relationships between the latter” (Ravich & Riggan, 2016, p. 113). All data collection procedures and data analyses in the current case study rest on two assumptions.

First, in the current case study, the choice of qualitative research method implies one central assumption. Specifically, the semi-structured interviews “are a common instrument for qualitative data collection” (Seidman, 2013, p. 145). Then, because this particular research instrument was utilized to collect data from a small sample of key informants closely familiar with the issues related to adoption of BIM, the central assumption of the current case study is representativeness. In particular, for the pragmatic purposes of this case study and the entire dissertation research project, it was assumed that if all sampling requirements were satisfied, then the sample drawn should reflect the entire research population that would offer significant insights into the nature of the overarching research question.

Second, another assumption is that the key decision makers would respond to questions openly, honestly, and substantively. The research purpose of the case study was to cross-validate the findings of the four quantitative studies through the analysis of qualitative data from the interviews of key informants with extensive experience in an advanced BIM-enabled construction environment (which is rare). To this extent, the second assumption of the case study allowed to analyse qualitative data with a high degree of conceptual validity and reliability.

***Limitations***. Limitations are "existing and potential weaknesses of research that may be completely out of control of researcher" (Knowlton & Phillips, 2013, p. 71). The case study has four limitations that affect the validity and reliability of its findings. First, the scope of the study is limited to only two key decision-makers because of the time constraints involved in data collection, amount of the qualitative data, and subsequent data analysis. Second, the case study results may be limited to the sample population and may not be fully transferable to the total population of construction industry professionals given the uniqueness of SFO as an organization. Although some BIM and IPD business practices discussed by the key decision makers in their interviews can be generalized to the entire population of U.S. construction industry professionals, some business practices, decision-making routines and organizational culture norms that are unique to SFO are difficult to generalize.

Third, the research instrument collected data on key decision makers' perceptions and experiences about specific business practices related to BIM and IPD utilization, not their actual managerial or organizational behaviours. Finally, the case study design itself represents a limitation. Although generally robust and reliable, case studies are not perfect research designs and suffer from a number of inherent limitations: (a) they do not allow establishing cause and effect relationships; (b) research constructs are explored at only one specific time point; and (c) case study designs may be subject to selection and measurement biases (Edmonds & Kennedy, 2017, pp. 143-144). However, because the results of the current case study were interpreted in the larger research context of the four quantitative studies of this dissertation, this measure to a substantial degree mitigates the majority of validity and reliability threats posed by the four limitations discussed above.

***Delimitations.*** The delimitations are "the characteristics that limit the scope and define the boundaries of research" (Knowlton & Phillips, 2013, p. 73). The case study had the following delimitations: (a) the choice of research questions; (b) the constructs that were investigated during semi-structured interviews with key decision makers; (c) the conceptual framework utilized to analyse the qualitative data collected in the interviews; (d) the choice of key informants out of the entire range of possible research participants; (e) geographic location of the case study; and finally, (f) the business processes and organizational culture at SFO.

The overarching research question and the constructs delimit the focus of the case study, the conceptual framework delimit the choice of theoretical explanations; the choice of research participants reflect a specific group of construction industry professionals who can provide valuable insights into the nature of the research question; the geography draws investigative boundaries in relation to the choice of specific locales available to conduct this study; and finally, the business processes and organizational culture at SFO during the two capital improvement projects discussed in the interviews define the Exceptional Project Delivery Paradigm.

# 5. Chapter 5: Conclusions and Recommendations

## 5.1. Review of the Findings

The preceding chapters provide the reasoning, methods, and results of the dissertation. In chapter five, those results are explored more deeply and their implications made clear for both academia and industry.

### *5.1.1. Findings of the Exploratory Study*

The exploratory study investigated construction industry practitioners' awareness of potential incentive problems and possible solutions to these problems in order to signpost the direction of future incentive research for BIM. The conclusions of the exploratory study were:

1. IPD accounts for a significant portion of BIM contracting arrangements.
2. Experience is a key determining factor in how respondents view incentive strategies, as was stakeholders' position within the supply chain.
3. With regards to the ranking of incentive methodologies, no two stakeholder classifications presented identical or even highly similar responses to the Likert scale and ranking questions, providing a wealth of data to be used in the follow-on deeper analysis.

Overall, the results of the exploratory study provided a partial confirmation to the predictions of the incentive theory. Specifically, the conclusions of the exploratory study suggest that the decision to adopt BIM as an innovative coordination tool is in fact associated with the need to increase organizational and management productivity, and that such decision usually lowers labour costs and increases profits for all organizations and stakeholders affected. However, on the other hand, the results also indicate that the scope of BIM utilization post-adoption decision appears to be dependent on the existence of a strategic opportunity for key decision-makers to maximize personal, organizational, and institutional benefits in the larger context of BIM. This finding is also consistent with the main tenets of the incentive theory.

### *5.1.2. Findings from the Analysis of Incentive Questions*

The research purposes of the analysis of incentive questions were: (a) to explore construction industry practitioners' actual level of situational awareness of potential incentive problems associated with BIM, and (b) to identify possible solutions in order to determine the future direction of incentive research for BIM. The analysis of incentive questions yielded the following findings:

1. Position within the supply chain is a critical factor for the perception of the importance of incentivization issues.
2. In terms of specific incentives, financial rewards are generally perceived to be of benefit to BIM collaboration; however, to be effective, the provision of incentives should be based on group performance instead of individual contribution.
3. Objective performance indicators and related incentives appear to work more effectively than subjective ones.
4. Owners appear to weight performance indicators differently in the determination of group compensation but achieve the motivational effect of financial incentives only when they use sufficient monetary remuneration.
5. BIM participants hold differing views on incentives in four respects: (a) main contractors display a stronger preference for group-based rewards and incentives than trade contractors and BIM IT experts; however, for trade contractors and information system infrastructure builders, the value they create for the project is relatively more discernible, and they prefer that their reward be directly tied to their contribution; (b) the importance of objective measures is rated low as the basis of incentive reward by trade contractors; (c) a marked difference in opinion appears between the owner and main contractor, where the former thinks more highly of the necessity of differentiating the relative importance of performance metrics and incentivization; and lastly, (d) main contractors appreciate the linear reward and incentives system to a much higher degree than other groups of parties,

particularly compared to trade contractors and IT experts, which is consistent with the finding that main contractors favour a simple reward system.

Overall, these findings are highly consistent with the predictions of the incentive theory. In particular, taken together, they suggest that (a) possibility to increase productivity appears to be the most important driver for the adoption of BIM by construction industry organizations; (b) in some instances, at least as far as the data allows to generalize, benefits maximization by some stakeholders may impose costs on other stakeholders involved; but (c) because BIM as a decision-making tool requires a substantially higher degree of information transparency, the use of BIM may de facto create a disincentive for unscrupulous economic agents to become involved in a construction project in the first place.

### *5.1.3. Findings of the Analysis of Individual Perceptions*

To address the gap in the current understanding of how specifically a decision to adopt and utilize BIM is made, this third quantitative study of the dissertation tested the application of the UTAUT constructs to the decision to adopt and utilize BIM. The conclusions are:

1. Effort Expectancy does have a positive influence with the individual's Behavioural Intention to use BIM.
2. Social Influence does have a positive influence with the individual's Behavioural Intention to use BIM.
3. Attitude does have a positive influence with the individual's User Behaviour of BIM.
4. Facilitating Conditions do have a positive influence with the individual's User Behaviour of BIM.
5. Behavioural Intention does have a positive influence with the individual's User Behaviour of BIM.

These conclusions and findings regarding individual correlations of lower-level decisions that lead to the ultimate decision to adopt and utilize BIM are highly consistent with the predictions of the UTAUT. Overall, they provide an additional empirical affirmation to the precepts of the UTAUT and thus increase its predictive capacity and boost its explanatory power in relation to the decision to adopt BIM.

### *5.1.4. Findings of the Status Quo Bias Analysis*

To fill in the gap in the current theoretical and practical knowledge of unique individual differences in decision-making processes, this study tested the propositions of the Status Quo Bias model within the context of BIM adoption, or more precisely, *lack* of adoption. The key findings of the analysis of the participants' responses were the following:

1. The respondents indicated a relatively high level of investment in BIM, which is consistent with the previous finding and the findings of the preceding studies of this dissertation.
2. However, a relatively high level of investment in BIM technology appears to be moderated by either significant or moderate levels of investment in standard non-BIM construction—these account for over 70% of the responses and imply that despite the observed level of advanced BIM usage, respondents' decisions to embrace BIM more may be counteracted by the sunk costs associated with more traditional technologies. This finding is highly consistent with the predictions of the Status Quo Bias model.

Also, four operationalized constructs of the Status Quo Bias model were analysed using SEM. The results of the analyses were the following:

4. Regret Avoidance and Control appear to have negative effects on the decision to adopt and utilize BIM.
5. Sunk Cost seems to exert positive effects on the decision to adopt and utilize BIM.

Taken together, the results of the analysis of the participants' responses and the outcomes of the SEM analyses partially confirmed the predictions of the Status

Quo Bias model. These results contribute to further increase the overall validity, explanatory power, and predictive capacity of the conceptual framework underpinning the dissertation research project.

### *5.1.5. Findings of the Synthesized Secondary Survey*

The preceding studies of this dissertation did not provide exhaustive explanations of BIM decision. To address this explanatory deficiency, the Synthesized Secondary Survey explored the issue of low BIM adoption in a blended instrument. To this effect, the Synthesized Secondary Survey empirically explored the predictions of the various models in an effort to attain better explanatory consistency and exhaustiveness. The primary conclusions of the Synthesized Secondary Survey are the following:

1. Trade contractors are more concerned with the choice of weightings than main contractors and designers.
2. Social Influence exerts a positive effect on the individual's Behavioural Intention to use BIM.
3. Attitude has a moderating influence upon individuals' Behavioural Intention.
4. Company type determines manifestation of the Status Quo Bias (i.e. sunk cost vs. regret avoidance).

The results of the Synthesized Secondary Survey increased general explanatory consistency and exhaustiveness of the dissertation. Reliance on the joint instrument clearly provided a more robust analytical traction and will provide a robust foundation for future research efforts. The findings were also highly consistent with the results of the four quantitative studies of this dissertation.

### *5.1.6. Findings of the Case Study*

The purpose of the case study was twofold: (a) to appropriately contextualize the results of quantitative analyses, and (b) to cross-validate those using methodologically different analytical instruments. The results of qualitative analyses were consistent both with the conclusions of quantitative studies of this dissertation and theoretical predictions of models used in extant analyses. The case study also found that the use of Exceptional Project Delivery Paradigm at San Francisco International Airport served as a strong mediator for BIM adoption and use. The conclusions of the case study are the following:

1. The qualitative analyses exhaustively confirmed the presence of exactly the same principal factors that were identified in prior quantitative analyses. This provides further support for the choice of the three key factors that extant theoretical literature and past empirical studies on the topic found to affect the adoption of BIM in the construction industry. These factors are related to the incentive theory, the UTAUT, and the Status Quo Bias model.
2. Similar to the findings of quantitative studies of this dissertation, the results of qualitative analyses strongly suggest overall that different factors that affect the adoption of BIM in the construction industry have differential effects on (a) the decision to adopt BIM, (b) the scope of BIM adoption, and (c) scale of BIM utilization for construction projects delivery.
3. Variation in the strength of the effects does exist not only across the three theory-driven factors but also within factors: not only do factors differ in the vectors and the strengths of their effects on decision-making regarding adoption of BIM, but also a significant variation appears to exist within these three factors. In other words, it was found that not only do the incentive theory, the UTAUT, and the Status Quo Bias have differential effects compared to each other, but their internal structural constructs possess different weights that may determine the strength and the vector of the factor’s effect.
4. Two additional factors emerged in the analysis as affecting the adoption and utilization of BIM — organizational culture and leadership. In the opinion of the participants, both factors were significant in the adoption of the Exceptional Project Delivery Paradigm at SFO and by extension were also important in the process of BIM and IPD adoption and utilization.

5. Exceptional Project Delivery Paradigm (EPDP) served as a strong mediator of BIM adoption at SFO.

## 5.2. General Conclusions

1. It appears that there is hierarchy of decisions related to BIM that may explain the observed slow adoption and insufficient utilization rates. The decision to adopt BIM is of a more general nature and requires higher-level decision-making that must reflect a broad consensus of all affected stakeholders. In contrast, the decision regarding the scope and scale of BIM utilization tends to be specific and involves a lower-level decision-making that is subject to some managerial discretion as long as the interests of the key stakeholders are not adversely affected.
2. The higher-level decisions, i.e., those that determine whether BIM should be adopted or not by managers, are most heavily influenced by the straightforward calculus of economic incentives and competitive pressure.
3. The lower-level decisions, i.e., those that ultimately determine the breadth and depth of BIM utilization by front line workers, appear to be more strongly influenced by non-economic factors related to human subjectivity. However, the latter are moderated by the type and size of the construction industry organization in which such decisions are made, with inverse relationship between the size of the organization and the degree of managerial discretion allowed.
4. Significant variation in the strength of the effects does exist not only across the three theory-driven factors that explain BIM adoption and utilization but also within these factors, i.e., not only do the factors related to the incentive theory, the UTAUT, and the Status Quo Bias have differential effects compared to each other, but their internal structural constructs possess different weights that may determine the strength and the vector of the factor’s effect.
5. Leadership and organizational culture appear to be largely unaccounted for their effects on the decisions to adopt and utilize BIM, yet they seem to exert

substantial influence on both higher- level and lower-level decision-making. It is obvious that different construction industry organizations have varying organizational cultures (e.g., bureaucratic-hierarchical, entrepreneurial, adhocracy, dysfunctional, etc.) and their leaders use different styles of leadership (e.g., transactional, transformational, laissez affair, servant, etc.). Consequently, the different permutations of the organizational culture and leadership style may affect the decision to adopt and utilize BIM differently.

### 5.3. Suggestions for Future Research

As mentioned in the outset of this dissertation, BIM is arguably the most important technological advancement in construction management in the last several decades. BIM offers significant benefits that can be clearly defined, easily quantified, and quickly realized by end-users. Yet, many construction industry organizations are slow in adopting and fall behind in full-scale utilization of BIM. Relying on the conceptual framework that combined: (a) the incentive theory, (b) the Unified Theory of Acceptance and Use of Technology (UTAUT), and (c) the Status Quo Bias model, this dissertation empirically identified a number of specific factors responsible for the observed low rates of BIM adoption and utilization.

The synthesis of theories that were used to guide this dissertation and the combination of the data analysis methods allowed to discover new information that signals an effective solution to the current problem of low adoption and utilization of BIM by construction industry organizations. At the same time, the findings of both quantitative and qualitative studies also suggest that further research is needed on this important topic in the following areas.

First, because this dissertation has discovered the existence of a two-level hierarchy of decisions to adopt and utilize BIM, the exact role of such hierarchy as a managerial decision-making tool needs to be investigated further. Specifically, if the higher-level decisions to adopt BIM are influenced by primarily economic incentives, while the lower-level decisions on how to utilize BIM are strongly affected by subjective non-economic factors, then these two sets of factors may interact differently in different decision-making and organizational contexts. For instance, based on the results of empirical analyses, it is possible to hypothesize that in different types of construction industry organizations, different kinds of economic incentives may play more prominent roles. The size of an organization may also play a role in how this two-level hierarchy manifests itself. For example, smaller organizations may not be able to absorb the costs of BIM adoption as easily as larger organizations. This set of issues merits further investigation.

Second, because the findings of empirical analyses have also identified significant within-factors variation, examination of the causes and strengths of such variation may bring more insights on whether individual constructs (e.g., information transparency, long-term orientation, profit maximization, streamlined tendering, etc.) can be used by construction industry managers to facilitate the decision to adopt and utilize BIM. Likewise, if future research identifies that, for instance, hyperbolic discounting or the recency bias have inhibitive properties, this future research finding may lead to a development of practical recommendations for construction industry managers on how to be aware of the negative effects of these constructs and mitigate their influence on managerial decision-making. Findings of this possible future stream of research may be highly beneficial in the sense that they may contribute to a more effective and efficient management practice in the construction industry.

Third, since this dissertation has determined that leadership in construction industry organizations exerts substantial influence on both higher and lower levels of the hierarchy of decisions, these effects of leadership need to be further investigated. The model that was utilized in this dissertation did not include variables related to organizational leadership. As mentioned in the previous section, business leaders of construction industry organizations as individuals may be prone to use a specific style of leadership (e.g., transactional, transformational, laissez-faire, servant, etc.) (Bass & Avolio, 1993; Eagly et al., 2003, Graham, 1991). Because these various styles of business leadership obviously differ in their key attributes and most importantly in their managerial outcomes, they also may have differential effects on the decision to adopt and utilize BIM. The researcher expects that there may be some correlation between a specific leadership style and its effects on the decision to adopt and BIM. It would be interesting to research this relationship further, especially within the context of this dissertation’s finding that the lower-level decisions on how to utilize BIM are strongly affected by subjective non-economic factors. Leadership is clearly one such factor.

Fourth, the effects of organizational culture on the decision to adopt and utilize BIM also require further empirical exploration. Similar to leadership styles, the effects of organizational culture were not accounted for in the model used in this dissertation. Yet, just as leadership styles differ, so do organizational cultures. Past theorizing and empirical research on the topic of organizational culture identified several types of organizational cultures that may exist in individual organizations. For example, (a) clan culture, in which organization is held together by loyalty and tradition; (b) adhocracy culture, in which individual professional initiative and productive innovation are encouraged; (c) market culture that emphasizes goals-focused competitiveness; (d) hierarchical culture that creates formalized and structured work environments (Babic & Rebolj, 2016; Pettigrew, 1979; Schein, 1996a, 1996b). Obviously, because different organizational cultures emphasize different organizational values, these differences may have far-reaching ramifications for the managerial decision-making in construction industry organizations. The effects of organizational culture may not be as strong as economic incentives, but they may be sufficient to influence the lower-level decisions on how to utilize BIM. Future research should look into this issue. Indeed, the researcher plans to undertake a follow-on study founded upon the synthesized secondary survey but taking into consideration the lessons learned from its results and the post-survey case study interviews. With an instrument supported by four successive quantitative and qualitative studies, and provided proper funding, such a future research effort could conceivably model the BIM-decision calculus comprehensively.

### 5.4. Research Limitations

The dissertation empirically examined factors responsible for the observed slow adoption and low utilization rates of BIM within the context of the project delivery environment. To address the overarching research question, the dissertation logically connected three streams of extant empirical research into a conceptual framework that was utilized for the data analyses. The three parts of the conceptual framework are: the incentive theory (Baddeley & Chang, 2015; Linderoth, 2010), the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh, 2000; Venkatesh & Davis, 2000; Venkatesh, Morris, Davis, & Davis, 2003; Venkatesh, Thong, & Xu, 2016), and the Status Quo Bias model (Kahneman, 2013; Kahneman, Knetsch, & Thaler, 1991; Kahneman & Lovallo, 1993; Rogers, Chong, & Preece, 2015).

Methodologically, the dissertation relied on a mixed methods research approach that was implemented in five closely interrelated but still separately conducted studies. Four studies were quantitative with identical *cross-sectional* designs and employed questionnaire-based surveys to collect data. The case study, the fifth study, was qualitative, employed a pretest-post-test design, and relied on multiple interviews of key informants with the standard sets of open-ended questions. Purposive sampling was used in all studies.

Given its scope, scale, purpose, research question, and the implementation modality, the dissertation has several limitations. However, the negative effects of these limitations have been either completely, or at least partially, addressed to a significant degree through a number of research validity and research quality mitigating measures. The first limitation was imposed by the mixed methodology which was challenging to implement as it increased the overall scale and complexity of analyses. In turn, such inevitable surge in analytical complexity required a certain degree of analytical reduction, simplification, and approximation of research findings at least in some instances. Therefore, the issues related to the choice of mixed methods approach may adversely affect generalizability of the findings of this dissertation. In addition, reliance on mixed methods research was labour-intensive and required more time and greater resources than those that otherwise would be needed to conduct a single-method study, which certainly negatively affected the efficiency of research efforts.

However, the negative effects of the limitations imposed by the methodological choice were ameliorated by the possibility to (a) cross-validate findings using both qualitative and quantitative data sources; (b) contextualize and explore quantitative findings using qualitative data; (c) develop and utilize better survey instruments, which were sequentially updated and significantly improved based on the results of each new study conducted; and finally, (d) directly involve key professional informants who provided valuable first-hand observations and relayed their direct managerial and decision-makers' experiences with the choices to adopt and utilize BIM in their respective construction industry organizations.

The second limitation is related to the cross-sectional designs that dominate the studies of this dissertation. In the fields of management and economics, cross-sectional designs are typically used in conjunction with surveys to measure the prevalence of certain organizational outcomes and consistency of managerial processes (Creswell, 2018). Despite their relative simplicity, cross-sectional designs yield only a one-time snapshot on a specific measurement, and therefore, it is difficult to derive causal relationships from the analysis of cross-sectional data. Furthermore, cross-sectional designs are also sensitive to certain biases (sampling, definitional, data interpretation, etc.). Finally, the prevalence of managerial processes and organizational outcomes actually depend upon their underlying institutional incidence as well as on the length of utilization following a specific organizational outcome (e.g., how long BIM is in use after the managerial decision to adopt it). All these factors together may negatively affect the internal and external validity of the study and as a result reduce its generalizability.

In this dissertation, the limitations caused by cross-sectional designs were mitigated through the initial Exploratory Study. This allowed to (a) correctly identify specific managerial processes and organizational outcomes related to the decision to adopt and utilize BIM in the AEC industry, which led to better operationalization of variables in later studies; and (b) to test and improve the design of the questionnaire-based survey that would be used for data collection in the subsequent studies. In turn, these significantly contributed to elimination of possible inclusion/exclusion biases and misidentification of managerial processes and organizational outcomes.

The third limitation was the use of purposive sampling, which is the deliberate choice of a group of key informants because of their unique knowledge, special qualifications, or exclusive expertise, i.e., exceptional qualities they possess (Edmonds & Kennedy, 2017, pp. 20-21). Purposive sampling is a non-random technique. The dissertation relied on purposive homogeneous expert sampling because only limited numbers of construction industry professionals can serve as primary data sources due to the nature of the research question and aims. While purposive sampling served its investigative purpose in this research, generally speaking, this sampling technique is prone to researcher bias (Ray, 2012) that negatively affects the degree of generalizability of research findings. However, this limitation was successfully mitigated by the use of standardized surveys. Those were repeatedly tested for convergent and divergent validity before every subsequent study and updated based on the results of preceding studies.

Lastly, while the dissertation provides contributions to the knowledge of the representative theoretical bases, and to BIM adoption specifically, it must be conceded that the simple fact that this was a dissertation resulted in some neophyte research mistakes. Minor operational errors were certainly made, such as the Likert scale questions on the exploratory study being difficult to read on mobile devices, but with each follow-on research effort, the questionnaires got stronger and the operational aspects more robust. The writer feels amply prepared to continue this research towards new and exciting future developments.

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# 1. Appendix A – Survey Cover Letter

(adapted as necessary for each survey)

Group: [redacted]

Subject: Announcement from [redacted]

[redacted] has partnered with researchers at the [redacted] – [redacted] to act as the sample population for a study on incentivizing BIM contribution. The study's purpose is to ascertain stakeholders' perceptions of potential BIM incentive strategies, and is the first step in a broader research effort aimed at the proliferation of collaborative BIM throughout the Architecture Engineering & Construction industry. The following link will redirect to the externally hosted questionnaire, which should take no more than 5 minutes to complete. All responses will remain strictly anonymous, and no proprietary data or protected intellectual property need be shared. Your participation in this study would be greatly appreciated.

Any questions, concerns or comments should be directed to lead researcher [redacted] at [redacted].

https://www.surveymonkey.com/s/BIM_Incentive_Questionnaire

# 2. Appendix B – Exploratory Study Questionnaire

| | Question | Answer Options |
|---|---|---|
| **Control Questions** | How would you characterize your level of experience with BIM? | No Experience |
| | | Some Experience |
| | | Moderately Experienced |
| | | Highly Experienced |
| | | Subject Matter Expert |
| | What is the best classification for the BIM system used on your Project? | **Level 0:** Unmanaged CAD, in 2D, with paper or electronic paper data exchanges. |
| | | **Level 1**: Managed CAD in 2D or 3D format with a collaborative tool providing a common data environment and standardized approach to data structure and format. Commercial data managed by standalone finance and cost management packages with no integration. |
| | | **Level 2**: A managed 3D environment held in separate discipline BIM tools with data attached. Commercial data managed by enterprise resource planning software and integrated by proprietary interfaces or bespoke middleware. This level of BIM may utilize 4D construction sequencing and/or 5D cost information. |

| | | |
|---|---|---|
| | | **Level 3:** Characterized by a fully integrated and collaborative process enabled by web services, and incorporating 4D construction sequencing, 5D cost information and 6D project lifecycle management information. |
| | In what role were you involved in BIM-enabled projects most of the time? | 1. Owner's internal project management team<br>2. Architect<br>3. Engineer<br>4. Quantity surveyor<br>5. Project management consultant<br>6. Main contractor<br>7. Trade contractor<br>8. Material supplier<br>9. Equipment supplier<br>10. Never involved<br>11. Other (please specify) |
| | What type of company do you work for? | Architectural company |
| | | Engineering consultancy |
| | | Project management company |
| | | Main contractor |
| | | Trade contractor |
| | | Material Supplier |
| | | Equipment Supplier |
| | | Other, please specify |
| | How many years have you worked in the construction industry? | Years: (fill in) |

| | | |
|---|---|---|
| | Where is your current or most recent project located? | 1. United States<br>2. United Kingdom<br>3.China<br>4. Japan<br>5. European Union<br>6. Australia<br>7. Other (please specify) |
| | Did you utilize Integrated Project Delivery (IPD) on any BIM-enabled projects? | Yes/No |
| | Which form of IPD was employed? (if multiple IPD formats have been used, please specify that which was utilized most recently) | AIA Form A295 Transitional IPD |
| | | AIA Form C195 Full Integration |
| | | ConcensusDocs 300 |
| | | Other (please specify) |

**To what extent do you agree with the following statements?** (5-point Likert scale)

| |
|---|
| Monetary rewards can improve the effectiveness of BIM considerably better than non-monetary rewards |
| Group based rewards will work considerably better than individual rewards in incentivizing contractor participation in BIM systems |
| Objective metrics are considerably better than subjective ones as the basis for determining incentive rewards for BIM participants |
| It is absolutely necessary to assign different weightings to performance metrics in the determination of incentive rewards for BIM participants |
| A simple linear reward sharing rule (e.g., reward linked to a fixed percentage of cost savings) will work considerably better than a more complicated nonlinear reward sharing rule in incentivizing contractors to contribute to BIM |
| There is a minimum amount of incentive reward that can motivate contractors' full participation in BIM |

**Based on your perception, to what extent do you agree with the following statements?**

(5-point Likert scale)

| |
|---|
| Provision of monetary rewards will actually harm cooperation between parties in the BIM system |
| Group based rewards would likely result in one party freeriding on another's effort |
| There are no objective metrics sufficient to measure contractors' contributions to BIM systems |
| It would be difficult for the owner to establish appropriate weightings for performance metrics used in a reward scheme |
| A linear reward sharing rule is too simple to reliably reflect the contribution of BIM participants |
| It would be difficult for the owner to determine the size of bonus pools that could effectively induce contractor participation in BIM |

**Please rank the following incentive methods in their likelihood to promote participation in BIM systems** (forced ranking 1 through 7)

| |
|---|
| Based on value: Incentivizes the project team by offering a bonus linked to adding value to the project |
| Innovation and outstanding performance: The team is awarded for hard work and creativity |
| Performance bonuses: An award based on quality |
| Profit sharing: Each party's profit is determined collectively rather than individually |
| Subjective measurement: Bonuses depend on the owner's subjective measurement |
| Key performance indicators: Reserves a portion of the project team's fees into a pool that can increase or decrease based on key performance indicators |
| Cost savings: Each party retains a share of cost savings resulting from early clash detection and other efficiencies |

# Appendix C – UTAUT Survey Questionnaire

| | |
|---|---|
| **Personal Information (optional)** | |
| Name: | |
| Organization Name: | |
| Division/Business Unit: | |
| Email: | |
| **Control Questions** | |
| Sex | Male |
| | Female |
| Age | Under 25 |
| | 26-35 |
| | 36-45 |
| | 46-55 |
| | Over 55 |
| In which area of the construction industry is your organization specialized? | Construction/Engineering |
| | Consultancy (cost management, project management, etc.) |
| | Design/Architecture |
| | Property Development |
| | Operations (property management, facilities management, etc.) |
| | Manufacturing |
| | Logistics |
| | Legal |

| | |
|---|---|
| | Real Estate and Financial Institution |
| | Other (please specify) |
| How much experience do you have with BIM (years)? | None |
| | Less than 2 |
| | 2 to 5 |
| | 6 to 10 |
| | More than 10 |
| **BIM Involvement** | |
| *Please complete the following statement by selecting one of the following options:* | |
| *1* | *Not at all* |
| *2* | *To a little extent* |
| *3* | *To some extent* |
| *4* | *Undecided* |
| *5* | *To a moderate extent* |
| *6* | *To a great extent* |
| *7* | *To a very great extent* |
| VOL | The decision to get involved with BIM was voluntary? |
| BI1 | I intend to work with BIM in the next 36 months… |
| BI2 | I predict I would use BIM in the next 36 months… |
| BI3 | I plan to use BIM in the next 36 months… |
| UB1 | Involvement with BIM in my job… |
| UB2 | My organization’s involvement with BIM… |
| **BIM Perceptions** | |

| *Considering your personal opinion on BIM, please indicate your level of agreement with the following statements:* | |
|---|---|
| *1* | *Strongly disagree* |
| *2* | *Disagree* |
| *3* | *Somewhat disagree* |
| *4* | *Undecided* |
| *5* | *Somewhat agree* |
| *6* | *Agree* |
| *7* | *Strongly agree* |
| PE1 | I would find BIM useful in my job. |
| PE2 | Working with BIM enables me to accomplish tasks more quickly. |
| PE3 | Working with BIM increases my productivity. |
| PE4 | If I work with BIM, I will increase my chances of getting a raise. |
| EE1 | My interaction with BIM would be clear and understandable. |
| EE2 | It would be easy for me to become skilled at working with BIM. |
| EE3 | I would find BIM easy to use. |
| EE4 | Leaning to operate BIM is easy for me. |
| AT1 | Using BIM is a good idea. |
| AT2 | BIM makes work more interesting. |
| AT3 | Working with BIM is fun. |
| AT4 | I like working with BIM. |
| SI1 | People who influence my behaviour think I should use BIM. |
| SI2 | People who are important to me think that I should use BIM. |

| | |
|---|---|
| SI3 | The senior management of this business has been helpful in the use of BIM. |
| SI4 | In general, the organization has supported the use of BIM. |
| FC1 | I have the resources necessary to work with BIM. |
| FC2 | I have the knowledge necessary to work with BIM. |
| FC3 | BIM is not compatible with the work tools I use. |
| FC4 | A specific person (or group) is available for assistance with BIM difficulties. |

# 3. Appendix D – Status Quo Bias Questionnaire

| | Question | Answer Options |
|---|---|---|
| **Control Questions** | What is the best classification for the BIM system used in the latest BIM-enabled project you were involved in? | Never used BIM (Employed unmanaged CAD, in 2D, with paper or electronic paper data exchanges) |
| | | **Level 1:** Managed CAD in 2D or 3D format with a collaborative tool providing a common data environment and standardized approach to data structure and format. Commercial data managed by standalone finance and cost management packages with no integration. |
| | | **Level 2:** A managed 3D environment held in separate discipline 'BIM' tools with data attached. Commercial data managed by enterprise resource planning software and integrated by proprietary interfaces or bespoke middleware. This level of BIM may utilize 4D construction sequencing and/or 5D cost information. |

| | | |
|---|---|---|
| | | **Level 3:** Characterized by a fully integrated and collaborative process enabled by web services, and incorporating 4D construction sequencing, 5D cost information and 6D project lifecycle management information. |
| | Position within your company | Frontline Employee |
| | | Middle Management |
| | | Executive |
| | What type of company do you work for? | Architectural company |
| | | Engineering consultancy |
| | | Project management company |
| | | Main contractor |
| | | Trade contractor |
| | | Construction Client/Owner |
| | | Material Supplier |
| | | BIM Consultant |
| | | Other, please specify |
| | Which of the following best describes your level of investment in BIM to date in terms of either time, money or both? | Zero |
| | | Minimal |
| | | Moderate |
| | | Significant |
| | | Zero |

| | | |
|---|---|---|
| | Which of the following best describes your level of investment in standard non-BIM construction practices (unmanaged Cad, etc.) to date in terms of either time, money or both? | Minimal |
| | | Moderate |
| | | Significant |
| **Project Delivery Method** | What type of project delivery method was utilized on the project in question? | Design-Bid-Build |
| | | Design-Build |
| | | Integrated Project Delivery |
| | | Other (please specify) |
| | (if IPD) Which form of IPD was employed? | AIA Form A295 Transitional IPD |
| | | AIA Form C195 Full Integration |
| | | ConcensusDocs 300 |
| | | Other (please specify) |

**Please indicate your level of agreement with each of the following statements (1 meaning strongly disagree and 5 strongly agree):**

| | Construct | Item | Statement |
|---|---|---|---|
| **Status Quo** | Regret Avoidance | RA 1 | My company or I may come to regret the decision to participate in a BIM-enabled project. |
| | | RA 2 | My company or I may come to regret investing the time and money necessary to become proficient in the use of BIM. |

|  |  |  |  |
|---|---|---|---|
|  | Control | CO 1 | Participating in BIM decreases the control I have to complete my job. |
|  |  | CO 2 | BIM decreases the control my company has in the success of the project. |
|  | Sunk Costs | SC 1 | Investing in BIM technology would waste my investment in standard non-BIM construction practices (AutocCad, etc.). |
|  |  | SC 2 | Investing additional time or money into other non-BIM construction practices represents a better use of resources. |

# 4. Appendix E – Synthesized Secondary Survey Questionnaire

| | Question | Answer Options |
|---|---|---|
| **Control Questions** | Have you ever utilized Building Information Modelling on a project? | Yes |
| | | No |
| | What is the best classification for the BIM system used on your Project? | **Level 1:** Managed CAD in 2D or 3D format with a collaborative tool providing a common data environment and standardized approach to data structure and format. Commercial data managed by standalone finance and cost management packages with no integration. |
| | | **Level 2:** A managed 3D environment held in separate discipline 'BIM' tools with data attached. Commercial data managed by enterprise resource planning software and integrated by proprietary interfaces or bespoke middleware. This level of BIM may utilize 4D construction sequencing and/or 5D cost information. |

| | | |
|---|---|---|
| | | **Level 3:** Characterized by a fully integrated and collaborative process enabled by web services, and incorporating 4D construction sequencing, 5D cost information and 6D project lifecycle management information. |
| | What type of company do you work for? | Architectural company |
| | | Engineering consultancy |
| | | Project management company |
| | | Main contractor |
| | | Trade contractor |
| | | Construction Client/Owner |
| | | Material Supplier |
| | | BIM Consultant |
| | | Other, please specify |

| | | |
|---|---|---|
| **Project Delivery Method** | What type of project delivery method was utilized on the project in question? | Design-Bid-Build |
| | | Design-Build |
| | | Integrated Project Delivery |
| | | Other (please specify) |
| | (if IPD) Which form of IPD was employed? | AIA Form A295 Transitional IPD |
| | | AIA Form C195 Full Integration |
| | | ConcensusDocs 300 |
| | | Other (please specify) |

**Please answer the following questions by selection of the available options:**

| | Construct | Item | Statement |
|---|---|---|---|
| **UTAUT** | Use Behavior | UB1 | What is your involvement with BIM within your job? |
| | | UB2 | What is your company's involvement with BIM? |
| | Voluntariness | VO1 | To what extent is the decision (on a personal basis) to work with BIM voluntary within your organization? |

| | |
|---|---|
| **Control Questions** | What is your personal level of investment in BIM to date in terms of either time, money or both? |
| | What is your personal level of investment in standard non-BIM construction practices (unmanaged AutoCad, etc.) to date in terms of either time, money or both? |

**Please indicate your level of agreement with each of the following statements:**

| | Construct | Item | Statement |
|---|---|---|---|
| **UTAUT** | Behavioral Intention | BI1 | I intend to use BIM if given the opportunity. |
| | | BI2 | I want to be among the first to adopt emergent BIM processes. |

|  |  |  |  |
|---|---|---|---|
|  | Performance Expectancy | PE1 | I would find BIM useful in my job. |
|  |  | PE2 | Working with BIM increases my productivity. |
|  |  | PE3 | If I work with BIM, I will increase my chances of getting a raise. |
|  | Effort Expectancy | EE1 | My interaction with BIM is clear and understandable. |
|  |  | EE2 | It would be easy for me to become skillful at working with BIM. |
|  |  | EE3 | Learning to operate with BIM is easy for me. |
|  | Attitude | AT1 | BIM makes work more interesting. |
|  |  | AT2 | Working with BIM is fun. |
|  |  | AT3 | I like working with BIM. |
|  | Social Influence | SI1 | People who are important to me think that I should use BIM. |
|  |  | SI2 | The senior management of my organization has been helpful in the use of BIM. |
|  |  | SI3 | In general, the organization has supported the use of BIM. |
|  | Facilitating Conditions | FC1 | I have the resources necessary to work with BIM. |
|  |  | FC2 | I have the knowledge necessary to work in BIM. |
|  |  | FC3 | A specific person (or group) is available for assistance with BIM difficulties. |
| **Status Quo** | Regret Avoidance | RA1 | My company or I may come to regret the decision to participate in a BIM-enabled project. |
|  |  | RA2 | My company or I may come to regret investing the time and money necessary to become proficient in the use of BIM. |
|  | Control | CO1 | Participating in BIM decreases the control I have to complete my job. |
|  |  | CO2 | BIM decreases the control my company has in the success of the project. |

| | | | |
|---|---|---|---|
| | Sunk Costs | SC1 | Investing in BIM technology would waste my investment in standard non-BIM construction practices (AutoCad, etc.). |
| | | SC2 | Investing additional time or money into other non-BIM construction practices represents a better use of resources. |

| | | |
|---|---|---|
| **Incentive Theory** | IT1 | Monetary rewards can improve the effectiveness of BIM considerably better than nonmonetary rewards. |
| | IT2 | Group based rewards will work considerably better than individual rewards in incentivizing contractor participation in BIM systems. |
| | IT3 | Objective metrics are considerably better than subjective ones as the basis for determining incentive rewards for BIM participants. |
| | IT4 | It is absolutely necessary to assign different weightings to performance metrics in the determination of incentive rewards for BIM participants. |
| | IT5 | A simple linear reward sharing rule (e.g., reward linked to a fixed percentage of cost savings) will work considerably better than a more complicated nonlinear reward sharing rule in incentivizing contractors to contribute to BIM. |
| | IT6 | There is a minimum amount of incentive reward that can motivate contractors' full participation in BIM. |
| | IT7 | Group based rewards would likely result in one party freeriding on another’s effort. |

# 5. Appendix E – Referenced Tables

*Table 51. Overall Average and Statistical Test*

| **Questions** | **1**<br>**strongly disagree** | **2**<br>**disagree** | **3**<br>**neither agree nor disagree** | **4**<br>**agree** | **5**<br>**strongly agree** | **Rating Average** |
|---|---|---|---|---|---|---|
| 1. Monetary rewards can improve the effectiveness of BIM considerably better than non-monetary rewards | 3.17% | 8.47% | 22.75% | 49.21% | 16.40% | $3.68^{***}$<br>(9.77) |
| 2. Group based rewards will work considerably better than individual rewards in incentivizing contractor participation in BIM systems | 2.12% | 7.41% | 30.69% | 42.86% | 16.93% | $3.64^{***}$<br>(9.46) |
| 3. Objective metrics are considerably better than subjective ones as the basis for determining incentive rewards for BIM participants | 2.12% | 4.23% | 31.22% | 48.15% | 14.29% | $3.70^{***}$<br>(11.40) |
| 4. It is absolutely necessary to assign different weightings to performance metrics in the determination of incentive rewards for BIM participants | 1.06% | 7.45% | 35.11% | 42.02% | 14.36% | $3.61^{***}$<br>(9.43) |
| 5. A simple linear reward sharing rule will work considerably better than a more complicated non-linear reward sharing rule in incentivizing contractors to contribute to BIM | 4.76%9 | 15.87% | 31.22% | 40.74 | 7.41% | $3.30^{***}$<br>(4.04) |
| 6. There is a minimum amount of incentive reward that can motivate contractors' full participation in BIM | 2.65% | 20.63% | 29.63% | 33.86% | 13.23% | $3.34^{***}$<br>(4.46) |

*Note: * p<0.05, ** p<0.01, *** p<0.001*

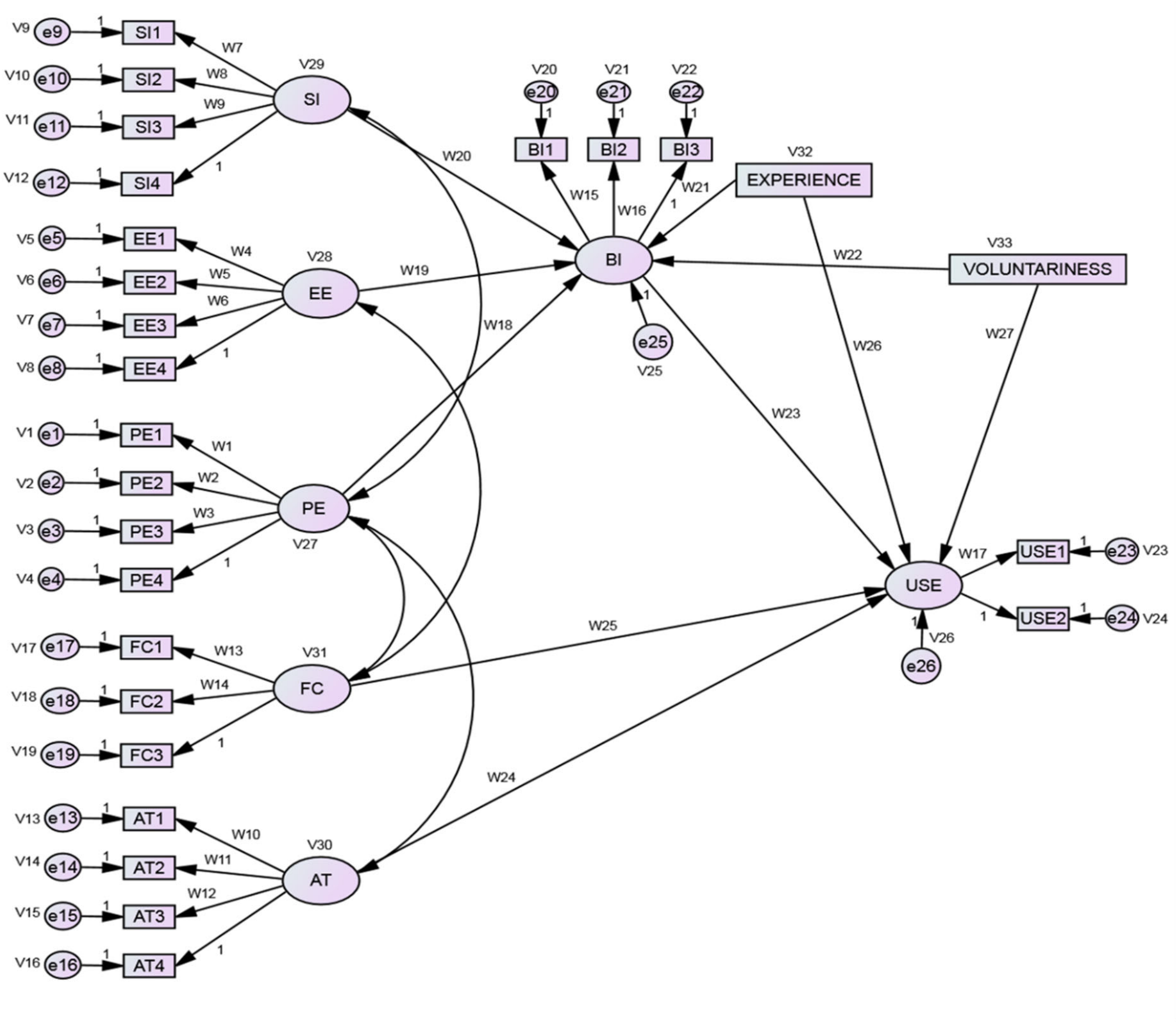

*Figure 12. Structural Model Using SEM*

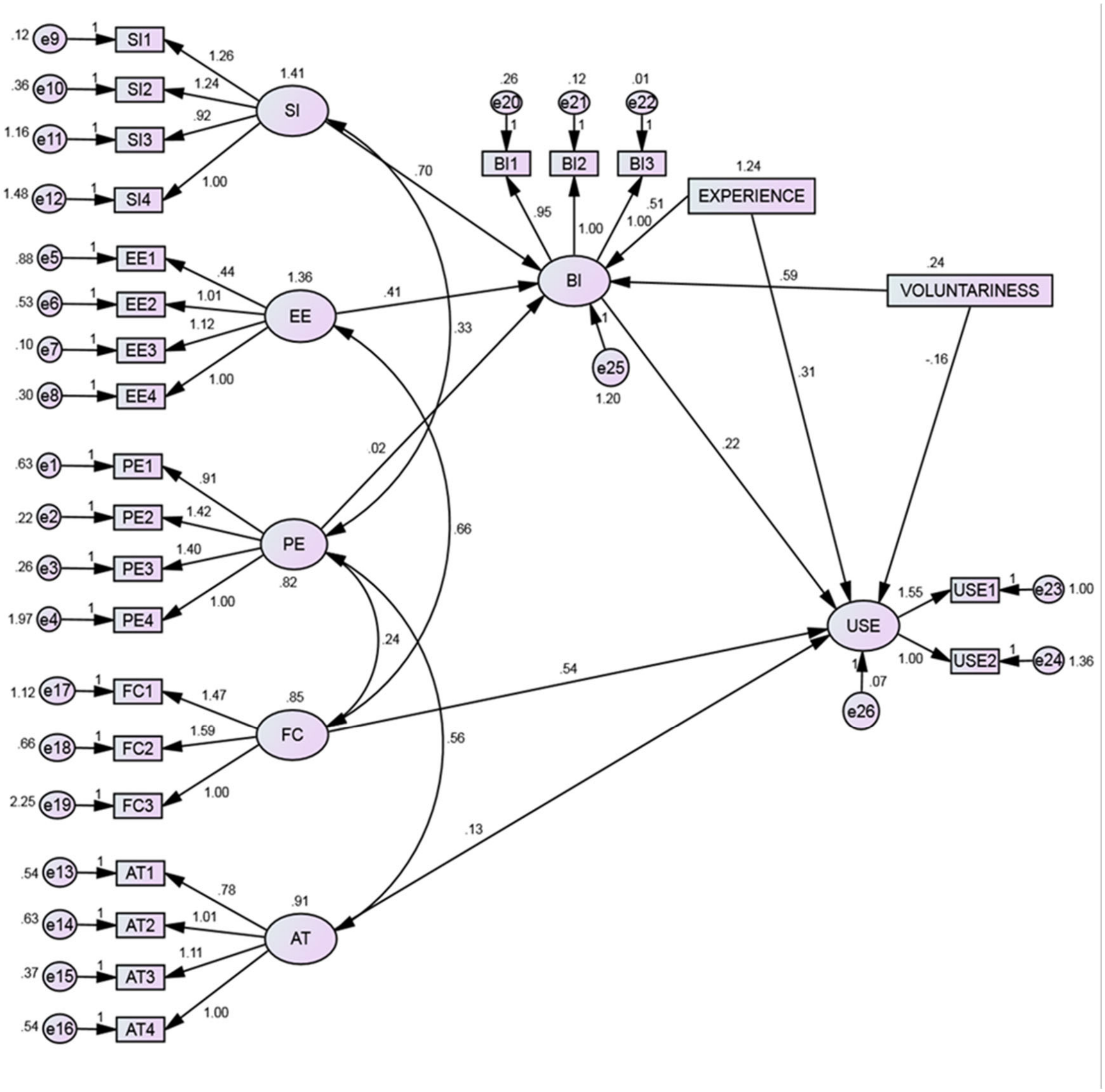

*Figure 13. Path Results for Structural Model*

*Table 52. Organizational Characteristics of the Participants*

| | N | % |
|---|---|---|
| ***Best Classification for the BIM System Used*** | | |
| Never used BIM (Employed unmanaged CAD, in 2D, with paper or electronic paper data exchanges). | 12 | 23.5% |
| *Level 1:* Managed CAD in 2D or 3D format with a collaborative tool providing a common data environment and standardized approach to data structure and format. Commercial data managed by standalone finance and cost management packages with no integration. | 13 | 25.5% |
| *Level 2:* A managed 3D environment held in separate discipline 'BIM' tools with data attached. Commercial data managed by enterprise resource planning software and integrated by proprietary interfaces or bespoke middleware. This level of BIM may utilize 4D construction sequencing and/or 5D cost information. | 23 | 45.1% |
| *Level 3:* Characterized by a fully integrated and collaborative process enabled by web services, and incorporating 4D construction sequencing, 5D cost information and 6D project lifecycle management information. | 3 | 5.9% |
| **Total** | **51** | **100.0%** |
| ***Type of company*** | | |
| Architectural company | 3 | 5.8% |
| Construction Client/Owner | 4 | 7.7% |
| Engineering consultancy | 6 | 11.5% |
| Main contractor | 17 | 32.7% |
| Material Supplier | 1 | 1.9% |
| Project management company | 10 | 19.2% |
| Trade contractor | 4 | 7.7% |
| Other | 7 | 13.5% |
| **Total** | **52** | **100.0%** |
| ***Position in Company*** | | |
| Frontline Employee | 6 | 11.5% |
| Middle Management | 24 | 46.2% |
| Executive | 22 | 42.3% |
| **Total** | **52** | **100.0%** |
| ***Level of Investment in BIM*** | | |

| | | |
|---|---|---|
| Zero | 11 | 21.6% |
| Minimal | 5 | 9.8% |
| Moderate | 16 | 31.4% |
| Significant | 19 | 37.3% |
| **Total** | **51** | **100.0%** |
| ***Level of Investment in Standard non-BIM Construction*** | | |
| Zero | 3 | 5.8% |
| Minimal | 12 | 23.1% |
| Moderate | 21 | 40.4% |
| Significant | 16 | 30.8% |
| **Total** | **52** | **100.0%** |
| ***Project Delivery Method*** | | |
| Design-Bid-Build | 16 | 30.8% |
| Design-Build | 15 | 28.8% |
| Integrated Project Delivery | 14 | 26.9% |
| Other | 7 | 13.5% |
| **Total** | **52** | **100.0%** |
| ***Form of IPD Employed*** | | |
| AIA Form A295 Transitional IPD | 3 | 23.1% |
| AIA Form C195 Full Integration | 5 | 38.5% |
| ConcensusDocs 300 | 2 | 15.4% |
| Other | 3 | 23.1% |
| **Total** | **13** | **100.0%** |

*Table 53. Pairwise Correlations*

| | | | Measure of reliability if item is deleted | | |
|---|---|---|---|---|---|
| Items | RA1 | RA2 | Cronbach’s Alpha | Split-half | Parallel |
| RA1 | 1.000 | 0.803 | - | - | - |
| RA2 | 0.803 | 1.000 | - | - | - |

| | | | Measure of reliability if item is deleted | | |
|---|---|---|---|---|---|
| Items | CO1 | CO2 | Cronbach’s Alpha | Split-half | Parallel |
| CO1 | 1.000 | 0.761 | - | - | - |
| CO2 | 0.761 | 1.000 | - | - | - |

| | | | Measure of reliability if item is deleted | | |
|---|---|---|---|---|---|
| Items | SC1 | SC2 | Cronbach’s Alpha | Split-half | Parallel |
| SC1 | 1.000 | 0.427 | - | - | - |
| SC2 | 0.427 | 1.000 | - | - | - |

| | | | | | Measure of reliability if item is deleted | | |
|---|---|---|---|---|---|---|---|
| Items | OA1 | OA2 | OA3 | OA4 | Cronbach’s Alpha | Split-half | Parallel |
| OA1 | 1.000 | 0.688 | 0.584 | 0.633 | 0.833 | 0.833 | 0.833 |
| OA2 | 0.688 | 1.000 | 0.599 | 0.532 | 0.835 | 0.835 | 0.835 |
| OA3 | 0.584 | 0.599 | 1.000 | 0.770 | 0.825 | 0.825 | 0.825 |
| OA4 | 0.633 | 0.532 | 0.770 | 1.000 | 0.822 | 0.822 | 0.822 |

* Inter-item correlations (for constructs with more than one items) and reliability measures if an item is deleted (only for constructs with more than two items in it).

*Table 54. SEM Performance Assessment (Group A vs. Group B)*

| **Model** | **DF** | **CMIN** | ***p*** | **NFI Δ-1** | **IFI Δ-2** | **RFI ρ-1** | **TLI ρ2** |
|---|---|---|---|---|---|---|---|
| Structural weights | 17 | 21.421 | .208 | .020 | .025 | -.004 | -.006 |

*Table 55. Presence of Codes in Files*

| **NODES/Codes** | **CDO1** | **CDO2** | **DIIM1** | **DIIM2** |
|---|---|---|---|---|
| **INCENTIVE THEORY** | Yes | Yes | Yes | No |
| **UTAUT** | Yes | Yes | Yes | Yes |
| **STATUS QUO BIAS** | Yes | Yes | Yes | Yes |
| Productivity | Yes | Yes | No | Yes |
| Profit Maximization | Yes | Yes | No | Yes |
| Contract Variations | Yes | Yes | No | Yes |
| Streamlined Tendering | Yes | Yes | No | Yes |
| Information Transparency | Yes | Yes | Yes | Yes |
| Long-term Orientation | Yes | Yes | No | Yes |
| Collaborative Process | Yes | Yes | Yes | Yes |
| Price Equalization | Yes | Yes | No | Yes |
| Risk Assessment | Yes | Yes | Yes | Yes |
| Cost-Benefit Analysis | Yes | Yes | No | Yes |
| Performance Expectancy | Yes | Yes | Yes | Yes |
| Effort Expectancy | Yes | Yes | Yes | Yes |
| Social Influence | Yes | Yes | No | Yes |
| Facilitating Conditions | Yes | Yes | No | Yes |
| Organizational Inertia | Yes | Yes | No | Yes |
| Organizational Isomorphism | Yes | No | No | No |
| Analytical | Yes | No | No | Yes |
| Emotional | Yes | Yes | Yes | Yes |
| Recency Bias | Yes | No | No | No |
| Availability Heuristic | Yes | No | No | No |
| Hyperbolic Discounting | Yes | Yes | No | Yes |
| Cost Efficiency | Yes | Yes | No | Yes |
| **ORGANIZATIONAL CULTURE** | Yes | Yes | Yes | Yes |
| **LEADERSHIP** | Yes | Yes | No | No |

*Table 56. Number of Coding References in Files**

| NODES/Codes | CDO1 | CDO2 | DIIM1 | DIIM2 |
|---|---|---|---|---|
| **INCENTIVE THEORY** | 46 | 21 | 5 | 0 |
| **UTAUT** | 17 | 12 | 2 | 26 |
| **STATUS QUO BIAS** | 26 | 5 | 1 | 17 |
| Productivity | 5 | 5 | 0 | 10 |
| Profit Maximization | 6 | 3 | 0 | 6 |
| Contract Variations | 6 | 2 | 0 | 4 |
| Streamlined Tendering | 8 | 3 | 0 | 3 |
| Information Transparency | 8 | 7 | 2 | 4 |
| Long-term Orientation | 5 | 5 | 0 | 7 |
| Collaborative Process | 18 | 13 | 4 | 18 |
| Price Equalization | 4 | 1 | 0 | 8 |
| Risk Assessment | 16 | 4 | 1 | 15 |
| Cost-Benefit Analysis | 8 | 2 | 0 | 3 |
| Performance Expectancy | 9 | 5 | 1 | 14 |
| Effort Expectancy | 4 | 1 | 1 | 13 |
| Social Influence | 10 | 2 | 0 | 1 |
| Facilitating Conditions | 10 | 4 | 0 | 14 |
| Organizational Inertia | 5 | 1 | 0 | 2 |
| Organizational Isomorphism | 1 | 0 | 0 | 0 |
| Analytical | 10 | 0 | 0 | 9 |
| Emotional | 6 | 3 | 1 | 6 |
| Recency Bias | 2 | 0 | 0 | 0 |
| Availability Heuristic | 3 | 0 | 0 | 0 |
| Hyperbolic Discounting | 4 | 1 | 0 | 1 |
| Cost Efficiency | 5 | 2 | 0 | 6 |
| **ORGANIZATIONAL CULTURE** | 7 | 1 | 1 | 10 |
| **LEADERSHIP** | 3 | 5 | 0 | 0 |

*Table 57. Words Coded in Files**

| NODES/Codes | CDO1 | CDO2 | DIIM1 | DIIM2 |
|---|---|---|---|---|
| **INCENTIVE THEORY** | 2545 | 1885 | 243 | 0 |
| **UTAUT** | 1387 | 1800 | 236 | 865 |
| **STATUS QUO BIAS** | 1864 | 457 | 37 | 506 |
| Productivity | 437 | 546 | 0 | 186 |
| Profit Maximization | 250 | 174 | 0 | 125 |
| Contract Variations | 352 | 36 | 0 | 17 |
| Streamlined Tendering | 316 | 264 | 0 | 67 |
| Information Transparency | 345 | 825 | 71 | 121 |
| Long-term Orientation | 426 | 555 | 0 | 98 |
| Collaborative Process | 1366 | 1226 | 203 | 280 |
| Price Equalization | 192 | 22 | 0 | 92 |
| Risk Assessment | 1219 | 273 | 37 | 190 |
| Cost-Benefit Analysis | 266 | 194 | 0 | 31 |
| Performance Expectancy | 553 | 569 | 185 | 317 |
| Effort Expectancy | 630 | 386 | 51 | 273 |
| Social Influence | 597 | 337 | 0 | 39 |
| Facilitating Conditions | 643 | 445 | 0 | 402 |
| Organizational Inertia | 200 | 147 | 0 | 7 |
| Organizational Isomorphism | 120 | 0 | 0 | 0 |
| Analytical | 893 | 0 | 0 | 104 |
| Emotional | 227 | 263 | 37 | 105 |
| Recency Bias | 235 | 0 | 0 | 0 |
| Availability Heuristic | 129 | 0 | 0 | 0 |
| Hyperbolic Discounting | 63 | 10 | 0 | 23 |
| Cost Efficiency | 227 | 185 | 0 | 139 |
| **ORGANIZATIONAL CULTURE** | 246 | 7 | 80 | 146 |
| **LEADERSHIP** | 252 | 159 | 0 | 0 |

*Colours indicate increasing incidence along the blue-red continuum.