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A CRITICAL ANALYSIS OF CONSTRUCTION MANAGER-AT-RISK PROJECT DELIVERY IN PUBLIC UNIVERSITY CAPITAL PROJECTS

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By

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A CRITICAL ANALYSIS OF CONSTRUCTION MANAGER-AT-RISK PROJECT DELIVERY IN PUBLIC UNIVERSITY CAPITAL PROJECTS

A DISSERTATION APPROVED FOR THE
GALLOGLY COLLEGE OF ENGINEERING

BY THE COMMITTEE CONSISTING OF

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Dr. Tamera McCuen

Dedication

I would like to dedicate this dissertation to the loving memory of my late grandparents C.O. and Juanita Gransberg who left a shining example of love and hard work that has been and continues to be the standard by which I have tried to measure up to in my life. My grandmother was the first person in our family to graduate with a bachelor's degree, which she received from Northwestern University in Music Education. My grandfather was a self-taught civil engineer, having curtailed his high school education to enlist in the US Navy, spending two years fighting in the Pacific during the 2nd World War, returned home in 1946 where he started out as a surveyor's assistant with the Montana Department of Transportation. He taught himself all the necessary higher math, theory, and practice of civil engineering design during his spare time, and after 30 years retired as an Area Engineer, having been grandfathered into the system as a professional engineer in the 1960's. During his 40-year career with the Montana DOT and as a contractor, he either built or designed almost 90% of Interstate 95, which runs east to west through the state. Their love, hard work, and emphasis on the great value on higher education has been a driving force in my life that I feel has, in many ways, been culminated in the completion of this research project. I only wish they could be here with me today to see what their influence has accomplished.

SET THE PACE – BRIDGE THE GAP – ESSAYONS

Abstract

This research project provides novel tools and applications of techniques to better understand and utilize Construction Manager-at-Risk (CMR) project delivery in the context of public university capital projects by evaluating CMR project delivery in comparison to Design-Bid-Build (DBB) project delivery to understand and quantify the value of owner-driven scope growth in achieving critical success factors. Machine learning algorithms were used to support construction research and analysis, modeling cost and schedule growth using a sample of 37 CMR and 74 DBB projects, and accurately imputing missing data values in a sample of 67 CMR and 99 DBB projects. In-depth analysis of design and preconstruction services contracts illustrates the importance of synchronizing contractual language governing the duties, responsibilities, and obligations of collaboration and cooperation between the designer and general contractor. Analysis of project performance metrics demonstrated that traditional cost and schedule growth metrics may not accurately describe CMR projects in this market segment and a novel metric to evaluate design fee efficiency in developing scope changes was developed to assess the quality of project team integration. Results were validated by data envelopment which included a survey of public university capital projects staff, a content analysis of 44 CMR procurement documents not previously included in the research, and case studies of three database projects which appeared to have performed poorly but were considered as successful projects to their owners and end users. Finally, a method of quantifying the value for money from using CMR over DBB is proposed that accounts for collaborative behavior and improved relationships within the project team. Four best practices synthesized from the research project are proposed as techniques to allow public university owners to maximize the potential benefits of CMR project delivery.

Acknowledgements

This research project that began in late 2018 and has finally drawn to a close in the fall of 2021, would not have been possible without the invaluable assistance, support, and participation a of many individuals and organizations. I specifically would like to thank my committee for graciously supporting me throughout this last two and a half years, who have greatly improved the quality of this dissertation project through their sage advice, pointed criticism, and invaluable guidance. I am greatly indebted to Dr. Dominique Pittenger for being willing to chair my committee and her unending support over these years. I would also like to thank Dean Randa Shehab for her willingness to co-chair my committee whose advice on coursework selection and perceptive critiques of my ongoing work have provided the springboard for this project's incorporation of machine learning supported statistical analyses and the development of novel metrics to better describe project performance. I would like to thank Dr. Jeff Volz for setting a high bar that has enhanced the rigor of this research, for challenging many of my base assumptions which led me to the discovery of the underlying causes of cost growth in construction manager-at-risk projects unique to the public university capital construction sector, and for his perspective as both a practitioner and a scholar. I would like to thank Dr. Tammy McCuen, whom I have had the pleasure of knowing since my undergraduate years at the University of Oklahoma, having first met her as one of her construction science students. Dr. McCuen has always supported me, been an encouragement, and has taught me much of what I know about alternative project delivery. I would like to finally thank Dr. Chris Ramseyer, who's enthusiasm and passion for the practice of engineering has been an inspiration to me for many years. Dr. Ramseyer was an early supporter of this endeavor, whose belief in me and my research focus tipped the scales for me in my decision to pursue a doctoral degree. I cannot thank him enough for being willing to continue to serve on my committee into his well-deserved retiring after a long and distinguished career.

The data with provided the basis for this project was graciously provided by the directors and project managers of the capital projects construction units at several major public universities. Their enterprising vision and forward-looking desire to improve their ability to deliver complex, multi-million-dollar capital projects that provide greater value to their clients, end-users, and 3rd party stakeholders is an inspiration and a source of motivation for me over these last years. Without their belief in this research, willingness to participate, and to provide access to their historical project databases, none of this would have been possible. Institutions that furnished the data necessary to support this study are Auburn University, California State Polytechnic University – Pomona, Colorado State University, the University of Colorado – Boulder, the University of Colorado – Colorado Springs, the University of Houston, North Dakota State University, and the University of Oklahoma. A very special thanks to Katherine Dunklau, Associate Director of Design and Construction at CU – Boulder, Mike Rush, Director of Design and Construction at Colorado State, Michael Ellingson, Director of Facilities Management at North Dakota State University, Nick Merry, PE, Executive Director of Project Management at the University of Houston, Scott Fuller, Executive Director of Construction Management at Auburn University, and Bruyn Bevans, Senior Project and Construction Management Program Coordinator at Cal Poly Pomona for sharing their incredible databases of projects without which this research would have been impossible. Their contributions have moved the state of the practice forward.

I would like to thank my father, Dr. Douglas Gransberg, for his love and guidance, not just over these last few years, but my entire life. His invaluable advice, guidance, mentorship, and friendship has been my unfair advantage in successfully navigating these last few years of research. He has always been an incredible, positive influence in my life, and it has been a joy to be able to work with him and follow in his footsteps.

I would like to thank my mother, Gwen Gransberg, who has always believed in me, encouraged, supported, and loved me. She helped me to find my voice and make my own way in this world, without her I would not be the man that I am.

I'd like to thank my friend, co-worker, and research partner Saf'a Maraqa for joining me on this journey. Her considerable expertise in data science analytics, relentless passion for learning, and penchant for innovation has had an immense impact on the development of these novel tools and techniques.

I'd like to thank my brother Erik for encouraging me to pursue a doctorate so many years ago, for always having my back, and for being a big brother to me so many times and in so many ways.

Finally, I would be gravely remiss if I failed to mention my loving wife, Scarlett, who has been my rock, my champion, my most passionate supporter, my fountain of strength, my best friend, my favorite person, and the secret source of my professional success for eighteen and a half years. She loved me and believed in me when I was just a young, enlisted soldier with big plans and big dreams. She has stayed by my side through combat deployments in Iraq and Afghanistan, multiple moves and relocations, joys and sorrows, achievements and losses, sudden career changes, and so much more. She's given me two incredible daughters, Kaitlynn and Annabelle, who have filled my heart with joy and give me great hope for the future. I will forever be indebted to her for her love for me and patience with my many endeavors. I thank God in Heaven that I am that lucky guy who gets to be Scarlett's husband.

Gloria Patri, et Filio, et Spiritui Sancto:
Sicut erat in principio, et nunc, et semper,
et in saecula saeculorum. Amen.

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1.0 Introduction

The annual value of higher education sector construction in the United States is roughly $250 billion, or 13% of total annual construction spending nationwide, as of August 2021 (US Census 2021). This market sector consists of close to 700 public institutions, ranging from two-year community colleges, four-year baccalaureate universities, advanced graduate degree-granting institutions, and independent professional doctorate-granting institutions in all 50 states, the District of Columbia, and several territories. Capital construction projects have traditionally been delivered using Design-Bid-Build (DBB) where the lowest bidder is awarded the contract for construction services in a competitive bidding scheme, however, in the 1990's, many states began to authorize legislation allowing the use of Construction Manager-at-Risk (CMR) project delivery in an effort to improve project performance and reduce the volume of construction claims driving both project cost growth and extensive litigation (Konchar and Sanvido 1998). Public university projects typically have many layers of administrative overhead, end users, campus 3rd parties, external 3rd parties, and various groups of stakeholders with varying levels of influence over the funding and development of a project which can result in multiple revisions, scope changes, additions, adjustments, and approvals that cannot be effectively managed by the capital projects staff with traditional delivery methods. Fortunately, CMR project delivery is a legal delivery method for the construction of public buildings in all but ten states as of 2021 (Figure 1.1) having almost doubled in six years (Gransberg et. al 2013). CMR is widely utilized by public institutions of higher education in an effort to deliver capital improvements in an effective, integrated approach that improves the typically contentious relationships between the owner, designer, and general contractor common to traditional low-bid construction projects. This project delivery method has had a significant amount scholarship generated over the last

30+ years as it has been steady adopted across the United States of America, however, research into the application of CMR in the public higher education sector has been limited to a handful of studies, of which this dissertation seeks to build upon and move forward the state of the practice in this important segment of the construction industry by studying a larger dataset of public university projects than has been previously attempted.

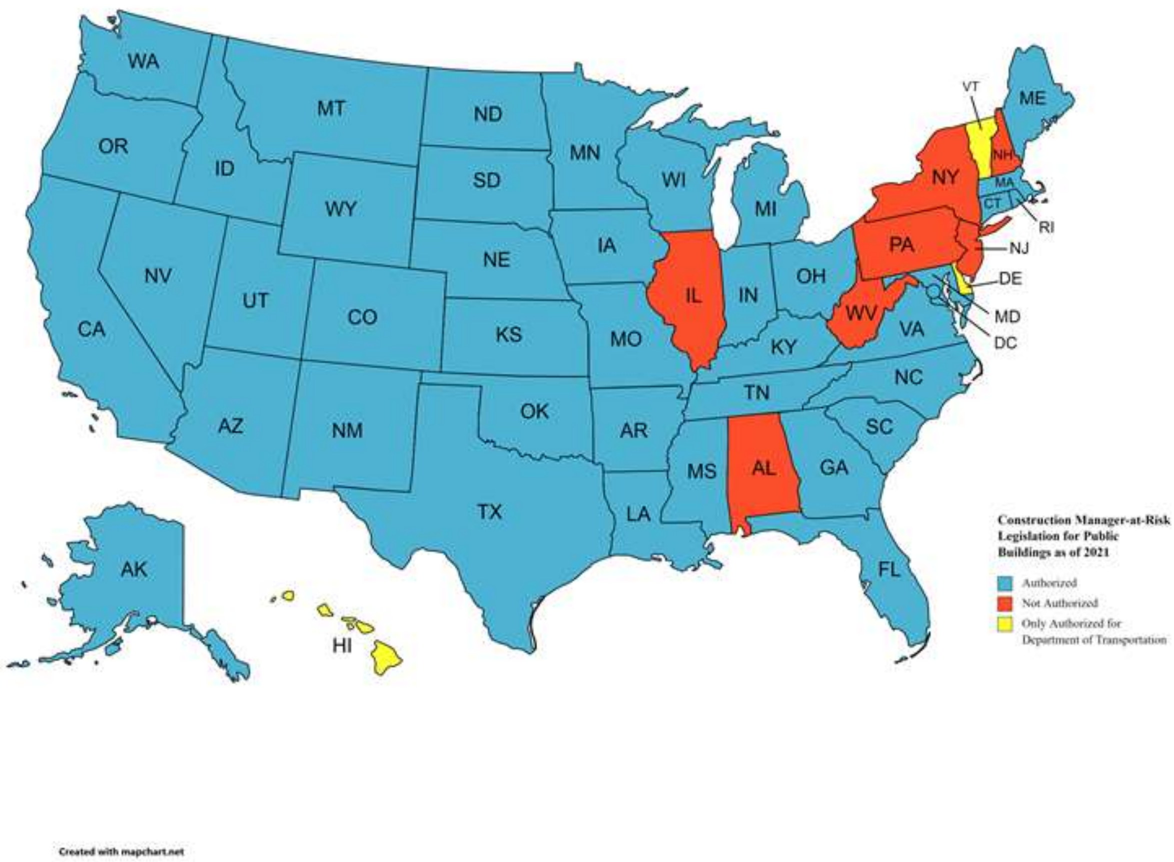

Figure 1.1 CMR Legislation by State (as of 2021)

1.1 Background Motivation

The genesis of this research project was a result of the author's experience as a capital projects manager at the University of Oklahoma. CMR had been the project delivery method of choice for larger capital projects since the University completed their first CMR-delivered project in 2003. CMR had been perceived to provide an effective way to deliver projects that were sufficiently complex to benefit from the early involvement of construction expertise provided by a general contractor selected primarily upon their qualifications. However, between 2015 and 2017, the University had more than one CMR-delivered project which experienced unacceptable scope, cost, and schedule growth as well as an increased level of contention and conflict between the parties to the contract. A decision was made to take a step back from CMR and try using DBB delivery to see if there was an appreciable improvement in the ability to control the project scope. These difficulties seemed contradictory to the existing literature which had proven CMR's capacity to increase schedule and cost certainty when compared to similar DBB-delivered projects. It seemed, at the time, that a wise course of action would be to conduct an in-depth analysis of historical projects completed under both delivery methods at the University. These projects were the seed from which this dissertation grew and eventually became a database of 173 projects gathered from more than 20 American public universities.

The initial focus was on building a framework to analyze two major project delivery methodologies employed in the execution of capital construction projects in public universities: Construction Manager-At-Risk (CMR) and Design-Bid-Build (DBB). There seem to be two conflicting schools of thought when comparing CMR to DBB among capital projects staff formed by their practical experiences managing projects. The first argues that CMR is usually not worth the additional initial cost for construction manager services provided during pre-construction and that the benefit to see improved project team integration and a reduction in contentious behavior is negligible. A commonly asked question is why should you pay the contractor more when you still end up dealing with the same difficulties and headaches generally associated with DBB delivered, low-bid projects? CMR projects do typically cost more upfront than DBB projects, they pay an additional fee to the general contractor for preconstruction services during the design phase, then a construction management fee is applied to the price of the work, and higher general conditions are typically paid throughout the life of the project. The second maintains that the additional up-front cost for preconstruction services in CMR is usually justified because 1) the owner gets to select the best qualified contractor and 2) it produces a better designed and constructed product, higher end user satisfaction, increased cost and schedule certainty, and 3) reduces contentious behavior between parties that could result in excessive claims and/or litigation. Most owners select their CMR general contractors using a combination of qualifications and price factors to identify the best qualified contractor for the job. Comparative research of CMR and DBB has been conducted in specific states, regions, and on the national scale for public infrastructure projects, and the vast majority seems to support claims of the second school of thought on CMR. This literature will be thoroughly investigated in the Literature Review section. However, there is little, if any, authoritative research in commercial building construction, or the specific subset of university capital projects, due to the difficulty of assembling a statistically significant population of project performance data. The existence of the first school of thought on CMR begs the question, when the literature seems to be overwhelmingly contradictory, why, and how, do capital projects staff come to these conclusions? Where are the knowledge gaps in the literature that need to be filled in? Is there something missing or improperly employed by capital projects staff at public universities when using CMR as a delivery method? Are there generalizations from existing research that do not apply to this industry segment? This research project intends to answer as many of these questions as possible.

1.2 Research Objectives

There are five research objectives and hypotheses related to answering the research question posed comparing CMR to DBB project delivery in the context of public university capital projects construction. They were formulated from a synthesis of findings present in the existing literature and practical experience from managing CMR and DBB projects in this context for multiple years (Table 1.1) with the intended purpose of generating findings, conclusions, recommendations, and best practices that could be readily applied by capital projects staff. Tasks associated with these objectives and hypotheses can be found under the Research Methodology (Section 1.4).

Table 1.1 Research Objectives and Hypotheses

Objective 1	Create a framework to evaluate public university capital construction projects delivered using Construction Manager-at-Risk and Design-Bid-Build project delivery methods.
Hypothesis 1a	Construction Manager-at-Risk project delivery provides greater value for money than Design-Bid-Build when applied to capital projects on public universities.
Objective 2	Understand the relationship between project delivery method and project performance.
Hypothesis 2	Capital projects on public universities, when delivered using CMR, outperform comparable projects delivered using DBB, when measured with traditional project performance metrics.
Objective 3	Understand the relationship between contractual language and project performance.
Hypothesis 3	CMR project delivery provides greater contractual flexibility to incorporate owner-directed and late scope changes to capital projects on public universities.
Hypothesis 3a	Late scope changes that would require a second procurement under DBB would not under CMR.
Objective 4	Develop metrics to measure the efficiency by which scope changes are incorporated into ongoing projects.
Hypothesis 4	The integration of owner, designer, and general contractor staffs found in CMR project delivery allows scope changes to be incorporated more efficiently into ongoing projects than in projects delivered by DBB.
Objective 5	Develop strategies for owners to increase their ability to maximize potential integration benefits of CMR project delivery.
Hypothesis 5	The quality of contractual language synchronization between the designer and general contractor directly impacts the relative effectiveness of project team integration in CMR delivered projects.

1.3 Literature Review

The section is a consolidation of the literature reviews conducted for each paper written for this dissertation, reducing the overall length of the report, and providing a single location to reference. Likewise, citations have been consolidated from each paper into a single section at the end of this report.

1.3.1 Previous Studies

The four most salient studies on this subject consist of a master's thesis, a doctoral dissertation, and two studies published in ASCE journals. Neidert's 2012 comparison of CMR and DBB delivery method performance of 19 CMR and 14 DBB projects showed that DBB projects took more time to deliver but cost less than CMR projects and that early contractor involvement in the design reduced change orders. This is the only study of its kind focused on this specific market segment. William's 2003 study of 111 CM/GC and 104 DBB public construction projects in Oregon, of which 23 CMR and 58 DBB were education-related, found that CMR projects were more efficient than DBB projects and provided greater potential to mitigate risk, however DBB projects outperformed CMR projects on both cost and schedule growth. Rojas and Kell's study of 297 CMR and DBB public secondary school construction projects completed in Oregon and Washington showed no statistical difference between delivery methods found that CMR projects were less efficient at controlling cost at buy out where subcontracts are awarded to trade partners. Carpenter and Bausmann's 2016 study of projects from 137 public schools in the southeastern US showed the DBB outperformed CMR on all cost metrics but CMR produced higher levels of service and product quality.

Table 1.2 Summary of Existing Studies

	Franz et al.*	Franz et al.*	Carpenter & Bausman	Molenaar et al.*	El Asmar	Neidert	Korkamz et al.	Rojas & Kell	Williams	Sanvido & Konchar	Pocock et al.	Oberlander & Zeitoun
Year Published	2020	2016	2016	2014	2012	2012	2010	2008	2003	1998	1996	1993
PDMS Compared												
DBB	X	X	X	X	X	X	X	X	X	X	X	X
CMR	X	X	X	X	X	X	X	X	X	X	X	X
DB	X	X		X	X		X			X	X	X
IPD		X		X	X						X	
Number of Projects	212	204	137	204	35	33	40	297	407	351	25	106
Commercial	23%	10%		10%						45%	44%	
Housing/Lodging	13%	13%		13%						8%	12%	
Office	58%	20%		20%			100%			42%	8%	
Correctional		2%		2%								
Educational		27%	100%	27%	25%	100%		100%	100%			
Manufacturing	5%	5%		5%						5%		
Sports & Recreation		5%		5%								
Transportation		1%		1%							16%	
Health Care		16%		16%	50%						8%	
Utilities		0%		0%							12%	
Public Sector	X	X	X	X	X	X	X	X	X	X	X	X
Private Sector	X	X		X	X		X	X		X		X

** These studies utilized some or all of the same projects for each analysis*

There have been many other studies comparing CMR and DBB projects which included projects from other public sector construction segments (Oberlander and Zeitoun 1993; Pocock et al. 1996; Sanvido and Konchar 1998; Menches and Hanna 2006; Rojas and Kell 2008; Korkmaz et al. 2010; El Asmar et. al 2013). These studies have generally found CMR to outperform DBB according to traditional metrics of cost and schedule growth. Konchar and Sanvido's 1998 seminal comparison of 351 US building projects, they found that over 50% of DBB projects experienced schedule growth of 4% compared to CMR where over 50% of projects fell below 0% schedule growth and median cost growth for DBB projects was 4.83% compared to 3.37% for CMR. Sullivan, et. al. (2017) captured two decades of literature produced researching CMR, Design Build (DB), and DBB projects of which only 8 out of 31 papers analyzed CMR cost growth and only 3 analyzed CMR schedule growth.

1.3.2 Project Delivery Methods

Project delivery methods are defined by the American Institute of Architects as "a *formalized contractual approach* which allows an owner to *secure planning and design services and build a project*, assuring effective management throughout" (AIA Minnesota (emphasis added)). TCRP Report 131 defines it as follows: "The project delivery method (or project delivery system) is the process by which a construction project is comprehensively designed and constructed for an owner. It refers to all the contractual relations, roles, and responsibilities of the entities involved in a project" (Touran et al. 2009). The Construction Industry Institutes maintains that there are only three project delivery methods (PDMs): Design-Bid-Build (DBB), Construction Manager-at-Risk (CMR), and Design-Build (DB) (CII 1997). There are multiple variations on each of these PDMs utilizing various combinations of procurement procedures, contract payment provisions, and scope development approaches (Mehany et. al 2018). PDMs can be understood as existing along a spectrum of risk and control shared between the owner and the contractor (Fig 1.2). Where the owner requires the greatest share of risk and control, DBB and its variants are more appropriate. Where the owner requires the least share of risk and control, DB and its variants are more appropriate. Where there is a moderate level of sharing between the owner and contractor, CMR is the more appropriate. Research has supported the benefits of employing alternative project delivery methods to improve project performance since the late 1990's (Konchar and Sanvido 1998, Ibbs et a. 2003, Oyetunji and Anderson 2006, Kuprenas and Nasr 2007, Sullivan et al. 2017, Gransberg and Gransberg 2019). The following section will describe the various attributes of each delivery method.

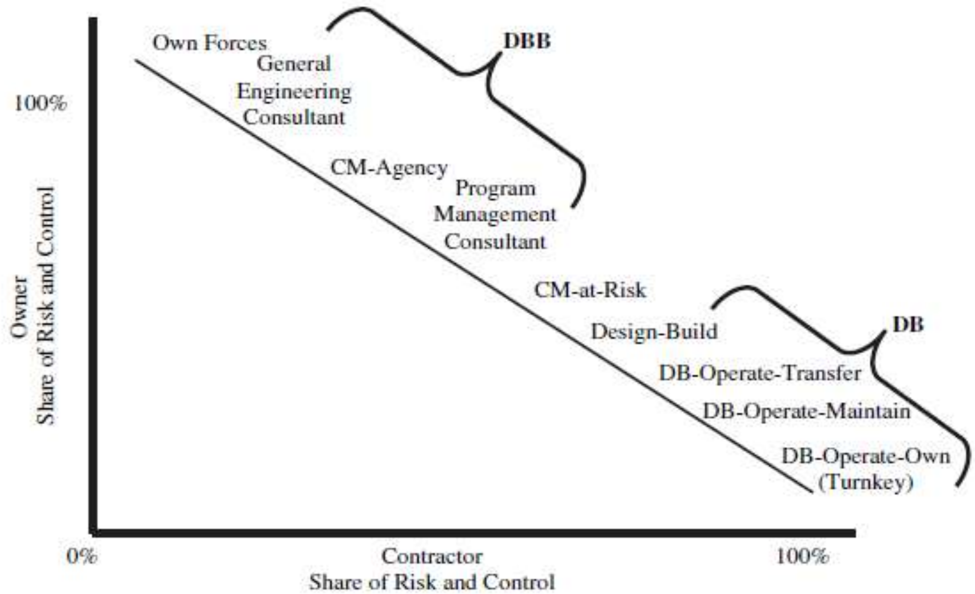

Figure 1.2 The Project Delivery Spectrum

(Courtesy Gransberg & Assoc., Inc.)

1.3.2.1 Design-Bid-Build

The traditional method for delivering construction projects in the United States is referred to as Design-Bid-Build (DBB) accepted by public agencies at the municipal, state, and federal levels which utilizes a three-step process where the designer is selected to produce complete construction documents, the project is advertised for bids from general contractors, and the, typically, lowest bidder constructs the project (Hallowell and Toole 2009). This PDM is characterized by two lines of contractual privity 1) between the owner and the designer and 2) between the owner and the general contractor (Gransberg and Gransberg 2019) as illustrated in

Figure 1.3. DBB contracts are typically awarded as a lump sum or on a unit price basis that does not require the bidder to disclose how they arrived at their bid prices ("closed books accounting").

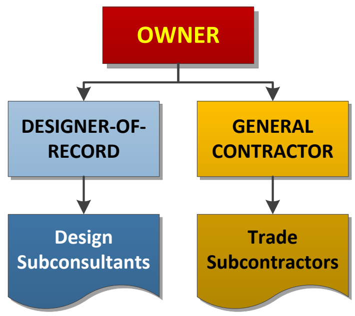

Figure 1.3 Design-Bid-Build Contract Model

(Courtesy Gransberg & Assoc., Inc.)

Some advantages of DBB are that the owner retains total control of the design, the designer provides strong representation for the owner acting in their traditional role as the owner's representative, the construction documents are complete prior to the procurement, and may provide early cost certainty for project financing. A primary disadvantage of DBB is the adversarial relationship between the contracting parties where the designer looks to defend the construction documents against claims made by the general contractor who is incentivized to actively look for errors and omissions made by the designer to increase the cost of the project through change orders to defend against losses due to errors and omission. A key feature of DBB contracts is active case building by the designer and contractor over potential claims that, if ineffectively resolved, may be litigated in the courts. Unsophisticated owners may seek to play the designer and the general contractor off each other to attempt to cut project costs or get more scope for less money. The other major disadvantage is that proposer with the lowest bid usually has the most mistakes in their estimate which may result in post-award change orders and poor project management resulting in a higher overall project cost than anticipated.

1.3.2.2 Design-Build

Design-Build (DB) project delivery combines design and construction responsibility in a single entity with a single line of privity between the owner and the Design-Builder, see Figure 1.4. DB project delivery is considered the oldest formalized method of procuring design and construction services through a "master-builder", in modern terms the "Design-Builder".

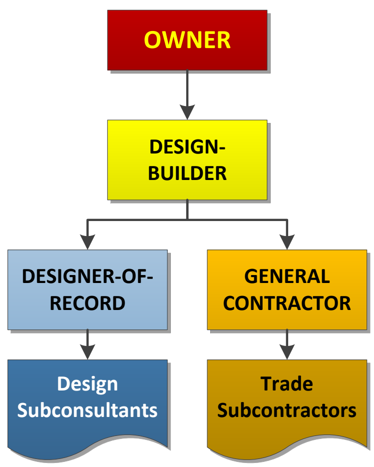

Figure 1.4 Design-Build Contract Model

(Courtesy Gransberg & Assoc., Inc.)

DB procurements may utilize a one or two-step competitive negotiation process. In a one-step process, the owner issues a Request for Proposal (RFP) to potential proposers and determines the award using a best-value selection that considers the best combination of the proposed technical aspects and project cost which provide the most advantage to the owner (Rocky Mountain DBIA 2012). Best-value refers to the method of evaluating a proposer on their qualifications and some sort of cost component. With the two-step process, the owner issues a Request for Qualifications (RFQ) which proposers respond to with a Statement of Qualifications (SOQ) that the owner then rank-orders to create a "short-list", typically between 3 to 5 proposers make this list. The short-listed proposers are then issued an RFP to develop cost and technical proposals which are evaluated using a best-value selection process to award the project. A common feature of two-step DB procurement methods are honoraria or cash stipends, usually worth a portion of the actual cost of proposal development, that help defray the technical and cost proposals for proposers that are not awarded the project contract. This is a best practice that improves the quality of technical and cost proposals, whose costs are not insignificant to prepare.

The primary advantage of DB project delivery for most public owners is the ability to accelerate the project schedule which is incentivized by 1) a lump sum contract for both design and construction and 2) the shift in Spearin Doctrine liability for the plans and specifications onto the design-builder. In public works, the owner warrants the completeness of construction documents produced by the designer and is liable to pay for any errors and omissions therein that are discovered during the project (United States vs Spearin, 1918). This legal principle was established in federal court in a 1918 lawsuit between a utility contractor and the US government for the construction of a drydock in Brooklyn Naval Yard. The design-builder is liable to review and approve the plans and specifications whereas the owner only reviews the plans and specs for compliance with the RFP. Another advantage is that work packaging allows the construction to begin without 100% complete construction documents which assists in accelerating the project schedule. Additionally, the designer has a greater incentive to adhere to the construction budget and schedule as most design-build partnerships are led by the builder. DB has been shown to improve overall cost and schedule certainty, especially with large and/or complex projects that may benefit from contractor innovations. A primary disadvantage is the major culture shift required from DBB project delivery for all parties. DB requires a greater level of trust, communication, and coordination to delivery on its benefits. Additionally, DB projects typically cost more than low-bid DBB delivered projects due to the qualifications-based and/or best-value selections. This is a tradeoff for increased quality and competence which may not be justified on smaller, simpler projects and/or for an accelerated construction schedule that would not be achievable with other delivery methods. A final disadvantage is the owner's loss of control over the design that accompanies the shift of Spearin Doctrine liability which requires a greater level of trust between the contracting parties to be successful. This can be mitigated with bridging documents that specify the portions of the scope that the owner is not flexible on, but the greater the quantity of bridging used, the bigger the reduction in potential benefits due to the loss of potential design-builder innovations from prescriptive bridging documents.

1.3.2.3 Construction Manager-at-Risk

Construction Manager-at-Risk (CMR), also referred to as Construction Manager/General Contractor (CM/GC) in the transportation sector among others, is an alternative delivery method used widely in public sector higher education construction projects in the United States of America. CMR project delivery can be considered a hybrid of DB and DBB delivery methods. In CMR project delivery "the public owner engages both a project designer and a qualified construction manager under a negotiated contract to provide both preconstruction services and construction" (AGC 2007). CMR contracts have the same lines of privity as DBB but include specific clauses mandating improved communication, coordination, and relationships between the designer and the general contractor to "achieve a high degree of collaboration among all parties" (Shane and Gransberg 2010). The general contractor is typically procured under a qualifications-based selection (QBS) and awarded a lump sum professional services contract, referred to as preconstruction services, at some point in the design phase of the project (Rojas and Kell 2008), as shown in Figure 1.5. The preconstruction services procurement may include some sort of cost component, usually a lump-sum fee for services and a percentage-based fee for post-design construction services, according to the state laws in force and the owner's particular policies. The general contractor ("construction manager") assists the owner and designer with constructability reviews, producing estimates using real-time cost data, conducting market surveys, and consulting on means and methods as well as current construction technology (Gransberg and Gransberg 2019). Typical preconstruction services may include market surveys, constructability reviews, real-time cost estimates, schedule estimates, construction technology recommendations, and coordination of preferred means and methods with the design. The owner and general contractor negotiate the construction cost prior to the completion of the design using open-books accounting and mutually agreeing to a Guaranteed Maximum Price (GMP) that theoretically is not to be exceeded, however the GMP is often in practice neither entirely guaranteed nor maximum. The designer is able to rely upon the general contractor's intimate knowledge of the local market as well as their preferred means and methods, reducing potential disputes over the plans and specifications (Choi et. al 2019). The designer's and the general contractor's contracts contain language in them that mandates communication and cooperation between both parties for the duration of the design and construction (Gransberg and Shane 2010). The owner may directly benefit from the integrated approach to developing design, which can improve the relational dynamics of the project team (Touran 2006) and avoid the adversarial relationships experienced between the owner, designer, and general contractor found in DBB

(West et al. 2012). Much of the literature shows that CMR projects improve cost performance relative to comparable DBB delivered projects (Konchar and Sanvido 1998; Molenaar et al. 1999; Francom et al. 2016).

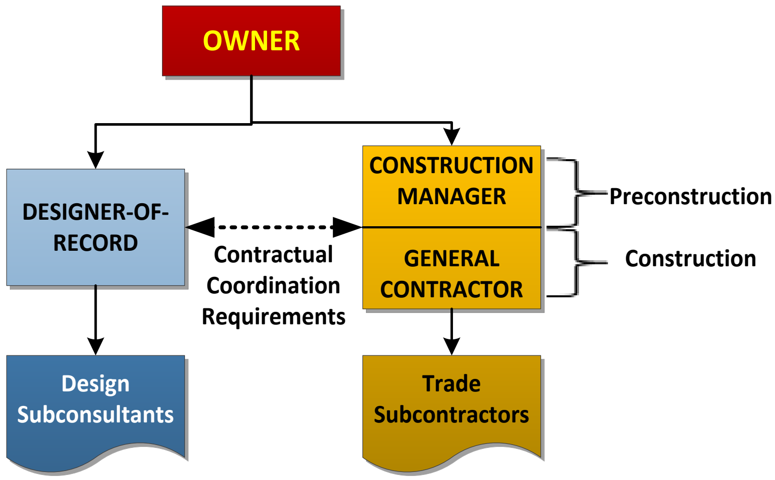

Figure 1.5 Construction Manager-at-Risk Contract Model

(Courtesy Gransberg & Assoc., Inc.)

The designer is also procured using a qualifications-based selection. The owner and general contractor typically negotiate a Guaranteed Maximum Price (GMP) for the construction scope during the design phase, sign a construction services contract, and issue a Notice to Proceed (NTP) when a GMP is agreed to. The preconstruction services contract can be terminated or converted into a construction services contract by amendment. At some point after the design is complete, a CMR contract may be converted from GMP to lump sum, at which point the construction administration is almost identical to DBB. An underappreciated benefit of preconstruction services is the ability to terminate the preconstruction services contract if the owner and CM fail to reach a mutually agreeable GMP for the project at which point the construction documents can be completed by the designer and let using DBB as the delivery method, commonly referred to in the industry as a contractual "off ramp."

CMR shares many of the advantages and disadvantages of DBB and DB delivery. Like DBB, the owner retains control of the design through contractual privity with the designer but can capitalize on proposed innovations from the CM as they choose. Construction work may be acerated by working packaging, like DB, so that early work packages are designed and released for construction prior to completing later portions of the scope. CMR can spin off design work packages faster than DB, even though DB is considered the PDM of choice for schedule compression, as the CM can be selected at the same time or before the designer is selected. This is rarely taken advantage of as owners using CMR tend to wait until there is some base level of conceptual design complete to procure the CM. The contractual coordination between the CM and the designer during construction services allows the designer to improve material selections, design within the means and methods that the general contractor will employ and rely upon significantly more accurate market surveys and cost estimates using real time data only available to general contractors. CMR requires a similar culture shift within the contracting parties' organizations to coordinate their efforts effectively and efficiently. This can be difficult to accomplish within highly bureaucratic government agencies lacking dedicated executive buy-in. Unsavvy owners can similarly attempt to play the designer and contractor off each other, as in DBB, which has a greater liability to ruin the advantages of CMR delivery. Finally, CMR projects typically cost more initially than comparable DBB projects due to the qualifications and best-value selection processes but have been shown to provide superior cost certainty.

1.3.3 Project Delivery Method Evaluation and Selection

Considerable literature has been developed over the last 30+ years on the topic of project delivery method evaluation and selection. A basic tenant of construction research is to assume that no two projects are identical, but a constellation of project characteristics can be derived that are generally applicable to all projects. Two hypothetical projects may have the identical plans, specifications, owner, and designer but they will inevitably have differences in work crews, construction management, staffing, weather, market conditions, etc. resulting differing outcomes of vary degrees. Furthermore, each project's unique characteristics will lend themselves towards a preferred method of delivery that it fits best. As far back as 1982, it was theorized that selecting the appropriate delivery method could reduce overall construction costs (Contractual 1982). The proper delivery method best addresses the needs of the owner, builder, and the unique technical requirements and project characteristics (Alhazmi and McCaffer, 2000). Early attempts to model project delivery focused on meeting the owner's specific needs for the project (Ireland 1985), built off or modified models incorporating multi-attribute techniques (Skitmore and Marden 1988, Bennet and Grice 1990), focused on meeting owner/client and contractor needs (Mohsini, 1993), and incorporated risk allocation and market considerations (Gordon 1994). Gordon (1994) posited that choosing the appropriate PDM for a project could "decrease project duration, provide flexibility for changes, reduce adversarial relationships, allow for contractor participation in design, [and] provide cost savings incentives to the contractor" and likened the process of PDM selection to a process of elimination wherein the owner discards inappropriate methods until a choice can be made between the remaining methods. These early models had their short comings and limitations, of which many were addressed by Alhazmi and McCaffer's Project Procurement Selection Model (PSSM) (2000) that employed a mixed qualitative-quantitative, four-step process based upon an alternative value engineering technique (Parker 1985) combined with an analytic hierarchy process (Saaty 1994) using proprietary software. This process first scored a set of 31 evaluation criteria based upon their appropriateness to a given set of PDMs without discarding any PDMs. The second step evaluated and scored each PDM for its benefits and drawbacks as perceived by the owner's team at which point low scoring PDMs would be discarded from the analysis. The third step conducted a weighted evaluation by first completing paired comparisons assessing only two needs at a time then compiling the results into an evaluation matrix where weights are assigned to the evaluation criteria. The final step was conducted using proprietary software to provide the optimum PDM recommendation. The Transit Cooperative Research Program (TCRP) Report 131 remains an important contribution to evaluating PDMs in transportation projects (Tourani et al. 2009) categorizes PDM selection into three tiers: qualitative approach, weighted matrix method that combines qualitative and quantitative features, and a final highly quantitative risk-based cost estimating method. The decision-making process is intended to begin with the first tier and proceed thru subsequent tiers as necessary to select an appropriate PDM, where the first two tiers should be conducted with owner staff and the third is recommended to procure an outside expert consultant to conduct.

Qualitative PDM selection approaches play an important role in matching projects to an agency appropriate PDM by facilitating discussions among the project team, building consensus, and exchanging ideas (Khwaja et al. 2018). Existing PDM decision tools are for the most part customized to the culture, objectives, and priorities of the organizations they were developed for, but all provide a good point of departure in developing a new decision model that is focused on the specific agency and market in need.

Gordon's 1994 study on PDM selection provided 6 examples of how alternative PDMs provide contractual solutions to improve project performance over the "zero-sum-game nature of fixed-price contracts" (Gordon 1994). Of these 6 examples, 4 directly address solutions to reducing the adversarial relationships typical in DBB and are as follows:

1. Flexibility to approve changes without paying a premium.
2. Creating opportunities for teamwork between the general contractor and designer.
3. Allowing the general contractor to meaningfully participate in the design process.
4. Incentivizing general contractors to save the owner money.

CMR and DB both provide improved flexibility to approve changes to the project scope that can reduce the potential markup that is typically included in DBB change orders. The use of a negotiated Guaranteed Maximum Price (GMP) enables the owner and the general contractor to process changes to the scope with minimal administrative overhead for any changes that fall within the GMP amount. Additionally, the GMP can be increased through a simple contract amendment or can utilize contingencies established in the GMP contract. The integration of the designer and general contractor within a DB entity under a lump sum contract incentivizes collaboration between these parties to provide innovating solutions to project changes to minimize the impact to their shared profit margin. Both CMR and DB create considerable opportunities for collaborative teamwork through contractual requirements for the designer and general contractor to communicate and collaborate on developing the design which can establish good relationships in the project timeline that improve overall communication when the project shifts from design to construction. Incorporating the general contractor into the project team during the design phase contributes to building positive teamwork and effective collaboration between the three parties to the contract (Irwin 2003, Minchin et al. 2007). The contractual model employed in DB project delivery decreases potential conflict between the general contractor and designer in that there is a single line of contractual privity with the owner and the DB assumes Spearin Doctrine liability for design errors and omissions, incentivizing close collaboration between both parties to mitigate them (Walewski et al. 2001, Harrison-Hughes 2002, Halpin 2006). In both delivery methods, frivolous claims are disincentivized to the design-builder and the CMR contractor as both are typically selected either on qualifications alone or a best-value selection that combines qualifications and a price factor (Touran et. al 2009). The author's 2019 multi-project cross-case comparison study of 24 vertical and horizontal CMR project case studies identified 17 common advantages to CMR of which 4 were strong influences to improved collaboration, coordination, and communication (Gransberg and Gransberg 2019) are as follows:

1. Select general contractor on qualifications
2. Spirit of trust
3. CMAR is owner's advocate during design
4. Flexibility during design/construction

Being able to select the general contractor on qualifications is powerful tool that allows the owner, and sometimes the designer, to eliminate proposers with records of poor performance, contentious or combative styles of interaction, and provides a forum to meet each contractor project team in person after a shortlist is developed. Personal relationships are incredibly important in CMR, and DB delivered projects, if the project team is serious about attaining project goals and objectives. Two of the lessons learned in this study were related to cooperation. The first was that the designer's contract and the general contractor's preconstruction services contract must be coordinated so that the designer's obligations to cooperate with the general contractor on design development are equal to those in the preconstruction contract. The second was that the general contractor should be procured as early as possible in the project development and design phase to maximize the potential benefits of project team integration and collaboration in developing the design (Shane and Gransberg 2010, Gransberg and Gransberg 2019). The owner can impact cooperative behavior in the project team, positively or negatively, by the way that risk is allocated (Zhang et al. 2016). CMR and DB both have advantages in risk allocation from participation of the general contractor in the risk allocation and management process (Touran et al. 2009). The ability to coordinate efforts within the project team allows risks to be allocated to the team member that is most capable at managing them or permits sharing of risks between project team members to reduce the overall exposure. In CMR, the general contractor may assist in developing prescriptive designs and specs that clearly spell out risk responsibility in greater detail. In DB, the design-builder takes on all errors and omissions risk which is a primary source of contention and claims in DBB delivered projects. Collaborative risk allocation is a practical way the alternate PDMs enable project team integration and build trust.

Project partnering seeks to provide project benefits from positive project team relationships by creating an environment of trust, interorganizational collaboration, and clear and safe communication (Sanders and Moore 1992). Project partnering is a common activity that is usually facilitated by consultants in a single or series of workshops that are a mix of social activities and collaborating goal setting. Often, partnering sessions are concluded with the signing of a partnering compact that may or may not be binding. Project partnering has become quite commonplace as an assistive tool for the culture shift required within an organization to maximize the potential benefits of alternative delivery. The Construction Industry Institute's definition of project partnering includes the phrase that the "relationship is based on trust, dedication to common goals, and an understanding of each other's individual expectations and values" (1991).

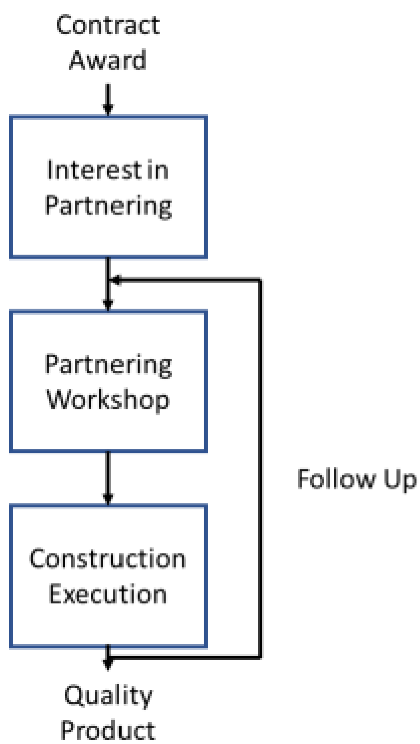

Figure 1.6 Partnering Process (Abudayyeh 1994)

The primary purpose of partnering is to prevent conflicts before they occur by transforming relationships between contracting parties from traditionally adversarial ones into cooperative relationships that create an environment where all parties are acting as a single team (Abudayyeh 1994). This process is simple, as seen in Figure 1.6, and workshops may be repeated periodically throughout a project to reinforce commitments and encourage teamwork and become more important when there is turnover in the project staff, which is typically on longer duration, larger scoped projects. The California Department of Transportation was an early adopter of project partnering in the early 1990's and their experience was covered in Abudayyeh's 1994 paper where the multiple benefits to the owner and the contractor were identified as seen in Table 1.3. Successfully partnered projects enable project team members to come to a common understanding of the project and are empowered to openly debate ideas, share information, challenge assumptions, and integrate viewpoints and knowledge (Barron 2000, Allen et al. 2005, Edmondson and Lei 2014, Manata et al. 2018). These potential partnering benefits are more readily achievable under an alternative project delivery method than a traditional one.

Table 1.3 Caltrans Partnering Program Benefits (Abudayyeh 1994)

Partnering Benefits	
Owner	**Contractor**
Potential claims reduction due to open communication	Reduced costs related to potential claims and litigation
Reduced cost overruns and delays due to improved cost and schedule control	Improved productivity due to focus on the project rather than on case-building
Improved conflict resolution strategies due to open communication and unfiltered information	Improved cost and schedule control
Lower administration costs due to the elimination of the effort required in defensive case-building	Lower risk of cost overruns and delays
Increased opportunity for innovation through open comminication that encourages proposal for new means and methods and constructability improvements	Increased opportunity for financial success through innovative construciton methods

The integrated project team environment plays an oversized role in the effectiveness in project partnering (Uhl-Bien et al. 2007, Li et al. 2019). It is important to maintain an open environment where free communication is safe for all team members, allowing people to speak freely, ask questions, and collectively learn from each other's mistakes (Edmonson and Lei 2014, Lloyd-Walker et al. 2014). Much of the literature comes from Australia and New Zealand who utilize a practice known as alliancing wherein the owner, designer, contractor, and applicable 3rd party stakeholders enter a joint contract where all parties share profit and loss (Lloyd-Walker et al. 2014). Under a project alliance agreement, the owner trades traditional contract prerogatives to bring project team organizations, like the designer and builder, into contractual parity so that all alliance parties will be incentivized to make “best-for-project” decisions to collaboratively achieve project objectives (Australian Department of Infrastructure and Transport 2015). Although this PDM does not exist in any similar form in the United States, there are many good points made that can be applied to American alternative PDMs, specifically regarding communication strategies and proactively encouraging “no-blame culture” practices where they can me practically applied within these existing PDM structures. Two problem solving models illustrated in Walker-Lloyd et al.’s paper that discussed the theoretical underpinnings of the Australian alliancing version of “no-blame culture” provide an excellent visual representation of the differences in traditional, adversarial constructs versus integrated alternative delivery models. Figure 1.7 shows the established (and problematic) mode of problem solving that revolves around placing and avoiding blame for problems. Figure 1.8 shows the alliancing model for problem solving that is substantially shorter and directly addresses problems in a collaborative manner. This sort of problem-solving culture requires project leadership to make a paradigmatic shift away from traditional, authoritative, command and control leadership modes and embrace flatter organizational models that capitalize on distributed leadership within the project team that encourages collaborative, solutions-oriented teamwork (Lloyd-Walker and Walker 2011).

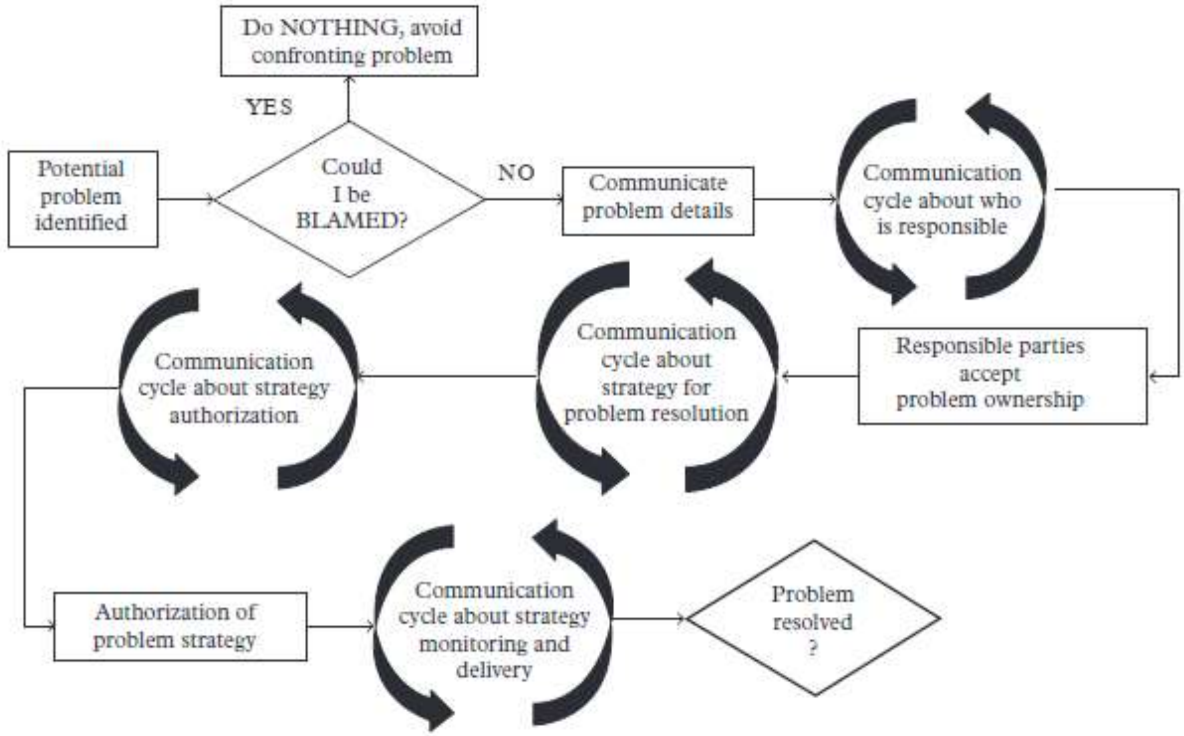

Figure 1.7. Established Adversarial Problem-Solving Model (Llyod-Walker et al. 2014)

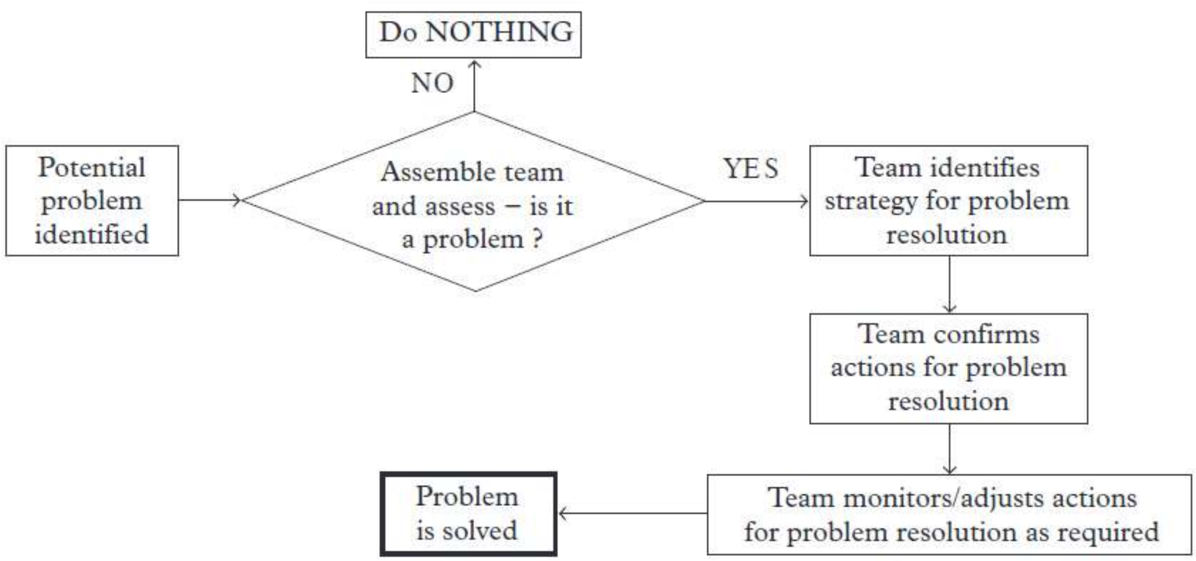

Figure 1.8 Integrated Project Team Problem-Solving Model (Llyod-Walker et al. 2014)

1.3.4 PDM Selection for Public University Capital Projects

Public universities have varying levels of capital projects administration and support staff depending on several factors including the size of the university, financial capacity, etc. Some universities have independent business units dedicated to capital projects, the University of Oklahoma' A&E Services division for example or may incorporate those functions within their facilities management organizations as Colorado State has their Planning, Design & Construction division within Facilities Management, or may even utilize a private construction management services consultant to provide the requisite expertise on their behalf. Larger universities have invested a significant of effort into developing highly competent capital projects staffs, employing a robust set of techniques, practices and procedures developed through practical experience gained delivering projects year after year. The University of Missouri System's (UMS) Planning, Design & Construction division utilizes five different project delivery methods and has developed an online manual (University of Missouri 2021) that provides guidance to capital project staff in a concise, effective manner that is particularly instructive given the focus of this research project. The spirit of this manual can be encapsulated by the following quotation from the introduction to Chapter 5: Project Delivery Methods:

> *"The University of Missouri intends to* ***make the best and most cost-effective use of construction funding*** *and to* ***build high quality facilities respective to functionality and appearance***."

This is a commonly expressed corporate goal among public university capital programs which intends to produce the greatest value in the resultant facilities for the funds available to procure the work. Value, for the owner, consists of objective (functionality) and subjective (appearance) components which are expressed as a function of an attainable level of quality for the available funds. Optimizing the level of attainable quality for the available funding is one of the driving forces behind project delivery method selection, recognizing that every project will be unique and have delivery method that provides more opportunity to be able to achieve key success factors and end-user goals. The UMS manual identifies nine project selection factors and seven owner success factors that should be considered when selecting the delivery method for a project (Table 1.4) which are considered in the early stages of project development so that the unique considerations of the project are balanced against identified owner success factors to identify the best fit delivery method to achieve them. The UMS manual does a nice job of concisely characterizing the advantages and disadvantages of each method and provides a best use scenario to assist projects staff. An extract of these criteria for DBB and CMR can be found in Tables 1.5 and 1.6, respectively.

Table 1.4 Selection Criteria Project and Owner Success Factors (University of Missouri System)

Project Factors	**Owner Success Factors**
Schedule requirements; or the cost of a linear schedule versus the cost to accelerate the schedule, or overlap the project phases	Desire to control design content/quality; ability to define and verify the program and to take responsibility for the design
Clarity of the project scope; is a longer planning phase needed	Experience with particular delivery system
Cash flow or funding cycles funding the project budget; when is cash available	Internal resources to manage particular delivery system: ability to manage multiple contracts for a single project
Need for early establishment of the contract for construction cost	Desire to control contingency budgets and to what extent
Potential for scope changes during construction phase	Desire to eliminate responsibility disputes between contractors and designer
Desire to encourage innovation and/or contractor input during design	Tolerance for change orders and flexibility to allow changes during construction
Special financing; developer-led project, etc.	Desire to control the project risk and contingencies
Unusual budget restraints	
Unusual quality or design control requirements	
*Consolidated from *UM System Facilities Management Policy and Procedure Manual*, Chapter 5 located at: https://www.umsystem.edu/ums/rules/fpm/5_professional_services	

Table 1.5 DBB Selection Criteria (University of Missouri System)

BEST SUITED FOR: Projects that are budget sensitive but are not especially schedule sensitive and not subject to change. Owner can completely control the design.	
Advantages	**Disadvantages**
Familiar delivery method	Linear process means longer schedule duration than other methods
Simpler process to manage	Price not established until bids are received; may require redesign and rebid if bids exceed budget
Fully defined project scope for both design and construction	Quality of contractors and subcontractors not assured
Both design team and contractor accountable to Owner	Cost estimates change during design process
Lowest price proposed and accepted; pricing, including contractor fee and overhead, developed competitively: "best price"	Fosters adversarial relationships between all parties; increases probability of disputes
Creates the most bidding opportunities for general contractors and subcontractors	No design phase input from contractor on project planning, budget or estimates
	Not optimal for projects that are sequential, schedule or change sensitive.
	Change orders and claims may increase final project cost.
*Consolidated from *UM System Facilities Management Policy and Procedure Manual*, Chapter 5 located at: https://www.umsystem.edu/ums/rules/fpm/5_professional_services	

Table 1.6 CMR Selection Criteria (University of Missouri System)

BEST SUITED FOR: Large new or renovation projects that are schedule sensitive, difficult to define or subject to potential changes; also for projects requiring a high level of construction management due to multiple phases, technical complexity or multi-disciplinary coordination.	
Advantages	**Disadvantages**
Selection of contractor based upon qualifications, experience and team	Difficult for Owner to evaluate the GMP or determine whether the best price has been achieved for the work
Contractor provides design phase assistance in budget and planning	Costs more than traditional bid due to reduced competition in pricing of contractor overhead, fee and sub-contract costs
Continuous budget control possible	A/E fees higher due to additional packages
Screening of subcontractors allows Owner and contractor quality screening	Costs often increase due to "details" not in the GMP
Faster schedule than traditional bid; fast track construction possible	CM may expand budget to create future savings
Ability to obtain GMP earlier in process; earlier than traditional bid, later than D/B	
Theoretically, more teamwork between design firm and contractor	
Provides more ability to handle change in design and scope	
Theoretically, reduced changes and claims once in construction	
*Consolidated from *UM System Facilities Management Policy and Procedure Manual*, Chapter 5 located at: https://www.umsystem.edu/ums/rules/fpm/5_professional_services	

1.3.5 Construction Administration

Construction administration is defined as "the *handling* of business *relations* between the parties to the contract" (Fisk and Reynolds 2010, emphasis added). "Handling" comes out of the contract clauses and "relations" comes from the people and organizations involved in the contract, ergo good relations can lead to a successful project. Promoting communication, collaboration, cooperation between the owner, designer, and builder are increasingly important as project increase in magnitude and complexity necessitating the implementation of alternative delivery methods that provide the contractual structures to allow these areas to be improved upon over the traditionally adversarial relations found in DBB contract models.

1.3.6 Preconstruction Services

Many authors point to the constructability review as an effective tool to control both scope growth and scope creep (Anderson et al 2007; Kifokeris, and Xenidis 2017; Stamatiadis et al. 2017; Alsafouri, and Ayer 2019), and recent research on project delivery methods has found that Construction-Manager-at-Risk (CMR) delivery provides an effective contractual mechanism to ensure constructability through its preconstruction services contract (Alleman et al. 2017; Gransberg and Molenaar 2019). "When the designer has access to the construction contractor's real-time pricing and the ability to review the constructability of the design before it is completed, there is no longer an excuse to exceed the published budget for the project" (West et al 2012). However, this quote presumes that the project scope will not change, and that cost growth is a negative performance metric. Previous research has also found that the negotiation of the construction cost during the preconstruction period of a CMR contract actually permits the owner to refine and enhance its expectations for the constructed scope of work in a manner that adds value to the final project even if the final negotiated price is higher than the original budgeted amount (Molenaar et al. 2009).

1.3.7 Measuring Project Performance

Project performance can be defined as techniques utilized to quantify "the measurable or tangible results of a project" (Jitpaiboon, et. al., 2019). The Project Management Institute (2016) states that cost management planning provides a "framework for efficient and coordinated cost management" through which cost controls are used as "a mechanism to monitor and control project costs". Public owners have a fiduciary responsibility to the taxpayer to efficiently deliver projects, where a prevailing goal among owners is the desire to maximize cost savings with a goal of finishing projects under budget. The concept of cost certainty looks at this from an opposite direction, with a goal of identifying the expected final price of a project early in the process (Touran et. al 2011) to reduce the incidence of unintended change orders. Change orders can contribute to cost and schedule overruns (Shrestha and Zeleke 2018, Shrestha et. al 2019). The most common cost control metric measures the percentage of cost growth from the commencement of construction activities to the completion of construction activities. Konchar and Sanvido (1998), in their seminal study of project delivery methods, defined cost growth as shown in the following equation:

Equation 1.1 Cost Growth (%) (Sanvido & Konchar 1998)

$$Cost\ Growth\ (\%) = \frac{Final\ Project\ Cost - Contract\ Project\ Cost}{Contract\ Project\ Cost} X100$$

This metric does not measure cost changes from the initial cost estimate developed to finance the actual construction scope, which would reflect an agency's relative ability to forecast project costs with a relatively immature design. However, El Asmar et al.'s 2013 study of integrated project delivery performance defined cost growth in the following equation:

Equation 1.2 Cost Growth (%) (El Asmar et al. 2013)

$$Cost\ Growth(\%) = \frac{Final\ Construction\ Cost - Original\ Estimated\ Construction\ Cost}{(Original\ Estimated\ Construction\ Cost)}\ x\ 100$$

This metric accounts for early agency estimates, providing some insight into their accuracy as compared to the cost at contract award and cost at completion. Equation 1.2 is used in the study as a basis for quantifying the amount of additional project cost growth. This measurement is a useful project management tool, but it does not characterize the source of realized cost growth.

Sanvido and Konchar (1998) defined schedule growth the difference between Total Time and Total As-Planned Time divided by Total As-Planned Time (Equation 1.3) where Total As-Planned is defined as "the period from the as-planned design start date to the as-planned construction end date," which is interesting given that cost growth measured did not account for changes over the design phase.

Equation 1.3 Schedule Growth (%) (Sanvido & Konchar 1998)

$$Schedule\ Growth\ (\%) = \frac{Total\ Time - Total\ As\ Planned\ Time}{Total\ As\ Planned\ Time}\ x\ 100$$

1.3.8 Scope Growth and Scope Creep

The literature points to poor scope definition as the underlying cause of cost growth in construction (CII 1986; Dysert 1997; Dumant et al. 1997; Gransberg et al. 2007) and that design changes are the root of construction cost growth as much as 60% of the time (Bresnen et al. 1991; Bubshait, et al. 1999; Craigie et al. 2016; Pinto et al. 2018). Scope growth, due to owner directed changes, is manifested by design cost growth (Kuprenas and Nasr 2003). On the other hand, scope creep is a function of "uncontrolled and unexpected changes in project requirements that extend the initial boundaries of the project [scope]" (Amoatey and Anson 2017). The term scope creep has several definitions (Amoatey and Anson 2017) but all of them characterize the phenomena as something that must be avoided if possible and controlled if not. Scope growth experienced during design and construction results in an increase in the design services contract amount through owner approved change orders or contract modifications; whereas the result of scope creep is a reduction in the designer's profitability as they must complete more work without additional compensation (Knight and Fayek 2002). Research has shown that uncompensated scope creep can lead to poor quality design documents (Love and Li 2000; Carr and Beyor 2005), which contributes to construction cost growth due to errors and omissions. Hence, it is important to differentiate between scope growth and scope creep. As such, the paper will use the following definitions to distinguish the underlying difference:

- Scope Growth: Rightfully recognized, compensable increases in the initial project scope during design or construction phases of a project, i.e., the result of a conscious decision to add new scope for which the designer is rightfully due a contractual change. Scope growth is generated by the owner as a recognition of end-user needs that have not been addressed in the existing design scope which are necessary for successful project attainment.

- Scope Creep: Recognized or unrecognized, uncompensable, uncontrolled increases in the project scope during design or construction phases of a project, i.e., product of change in quantities of work and incremental adjustments to the working design not covered in the designer's contract. Scope creep is a type of incremental scope growth that can be generated by minor changes to design details, materials selection, means and methods, etc. that, in aggregate, contribute to unintended project scope growth.

In a thought-provoking essay entitled "In Defense of Scope Creep," Helm (2012) posits that scope creep is merely "the pejorative name we give to the natural process by which clients discover what they really want." Helm maintains that scope creep is not only inevitable but necessary to the "requirements gathering" process for defining the project's actual scope of work as more detailed requirements is developed during the design process. Helm uses the term "scope creep" to cover all scope increases during the design process without regard to whether the change is recognized or not. "Scope growth" will be used as the term to define additional owner-generated scope in this paper. It is important to note that scope change is not necessarily a negative phenomenon, as it provides a vehicle by which the owner refines its expectations for the final constructed project after the designer is engaged, adding value to the process rather than detracting from it. Thus, Helm argues that the project delivery process must be crafted to allow for the addition of inevitable owner-generated scope to attain successful project completion.

1.3.9 Beneficial Scope Growth

Sobin et al.'s finding (2010) demonstrates that scope growth during project delivery can add value, even if it adds cost. It also illustrates the impact of negotiating the construction price during design and preconstruction as opposed to fixing it prior to award of the contract, as happens in DBB and DB. Similar examples can be found elsewhere in the literature regarding the ability to adjust the final scope of work during preconstruction in CMR (Carlisle 2006; Touran 2006, West et al 2012). This leads one to infer that the ability to add scope to a project after its award is a feature that can add value for money and that cost growth resulting from a conscious decision by the owner to add desirable scope should not be considered a negative event. Considering the position described by Helm (2012) regarding scope growth, the paper will explore the notion that CMR project delivery provides an opportunity for the owner to add scope as needed in a manner that is more efficient than DBB, and this aspect creates a previously unrecognized value to the owner. A major contribution of this research dissertation is quantitatively assessing the concept that project cost growth resulting from owner-directed scope enhancements and additions can be a positive indication of project performance.

1.3.10 Change in Construction

Change in most construction projects is inevitable (Ibbs 1997, Hanna et. al 2002, Hanna et. al 2004, Alnuaimi et. al 2010, Syal and Bora 2016, Duah and Syal 2017, Kim et. al 2020). Owners have the right to make changes to their projects, before or after they have been awarded for construction, due to changes in their requirements as the work progresses "as long as they are willing to pay for them" (Günhan et. al 2007). Researchers have long sought to better understand and characterize the causation of cost and schedule growth in construction projects, differentiating the sources generating deviations to the project scope generally into design and construction (Jacobs and Richter 1978, Diekmann and Nelson 1987, Clark 1990, Burati et. al 1992, Ibbs 1997, Hwang et. al 2009). Changes can be generally characterized as resulting from alterations to the project scope, design errors and omissions, delays, differing site conditions, project suspensions, or acceleration (Ibbs 2007). Diekmann and Nelson's 1987 investigation into the cause of claims in 22 federal projects (18 low-bid, 4 negotiated, total value of $104 million) found that design changes where the greatest cause of claims, where 72% of design changes resulting from either design errors or owner-initiated changes. Burati et. al's 1992 study of mid-1980's industrial projects (9 each, total value of roughly $7.8 billion) produced similar findings with design deviations responsible for 78% of total deviations and 78% of total costs due to deviations, where an average of 9% of total deviations per project were owner-driven, and all but one project seeing owner-initiated deviations to the project scope ranging from 0.2% to 18.8% of total project deviations. Ibbs' 1997 study characterized the results of three earlier studies (Jacobs and Richter 1978, Diekmann and Nelson 1987, Clark 1990) showing that of the primary causes of change in the studied sample of projects, 30% were due to design changes not related to errors and omissions, which can be interpreted as an attribution of owner-driven changes to the scope. His study (104 private-sector projects, total value roughly $8 billion, 37% DB, 46% DBB, 17% other) found that most changes identified were executed inefficiently, seeing a reduction in overall project productivity by 2.48% for every additional 10% of change added to a project and that the costs of labor directly associated with completing project changes increased proportionally with the magnitude of the cost of change (Ibbs 1997), ergo the greater the scope of the change, the more expensive the per unit cost of labor for the work. Additionally, this study produced productivity regression curves which found that design phase changes reduced productivity by 10% less than construction phase changes (-24.8% versus -34.4%), while not being specifically noted in the findings, was attributed to "turn-key" contractors (Design-Build) spending more on design to improve construction phase productivity. This productivity impact relationship sheds light onto the efficacy of incorporating scope changes before physical work commences while affirming the additional costs associated with altering the scope at any point after project design has commenced. Hanna et. al’s 2004 study of the cumulative effect of change in DBB-delivered mechanical/electrical projects also found that the most common causes of change were design related “additions, design changes, and design errors” of which the first two categories are owner-directed. Günhan et. al’s 2007 study of five years’ worth of change orders (more than 6,500) issued by a major American school district employing construction management firms issued between 1999 and 2004 explored the relationship between the causes, management, and magnitude of change orders. They found that over the period of the study, the average contribution of owner-directed changes was worth at least 21% of the total cost of post-award contract change orders; this could have been more as 26% of the total average changes were categorized as “other” due to ambiguities in causation. The school district studied initiated a policy change in 2002 to reduce the volume of owner-directed changes by requiring school administrators to identify and communicate their desires during preconstruction with the promise that construction phase change requests summarily rejected. This is a noted benefit of CMR project delivery which provides a vehicle for collaborative project scope development (Shane and Gransberg 2010). Hanna et. al, in their 2017 study quantifying the cumulative impact of change orders in 68 DBB projects demonstrated that 50% of changes were caused by scope additions, deletions, and design coordination, with 26% caused by design changes, 18% due to errors and omissions on the designer’s part, 4% due to schedule compression, and only 2% due to value engineering. This study noted that productivity losses due to changes could be better managed through improved owner-contractor relationships, however these circumstances “rarely occur in design-bid-build projects, such as collaboration, mutual trust, and efficient and transparent communications between owners and contractors" (Hanna et. al 2017) which are common characteristics of CMR delivered projects.

1.4 Research Methodology

This dissertation is paper based, so specific research methodologies can be found within each chapter as is applicable. This section covers the general methodology employed throughout the life of this research project and guided the synthesis of information gleaned by various analyses and sources into findings and conclusions. The primary sources of information for this project consisted of:

1. a comprehensive review of existing literature,
2. a project database gathered from public universities in the United States,
3. a collection of public university Requests for qualifications (RFQs) and Requests for Proposal (RFPs),
4. a review of common CMR contracts for both design and construction services,
5. informal interviews of individual representatives for owner, designer, and general contractor with recent experience in CMR projects delivered on the University of Oklahoma campus, and
6. a survey of public university capital projects staff.

The following research instruments were employed in this project:

1. a qualitative analysis of lessons learned from existing case study research,
2. a quantitative analysis of the public university construction projects database,
3. a qualitative analysis of individual perceptions regarding CMR and DBB delivery,

4. content analysis of CMR contract documents,
5. content analysis of RFQs and RFPs,
6. a survey of public university capital projects staff, and
7. case study analysis of sample projects.

1.4.1 Research Approach

The research objectives (Table 1.1) were executed by completing the tasks set forth in this section. A framework was constructed to evaluate public university capital projects delivered using CMR and DBB by synthesizing results of the literature review and the results of the quantitative analysis of the projects database. Qualitative research tools were employed to fill perceived gaps and validate findings through data envelopment. The final deliverables are 1) project performance metrics for projects within the database, 2) a metric for measuring design fee efficiency, 3) recommendations for improving CMR contracts, and 4) recommendations and best practices for university capital projects staff. This approach is illustrated in Figure 1.9 and is fully discussed in subsequent paragraphs.

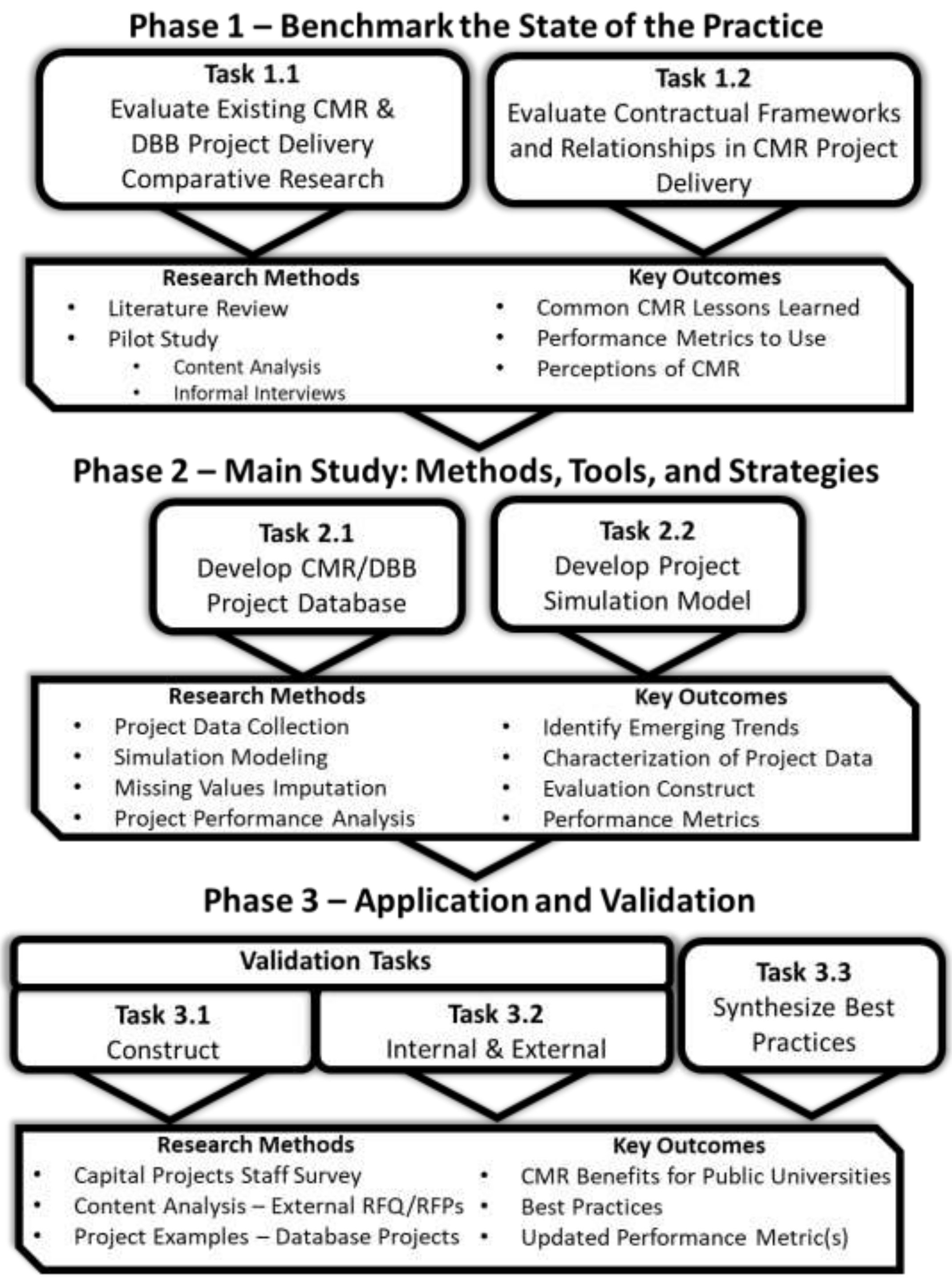

Figure 1.9 Research Approach

Task 1.1 Evaluate Existing CMR and DBB Project Delivery Comparative Research

An extensive literature review was used as the primary research tool for Research Task 1.1, providing a benchmark of the body of knowledge behind CMR project delivery, specifically applied to projects completed by public universities to understand where the state of the practice currently sits. There is a great deal of scholarship produced over several decades surrounding the theory and application of this alternative project delivery method due to its widespread adoption in the United States of America. Identifying seminal studies which established widely accepted best practices, evaluation metrics, documented practical applications, challenges, risks, and opportunities associated with CMR delivery provides an opportunity to find where gaps exist in the literature. These gaps are where this research project seeks to add new knowledge to the practical application and evaluation of CMR project delivery in the public higher education construction sector.

Literature Review

A comprehensive literature review was conducted over the existing literature on CMR project delivery, in public and private as well as vertical and horizontal applications, which is covered within this chapter. To summarize, the literature repeatedly demonstrates that CMR delivered projects outperform comparable DBB delivered projects regarding cost and schedule growth. There was a very limited selection of papers focusing on CMR project delivery in the context of capital projects construction at public universities in the United States, which were generally in agreement with the other extant literature that CMR delivery can improve cost and schedule certainty, however studies in the related field of public school construction diverged with the consensus on the point of schedule and cost certainty showing that, in certain cases, CMR delivery took longer and/or experienced more cost growth than comparable DBB projects.

There was sufficient literature to guide the development of research methods, tools, and strategies utilized in subsequent research tasks.

Task 1.2 – Evaluation Contractual Frameworks and Relationships in CMR Project Delivery

Research Task 1.2 was accomplished with a pilot study that tested initial assumptions to determine if a full study should be undertaken. This study consisted of 1) a content analysis of pairs of contracts, design services and preconstruction services, to evaluate clauses and language governing integration and collaboration between the designer of record and the general contractor during the design/preconstruction phase of the project and 2) a series of informal interviews of experienced representatives for owners, designers, and general contractors that had worked on university projects locally to ask candid questions about their thoughts and perceptions on the practical application of CMR. Findings were synthesized from both tasks that were used to guide the development of the main study.

Content Analysis of CMR Contracts

Contract documents were collected from several public universities and examples of common standard form contracts were obtained for analysis. Contract document types included 1) agreements for design services, 2) agreements for preconstruction services, 3) agreements for construction services, and 4) change orders and contract modifications. Standard form contracts samples from the American Institute of Architects (AIA) were included in the analysis due to their ubiquity. Two rounds of content analysis were conducted: 1) on a set of contracts for a $30 million academic building and 2) on three sets of contracts (AIA, University of Oklahoma (OU), State of Colorado). Analysis of OU contracts consisted of a word count and analysis of "shall +

verb" statements and count of the words "Architect" and "Construction Manager" providing an insight into the power dynamics and generation of the contractual relationship between these parties. The second analysis of three sets of contract documents was focused on identifying the contractual language regulating the relationship between the project designer and the general contractor to identify gaps and continuities between each set of contracts regarding the duties of each party to the other with an emphasis on identifying examples, or the lack, of synchronization between the two. Results of the content analysis are laid out in Chapter 4, to summarize there is a significant gap between the duties of the designer and the duties of the general contractor in the AIA standard form contracts that strongly favors the designer. Examples of well synchronized contracts were produced. Outputs of this analysis assisted in the development of a questionnaire used in informal interviews.

Informal Interviews

Informal interviews were conducted with representatives for an owner, a designer, and a general contractor which had all recently participated in various CMR-delivered projects on the University of Oklahoma campus. These interviews provided insights into perceptions of what each party considered to be important to a successful project which were 1) the importance of expectations management of the owner/client (common responsibility), 2) setting the tone for the project early (owner responsibility), and 3) responsibilities of the architect (critique). Results of the analysis illuminated the critical roles the owner and architect play in enabling a successful CMR and highlighted the cultural shift necessary for these parties to undergo when transitioning into the use of alternative delivery methods.

Task 2.1 – Develop CMR/DBB Project Database

Research Task 2.1 had two parts: project data collection and project performance analysis. Data collection was the longest task to complete in this study, taking roughly a year and a half to collect sufficient public university construction project data to analyze and draw conclusive findings from. Project data was received in varying levels of completeness and many times in different formats than requested. Additional data was collected by internet search and was more incomplete than data provided voluntarily by capital projects staff at several public universities that were both forward thinking and kind enough to support this research project. This task was conducted concurrently with simulation modeling in Task 2.2, which had to be completed to allow missing values to be properly imputed and then conduct a project performance analysis of the database projects.

Project Data Collection

Project data was collected from public universities between 2018 and 2019 by two methods: 1) voluntarily provided by capital projects staff at the request of the researcher and 2) through internet web search of publicly available data. Project data for 74 CMR and 104 DBB projects, valued at roughly $3 billion, was consolidated into an excel database and missing data points were imputed using the Random Forests algorithm. This dataset was reduced to a matched "shadow projects" database of 86 projects was analyzed. A second interim dataset of 37 CMR and 74 DBB public projects completed by the public universities as well as state and federal agencies were obtained to provide a statistically significant sample of projects to assist in model development. These federal projects were removed from the database once sufficient public university capital projects were obtained. Data collection was conducted primarily electronically over email except for projects provided by two public universities in Colorado. The primary investigator visited the University of Colorado – Boulder and Colorado State University who graciously provided access to their project records and explanations of how some projects included in the database which appeared to have had serious problems had been highly successful in reality. These discussions were the catalyst that led to the development of a novel method of measuring the performance of CMR delivered projects by quantifying the efficiency of design dollars expended for owner-directed scope changes. Data collected via internet search suffered from high rates of data missingness which necessitated the following research task. Projects were categorized based up their delivery method, project type, and project subtype.

Task 2.2 Develop Project Simulation Model

Development of an analytical model was necessary to test the utility of the project database, guide the development of an evaluation construct, and provide a tool to impute missing values in the dataset. This process provided a useful tool to characterize the project data in preparation for project performance analysis.

Simulations Modeling

A statistical model was constructed using machine learning algorithms programmed with Python that employed multiple regression analysis as an early goal to predict project final cost by modeling cost and schedule growth of CMR and DBB projects. This model used an early version of the projects database that had been supplemented by a sample of federal building projects, for a total of 37 CMR and 74 DBB projects. The model compared cost and schedule growth as a function of the initial budget and schedule estimates developed for the project. Statistical analysis was conducted in Python using Jupyter Notebook to characterize the dataset. Results of the analysis both supported and contradicted the literature. Results supported the literature by showing that CMR project delivery provided better schedule certainty ($r^2 = 0.767$) than DBB ($r^2 = 0.242$). The analysis showed that Initial Cost and Final Cost variables were significant at $\alpha = 0.05$ for both DBB and CMR and Preconstruction variables were significant to both Initial and Final Cost variables in CMR at $\alpha = 0.15$. However, cost variables were poorly correlated to schedule variables were poorly correlated for both delivery methods. Results partially contradicted assertions from the literature that CMR provides greater cost certainty than DBB but there was no appreciable difference between the two datasets (DBB r^2=0.952; CMR r^2=0.945) and that the cost for preconstruction services had a limited impact on predicting the final project cost for CMR projects. However, due to limitations inherent in the dataset (project type, use of "Best Value DBB" by the Navy, etc.), these findings were categorized as emerging trends and were used to focus the analysis in conducted in Task 3.1 on cost performance. This model provided a valuable opportunity to characterize project data extracted from public DBB and CMR projects providing a baseline from which the subsequent analysis could be evaluated by. The full details on the development and outcomes from the simulation model can be found in Chapter 5.

Missing Values Imputation

The Random Forests data imputation algorithm was employed to eliminate missingness in the database. Data for many projects in the database was either not publicly available over the internet or was missing from historical project files at participant universities, necessitating the development of a robust technique to impute missing values. Although this is a novel technique in construction research, it is well-established in other fields of scientific research. Missing values were successfully imputed using this algorithm allowing subsequent analysis of project performance and the development of novel metrics. Details of this procedure are illustrated in Chapter 6.

Project Performance Analysis

A sample of 86 projects was selected from the project database using a well-established construction research technique, known as "shadow projects", which is used to reduce dissimilarities between projects being analyzed. There was a total of 43 CMR projects in the database that had totally complete datapoints whereas there were over 70 DBB projects with complete datapoints, so DBB projects were matched to the CMR project they were most similar to according to these descending criteria:

1. Initial Estimate Value
2. Project Type (New Construction or Renovation)
3. Project Subtype (Academic, Administrative, Athletic, Utilities, Health Sciences, Housing, Paving)

The CMR projects with their DBB "shadow projects" resulted in a sample dataset of 86 projects where 19 CMR and 20 DBB were new construction and 24 CMR and 23 DBB were renovations. A further breakdown of these values and measurements of central tendency can be found in Chapter 6. An initial analysis was conducted to identify trends in the updated project database by calculating the following cost performance metrics for each project:

1. Cost growth from early construction estimate to project completion
2. Cost growth from construction contract award to project completion
3. Cost growth from the design contract award to project completion

When compared, DBB projects outperformed CMR projects in the dataset with CMR projects experiencing between 3.7% to 13% (median to mean) more cost growth from early estimates, 1.9% to 4.2% (median to mean) more cost growth from construction contract award, and between -1% to 4.1% (mean to median) cost growth in design fees. The results were a true surprise as they seemed to contradict the literature which posits that CMR projects outperform DBB projects using these traditional metrics. It had been assumed that by eliminating the interim federal projects from the database used in Task 5 would reduce the amount of cost variability in the CMR projects in the sample, as would be expected according to the literature, yet the opposite occurred, seemingly disproving the second hypothesis. A summary of the initial analysis can be seen in Table 1.7.

Table 1.7 Initial Results of "Shadow Projects" Sample

VAL = CMR - DBB	**Trad. Cost Growth Metrics**		
	Early Est.	**Contract Award**	**Design Fees**
Variance	3.8%	2.4%	67.2%
Standard Dev.	5.9%	10.5%	69.6%
Mean	13.0%	4.2%	-1.0%
Median	3.7%	1.9%	4.1%
Total Value	$ 1,543,749,884.55		

A second analysis was carried out on the sample data to identify outliers, using an outlier threshold calculation (Tukey 1977) where the threshold value is either Q3 plus 1.5 times the interquartile range or Q1 minus 1.5 times the interquartile range. This resulted in the identification of eight outlier values for CMR and four for DBB. Cost growth metric characterization was recalculated, and the results can be seen in Table 1.8. There were modest adjustments downward in the difference between CMR and DBB, the greatest being the difference in variance for growth from early estimates (from 3.8% to -2.3%), however there was a rather pronounced positive shift in the difference in mean values for design cost growth with CMR seeing 8.5% more mean cost growth than DBB.

Table 1.8 Results after Outliers Removed

VAL = CMR - DBB	Trad. Cost Growth Metrics		
	Early	Contract	Design
Variance	-2.3%	1.0%	2.8%
Standard Dev.	-5.3%	6.7%	9.0%
Mean	12.6%	1.2%	8.5%
Median	3.5%	1.7%	3.8%
Total Value	$ 1,543,749,884.55		

These results demanded a reevaluation of key assumptions held regarding CMR project delivery, specifically if CMR delivery doesn't typically outperform DBB in public university projects, then why does it continue to be a widespread, respected delivery method? What is the perceived value of CMR to owners that leads them to choose it over DBB, even though it would most likely experience greater scope growth? The design fee cost growth shift led to the realization that traditional project performance metrics do not account for the value an owner might place on being able to incorporate scope into an existing project. Owners typically only pay a designer a change order for additional fee if the owner is the cause of the change. If the designer has made a mistake in the plans, it is considered an error or omission which they cannot expect to be compensated for discovering and fixing. Therefore, the greater positive cost growth for design fees in CMR (15% to 21%) means that owners are more likely to add scope to a CMR delivered project after it has been awarded than a comparable DBB project (11.2% to 12.5%).

Traditional performance metrics cannot account for this, so a novel metric was developed to measure the relative efficiency design fee dollars expended by the owner for owner-driven scope additions to construction dollars of scope in those scope additions. This metric is expressed as a ratio of construction dollars to design fee dollars (C$:D$) and may be used to measure the relative efficiency of design fees expended at any point in a project. The eureka moment of this research project occurred when the design fee and construction scope dollars associated with owner-directed scope additions were isolated and used in calculating the efficiency ratio. It was discovered, for the projects in the sample population, that design fee dollars expended for owner-directed scope additions were roughly twice as efficient in CMR projects as they were in DBB projects. CMR projects saw between $8.43 to $14.87 of construction scope for every design dollar whereas DBB projects saw $4.42 to $8.48 of construction scope for comparable design fee dollars, providing evidence that CMR delivered projects allow owners to incorporate new scope into an existing project in a more efficient manner, providing a previously unrecognized benefit of CMR that needs to be investigated. These findings were validated in subsequent research tasks that included a survey of public university capital projects staff, a content analysis of external RFQs and RFPs, and an additional literature review focused on change and change management in CMR delivered projects.

Phase 3: Validation and Application

This research study was validated through “data envelopment” by approaching the findings and conclusions with different sources, tools, and techniques. Tools used to accomplish this envelopment included 1) an online survey of public university capital projects staff, 2) a content analysis of Requests for Qualifications (RFQs) and Requests for Proposals (RFPs) from institutions not represented in the study's database of construction projects, and 3) an exploration of projects from the database that appear to have been poorly administered according to traditional metrics but demonstrated a high ratio of owner-driven construction scope change dollars to design fee change dollars (as covered in Chapter 6). These tools provided an effective way to validate research hypotheses.

Tasks 3.1, 3.2 and 3.3: Construct Validation, Internal Validation, and Best Practices

Construction validation was conducted by using the tools developed over the course of the research project to evaluated CMR projects with poor traditional project performance metrics to determine if 1) the project was over budget or over schedule due to owner-driven scope change by assessing the cost growth of design fees and 2) if the project team was able to efficiently incorporate that scope into the project to the benefit of the owner by calculating the design efficiency of post-award change. There was significant overlap between validation tasks, as is evident in Chapter 7. Three projects were identified by poor traditional performance metrics: the 5 Partners Place building at the University of Oklahoma (43.9% schedule growth, 29.9% design fee growth), the Biotechnology E-Wing at the University of Colorado Boulder (39% post-award cost growth, 159.2% schedule growth, 11.1% design fee growth) and the Multipurpose Stadium at Colorado State University (12.6% post-award cost growth, 91.3% schedule growth, 9% design fee growth). Design efficiency ratios were calculated for each project (OU - $13.32, CUB - $32.82, CSU - $21.18) which showed that all three projects provided the means to incorporate post-award change theoretically more efficiently than comparable DBB projects, using values calculated in Chapter 5. These results provided an indication that these projects may have been completed successfully, which led directly to the internal validation task accomplished by a detailed investigation of each project.

Research was then conducted into the history of each project to investigate the various constraints and goals associated with each project, to understand contractual relationships, project financing, project team integration, and the sources of the realized cost and schedule growth. This research was developed into case studies of example projects exploring the relevant history of each project with a focus on 1) validating research hypotheses and 2) synthesizing best practices. These examples are found in full detail in Chapter 7.

Task 3.2 External Validation:

External validation consisted of three subtasks with included 1) an additional focused literature review of change management in CMR, 2) a content analysis of RFQs and RFPs not previously included in research data, and 3) a survey of capital projects personnel at a combination of public universities that had provided and not provided project data to the research.

Additional Literature Review on Change Management in CMR

An additional literature review focused on changes and change management in CMR delivered projects was conducted as a technique to assist in validating findings from the data analysis, content analyses of contract documents, and informal interviews. The literature provided the results of several studies on the causation and effects of change in construction projects delivered using both traditional and alternative delivery methods, including a five-year study over 6,500 change orders approved on CMR delivered construction projects undertaken by a major American school district with an average annual volume of $550 million. This study provided an excellent insight into the behavior of the owner's representatives and their internal clients' methods of fully developing the scope of a project, which directly contributed to cost and volume of change orders executed, supporting Hypotheses 1 and 3. The school district instituted a policy near the midway of the study that required end users to make requests for additional scope during the preconstruction or be rejected automatically if construction had become, which capitalizes on the ability to collaboratively develop project scope, an established CMR benefit, supporting Hypothesis 3. Additional studies focused on productivity losses associated with change orders in DBB-delivered projects found that productivity impacts could be significantly reduced through collaboration, mutual trust, and improved communications between the project parties which are all established characteristics of the CMR project delivery model, supporting Hypotheses 4. The full results of this review are laid out in Chapter 7.

Content Analysis of RFQs and RFPs

RFQs and RFPs for CMR projects were collected by publicly available internet search, resulting in the collection of 44 individual procurement documents. Content analysis produced a count, by document, of the number of incidences that an RFQ/RFP addressed a selection of 95 criteria common to these types of documents. Results of this analysis provided an insight into 1) characteristics of general contractors that are perceived as indicators of competence and 2) common patterns in the methodologies of public university owners in procuring general contractors for CMR delivered projects. These results ultimately served to validate findings that had been attained by other research tools.

Validation Survey

A 13-question survey was composed and sent to over 220 public university capital projects staff, receiving 27 responses of which 23 were fully responsive, which met the target response rate of 10%. There was fortuitous near 50-50 split in respondents between executives and project management and support staff that allowed a more sophisticated analysis of the data. Questions were formulated to test each research hypothesis and results supported Hypotheses 1, 3-5 and disproved Hypothesis 3a. The survey provided support that 1) CMR provides greater contractual flexibility to incorporate late scope than DBB, 2) that project team integration and relationships are improved in CMR, 3) that CMR provides a better delivery method to deliver complex projects, and 4) that the ability to support the incorporation of owner-driven scope into the project is recognized as a benefit of CMR.

1.5 Dissertation Organization

This dissertation is organized in journal paper format with the papers organized logically from the genesis to completion of this multi-disciplinary research project. The dissertation body consists of four parts:

Part 1: Introduction (Chapters 1 and 2):

> This part consists of the introductory chapter and a benchmark of the state of the practice provided by a comparative analysis commercial and infrastructure projects delivered using CMR. This paper was published in 2020 in the *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*.

Part 2: Pilot Study (Chapters 3 and 4):

This part consists of the pilot study conducted using qualitative (textual analysis of contract documents and informal interviews) and quantitative (linear and multiple regression simulation modeling) methods. These papers were submitted to the *Journal of Engineering Management*.

Part 3: Quantifying the Value of Owner-Directed Scope Growth in CMR (Chapter 5) This part consists of a study that 1) evaluates the level of contractual synchronization between the designer and general contractor's professional services agreements, 2) assembly and initial analysis of a statistically significant database of public university capital projects using the Random Forests machine learning algorithm for data imputation, 3) an analysis of a sample of CMR projects with comparable DBB "shadow projects" drawn from the main database, and 4) development of a novel metric to evaluate design fee efficiency in post-award changes that accounts for owner-directed scope growth. This paper will be presented at the ASCE Joint Construction Institute and Construction Research Congress Conference in Alexandria, VA on March 9-12, 2022, and will be subsequently published in was submitted to the *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*.

Part 4: Validation (Chapter 6):

This part consists of internal, external, and construct validation, providing a novel method of calculated value for money realized in a CMR-delivered project that has benefited from the efficient incorporation of owner-driven scope growth and a synthesis of best practices.

2.0 Comparative Analysis of Public Commercial and Infrastructure Projects Delivered Using Construction Manager-at-Risk

Gransberg, N.J. and Gransberg, D.D., "Public Project Construction Manager-at-Risk Contracts: Lessons Learned from a Comparison of Commercial and Infrastructure Projects," *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, 2020, 12(1): 04519039.

2.1 Paper Synopsis

The primary benefits of Construction Manager-at-Risk (CMR) project delivery are associated with increasing the ultimate constructability of a project by bringing the construction contractor to the project during the design phase. This paper reports the results of a content analysis of 24 published CMR case studies worth $5.4 billion in both the commercial and public infrastructure sectors and derives four lessons learned. The major finding is that the owner must synchronize the clauses of the design contract with those of the preconstruction to promote the level of collaboration necessary to realize enhanced constructability. It also finds that engaging the CMR contractor as early as practical and clearly defining the deliverables it will produce during preconstruction as well as limiting the cost component of best value selections to only CMR fees facilitates project success. The paper's major contribution is in the comparison of both commercial and infrastructure CMR projects, finding common lessons learned.

2.2 Introduction

The Associated General Contractors of America (AGC) defines Construction Manager-at-Risk (CMR) project delivery (also called Construction Manager/General Contractor) as a project delivery system where "the public owner engages both a project designer and a qualified construction manager under a negotiated contract to provide both preconstruction services and construction" (AGC 2007). The same source describes the CMR's responsibilities as: "provid[ing] consulting and estimating services during the design phase of the project and act[ing] as the general contractor during construction, holding the trade contracts and providing the management and construction services during the construction phase." CMR removes the contractual separation of design and construction by bringing the contractor onto the project at a point where it can provide substantive input to the final design in a manner that enhances constructability and increases both cost and schedule certainty (Alleman et al. 2017). The result is a shift in the contractual paradigm found in traditional design-bid-build (DBB) construction contracting. Opportunities for improving cost and schedule certainty by procuring preconstruction services from the general contractor during project design can be an attractive option to public owners operating within fixed budgets.

This study reviewed the literature on CMR contracting, including 24 CMR case study projects, representing a greater number and variety of projects found in the 2010 research by Shane and Gransberg. That study surveyed 11 CMR projects executed by 6 department of transportation (DOTs) and 3 non-highway owners (Shane and Gransberg 2010) as well as the results of National Cooperative Highway Research Program (NCHRP) Synthesis 402: *Construction Manager-at-Risk Delivery for Highway Programs* (2010). The 24 case study projects represent both public building and infrastructure projects from 11 US states and 1 Canadian Province procured by city, county, state, province, and federal government public agencies. The projects range from $3.3 million to $1.3 billion with a combined contract value of $5.4 billion. The objective of the paper is to synthesize the broad set of experiences represented in both the literature and the case study projects into a set of lessons learned regarding the contractual application of CMR project delivery in the public sector, which represents its contribution to the body of knowledge in this area.

2.2.1 Multi-Project Cross-Case Comparison Protocol Generation

Each of the case studies reviewed during content analysis followed the protocol proposed by Yin (2008), which maintains “case studies are empirical inquiries that investigate contemporary phenomenon in its real-life context.” Case study research methods are attractive because they permit the researcher to drill down into the details of the CMR project performance and seek answers for the “how” and “why” questions from case study project participants within the context of the specific agency’s procurement policies and restrictions. Hence, the method furnishes a mechanism to capture contractual lessons learned from a variety of public agencies where the “how” and “why” are the primary variables of interest (Miles and Huberman 1994).

While CMR project delivery has long been used in public building construction, it is a recent development in public infrastructure projects, requiring the researchers to augment Yin’s approach with a protocol proposed for “inductive” case studies by Barratt et al. (2011). “Inductive case studies are conducted to extend, develop and build theory *because existing theory is incomplete*… the generated theory is directly derived from the researcher’s data to fill a gap in the literature” (Barratt et al. 2011 italics added). Boutellier et al. (2011) posit that multi-project case study analysis demands that the final protocol determine how to consolidate existing case studies, which case study data elements will be extracted, the additional information to be collected to ensure that all case study projects in the study population are at the same level, and the manner in which the resultant case study data will be analyzed. The case study protocol followed rigorous qualitative research design and analysis methodologies proposed by

Eisenhardt, (1989, 1991); refined by Miles and Huberman, (1994); and formalized by Yin, (2008). The protocol included a research synopsis of project objectives, field procedures that detail the logistical aspects of the investigation (such as permission to access projects for data collection), and a format for documenting and analyzing the individual case studies (Eisenhardt 1989, 1991; Yin 2008; Boutellier et al. 2011). A plan was also developed for cross-case comparisons to determine similarities and differences between cases (Eisenhardt 1989; Miles and Huberman 1994). Qualitative research tools were utilized to aid in the coding and analysis of the case study output (Bazeley and Richards 2000). The final protocol became a tool that permitted the researchers to manage data and ideas as well as query the data to report results across multiple cases, collected at different times.

2.2.2 CMR Advantage/Disadvantage Content Analysis

Table 2.1 is the result of the literature content analysis of cited advantages and disadvantages. Additionally, each data point was classified regarding the aspect of project delivery to which it pertained. The "Type" column in Table 2.1 contains that information. The "Times Cited" column shows the number of instances where a given advantage or disadvantage was observed in an article. For example, "CMR design input" was the most highly cited advantage and was observed in 27 of the 32 papers reviewed. The percentage column is the percentage of articles where a given advantage or disadvantage was observed as a percentage of the highest total number of citations for the category.

Table 2.1 Summary of advantages and disadvantages found in the literature

Type	Advantages	Times Cited		Type	Disadvantages*	Times Cited	
D	CMR design input	27	100%	D	CMR and designer have different agendas	23	100%
C	Early knowledge of costs	20	74%	D	Still have two contracts to manage	16	70%
D	Owner control of design	20	74%	D	Designer not obligated to use CMR input	15	65%
S	Ability to bid early work packages	16	59%	D	Potential CMR design liability via review comments	15	65%
S	Ability to fast-track	15	56%	C	Actual cost not known until GMP is set	14	61%
R	Risk transfer	15	56%	A	Training required for agency personnel	11	48%
C	GMP creates cost control incentive	14	52%	A	Requires different procurement culture	10	43%
A	Select GC on qualifications	11	41%	C	Contingencies difficult to allocate	10	43%
A	Spirit of trust	11	41%	S	CMR doesn’t control the design schedule	7	30%
C	Open books contingency accounting	10	37%	A	Must pick CMR early in process	5	22%
D	Focus on quality and value	8	30%	D	Lack of clear leadership during design	5	22%
D	CMR is owner’s advocate during design	8	30%	C	CMR underestimates cost of preconstruction services	2	9%
C	Reduces design costs	7	26%	C	Reduced competition among subs	2	9%
A	Flexibility during design/construction	7	26%				
A	Third party coordination facilitated	7	26%				
A	Competitive bidding possible	5	19%				
A	Less radical change from DBB than DB	4	15%				

***** 4 articles did not list any disadvantages.
Type: A = Administrative-related; C = Cost-related; D = Design-related; S = Schedule-related; R = Risk-related
Definitions: Sub = subcontractor, GC = general contractor, GMP = guaranteed maximum price

Table 2.2 is a summary of the number of types of advantages and disadvantages contained in the NCHRP synthesis’ list. It shows that Administrative-related, Cost-related, and

Design-related are the three most often cited types. This leads one to infer that the lessons learned within these three categorical types will have the broadest application. Therefore, the case study interview results were focused on gleaning potential lessons learned from these three categorical types as a means to separate anecdotal lessons applying to a single agency or project type from ones that were potentially valuable to most CMR projects, regardless of the specific agency and/or project characteristics.

Table 2.2 CMR advantage/disadvantage types

Type	Advantages	Disadvantages
Administrative (A)	6	3
Cost (C)	4	4
Design (D)	4	5
Risk (R)	1	0
Schedule (S)	2	1

2.2.3 Benchmark CMR State-Of-The-Practice

CMR is considered an integrated approach to the delivery of public construction projects. In most cases, public owners chose CMR to better control schedule and budget (referred to as cost and schedule certainty) and to assure the quality of the constructed project via enhanced constructability achieved through early contractor design involvement (Gransberg 2013). The public project delivery team comprises the owner, the designer, who might be an in-house engineer, and the at-risk construction manager. CMR procurement involves first executing a contract for preconstruction services at some point during the project’s design phase. Once price negotiations are concluded, a construction contract is awarded.

One of the most oft cited advantages of CMR is the ability to influence design decisions early by utilizing contractor-provided preconstruction services (Alder 2007, Anderson and Damnjanovic 2008, Kwak and Bushey 2000, Martinez et al. 2007). Contractor input to the design is generally referred to by the term constructability (Shane and Gransberg, 2010) which, according to Anderson and Fisher (1997), “can be defined as the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives.” Furthermore, Dunston, et. al. (2002) states that constructability reviews “are the key mechanism for insuring that plans and specifications fulfill these quality objectives” and that “the early infusion of construction knowledge into the project development process … results in the greatest impact and the least disruption in terms of cost” although “[i]ncorporating constructability ideas may sometimes call for changes which will add time to the design schedule.” These design schedule impacts occur early enough in the design phase to reduce schedule growth caused from errors and omissions, increasing schedule certainty by expanding the level of scope definition provided in the design. Lopez del Puerto et. al. (2016) defined cost certainty by contrasting it against cost savings as “changing the overarching preconstruction decision criterion from ‘minimize cost’ to ‘maximize cost certainty’” and demonstrated an inverse relationship exists between cost growth and the percentage of project funds allocated towards preconstruction services.

There are several variations on how these contractual obligations are developed (two separate contracts, modifying the preconstruction contract to include construction, etc.), but regardless of the jurisdictional idiosyncrasies, the result is the same. The public project delivery team comprises the owner, the designer (which may be an in-house engineer), and the at-risk construction manager selected by the owner to provide preconstruction services. During preconstruction, the construction manager (also referred to as the CM or CMR) assists with scope development, constructability reviews, and updated cost estimates and engages with the owner in negotiation over the construction cost of the project. If agreement is reached, the CMR is awarded a general contract to complete the construction at the agreed price. If agreement on price is not reached, the public owner closes the preconstruction contract, takes the design to final construction documents, and advertises the construction project using DBB procurement procedures.

CMR delivery requires the contractor and the designer to maintain a high degree of collaboration (Shane and Gransberg 2011) and creates a mechanism for the owner to negotiate the allocation of risk with the contractor through its pricing mechanism. The project's construction contract amount is typically agreed when the design has reached a point where the contractor can minimize contingencies for potential scope increases. "The aim of this project delivery method is to engage at-risk construction expertise early in the design process to enhance constructability, manage risk, and facilitate concurrent execution of design and construction without the owner giving up control over the details of design, as it would in a design-build project" (Gransberg and Molenaar 2019). Hasanzad et al. (2018) looked at the impact of alternative delivery methods including CMR and concluded they "reduce the frequency and severity of disputes." This validates earlier assertions in the literature (Beard et al. 2001) that when a contractor's past performance impacts its competitive position for future contracts with the same owner an incentive is created to resolve issues without resorting to external means.

2.2.4 CMR Procurement Process

According to Schierholz et al. (2012), one advantage of CMR is being able to “select the contractor on a basis of its qualifications, past performance, and record of success rather than getting the contractor that submitted the lowest bid, perhaps by mistake.” National Cooperative Highway Research Program Synthesis (NCHRP) 390 found that “the ‘soft’ factors related to managerial competence and past performance are more important to the prequalification process than the ‘hard’ aspects related to bonding and financial status” (Gransberg and Riemer 2009). As a result, CMR contractors are either selected on a basis of qualifications alone, termed qualifications-based selection (QBS), using a request for qualifications (RFQ) process or on a best-value basis using a request for proposals (RFP) procedure. The major difference is the RFQ process does not include pricing information as a part of the contract award decision, whereas, the RFP process does (Scott et al. 2006). Again, variations on the composition of the CMR best-value selection process abound (Alleman et al. 2017).

The American Council of Engineering Companies (ACEC) and the American Institute of Architects (AIA) both advocate qualifications-based selection (QBS) for awarding design contracts (AIA 2015). ACEC (2004) maintains that “when multiple prices are on the table, the owner is not in control; the price is. When price is on the table it trumps other considerations, even quality and innovation.” Thus, the issue in best-value awards becomes assigning an appropriate relative weight to the price factors with respect to non-price selection plan evaluation factors. QBS is the dominant procurement practice in the commercial building sector (Trauner 2007; Carlisle 2006); whereas best value is more frequently used in public infrastructure CMR projects (West et al. 2012).

2.2.5 Defining Lessons Learned

The term "lessons learned" is commonly used in the literature on project management; however, it has several accepted definitions. According to the American Institute of Architects (AIA), lessons learned is "the deliberate act of building knowledge during the accomplishment of projects, under the watchful eye of the project manager" (AIA 2018). The primary benefits of generating lessons learned are the ease of implementing the process as part of an ongoing project and can provide dynamic learning for professionals by capturing knowledge gained from recent, direct experience. The AIA considers utilizing lessons learned as an effective tool to incorporate professional development with billable activity (AIA 2018). The Project Management Institute (PMI) similarly defines lessons learned as "the learning gained from the process of performing the project" categorized into three levels: 1) Lessons Learned Process, 2) Evaluation of Lessons Learned Repository, and 3) Metrics (PMI 2004). The first level process consists of five steps: 1) identify valuable comments and recommendations, 2) document and share findings, 3) analyze and organize for the application of results, 4) store in a repository, and 5) retrieve for use on current projects (Rowe and Sikes 2006).

Given the above discussion, the study used the following definition for purposes of this paper:

> *Lessons learned are knowledge gained from the insights of project participants through the deliberate documentation and analysis of positive and negative aspects of ongoing and completed projects providing useful recommendations to improve the prosecution of current and future projects.*

2.3 Research Methodology

The study's methodology is based on a formal content analysis of previously published CMR case studies from eight previous research projects on the topic. Table 2.3 summarizes the salient aspects of the case study research. The projects were drawn from 20 public agencies in 11 states and one Canadian province. The agencies included federal, state, and municipal entities. The value of the projects ranged from $3.3 million to $1.3 billion. The criteria for inclusion in the sample population are as follows:

- The project was delivered under published public procurement procedures.
- The details of the previous case study interview process were available.
- Project interview data included project participant perceptions of project performance.
- Project interview data included lessons learned.
- The agency had completed more than five projects using CMR or at least two CMR with at least three using Design Build (DB).

The last factor was added to eliminate nonrepresentative, anecdotal experiences and ensure that the agency had a maturing alternative project delivery process where lessons learned were captured and fed back into the agency procurement process. The procurement paradigm shift from DBB to alternative delivery methods has been well-documented as demanding a business culture shift for public agencies (Shierholz et al. 2012). The DB requirement was added due to the recent advent of CMR contracting in state DOTs. The DOTs in the population had at least two completed CMR projects plus previous experience in DB contracting. By excluding agencies with only one CMR project, the final pool of cases reflects those changes made as a result of initial experience. In other words, the experience with the first CMR project tested the agency's procurement assumptions regarding the delivery method, and adjustments to the process would subsequently be made to reflect lessons learned regarding the agency's CMR procurement process. Finally, where an agency's experience included only two CMR projects, only the second project is included.

Table 2.3 Case Study Project Synopsis

Case No.	State/Agency	Project	Value (Million)	Project Type	CMR Model
1	Alaska DOT	Fairbanks Intl Airport Expansion	$99.0	Building	RFQ
2	Arizona DOT	State Route 89 Chino Valley	$21.0	Road and Bridge	RFQ
3	Arizona DOT	Loop 303 Waddell Road	$128.0	Road and Bridge	RFQ
4	Arizona/ City of Glendale	Glendale Pedestrian Improvements	$16.2	Road, Utilities	RFQ
5	Arizona/City of Phoenix	Phoenix Sky Harbor Transit Guideway	$650.0	Rail Transit, Bridge, Building	RFQ
6	Arizona/ Pinal County	Ironwood-Gantzel Road (US 60) Improvements	$63.7	Road, Bridge	RFQ
7	Colorado DOT	I-70 Eisenhower/ Johnson Tunnels,	$3.3	Mechanical-Electrical Upgrade	RFP
8	Colorado/ Regional Trans District	West Rail Line Corridor	$708.0	Rail Transit, Building	RFP
9	Florida DOT	State Route 699.	$21.0	Road and Bridge	RFQ
10	Florida DOT	Miami Intermodal Center	$1,300	Building, Rail, Road, Bridge	RFQ
11	Kansas/ USA Corps of Engr	Tuttle Creek Dam Modification	$175.0	Geotechnical	RFP
12	Michigan DOT	Passenger Ship Terminal	$10.0	Building, Marine, Utilities	RFP
13	Michigan DOT	Michigan Route 222 Slope Stabilization	$8.8	Geotechnical	RFQ
14	University of Oklahoma	Gaylord Journalism Building	$14.0	Building	RFQ
15	Oregon DOT	I-5 Willamette River Bridge	$150.0	Road, Bridge	RFP
16	Oregon/ Multnomah County	Sellwood Bridge	$160.0	Bridge	RFP
17	Oregon/TriMet-Portland	Portland Mall Project	$143.8	Light Rail Transit, Building	RFQ
18	Ontario/ Ministry of Transportation	Highway 3 Grand River Bridge	$20.0	Bridge	RFP
19	Tennessee/ Memphis Airport	Whole Base Relocation	$245.0	Runway, Building	RFP
20	Texas/ Texas Tech University	Lanier Law School Center	$13.7	Building	RFQ
21	Utah DOT	I-80 State St to 1300 East Reconstruction	$130.0	Road, Bridge	RFP
22	Utah DOT	Mountain View Corridor	$730.0	Road and Bridge	RFP
23	Utah Transit Authority	Weber County Commuter Rail	$241.0	Rail, Road, Bridge, Building	RFQ
24	Washington DOT	Colman Dock	$320.0	Building, Marine, Utilities	RFP
Summary		# Building (as the major amount of work)	8	#RFQ	12
		# Infrastructure	16	#RFP	12

2.4 Results

NCHRP Synthesis 402: *Construction Manager-at-Risk Delivery for Highway Projects* (2010) developed a list of common 17 advantages and 13 disadvantages cited in the peer-reviewed literature. Since lessons learned are directly related to attempts to benefit from potential advantages and avoid potential disadvantages, the Synthesis 402 list was used as the basis for analyzing the content of literature published since the synthesis was competed in 2009. A total of 32 journal articles on the topic of CMR in both building and infrastructure projects were reviewed, and their content was synthesized into the aforementioned advantage/disadvantage sets.

2.4.1 Case Study Interview Lessons Learned Content Analysis

Reporting the entire body of experiential knowledge gained by case study project participants went beyond the scope of this study, and additionally, much of that information is specific to a given agency or type of project. There were also conflicting lessons among the case studies. For example, two of the public building projects (cases 4 and 14) interviewees indicated that the design should be advanced to roughly 35% or more before selecting CMR contractor; whereas 12 other cases indicated that they did not bring the CMR contractor on board soon enough to maximize its effectiveness. Table 4 is a summary of the lessons learned observed in more than 50% of the case study projects. It must be noted that the lesson regarding best value cost information only applies to projects using a best value RFP selection process. Hence, the 7 observed lessons are out of the 11 RFP cases.

Table 2.4 Summary of CMR Lessons Learned

Lesson Learned	Case Study Project #	No. Cases	CMR Selection Model (RFQ/RFP)	Project Type (Building/ Infrastructure)
Coordinate preconstruction contract with design contract	1,2,3,5,7,10,11,13, 15,16,18,19, 21,22,23,24	16	6/10	4/12
CMR reviews of design deliverable should be clearly defined in both the design and preconstruction services contracts.	4,7,8,12,14,16,19,20	8	3/5	4/4
Restrict best value cost information to CMR fees to maintain open books accounting	7,11,15,16,21,22, 23	7	0/7	0/7
Select CMR as early as practical	2,3,5,6,9,10,11, 15,17,18,21,22	12	7/5	2/10

2.4.2 Case Study Examples of Each Lesson Learned

This section will briefly provide the salient information for one example of each of the lessons learned shown in Table 2.4. Its intent is not to repeat the case study in its entirety. The reader is referred to the literature where the details of all the cases shown in Table 2.3 are available. Rather, the next section is intended to put each lesson in a representative project context, demonstrating how the issues arose and were resolved.

2.4.2.1 Lesson Learned #1: Coordinate Preconstruction and Design Contracts

As shown in Table 2.4, the first lesson learned was found in 16 of the 24 cases. A typical example for this lesson comes from Tennessee where the Memphis Shelby County International Airport Authority was tasked with constructing new facilities to permit the relocation of the

Tennessee Air Guard unit stationed at the airport to be moved so that Fedex could occupy the existing ramps (Gransberg and Shane 2010). The $245 million project consisted of five phases, three of which were CMR, three large span aircraft hangars, each delivered using CMR. The agency had completed more than 10 previous CMR projects and awarded the first design contract using its standard architect/engineer (AE) form for design services. The CMR was selected when the design had been advanced to approximately 30%. After commencing preconstruction services for the first hangar project, difficulties arose between the designer and the contractor with the designer resisting making any changes to its design as a result of constructability suggestions provided by the contractor. An investigation ensued and found that "the consultant initially viewed the CMR reviews as unwelcome and unnecessary interference by an unqualified entity" (Shane and Gransberg 2010). Additionally, the consultant revealed that it had not allocated any time in its fee for dealing with the additional reviews by the CMR, even though the owner had awarded the design contract stating that CMR was the project delivery method but providing no details as to what changes from a DBB AE contract would entail. The collaboration issue was resolved, and to ensure it did not arise in the future, the airport modified the design contract for the next phase of the project to put 10% of the design fee at risk for the final quality of the construction documents (5% for design quality and 5% for construction issues due to design quality problems) as well as codified design milestones, budget review points, a requirement to coordinate the design work with the construction work packages, and mandated joint coordination with third parties. This change created a different environment in which the consultant saw the CMR reviews as another layer of design quality control, and the cooperation required for successful completion of the CMR project occurred (Shane and Gransberg 2010). The airport felt that the value of the changes to its CMR design contract lay in creating an incentive for both the designer and the CMR to mutually contribute to the design quality management program.

The Table 2.1 benefit addressed in this example is maximizing the value of early contractor design involvement to make the project more constructible. In the same vein, Gribbon et al. (2003) found that on a CMR project reported in the literature that the "City of Portland reported that the contractor's early involvement with design review, value engineering, and risk analysis prior to design completion contributed to significant cost and schedule savings." One of the Utah DOT interviewees states it in these words:

> "The CMGC [*Construction Manager/General Contractor*] process gives the contractor more time to understand and improve the design and to learn new construction methods not used before. Constructability is continuously reviewed in the design phase, so the design is optimized for construction and project costs are reduced. The contractor is able to inform the team of what construction methods would simplify construction and reduce cost and schedule." (Alder 2007).

Given the above, the lessons learned from the cases shown in Table 2.4 can be articulated as follows:

> *To gain the most benefit from the early involvement of the construction contractor in a CMR project, the design contract and the preconstruction services contract should be synchronized to include key design deliverable review milestones, budget review points, coordination of the design work packages with the construction work packages, and joint coordination with third parties.*

2.4.2.2 Lesson Learned #2: Clearly Define CMR Design Deliverable

The second lesson learned was found in 8 of the 24 cases and a typical example comes from the University of Oklahoma's Gaylord Journalism Building project and is really a corollary to the first one regarding the extent to which an agency can expect the CMR to identify design errors and omissions during its constructability reviews of intermediate design deliverables. The Gaylord Journalism Building at the University of Oklahoma was delivered by an agency with seven previous CMR projects. The agency's policy was to award the architectural design contract and advance the design through schematic design before selecting the CMR contract using a QBS award. The preconstruction services contract required the contractor to provide estimates of cost and schedule, constructability reviews of the construction documents at each stage of design, and several other services.

The project progressed without incident, until the CMR bid out the mechanical subcontract package. During bidding, each of the bidders indicated that the plans showed four zones for the HVAC system but only three air handling units (AHU). The CMR instructed them to bid what was on the construction documents, e.g., three AHUs. After the subcontract was awarded, the CMR informed the owner of the omission of the fourth AHU in the design. The owner's initial response was to state that since the CMR's preconstruction staff had reviewed the mechanical drawings at least three times before the package was advertised for bidding, that the omission was the CMR's responsibility, and the missing AHU would need to be provided at no cost to the project. The CMR took the position that a constructability review, as defined in the preconstruction, was not a technical engineering review of the plans and specifications. Additionally, the missing AHU had not been detected by the architect, its mechanical engineer, nor the owner's review staff; furthermore, as the preconstruction staff were not licensed design professionals, they were not qualified to perform a technical review and had to rely on the licensed design professionals on the architect's and owner's staff to ensure that the documents they used to produce estimates and constructability studies were technical sufficient. Finally, the *Spearin Doctrine* in construction contract law maintains that the owner furnishes an implied warranty of the quality of the construction documents prepared under its supervision and the use of CMR delivery in no way abrogates that doctrine (Loulakis et al. 2015).

The dispute was taken to mediation and eventually settled in accordance with the CMR contractor's interpretation of the preconstruction contract. The case study interviewee representing the owner expressed continued frustration and concluded that the value of preconstruction services was diminished if it could not depend on the contractor's reviewers to point out design errors and omissions. The contractor's interviewee pointed out that while they are expected to do a thorough technical review, they do find and report potential design errors and omissions if they see them, they cannot be held responsible for any of the designer's errors or omissions that they miss. In fact, the preconstruction staff had pointed out several which were corrected during the design process. This and similar issues in the other case study projects leads one to infer the following lesson learned:

> *The expectations and limitations of the CMR's preconstruction review of design deliverable should be clearly articulated in both the design and the preconstruction services contract. Additionally, the design contract should explicitly state that the CMR review comments are not to be construed as directive nor indicative of an assumption of liability for the quality of the design by the CMR.*

2.4.2.3 Lesson Learned #3: Restrict Best Value Cost Evaluation to CMR Fees

The third lesson learned was found in 7 of the 24 cases. The example comes from the Utah Department of Transportation's Mountain View Corridor project and is the only one devoted to the cost category of advantages and disadvantages. Since 2004, UDOT has completed 34 CMR (it uses the term CMGC) projects, more than any other DOT in the nation. Thus, its experience provides an excellent example for public infrastructure CMR projects. UDOT awarded its first five CMR projects using QBS and received criticism from the construction industry that the selection process amounted to a subjective "beauty contest" (Park 2012). Additionally, the agency's inexperience with negotiating construction pricing versus merely receiving competitive unit prices led it to change the process to a best value award and require competing contractors to submit several unit prices for key pay items as part of their proposals. Weights were assigned to both the price and the non-price evaluation factors, which allowed the calculation of the best value and identify the winning contractor. Over time, UDOT found that the value of the pricing was significantly less than the value added by the non-price contractor qualification and project approach factors. Figure 1 (Park and Gransberg 2018) shows the change in the weight given price versus non-price factors over time.

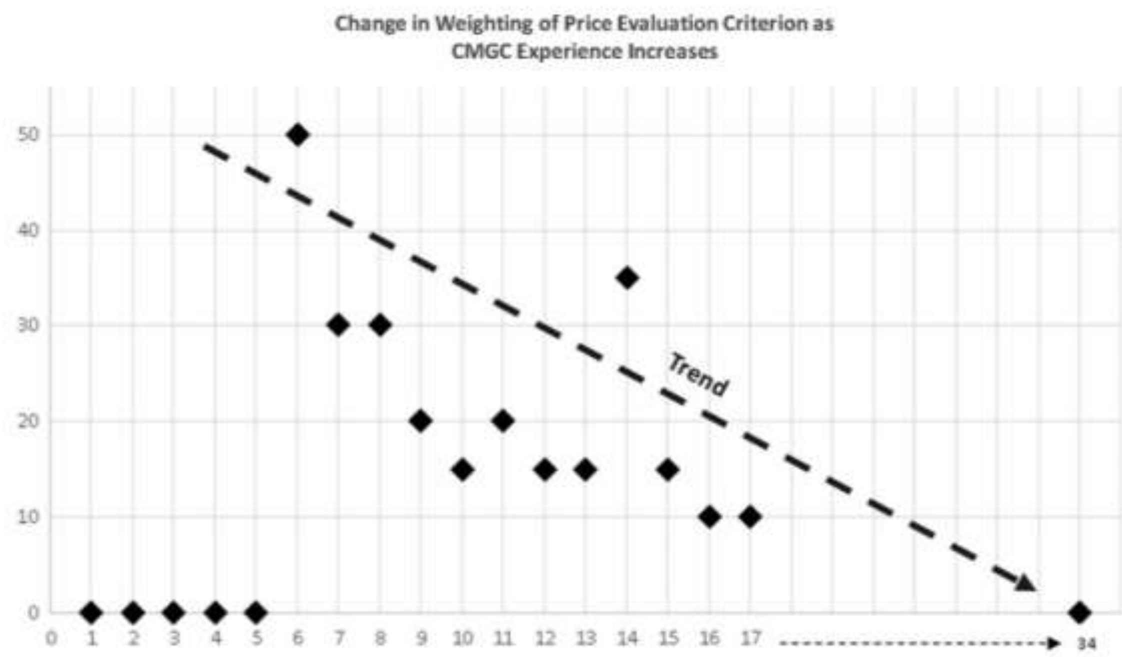

Figure 2.1. Change in price versus nonprice evaluation weight over time. (Reprinted from Park and Gransberg 2018, with permission from the Transportation Research Board.)

More importantly, the inclusion of unit prices in the proposal essentially eliminates the ability to develop the negotiated construction cost using open-books accounting procedures, an advantage cited in 10 of the articles shown in Table 2.1. This is because the contractor's fixed costs and profit are buried in the competitive unit pricing and no longer visible. Alleman et al. (2017) also found that requiring unit prices also "moves the preconstruction focus away from innovation to ensuring the final design does not violate the pre-award pricing assumptions… [and] fixes the project risk profile rather than furnishing an opportunity to discuss project risk and determine the best way to allocate and/or share the risks." The solution arrived at in the Mountain View Corridor case study was to ask the competing contractors to submit only their preconstruction services fee in the proposal and assign no weight to it in the evaluation and award process. Doing so, makes the contractor's profit and overheads open for negotiation in a highly transparent fashion, allowing UDOT to capture the benefit of open-books accounting during construction cost negotiations.

A similar approach that has seen limited use but holds the same potential is to ask for competing CMRs to submit two lump sum fees. The first is for preconstruction and the second is the fee for managing the actual construction project. The construction management fee would include overheads, general conditions, and profit. The rationale articulated for a Rhode Island DOT CMR project not included in the case study population cited the following factors:

- In DBB, competing contractors will generally bid the prevailing labor rates, cost of materials from the nearest sources, roughly the same equipment costs, and subcontractors from the same local pool of trades. Thus, most of the competitive pricing action is contained in the contractor's indirect costs and profit margin.
- Based on experience from DBB change order negotiations, the most difficult aspects of the contractor's price to determine are (1) coming to reasonable costs for home office overhead, (2) general conditions, and (3) profit.
- If these items are submitted as part of the procurement process as a lump sum, the benefit of competitive pricing is received by the agency, and subsequent negotiations can be completely open book and if necessary, the owner can audit cost items like payrolls, subcontractor, and supplier invoices, etc. (Gransberg 2016)

The lesson learned here is not whether to use a purely qualifications-based selection. Table 2.1 shows the case studies to be split 50-50 regarding the procurement model used and all projects were considered to be successfully completed. The lesson shows owners to avoid structuring the procurement in such a fashion that reduces or eliminates the ability to accrue the benefits associated with being able to negotiate the construction cost using open-books accounting with the CMR. This lesson learned has two parts and can be described as follows:

> *Restrict any pricing information required during the procurement process to items that do not preclude the ability to negotiate using a highly transparent process; do not let the weight assigned to price factors in a best value award overwhelm the benefits of being able to select the best qualified contractor*.

2.4.2.4 Lesson Learned #4: Select CMR as Early as Practical

The final lesson learned was observed in 12 of the 24 cases and examples from the US Army Corps of Engineers' Tuttle Creek Dam Modification and the Sellwood Bridge Replacement project are worthy of discussion. The Tuttle Creek Dam Modification project came about because of the discovery that the foundations of the dam located upstream of Manhattan, Kansas were being undermined by groundwater flow, threatening a catastrophic failure and flooding (Hoffman et al. 2008). This project is unique because the agency did not outsource the design services, but rather performed those using its internal design assets. The project is the largest in situ ground modification ever performed on an active dam in the world. It became obvious at the start of the project that the key success factor was related more to constructability than a theoretical design solution. Thus, the agency chose to advertise a CMR contract (termed Early Contractor Involvement (ECI) by the agency) to gain the necessary expertise at a very early point in the design process with the key qualification being past experience on high-risk dam ground modification projects.

The project was also unique in that, as it progressed, it became apparent that the owner and the contractor were going to have to implement a solution that had never been tested in the field. To manage the performance risk, the CMR was paid to conduct full-scale performance testing of design alternatives. The result was a final design that was constructed two years earlier than planned at a savings of nearly $75 million. The owner's interviewee stated that if they had waited to bring the contractor into the design process at the 30%+ point, the design effort expended to that point would have probably been lost as the final design solution was nothing like the initial design concept.

The Sellwood Bridge Replacement project is an example of the other side of this lesson. Multnomah County Oregon originally planned to deliver this urban bridge replacement project using DBB, but as the design advanced, the estimated cost exceeded the available funding (Multnomah 2010). The owner decided to change to CMR delivery to capture the ability to get real-time pricing from a contractor as well as expert project work sequencing and scheduling assistance. After selecting the CMR, the first review and estimate revealed that the current engineer's estimate was also missing costs for temporary marine structures necessary to construct the project. During preconstruction, the contractor proposed an alternative technical concept to resolve the budget overage and improve the project's schedule. In essence, the proposal was a change from the original concept of removing and rebuilding one lane of the two-lane bridge at a time, using the open lane for traffic (McLain et al. 2014). The contractor recommended that the existing bridge be jacked laterally about 40 feet, allowing the contractor to build both new lanes simultaneously and greatly improving the traffic flow across the Willamette River during construction. The result was a one-year schedule reduction and nearly $11 million in cost savings, not to mention the huge reduction in congestion that was provided to the traveling public during construction.

Early contractor design involvement cannot start until the contractor is brought onto the project team. The earlier that construction expertise is procured, the more opportunity there is to benefit from constructability input. It also minimizes the amount of lost design effort when a constructability recommendation is accepted and implemented that changes the current design approach. As can be seen by the two case study examples, the lesson learned here is:

Select the CMR as early as practical to maximize the probability of benefits accrued from enhanced constructability.

2.5 Conclusions

This paper's primary contribution is to assemble a reasonably large body of detailed case studies on CMR projects in both public building and infrastructure projects and evaluate the content of the detailed interview of CMR project participants conducted for previous research projects. The paper demonstrated that not only are there a well-defined set of advantages and disadvantages but that there also are a reasonably large set of lessons learned captured and published by public agencies using CMR. The paper identified the four most common lessons learned and illustrated by examples drawn from five of the twenty-four case studies in the population. While the results can be generally applied, they may be limited in their application to private projects because of the nature of the data set, consisting entirely of public project case studies.

The four lessons learned from the major conclusions are supported by the information in this paper. Two other conclusions can also be drawn. First, CMR projects can be successfully delivered using either a QBS or best value process, demonstrated by the even split between the two approaches in the case study projects included in this research. When using best value, the agency should not assign so much weight to the price evaluation criteria that it overwhelms the ability to select the best qualified contractor.

Secondly, early contractor design involvement results in a paradigm shift from DBB delivery's "design-centricity" to CMR delivery's "construction-centricity." Logically, the owner would not need to pay for the design if it did not intend to build the project. Therefore, making design decisions in the context of their impact on constructability is both reasonable and realistic. The Memphis airport and Oklahoma Journalism building projects demonstrated the need to change the DBB procurement culture when using CMR by synchronizing the design and preconstruction contracts and spelling out the role of preconstruction reviews during the design process. The case studies discussed from Utah, Kansas, and Oregon demonstrated the potential benefits of negotiating construction costs by sharing the risks with the contractor by "optimizing the design for construction" (Alder 2007) rather than attempting to shed the construction risk to the low bidder on a design that has been optimized for cost alone.

In summary, the results of this study demonstrate that owners choosing CMR project delivery must be careful to create a project procurement and delivery process that does not unintentionally eliminate the potential benefits they are seeking from the delivery method. The public owner's business culture must shift from an antagonistic, hard-bid mentality found on public DBB projects and embrace early contractor involvement in the design process as the key to CMR project success.

2.5.1 Acknowledgements

The authors would like to acknowledge the members of the nineteen agencies listed in Table 2.3 that provided the interviews for the original case studies. Without their insight and contribution of time, the lessons they learned the hard way in the field might have been lost.

3.0 Quantifying Perceived Value of Preconstruction Phase Construction Manager Involvement: A Pilot Study

Gransberg, N. (2019). "Quantifying Perceived Value of Preconstruction Phase Construction Manager Involvement" Submitted to the *Journal of Engineering Management*.

3.1 Paper Synopsis

This pilot study was conducted to investigate initial assumptions that contractual language found in Construction Manager-at-Risk (CMR) preconstruction services and design services contracts impacts collaborative relationships between the designer and construction manager. Results of this study showed that contract language in University of Oklahoma CMR contracts was biased in favor of the designer by 1) placing the construction manager in a subordinate position and 2) making them more responsible for collaboration than the designer. These findings were validated with informal interviews of an owner's representative, an architect, and a construction manager who were all experienced and had recently completed CMR delivered projects on the University of Oklahoma campus. Interviews resulted in identifying three emergent themes: 1) the shared responsibility between the owner, designer, and construction manager to manage expectations of end users and 3rd party stakeholders, 2) the owner's responsibility to set the tone for project team integration, and 3) responsibilities of the architect to improve construction document quality and to be more cognizant of the impact of design delay upon the construction schedule.

3.2 Introduction

The feature that differentiates CMR from all other project delivery methods is the preconstruction services contract, creates a mechanism to gain early contractor involvement in the design project (Allemann et al. 2017). In fact, the perceived value of contractor design input is cited in most peer reviewed studies of CMR project performance (Bresnen and Haslam 1991; Alder 2007; Rojas and Kell 2008; Molenaar et al. 2009; Schierholz et al. 2012; Gransberg 2013; Kim et al. 2020). In the words of one typical study, "contractor design input is the most commonly recorded benefit in literature [on CMR delivery] … because it enhances constructability and innovation and creates potential for cost savings through effective design solutions" (West et al. 2012). Thus, the perceived value of the preconstruction phase of a CMR contract is well-documented in the literature. However, only one of the previously cited studies evaluated CMR educational projects and none were focused on CMR project performance in the university capital delivery program context. Therefore, the purpose of this pilot study is to test the perception found in the literature that preconstruction services add a unique value in CMR that is not found in DBB. The pilot will focus specifically on the higher education context and quantify its perceived benefits, if any.

The motivation for this preliminary analysis springs from the author's personal experience working as capital projects manager for the University of Oklahoma (OU), The author's personal experience delivering both CMR and DBB leads one to question whether the value-added during preconstruction services justifies the added expense of the preconstruction services fee (Rojas and Kell 2009) by leveraging the construction contractor's experience during the design phase. Past research has shown that the result is a more constructible project with fewer design change orders during construction and reduced cost and schedule growth (Alder

2007; Alleman et al. 2017). However, this theory has not been tested in the higher education capital project delivery context. Additionally, preliminary analysis of data collected from CMR and DBB projects in this sector indicates that the assertion of enhanced cost certainty may not be applicable in higher education. Therefore, it is important more fully understand the contractual dynamics at play in CMR projects delivered by OU as a starting point to the greater research plan. Since the author has intimate working knowledge of the contracts used by OU as well as, the parties to OU CMR projects, this provides a level of insight not available from other sources.

3.3 Research Methodology: Contract Documents

The pilot study uses two primary research instruments. The first is a content analysis of the CMR and DBB contracts used by OU. The second consists of informal interviews with architects, contractors, and OU project management personnel to further explain and validate the results of the content analysis. Content analysis is a systematic, replicable technique for condensing text into content categories based on explicit rules of coding (Krippendorff 1980; Weber 1990). This method can be used with either qualitative or quantitative data and in an inductive or deductive way (Elo and Kyngäs 2008). Categories are derived from the data in inductive content analysis whereas a theory or model moves from the general to the specific in deductive content analysis (Grove et al. 2013). In the pilot study, inductive content analysis is used to assemble the coding structure and deductive content analysis is used to identify trends in the data output and formulate conclusions.

The primary research questions explored through this textual analysis are as follows:

- What are the similarities and differences between the responsibilities of the Architect and the Construction Manager (CM) found in CMR and DBB contracts used by OU?

- How do they influence stakeholder behavior in the preconstruction phase of a project?

Critically comparing the textual content of architectural and construction management contracts permits the analyst to gain an increased understanding of the importance and application of common terms and phrases used in contract documents. These terms and phrases allow for connections and inferences to be drawn that illuminate the Owner's expectations for the respective duties of the Architect and the CM during project design which an objective mechanism to better understand the gaps between actual contract requirements and inferred stakeholder expectations.

3.3.1 Text Selection Criteria and Sampling

Two contracts were selected from an engineering academic facility project on the OU Norman campus. The first contract is for architectural design services and, the second, for preconstruction phase construction management services, permitting a comparison of contractual obligations of the two major players in the preconstruction/design process. The architectural services contract was executed in November of 2015 and the preconstruction services contract in March of 2017. These texts were chosen from the Architectural and Engineering Services' digital project database stored on local servers on the University of Oklahoma's south research campus. This database contains contracts, contract modifications, applications for payment, project correspondence, approved permits, and miscellaneous project related data dating back to 2009. The text selection was based upon the availability of digital copies that could be converted from digital scans into searchable documents using optical character recognition (OCR) software on hand. These texts were written for the same project to reduce potential contextual variables arising from differing scopes of the work. Additionally, procuring contractual documents from a recent or on-going project allows for follow-on analysis to be conducted with personnel engaged in the work covered by these contracts. Finally, the documents needed to be illustrative of typical Architect and CM duties as they pertain to the delivery of institutional capital projects as part of this overarching inquiry into understanding the perceptions of stakeholders in CMR contracting.

These texts are a good choice to explore the relationship between Architects and CMs while engaged in preconstruction design activities as they satisfy all the selection criteria. The CM has provided preconstruction services on multiple projects for the University over the last five years that have, in turn, been designed by various local and national architectural firms. The project covered under this contract is a $30,000,000 new three-story, engineering academic building. Both sets of contracts have sections devoted specifically to the preconstruction activities required of each of the contracted parties that are similar and unique in scope. This specific project was chosen out of over one hundred other projects because of its similarity to another recently completed project on campus that utilized the same project delivery method and is of a similar scope and contract value so that further comparisons conducted between these projects may be illuminating when guided by the results of this investigation.

Sampling of the text focused on selecting sections of each contract that covered pre-construction activities. Within the Architect's contract, sampled sections included (1) Preliminary Consultation and Schematic Design Phase Responsibilities, (2) Design Phase Responsibilities, (3) Construction Documents Phase Responsibilities, (3) The Project Construction Manager, (4) Duties, Obligations and Responsibilities Prior to Construction, (5) Optional Duties, Obligations and Responsibilities During Design and Construction Phases, and (6) Duties, Obligations and Responsibilities of the Owner. Within the CM's contract, sampled sections included (1) The Services, (2) Owner's Duties, and (3) Construction Manager's Representations. The Architect's contract had significantly more text sampled from it than the CM's as it was the complete contract for design services whereas the CM's contract was an initial contract that covered only preconstruction service and was followed up by a contract for full construction services.

3.4 Results: Contract Documents

3.4.1 Analysis of Sampled Texts

The contracts were first read in their entirety, without making any annotations or selections, then a second time to identify common terms and phrases. Scans of each document were converted into searchable word documents using OCR conversion software. A list of 136 terms and phrases was tabulated, and counts were taken for each document to detect instances of repetition and correlation between the documents, of which there were 66 shared terms and phrases. Of these shared terms and phrases, the top ten were (1) construction, (2) shall, (3) project, (4) cost/costs, (5) design, (6) phase, (7) requirements, (8) approval, (9) construction documents and (10) estimate.

Of the ten most common terms, the word "shall" was chosen for the first round of analysis. In contractual language the term "shall" implies an obligation of duty from the parties in contract. Thus, it provides an objective means to begin elucidating the express requirements of the CM and Architect. A count was taken of all the "shall + verb" statements in both samples of the text resulting in list of 52 unique obligatory statements. Of these statements, 11 were found to be shared between both contracts with the top four being (1) shall prepare, (2) shall provide, (3) shall include, and (4) shall review. The text associated with these "shall + verb" statements defined the Architect and CM's relationship, in that the Architect is to provide design documentation, project requirements and estimates and the CM is to primarily provide estimates and schedules based on the Architect's deliverables. This clearly defined their contractually perceived roles during the design phase of a project but did not shed any light onto the dynamics of the relationship between CM and Architect, leading one to posit that the two contracts were not synchronized to create the necessary collaboration required to achieve value for the money spent on the preconstruction services fee. Synchronization of the design and preconstruction services contracts is repeatedly emphasized in the literature as an essential component for realizing potential benefits from CMR delivery (Shane and Gransberg 2010; Schierholtz et al. 2012; West et al. 2012). That finding demands that a deeper look be taken into the explicit contractual requirements of the architect and the CM in the OU contracts.

3.4.1.1 Analysis of "Architect" and "Construction Manager"

Another word count was taken of both text samples to identify where each party had specific duties to the other party by counting the terms "Architect" and "Construction Manager" in the other party's contract sample. The term "Architect" occurred 33 times in the CM's contract sample and the term "Construction Manager" occurred 56 times in the Architect's contract sample. Six excerpts were taken from the CM contract sample and 15 from the Architect's contract sample that spoke directly to the interaction of the Architect and the CM. Of the 15 excerpts taken from the Architect sample, all but three roughly approximated with the six CM excerpts. The most direct excerpts requiring consultation between parties are as follows from the Architect contract sample:

Section 2. The Architect shall consult in detail with the Owner and the Construction Manager, and shall carefully analyze any information furnished by the Owner and/or the Construction Manager, concerning requirements of the Project, including but not limited to, any design, construction, scheduling, budgetary or operational requirements.

Section 8.a. The Architect shall cooperate with the Construction Manager with respect to any duties, obligations, and responsibilities of the Construction Manager including those set forth in the Agreement for At Risk Construction Management Services executed by and between the Owner and the Construction Manager. The Architect's duty of cooperation shall include, but shall not be limited to, the duty of providing information to the Construction Manager concerning the Project; the duty of providing requested Project documents to the Construction Manager including those documents identified in Paragraph 14 herein below; the duty of meeting and consulting with the Construction Manager concerning any matter relating to the Project; and the duty of working with the Construction Manager with respect to any inspection, testing, or analyses of any work performed on the Project;

The language of these excerpts from the Architect contract are interesting in that they require consultation with the CM and "*shall carefully analyze any information furnished by the Owner and/or Construction Manager...*" which falls under an open-ended umbrella of general categories. Furthermore, the Architect is required to cooperate with the CM with respect to the CM's duties covered in the Agreement for At-Risk Construction Management Services, a contract to which the Architect is not signatory. Missing from the CM's contract is any language of cooperation. The CM is required to consult with the Owner and the Architect, but the word "cooperate" is entirely absent. This speaks directly to the power relationship between the Architect and the CM, one of superior to subordinate, where the Architect is the superior party. The subordinate party's requirement to cooperate is implied and the superior party, which wouldn't otherwise be mandated to cooperate has extra conditions placed upon them to work with the subordinate. Support for this assertion is found the following quote from the Architect contract where it is designated as the Owner's Representative, its decisions and directions carrying the weight and authority of the Owner themselves:

> 7.b. The Architect shall represent the Owner during construction. Instructions and other appropriate communications from the Owner to the Construction Manager shall be communicated through the Architect unless the Owner directs otherwise. The Architect shall act on behalf of the Owner only to the extent provided in this Agreement;

There is no similar language to this section within the purview of the CM's contract. Furthermore, the CM is required contractually to submit applications for payment to the Architect for certification of work completed before they are sent on to the Owner for payment. This informs a better understanding of the contractual dynamic established by the Owner from the beginning of the project that is very similar to the traditional project delivery method of DBB where the Owner contracts with the Architect to produce complete plans and then bids them out to the lowest bidder.

The excerpt from CM's contract that is most similar to the Architect's sample from Section 2 is as follows:

> Section 1.b. The Construction Manager, with the Architect, shall jointly schedule and attend regular meetings with the Owner and Architect. The Construction Manager shall consult with the Owner and Architect regarding site use and improvements, and the selection of materials, building systems and equipment. The Construction Manager shall provide recommendations on construction technology and feasibility; the availability of materials and labor; and other market conditions necessary to insure that the Project's design stays within the budget for construction; time requirements for procurement, installation and construction completion; and factors related to construction cost, including estimates of alternative designs or materials, preliminary budgets and possible economies;

The language found in the above excerpt is strikingly similar to that found in design consultants' subcontracts to the prime Architect. The CM is required to bring its experience and knowledge of current means and methods of construction to assist with keeping the design within the budget and schedule for construction by reviewing the Architect's design documents and preliminary estimates then providing updated construction schedules and cost estimates to inform improvements to the design. Of interest in this matter is that the language of both contracts requires <u>only consideration</u> of the CM's recommendations by the Architect, and that the Architect is empowered to reject any and all CM recommendations as it sees fit. Depending on the attitudes and relationship of the contracted parties, this may become problematic for the

Owner. In this instance, the Architect was brought under contract roughly 18 months prior to the CM to begin developing the conceptual design of the project. The primary relationship forged in the context of this project is between the Owner is with the Architect, which translates to 18 months of decision-making without constructability input from the CM. This is an apparent weak point in the contractual arrangement for this project that could detrimentally impact the effectiveness of the CM's involvement in completing the design as the onus is apparently upon them to establish a positive rapport with the Architect where they are viewed as a project partner not a potential adversary.

3.4.2 Discussion of Trends – Contract Analysis

Analysis of excerpts from contracts for design and preconstruction services provided insight into the contractually arranged relationships between the Architect and the Construction Manager. Analysis of "shall + verb" statements clearly established the boundaries of the respective parties' mutually supportive responsibilities yet did not shed much light into the dynamics of their relationship. A second analysis conducted, counting instances of the terms "Architect" and "Construction Manager" in their counterpart's contracts, revealed the power structure inherent to these contractual relationships. Prescribed roles for both parties place the Architect above the CM as the representative of the Owner both explicitly in the contract and through the various subordinating roles required of the CM, which range from submission of pay applications to inspections of the work to conformance with the design documents as they are issued. These roles are the same between the Architect and the General Contractor in traditional DBB project delivery methods, in which the Owner places the parties in an adversarial arrangement (Pinto-Nunez et al. 2018). The literature cites the reduction these potentially adversarial relationships between the designer and builder by enforcing mutual cooperation during the design phase has a key benefit to CMR delivery (Carlisle 2006; Allemann et al. 2017; Hasanzadeh et al. 2018).

The time gap between the execution of the OU Architect's contract and the CM's contract reveals an unrecognized disconnect in the establishment of rapport between the CM that may discourage effective collaboration during preconstruction. Relationships are built organically over time through shared experiences of the parties to the CMR contract (Carlisle 2006). The timing of the design contract award versus the award of the CMR contract creates a situation where the relationship between the Owner and Architect has matured to a point where the effectiveness of that tripartite relationship between the Owner-Architect-CM contemplated in CMR delivery can no longer be leveraged for the benefit of the project.

To summarize this abbreviated attempt to become fluent with the dynamics of the OU design and CM contracts in CMR, two issues were identified that require further investigation. First, the time-gap between the start of design and when the CM is brought to the project would appear to limit the value of early contractor involvement has been found to add in previous research (Carlisle 2006; Allemann et al. 2017; Hasanzadeh et al. 2018) simply because many of the fundamental design decisions are made by the Architect and Owner and to change them based on constructability input from the contractor would not only create the need to redesign, but also a delay in the project schedule.

The second issue involves the contractual structure in place when the CM is brought to the project, which appears to preserve the adversarial relationships found in DBB projects. The OU contracts clearly place the CM in a subordinate relationship to the Architect. Successful CMR delivery is predicated on an enhanced level of collaboration with a tripartite decision-making process where the CM furnishes priced alternatives to the Owner and Architect before fundamental design decisions are made (Hoffman et al. 2008; Park and Gransberg 2018) so that the Owner determine if the value added by a higher priced alternative justifies its cost.

To answer these two questions requires that participants in actual OU CMR projects be interviewed to determine if the effectiveness of preconstruction services provided by a CM is indeed limited in practice or if the procurement climate at OU is such that contractual structure limitations are actually surmounted by internal collaboration amongst the individuals that deliver the project.

3.5 Research Methodology: Interviews

Interviews were conducted with representatives from each of the three contracting parties over the period of a one week. Three interviewees were chosen primarily for their experience participating as project managers in the execution of recently delivered CMR projects. Their industry experience ranged from 16 to 40 years, all had participated in CMR delivered projects within the last two years and had experienced both positive and negative outcomes. Additionally, none of the interviewees had worked with each other on recent projects. Two interviews were conducted over the phone and the third was conducted in person, with the interviews taking between 25 and 42 minutes. All three interviewees were professional acquaintances of the researcher who have worked with him, in some capacity, over the last four years and were willing and available to be interviewed as part of this pilot study. All interviewees were informed that their interviews would be digitally recorded then transcribed by the researcher, removing any identification of their name, employer, or projects to preserve their anonymity, at which point the digital recordings would be destroyed. Each interviewee consented prior to the commencement of the interview. Each interviewee was asked a series of questions about their roles and responsibilities within their organizations as well as specific questions from the same interview protocol, asking them to describe their understanding of their own responsibilities and the responsibilities of the other two contracting parties to draw insights into the potential sources of misunderstanding within the contract. The protocol and transcripts of the interviews are found in Appendix A.

A selection of responses to the questions asking the interviewees to describe the responsibilities of the Architect and the Owner. These questions provided several insights into the dynamics of the contracting project team that are usually given less attention than that of the Construction Manager as CMR projects tend to be construction-centric (as opposed to design-centric in traditional methods). The roles of the Owner and Architect are critical to the success of the project, and they provide different sets of skills and leadership to the team. A summary of responses to questions asked relating to the various topics that form basis of the two issues found in the contract textual analysis are contained in Table 3.1, full transcripts can be found in Appendix B. A brief analysis of their content that informs the development of the formal research plan.

Table 3.1: Synopsis of Interview Responses.

Topic	Owner Response	Architect Response	CM Response
Developing the final scope of work	The owner values the CM's input to the scope development process by providing constructability and budget checks on the architect's recommendations.	The architect is responsible for developing the project program and telling the owner what it needs to meet its requirements.	The owner must communicate its vision for the project and open discussion with the architect and the CM about technical, budget, and time constraints
Collaborating on design alternatives during preconstruction	The owner should reserve the right to prioritize options.	The owner sets the tone for the level of collaboration it desires.	The architect must be realistic when communicating technical requirements to the owner.
Establishing design criteria	The owner needs to understand the cost and schedule implications associated with design criteria before making the final decision.	In most cases, the owner wants the architect to lead the design criteria process.	The architect should design to a minimum standard and allow the owner to chose to increase it after knowing the cost and schedule implications.
Timing of the CM contract award.	Having a conceptual design complete before awarding the CM contract provides a better basis for selecting the most qualified CM.	On highly technical projects, the CM's input is valuable as early as possible. That is not the case on routine projects, where CM input tends to create budget controversy rather than frank dialog about schedule and constructability.	When the CM is engaged after significant design has been completed, it creates distrust between the owner and the CM when the CM points out budget limitations.
Managing expectations for project scope	The owner must have the information necessary to communicate the limitations inherent to a project's program to the end users.	The architect's program sets the standard for project scope expectations and usually involves minimal input from the owner and none from the CM.	When project scope expectations are fixed without the CM's constructability and budget analysis, an adversarial relationship develops and distrust of the CM's motivations becomes an issue.
OU contract structures	There is no need to change the DBB design contract for use in CMR because the architects know what the differences are.	By definition, the architect is best suited to lead the project in its entirety and as such the contracts should reflect that hierarchy.	The current contracts place the CM at a disadvantage and do not encourage the level of collaboration possible in CMR to achieve maximum value for money.

3.6 Results: Interviews

3.6.1 Analysis of Interview Output

Analysis of common themes within the interview texts can be synthesized into three categories: 1) expectations management, which was expressed as a responsibility for all parties, 2) setting the tone, expressed primarily as the responsibility of the Owner and 3) responsibilities of the Architect.

3.6.1.1 Theme 1: Expectations Management

Expectations management was expressed by each interviewee as a critical function for each member of the project team that needed to be established during preconstruction. The Owner expressed this as being one of their primary responsibilities:

> *"Managing [end-user expectations] and making sure that they don't think they're going to get more than they are, so that they're not disappointed later. But then also, seeing what the needs are for the university and what's really critical to have a successful program. "*

Both the Architect and CM expressed the same opinion, in so many words, as being crucial to project success. A failure to manage expectations for the Owner and end-user can cause significant delays and cost growth in a project when changes are introduced late in a project. The CM gave an example of an Owner requesting to add a hot tub on a second floor of a hypothetical project four months prior to completion and being shocked at the cost to add it to the project scope:

"And they're like, "Well, you know, the Architect told me it would be like half of that.""

His relation of this example illustrates a causal failure to manage expectations wherein the Owner, failing to manage the expectations of their end-user, sought out the Architect to explore a late change. The Architect, looking to please the owner, obliged with, what would otherwise be an unacceptable late change to the scope, resulting in the conflict between the CM and the Owner, when the CM had to provide the financial reality check. The Owner had this to say about his experience with Architects being too eager to please the Owner's whims when they are unreasonable:

"The CM's going to fight with his subcontractor about what he's getting, what he's doing. The owner's going to fight with the CM about not getting what we're paying for and the Architect is going to, hopefully protect the Owner, but they end up fighting with the CM, too. ***Rarely does the Architect fight with the owner****, too often Architects don't end up paying for their mistakes."*

Consideration should be taken by each party as how to best represent the interests of the Owner and be willing to provide critical feedback to end-user generated changes to the scope.

3.6.1.2 Theme 2: Setting the Tone

Setting the tone was a commonly expressed as a primary responsibility of the Owner by all interviewees. Additionally, responses indicated that the Owner's level of active involvement seems to directly influence the success of the project. The general opinion illuminated the potential value that could be gained by the Owner by their participation in establishing a clear scope of the work associated with a solid budget at the beginning of the project so that when issues arose later on, there would be a clearly established way to address them without substantially impacting the project schedule and budget. The Architect had this to say about Owner involvement:

> *"If they are actively involved form the git-go and can contribute and kind of build that collaborative atmosphere, I think that any project, no matter if it's compressed in time or challenged in money or whatever issue may be challenging that project, that project will be a success.* ***I think that if the Owner is engaged, especially as it comes to the preconstruction side, can understand cost issues, can understand scheduling issues, the ramifications of decisions, the project will succeed.*** *End of story."*

The CM expressed a similar desire for the Owner to provide clear guidance on their expectations for the project during preconstruction:

> *"The best thing that an Owner can do is to talk about what their vision of the project is with the Construction Manager and the Architect in the room…"*

His primary complaint was the Owner preferring to converse with the Architect alone when relating their vision for the project. His observation was compelling, the need for the CM to be privy to conversations regarding the project is crucial when the CM will end up being responsible for the decisions made as a result.

The Owner's response to the question about his role was affirmative and informative regarding the need to set the tone of the project:

> *"[C]aretaker comes to mind. Protector of our resources. Guide through the design process to protect the integrity of our campus. Architectural integrity as well as the functionality of all the systems that go into it."*

The Owner's ability to communicate their vision and set the tone for the project, up front, is a critical role that they alone can play. This establishment of goals and norms provides the framework within which the Architect and CM can produce a successful project that satisfies the needs of the Owner and end-user.

3.6.1.3 Theme 3: Responsibilities of the Architect

Views of responsibilities of the Architect were much more diffused than those expressed for the Owner and Construction Manager. The Owner's primary requirement of the Architect was the provision of complete, accurate plans that would provide clear guidance to the subcontractors in the execution of the project. The Owner had observed degradation in the quality control of design documents over the last several years and most notably in those associated with CMR projects.

"One of the things that's happened with CM[R] is that there's been a lack of quality control once you get to construction documents, just to answer your precon[onstruction] question. It is a problem, since the Architect is working with a CM, working through details and ways to do things. I don't think they button up their CD's [construction documents] as tightly as they used to, but that's not the only reason, it's not taught as well as it once was taught."

A function of CMR procured projects is the production of construction documents by the Architect in collaboration with the CM to improve the constructability of plans, select appropriate construction technology, and provide current pricing to inform the selection of materials and methods. Both the Owner and the CM related instances from their experience where incomplete or a delay in providing plans had a negative impact upon the project. The Architect's response to the question about their responsibilities provided an interesting if oblique support for the Owner and CM's critique.

"As my experience has been, it's varied. I think it has a lot to do with who is really leading the project... It gets a little grey ….and a little nebulous in terms of the responsibilities, based upon the experience and the capabilities of the contractor, in my opinion."

This response is reasonable when considering the shifting of focus from design-centric to construction-centric that has occurred with the growing acceptance of negotiated bid procurement methods. Over the last century, the Architect's role has changed considerably from the concept of the "Master Builder" that prevailed until the 20th Century, where the Architect was designer, contractor, and owner's representative, through the hard bid era following the Second World War to the current situation. In a sense, negotiated bid procurements are very much a return to the old way of procuring projects which combines all of the disciplines of the project team during the design. It is understandable then that there seems to be a general acknowledgement that the Architect's responsibilities appear nebulous within a collaborative paradigm. The CM's response to the question of Architect responsibilities is also illustrative:

> *"My big thing from them is that they're communicating with the Owner and being realistic of what they're going to deliver."*

This seems to be a common opinion from CMs regarding the products provided by the Architect for construction and is one of the reasons why CMs are involved in preconstruction, to provide a greater level of realism to the design as it affects the materials and methods employed to execute the project.

3.7 Conclusions

Interviews conducted with experienced representatives of the Owner, Architect, and Construction Manager provided valuable insights into the perceived responsibilities of each party as they relate to the CMR procured project. Three main conclusions can be drawn from the analysis of these texts. First, expectations management is crucial function of all parties within the project team. The preconstruction phase should be utilized to establish the project baseline expectations regarding the scope of the work, the hard ceiling on the project budget, and outline the process to deal with changes to the scope in a collaborative manner to prevent unacceptable scope and schedule growth. Second, the Owner's responsibility to set the tone for the project is directly correlated to the ability to successfully navigate the inevitable challenges of the project. Owners should make active involvement in their projects a clear priority with a focus on establishing and maintaining expectations, vision, and norms throughout the project in a highly consistent manner. Consistency is fundamental to preserving the integrity of the project scope and the viability of the financing associated with the program. Finally, the responsibilities of the Architect need to be clearly communicated by the Owner during the selection process to prevent confusion between the contracting parties of the project team. The varied responses of each interviewee demonstrated that the lack of clarity for this crucial member of the project team has the potential to create significant challenges for CMR projects. Expectations for the Architect's responsibilities should be more clearly communicated by the Owner during the designer selection process with preference given to design firms that can clearly demonstrate solid past performance in negotiated bid projects. A potential metric for measuring designer performance in a negotiated bid scenario could be a cursory count of the Requests for Information from the CM as compared to the overall cost growth experienced by the budget. Additionally, Architecture firms may benefit from adopting the practice of politely, but firmly, questioning Owner requested changes that may have negative impacts to the project.

4.0 Modeling Construction Cost and Schedule Growth of Construction Manager-At-Risk and Design-Bid-Build Delivered Projects

Gransberg, N., Maraqa, S., Roksa, O., Pittenger, D. (2019). "Forecasting Project Contingency through Construction Cost and Schedule Growth Modeling of Construction Manager-at-Risk and Design-Bid-Build Delivered Projects." Submitted to the *Journal of Engineering Management*.

4.1 Synopsis

This study developed a statistical simulations model utilizing linear and multiple regression machine learning in Python software to model and evaluate the performance of CMR and DBB project data with the goal of predicting final project costs and durations. Cost and schedule data consisted of 101 capital projects from the University of Oklahoma, Texas Tech University, US Naval Facilities Command (NAVFAC), Oklahoma Central Services, and other public owners utilizing CMR and/or DBB delivery methods. The analysis found that 1) CMR projects tended to have lower variability between estimated and actual project schedule, 2) there was no significant difference in cost performance between DBB and CMR projects, and 3) that the cost of preconstruction services has relatively little impact in the final cost of a project.

4.2 Research Methodology

The following section describes the scope of the predictive analysis, data sets, assumptions, parameters, and decision variables employed. Data was organized into Excel worksheets which were uploaded into Jupyter Notebook for analysis utilizing a series of Python libraries. First, the combined dataset was characterized and split into two subsets, based on project delivery method, which were also characterized. Outliers were identified and removed from each subset and statistical analyses were conducted. Simple linear regressions were conducted to check model assumptions for linearity and independence of variables. Multiple regression models were employed as the final step using machine learning algorithms to train and test the model's ability to predict project final cost.

A brief literature review relating to comparative analysis of public capital construction projects delivered under DBB and CMR contracts has been included as well.

4.2.1 Scope of the Analysis

The purpose of the analysis was to compare public projects delivered under CMR and DBB contracts by analyzing cost and schedule growth as a function of initial budget estimates and contracted project durations, respectively, and determine the relationship between cost and schedule growth and project delivery method. Additionally, the value of preconstruction services procured in CMR projects was calculated as a percentage of the early budget estimate to determine if there was a relationship between the amount invested in preconstruction and cost and/or schedule growth associated with the projects analyzed. The goal of the model was to see if final cost could be reliably predicted using values for an initial cost and expected schedule growth.

4.2.2 Data Sets & Parameters

Data sets utilized were drawn from the University of Oklahoma, the US Naval Facilities Command (NAVFAC), Oklahoma Department of Central Services, Texas Tech University, and several individual projects conducted by state and municipal public owners. Data included in the database for CMR projects is as follows:

1. Project Name
2. Early Budget Estimate (in $)
3. Actual Completed Cost (in $)
4. Preconstruction Amount (in $) (CMR projects only)
5. Original Contract Duration (in days)
6. Actual Contract Duration (in days)

Data included in the database for DBB projects is as follows:

1. Project Name
2. Early Budget Estimate (in $)
3. Actual Completed Cost (in $)
4. Original Contract Duration (in days)
5. Actual Contract Duration (in days)

Projects missing any of the data points were eliminated from the data set. NAVFAC project durations were converted from months to days using an average working days per month of 21.5 multiplied by the number of months listed to provide a working day duration.

4.2.3 Performance Metrics

Cost growth was calculated using the following formulation:

Eq. 4.1 Cost Growth from Award

$$Cost\ Growth = \frac{Actual\ Completed\ Cost - Award\ Cost}{Early\ Budget\ Estimate} \times 100$$

Schedule growth was calculated using the following formulation:

Eq. 4.2 Schedule Growth from Award

$$Schedule\ Growth = \frac{Actual\ Contract\ Duration - Original\ Contract\ Duration}{Original\ Contract\ Duration} \times 100$$

Preconstruction (dollar value) percentage of project was calculated using the following formulation:

Eq. 4.3 Preconstruction % of Project

$$Precon\ \%\ of\ Project = \frac{Preconstruction\ Amount}{Early\ Budget\ Estimate} \times 100$$

4.2.4 Statistical Assumptions

Normality was assumed based upon the sample size of the data being greater than 30 projects by contract type: 37 CMR projects and 74 DBB projects. Cost and Duration variables were assumed to be independent.

4.2.5 Delivery Method Behavioral Assumptions

DBB project delivery tends to produce an adversarial climate between project stakeholders that places the designer and general contractor at odds with each other and the owner. Design contracts designate the designer of record as the owner's representative for the project, delegating them decisional authority for matters of design, responding to contractor generated requests for information, issuing of instructions on means and methods of construction, validating pay requests, and authorizing changes to the scope of work. The designer of record is the gate keeper of the project scope for the owner and is incentivized to 'play defense' responding to questions that identify gaps or missing information that was left out of the construction documents during design. The designer has a vested interest to be perceived as defending the owner's interest primarily expressed by reducing cost growth against contractor claims and maintaining their professional reputation of reliability in producing complete plans and specifications. Conversely, the general contractor has an incentive to discover missing data and gaps in the plans and specifications that will be required for the project to be successfully completed. Discovering these gaps during the advertising period can allow general contractors to submit lower bids than their competitors, with the knowledge that they can make back the difference in their bid by applying for change orders after project awarded. Some savvy general contractors in the low bid market have been quite successful at winning jobs and making their target profits by utilizing this technique.

Many public construction contracts, both DBB and CMR, include liquidate damages clauses triggered typically by missing completion milestones in the contracted schedule. The general contractor agrees to pay damages at a fixed dollar value for each day's delay usually past the contract completion date. The University of Oklahoma ties liquidated damages to the substantial completion date, which occurs when all of the major scope is complete, the end user can begin to move furniture and equipment into the facility, but there are still minor tasks for the general contractor to complete to obtain final completion. In some cases, the liquidated damages amount is reduced by half for delays past final completion (typically 15 to 30 days following certification of substantial completion). Contractors are understandably averse to paying liquidated damages and will increase their bids to cover the value of liquidated damages they may be expected to pay if there are unauthorized project delays. This internal allowance is converted into additional profit or used to cover shortfalls if the general contractor obtains substantial completion on time. Additionally, change order requests typically include a request for additional time to be added to the contract to cover the schedule impacts of authorized changes. An increase in variability between the initial budgets and schedules and the finals can be readily assumed based upon these modes of behavior generated by incentives and disincentives created by an owner's DBB contract.

CMR contracts are designed to reduce the adversarial relationship between the designer and general contractor through early contractor involvement. Lopez del Puerto, et. al's 2016 analysis of 1,200 public CMR projects demonstrated that increasing the owner's investment in preconstruction design services, up to a point somewhere between 11-15% of the total project, improved cost certainty in CMR procured projects. Gransberg and Gransberg (2019) posited that the earlier the general contractor is involved in the design process, the greater the effect they have upon improving cost and schedule certainty. Owner do not always follow best practices, failing to maximize the potential benefits of CMR delivery which may result in increased variability in cost and schedule performance on their projects. It was expected, based upon the literature, that there should be less variability experienced between the initial and final budgets and schedules in CMR projects when compared to DBB projects.

4.2.6 Linear Regression Analysis

Statistical analysis of the data was conducted in Python utilizing Jupyter Notebook and employed eight libraries (pandas, pylab, matploylib.pyplot, numpy, seaborn,xlrd, scipy.stats, statsmodels.api). Project data was imported from excel with initial outlier detection employing box plots for the four defined data types per contract (Initial Cost, Final Cost, Initial Duration, Final Duration) for both CMR and DBB projects and characterized statistically and with boxplots which identified the presence of outliers in the data set (Figure 4.1).

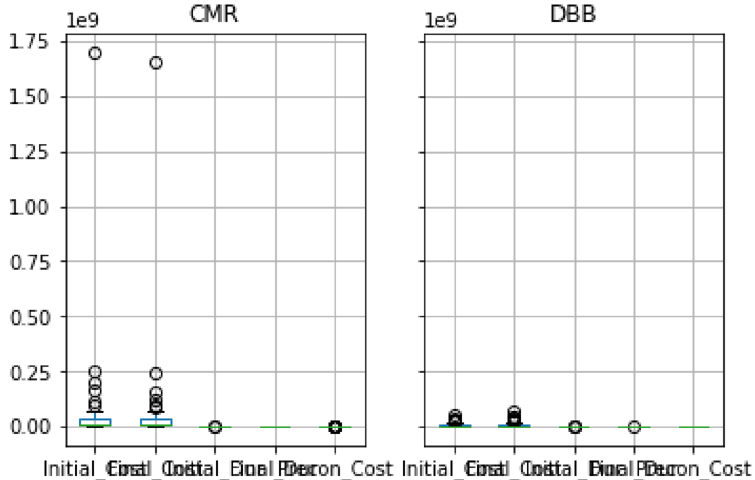

Figure 4.1 Initial Box Plots of Project Data Points

Subsequently, box plots were prepared comparing distributions of the same data type for DBB and CMR projects.

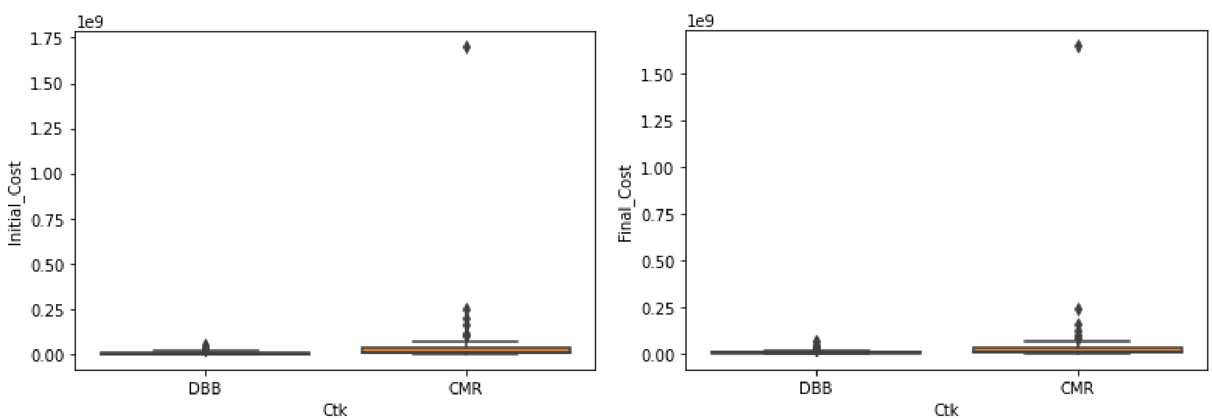

Figure 4.2 Initial Box Plots of Project Cost Variables

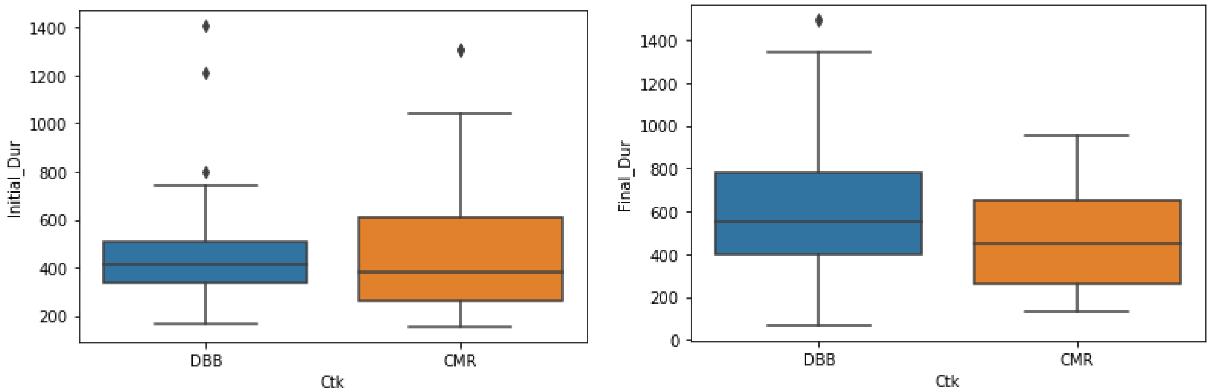

Figure 4.3 Initial Box Plots of Project Duration Variables

Analysis of DBB and CMR projects was conducted, isolating the 74 DBB projects and the 36 CMR projects from the database. Outlier detection was conducted by calculating the Z-Scores for the Initial Costs of each project and discarding any with a score greater than the threshold of 3. Three outliers were removed in total: DBB-40 DREDGING, z = 3.01; DBB-57 BERTHING WHARF, z = 5.22; n-34 MULTIMODAL AIRPORT, z = 5.79. Statistical analysis of data variables was then recalculated (Tables 4.1 & 4.2) and boxplots replotted (Figures 4.5 & 4.5).

Table 4.1 DBB Projects Sample Dataset Statistics

	Initial Cost	Final Cost	Initial Duration	Final Duration
Count	72.00	72.00	72.00	72.00
Mean	5,623,135.00	6,481,098.00	439.32	584.08
Standard Deviation	6,145,258.00	7,826,317.00	194.71	278.35
Minimum	194,820.00	194,820.00	165.00	68.00
1st Quartile	1,586,500.00	1,780,178.00	330.00	393.50
2nd Quartile	3,495,934.00	3,686,485.00	404.00	539.00
3rd Quartile	7,713,402.00	8,785,644.00	502.75	741.75
Maximum	30,139,090.00	43,995,320.00	1,407.00	1,492.00

Table 4.2 CMR Projects Sample Dataset Statistics

	Initial Cost	Final Cost	Precon Cost	Initial Duration	Final Duration
Count	36.00	36.00	36.00	36.00	36.00
Mean	36,501,527.78	32,991,975.39	92,411.81	472.17	435.17
Standard Deviation	58,065,050.82	50,926,619.50	125,159.27	266.28	212.66
Minimum	550,000.00	635,339.00	5,000.00	154.00	131.00
1st Quartile	6,281,250.00	5,309,278.25	12,750.00	261.00	261.00
2nd Quartile	11,000,000.00	11,000,000.00	43,500.00	364.50	406.00
3rd Quartile	33,250,000.00	32,501,594.00	85,069.50	609.00	625.75
Maximum	250,000,000.00	241,000,000.00	500,000.00	1,305.00	827.00

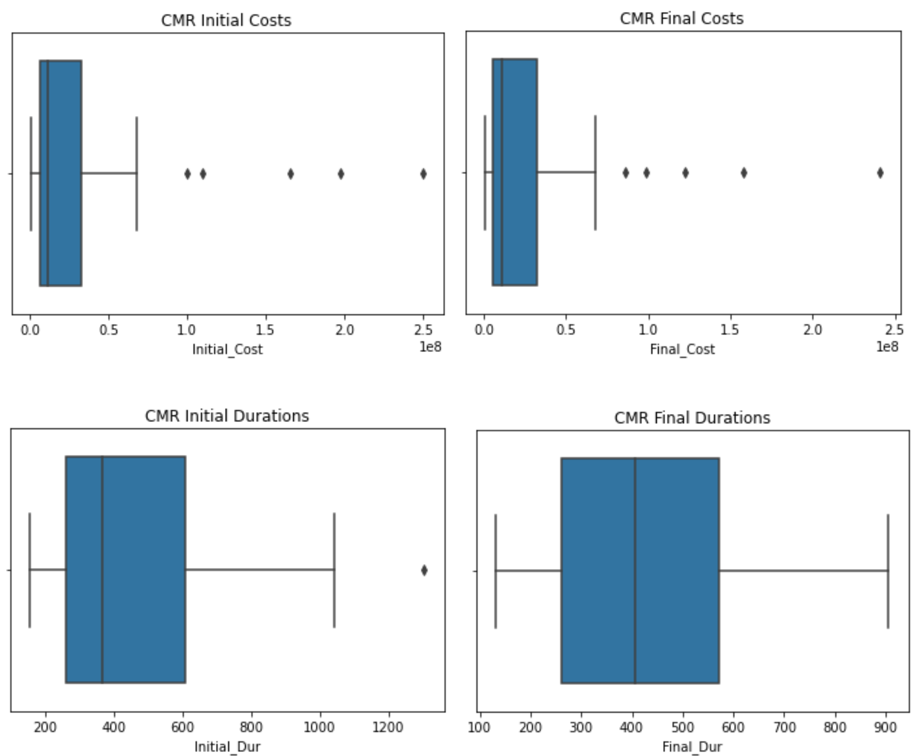

Figure 4.4 CMR Variables after Outlier Removal

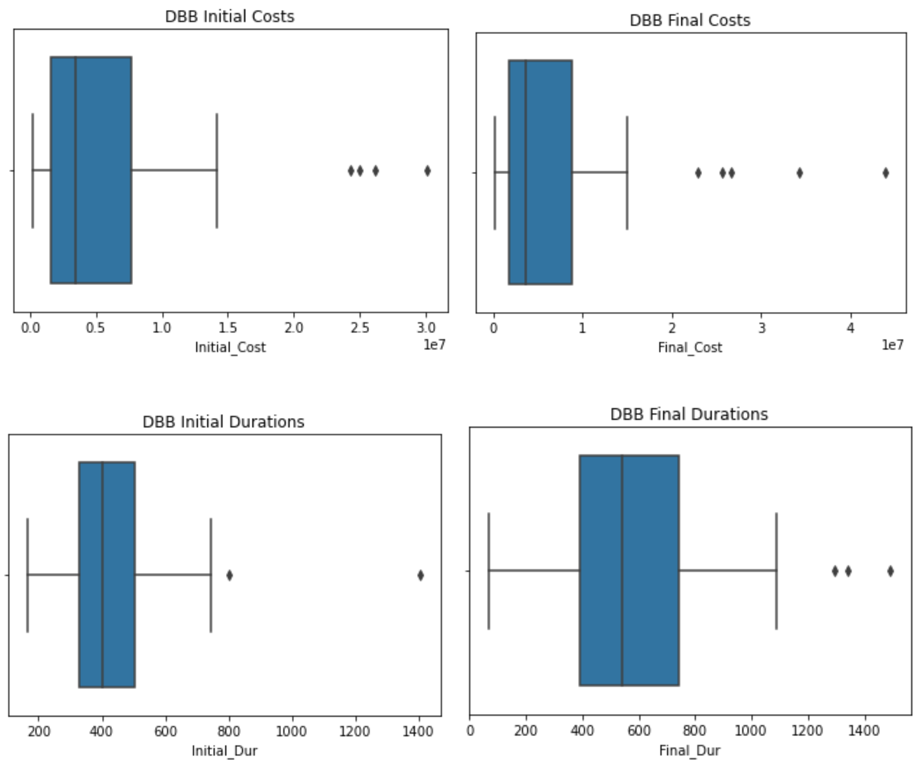

Figure 4.5 DBB Variables after Outlier Removal

4.2.6.1 Project Costs Analysis

Simple linear regression was calculated to check model assumptions of linearity and variable independence. Cost variables were plotted with Initial Cost on the x-axis and Final Cost on the y-axis on a scatter plot (Figure 4.6) followed by curve fitting (Figures 4.7) and a composite joint plot for the regression (Figures 4.8). Regression results using Final Cost as the dependent variable for DBB and CMR projects are shown in Tables 4.3 and 4.4.

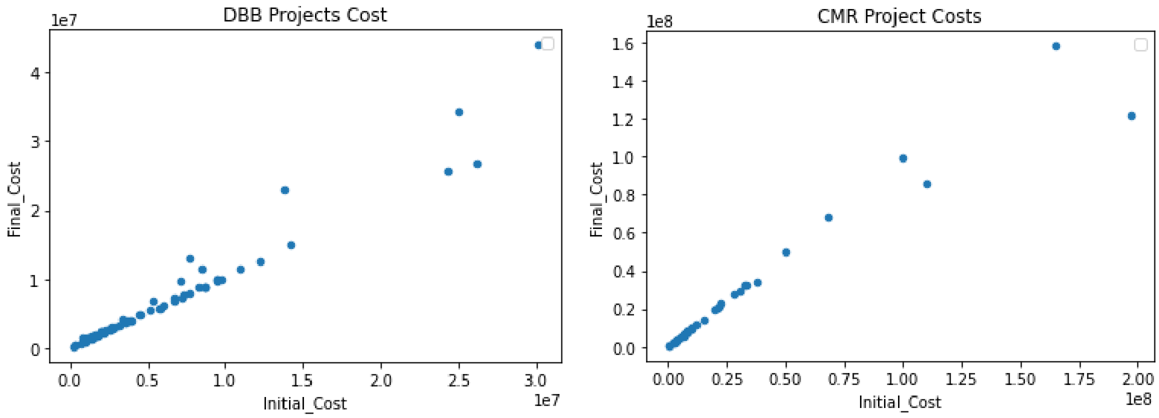

Figure 4.6 DBB and CMR Project Costs Scatter Plots

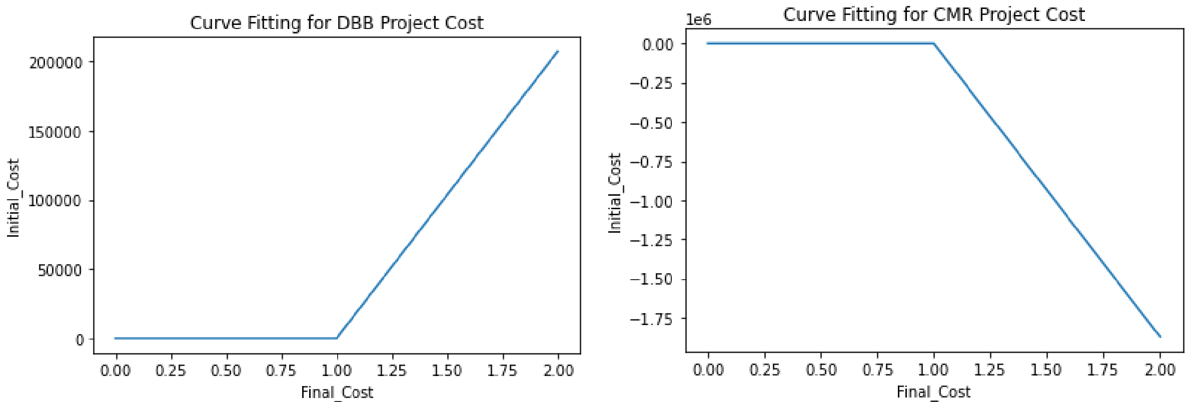

Figure 4.7 DBB and CMR Projects Curve Fittings

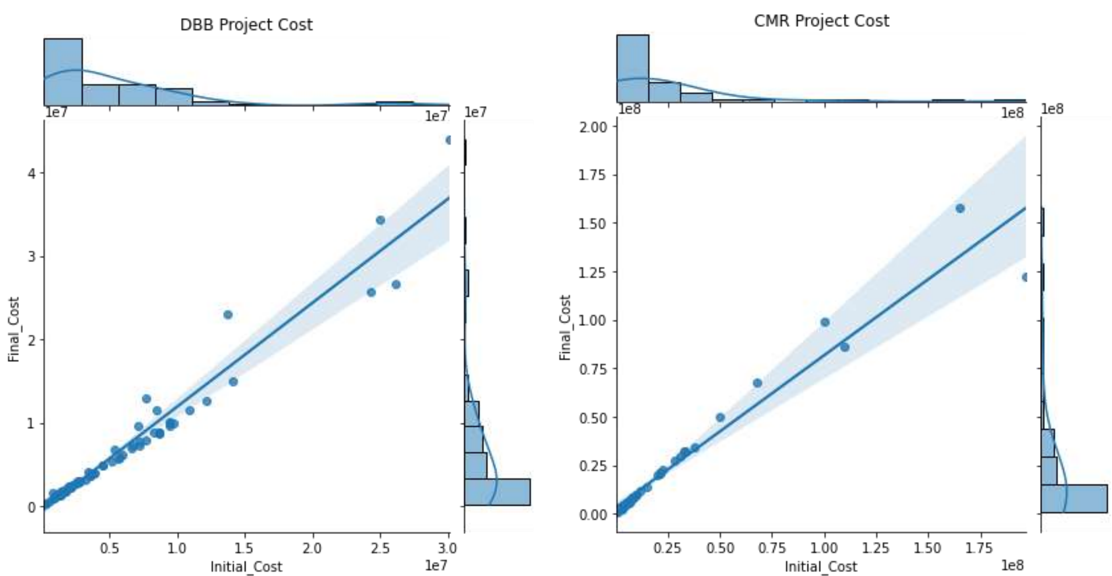

Figure 4.8 DBB & CMR Project Cost Composite Joint Regression Plots

Table 4.3 DBB Final Cost Regression Results

OLS Regression Results

Dep. Variable:	Final_Cost	R-squared:	0.952
Model:	OLS	Adj. R-squared:	0.952
Method:	Least Squares	F-statistic:	1400.
Date:	Mon, 01 Nov 2021	Prob (F-statistic):	5.08e-48
Time:	15:35:44	Log-Likelihood:	-1134.9
No. Observations:	72	AIC:	2274.
Df Residuals:	70	BIC:	2278.
Df Model:	1		
Covariance Type:	nonrobust		

	coef	std err	t	P>|t|	[0.025	0.975]
const	-5.077e+05	2.76e+05	-1.842	0.070	-1.06e+06	4.19e+04
Initial_Cost	1.2429	0.033	37.423	0.000	1.177	1.309

Omnibus:	35.557	Durbin-Watson:	2.010
Prob(Omnibus):	0.000	Jarque-Bera (JB):	149.040
Skew:	1.331	Prob(JB):	4.33e-33
Kurtosis:	9.527	Cond. No.	1.13e+07

Table 4.4 CMR Final Cost Regression Results

OLS Regression Results

Dep. Variable:	Final_Cost	R-squared:	0.945
Model:	OLS	Adj. R-squared:	0.943
Method:	Least Squares	F-statistic:	563.8
Date:	Mon, 01 Nov 2021	Prob (F-statistic):	2.54e-22
Time:	16:51:28	Log-Likelihood:	-608.31
No. Observations:	35	AIC:	1221.
Df Residuals:	33	BIC:	1224.
Df Model:	1		
Covariance Type:	nonrobust		

	coef	std err	t	P>|t|	[0.025	0.975]
const	3.215e+06	1.8e+06	1.791	0.082	-4.37e+05	6.87e+06
Initial_Cost	0.7840	0.033	23.745	0.000	0.717	0.851

Omnibus:	23.344	Durbin-Watson:	1.919
Prob(Omnibus):	0.000	Jarque-Bera (JB):	110.843
Skew:	-0.999	Prob(JB):	8.53e-25
Kurtosis:	11.486	Cond. No.	6.56e+07

4.2.6.2 Residual Error – Project Costs

The normal distribution was then checked for residual errors, the predicted value was calculated for Final Cost, and the residual calculated by subtracting the predicted value from the Final Cost and plotted for both DBB and CMR projects (Figure 4.9).

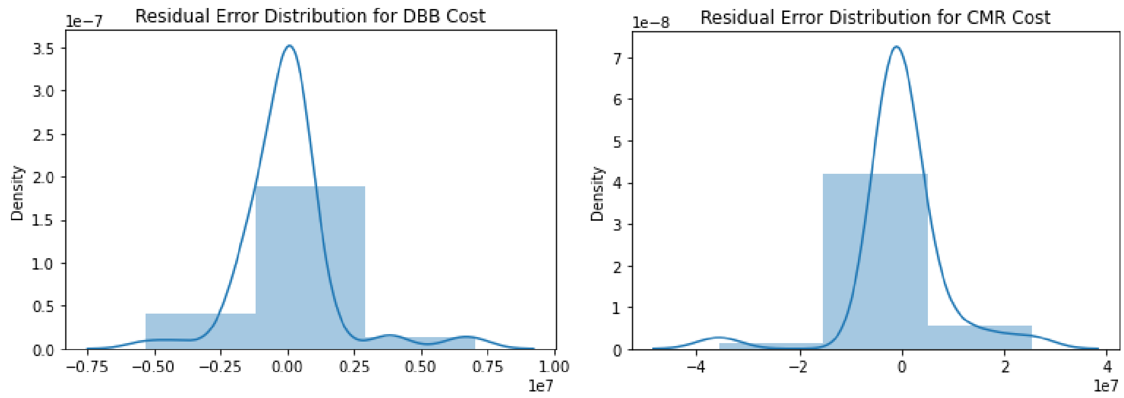

Figure 4.9 Residual Error Distribution Plots for DBB and CMR Cost

4.2.6.3 Project Durations Analysis

Schedule variables were plotted with Initial Duration on the x-axis and Final Duration on the y-axis on a scatter plot (Figure 4.10) followed by curve fitting (Figure 4.11) and a composite joint plot for the regression (Figure 4.12). Regression results using Final Duration as the dependent variable for DBB and CMR projects are shown in Tables 4.5 and 4.6.

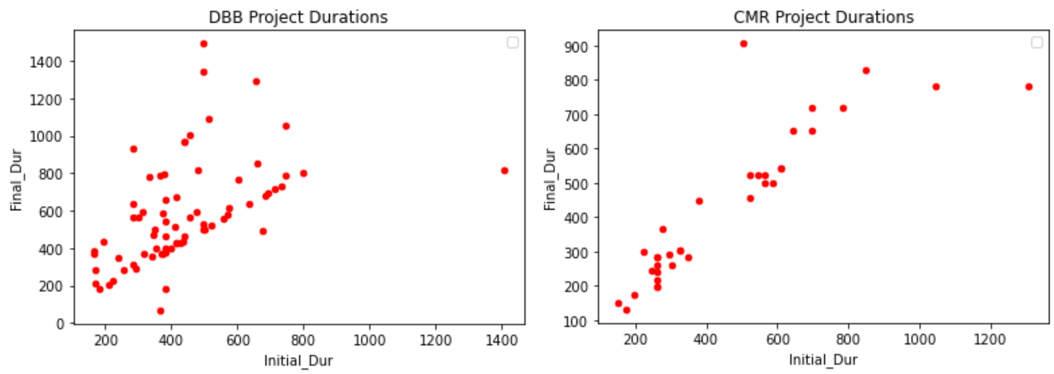

Figure 4.10 DBB and CMR Project Duration Scatter Plots

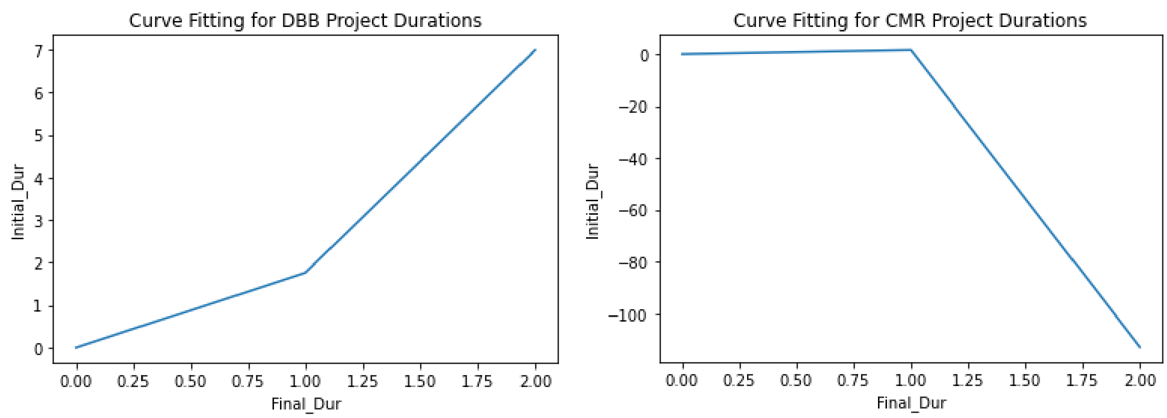

Figure 4.11 DBB and CMR Project Duration Curve Fittings

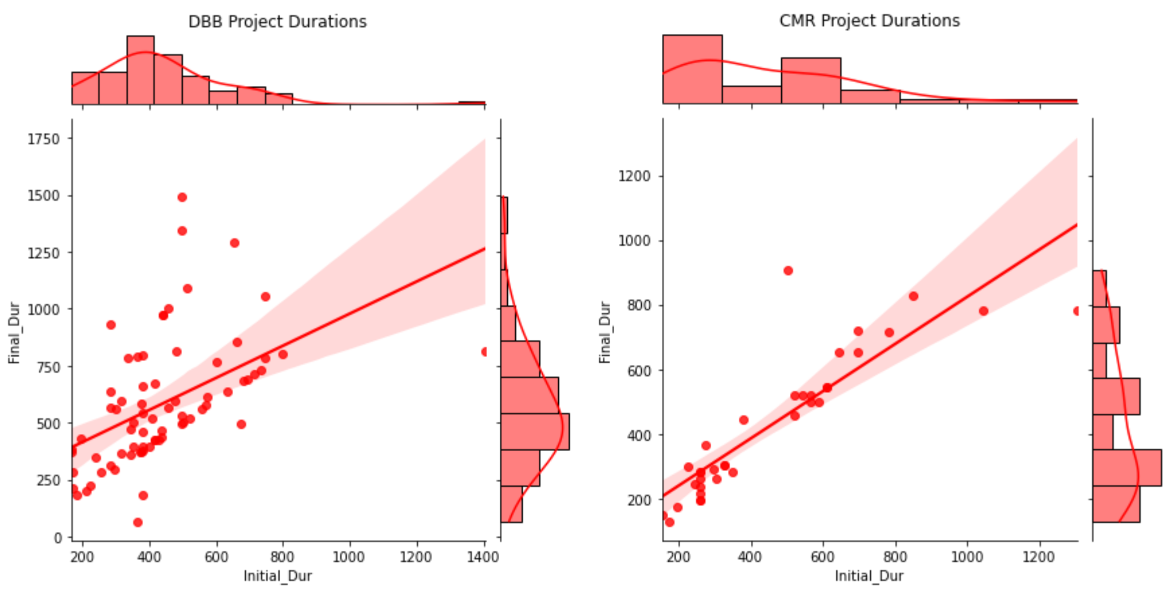

Figure 4.12 DBB & CMR Project Duration Composite Joint Regression Plots

Table 4.5 DBB Final Duration Regression Results

OLS Regression Results

Dep. Variable:	Final_Dur	R-squared:	0.242
Model:	OLS	Adj. R-squared:	0.231
Method:	Least Squares	F-statistic:	22.38
Date:	Mon, 01 Nov 2021	Prob (F-statistic):	1.13e-05
Time:	15:38:33	Log-Likelihood:	-496.95
No. Observations:	72	AIC:	997.9
Df Residuals:	70	BIC:	1002.
Df Model:	1		
Covariance Type:	nonrobust		

	coef	std err	t	P>|t|	[0.025	0.975]
const	274.9625	71.393	3.851	0.000	132.574	417.351
Initial_Dur	0.7036	0.149	4.731	0.000	0.407	1.000

Omnibus:	23.136	Durbin-Watson:	1.883
Prob(Omnibus):	0.000	Jarque-Bera (JB):	33.959
Skew:	1.298	Prob(JB):	4.23e-08
Kurtosis:	5.139	Cond. No.	1.19e+03

Table 4.6 CMR Final Duration Regression Results

OLS Regression Results

Dep. Variable:	Final_Dur	R-squared:	0.767
Model:	OLS	Adj. R-squared:	0.760
Method:	Least Squares	F-statistic:	108.6
Date:	Tue, 02 Nov 2021	Prob (F-statistic):	5.69e-12
Time:	09:59:20	Log-Likelihood:	-212.11
No. Observations:	35	AIC:	428.2
Df Residuals:	33	BIC:	431.3
Df Model:	1		
Covariance Type:	nonrobust		

	coef	std err	t	P>|t|	[0.025	0.975]
const	94.2718	37.015	2.547	0.016	18.965	169.578
Initial_Dur	0.7309	0.070	10.422	0.000	0.588	0.874

Omnibus:	31.083	Durbin-Watson:	1.292
Prob(Omnibus):	0.000	Jarque-Bera (JB):	110.950
Skew:	1.780	Prob(JB):	8.08e-25
Kurtosis:	10.963	Cond. No.	1.08e+03

4.2.6.4 Residual Error – Project Durations

The normal distribution was then checked for residual errors, the predicted value was calculated for Final Cost, and the residual calculated by subtracting the predicted value from the Final Cost and plotted for both DBB and CMR projects (Figure 4.13).

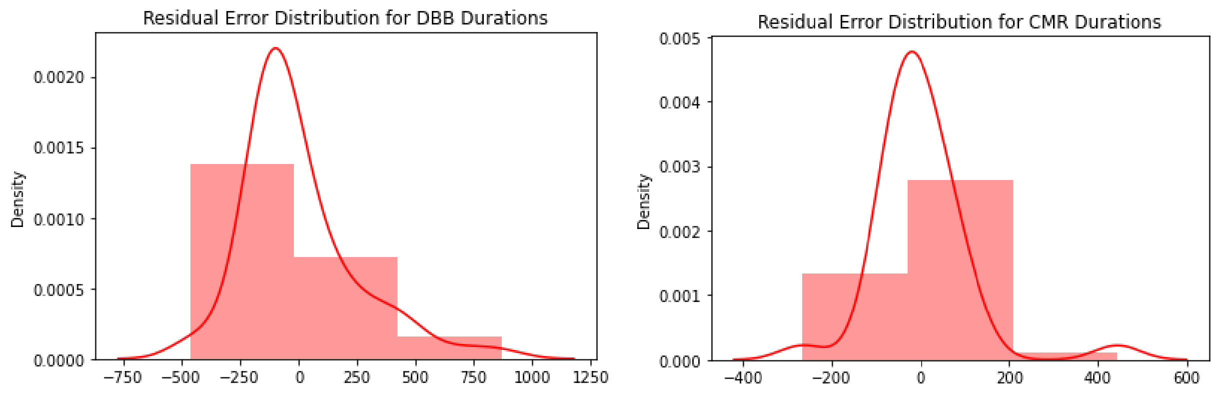

Figure 4.13 Residual Error Distribution Plots for DBB and CMR Durations

4.2.6.5 Variable Correlation

The final step of the linear regression analysis for the DBB and CMR projects employed correlation tables, a heatmaps, and pair plots to identify the strength of relationship between variables.

Table 4.7 Correlation of Variables p-Values (DBB)

	p-Values (DBB)			
	Initial Cost	**Final Cost**	**Initial Duration**	**Final Duration**
Initial Cost	0.000	0.024	0.469	0.657
Final Cost	0.024	0.000	0.419	0.619
Initial Duration	0.469	0.419	0.000	0.508
Final Duration	0.657	0.619	0.508	0.000

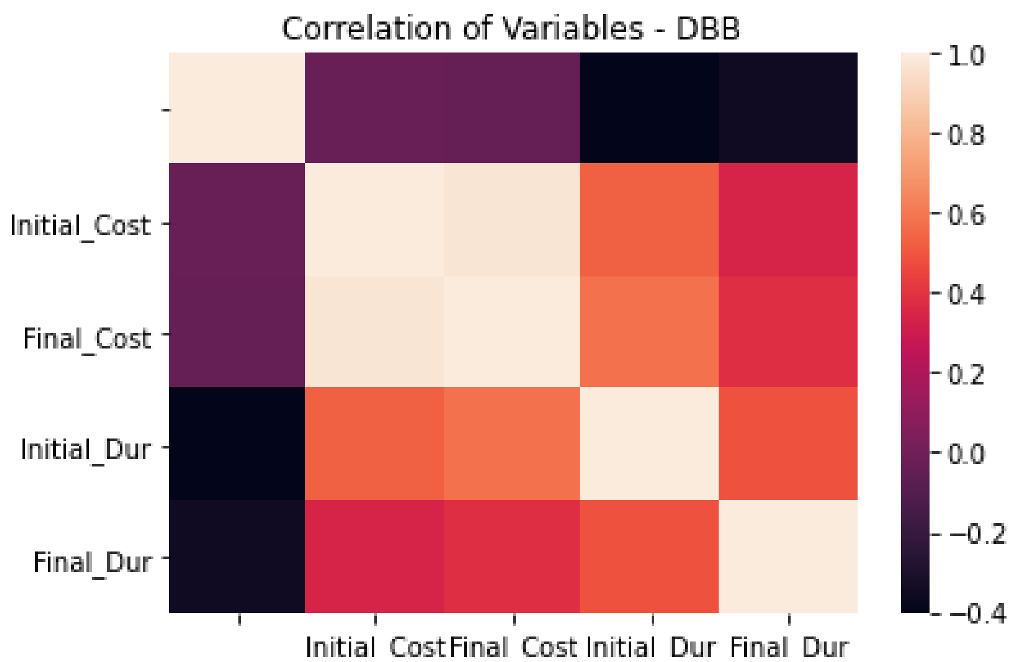

Figure 4.14 Correlation of Variables Heatmap (DBB)

Table 4.8 Correlation of Variables p-Values (CMR)

	p-Values (CMR)				
	Initial Cost	Final Cost	Precon Cost	Initial Duration	Final Duration
Initial Cost	0.000	0.028	0.099	0.179	0.397
Final Cost	0.028	0.000	0.109	0.200	0.370
Precon Cost	0.099	0.109	0.000	0.170	0.371
Initial Duration	0.179	0.200	0.170	0.000	0.124
Final Duration	0.397	0.370	0.371	0.124	0.000

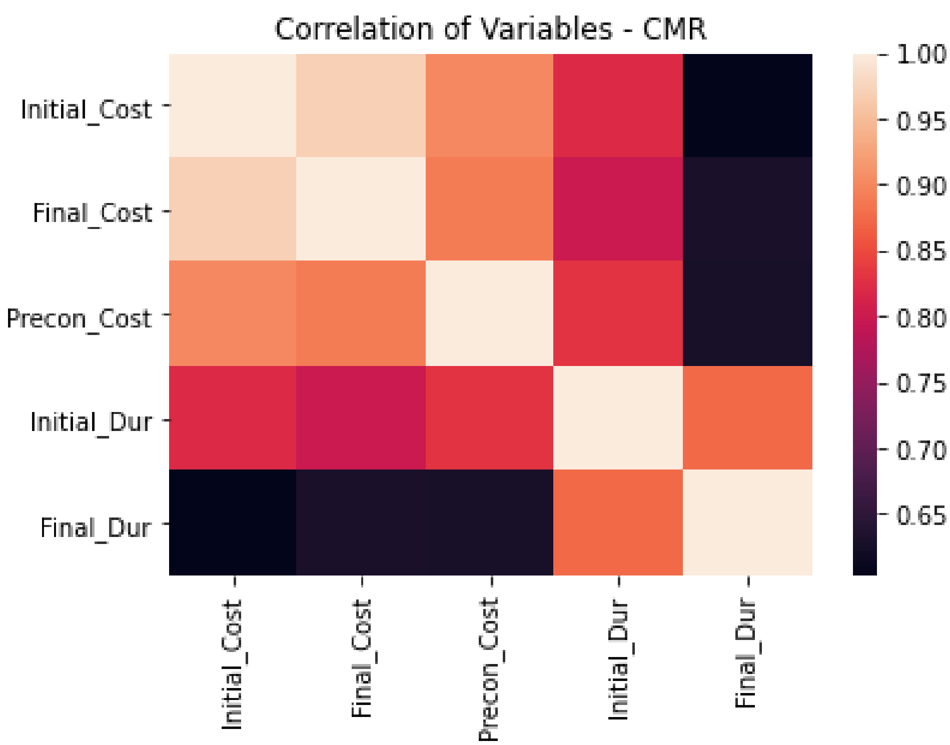

Figure 4.15 Correlation of Variables Heatmap (CMR)

4.2.6.6 Correlation Analysis

Correlation of variables analysis used α = 0.15 to test for statistical significance. Strong, statistically significant (α = 0.05) relationships between variable pairs were limited to one sets of variables in both models: Initial Cost to Final Cost in DBB (**p-value = 0.024**) and in CMR (**p-value = 0.028**). In the CMR dataset, Precon Cost to Initial Cost was significant at α = 0.1 (**p-value = 0.099**), Precon Cost to Final Cost significant at α = 0.15 (**p-value = 0.109**), and Precon Cost to Initial Duration was not significant at α = 0.15 (**p-value = 0.17**). Initial Duration to Final Duration were the only significantly correlated variables at α = 0.15 (**p-value = 0.124**). The remaining DBB variable correlations did not meet a threshold of α = 0.15, with p-values between **0.419** to **0.657**.

4.2.7 Multiple Regression Model Analysis

Multiple regression simulations were developed and run for DBB and CMR projects using several Scikit-Learn library tools imported into the Jupyter Notebook console (Table 4.9) using the same protocols to attempt to predict project Final Cost using Initial Cost, Initial Duration, and Final Duration to determine if 1) the model was valid and 2) was able to predict Final Cost within an acceptable level of statistical confidence. The model variables were then changed for the CMR projects, replacing Final Duration variables with Preconstruction Cost variables.

Table 4.9 Scikit-learn Tools Utilized in Simulation

Library	Tool
sklearn.linear_model	LinearRegression
sklearn.model_selection	train_test_split
sklearn.metrics	r2_score
sklearn	datasets

The dataset values were filtered and separated, setting the final cost as the dependent variable with initial cost, initial duration, and final duration as independent variables. Data was split into test and train sets which were run through multiple regressions: Training Set – Independent Variables (XDBB_train/XCMR_train), Test Set – Independent Variables, (XDBB_test/XCMR_test), Training Set – Dependent Variables (yDBB_train/yCMR_train), and Test Set – Dependent Variables (yDBB_test/yCMR_test). The model was first trained and then tested with the independent variables sets, the trained again with the dependent variables test set (yDBB_test/yCMR_test). The independent variables test sets were used to predict the Final Cost in the trained regression model. The DBB model (Model 1) predicted the Final Costs for 18 projects with an r^2 value of 0.949 and the CMR model (Model 2) predicted the Final costs for 9 projects with an r^2 value of 0.928. Mean values calculated in Tables 4.1 and 4.2 were entered as individual values into the model to check the accuracy of the prediction against mean final costs. The DBB model's predicted final cost was returned within 1% of the mean value and the CMR model's predicted final cost was returned within 10% of the mean value. The model code was copied, and the Final Duration variables were removed to determine the accuracy of predicting final costs with only initial variables. The DBB model (Model 3) returned predictions with an r^2 value of 0.947 and the CMR model (Model 4) returned predictions with an r^2 value of 0.914. Mean values were entered into the model again with the DBB model's predicted final cost was

0.90% less than the mean value and the CMR model's predicted final cost was 9.82% greater than the mean final cost. The CMR model code was copied again to test predictions by including preconstruction cost in the independent variables (Initial Cost, Precon Cost, and Initial Duration) to predict final cost. This model (Model 5) returned predictions with an r^2 value of 0.90995. Mean values were entered into the model and the predicted final cost was 9.82% greater than the mean value. The CMR model code was copied one final time to remove duration from the dependent variables to determine the change in accuracy predicting final cost with the preconstruction and initial costs alone. The model (Model 6) returned predictions with an r^2 value of 0.911, a slight improvement from the previous model.

Table 4.10 DBB Results of Multiple Regression Simulation

DBB Mean Values		**Model 1**	**Model 3**
Initial Cost	$5,623,135	Independent	Independent
Final Cost	$6,481,098	Dependent	Dependent
Initial Duration (days)	439	Independent	Independent
Final Duration (days)	584	Independent	-
r-Squared Value		0.949	0.947
Predicted Final Cost		$6,531,674	$6,539,265
Error (Mean - Pred)		($50,576)	($58,167)
% Error		-0.78%	-0.90%

Table 4.11 CMR Results of Multiple Regression Simulation

CMR Mean Values		**Model 2**	**Model 4**	**Model 5**	**Model 6**
Initial Cost	$36,501,528	Independent	Independent	Independent	Independent
Final Cost	$32,991,975	Dependent	Dependent	Dependent	Dependent
Precon Cost	$92,412	-	-	Independent	Independent
Initial Duration (days)	472	Independent	-	Independent	-
Final Duration (days)	435	Independent	Independent	-	-
r-Squared Value		0.928	0.914	0.90995	0.911
Predicted Final Cost		$29,906,713	$29,751,536	$29,397,249	$29,454,467
Error (Mean - Pred)		$3,085,262	$3,240,439	$3,594,726	$3,537,508
% Error		9.35%	9.82%	10.90%	10.72%

4.3 Results

The cost data included in this analysis provided several interesting insights into the similarities and differences between DBB and CMR delivery. There were twice as many DBB projects as CMR projects (72 vs 36) in the sample and mean values were an order of magnitude less than CMR's (millions versus tens of millions). Mean initial duration values for both project datasets were surprisingly close (DBB 439 days vs CMR 472 days) but final durations were not with DBB mean final duration of 584 days being 34% greater than the mean final duration of 435 days for CMR. Additionally, mean values for cost and duration trended upward for DBB (+15.3% cost growth, +33% schedule growth) and downward for CMR (-9.6% cost growth, -7.8% schedule growth). These trends indicate that a portion of the higher upfront cost associated with CMR delivered projects may be recaptured in overall cost savings by project completion along with the potential for schedule acceleration whereas the lower upfront cost of DBB may not provide overall lower construction costs or durations.

Linear regression analysis provides several insights into the comparative behavior of DBB and CMR delivered projects. Cost growth variability between DBB and CMR projects were similar and could be reliably predicted at or near a 95% confidence level (DBB r^2=0.952; CMR r^2=0.945). Initial and final cost variables were highly correlated for both delivery methods at $\alpha = 0.05$ (DBB $p = 0.024$; CMR $p = 0.028$). Preconstruction Cost was correlated to initial and final cost variables in CMR $\alpha = 0.1$ to Initial Cost (ρ-value = 0.099) and at $\alpha = 0.15$ to Final Cost ρ-value = 0.109). This is of particular interest as the preconstruction services fee is typically the first hard number provided to an owner that can give an indication as to the total cost of the project. These results show that owners should be able to accurately forecast the final costs for their projects regardless of the delivery method employed.

Schedule growth, however, was highly variable in both delivery methods with DBB producing the highest levels of variability ($r^2 = 0.242$) compared to CMR which was much more predictable ($r^2 = 0.767$) even if not at a statistically significant confidence level. As a side note, the Federal Highway Administration requires cost and schedule risk analyses to be completed for projects receiving federal funds with an estimated total cost greater than $500 million at a 70% confidence level (FHWA 2017). Duration variables were for DBB were not significantly correlated $\alpha = 0.15$ (p-value = 0.508) as compared to CMR durations which were correlated significantly at $\alpha = 0.15$ ($p = 0.124$) which lends support to literature claims that CMR project delivery may improve project schedule certainty, however, the reliability of this improvement may not be consistently experienced.

Correlation between cost and duration variables provided an insight in comparing both project delivery methods. Although neither dataset relationship between Initial Cost and Final Duration was significant at $\alpha = 0.15$, these results can be useful indicators of how a project's initial budget can impact the total duration needed to complete it and the relative value of improving cost certainty at award to improve overall schedule certainty. These values indicate that for DBB projects, increasing the initial budget of a project may not provide any positive impact on the overall project schedule and that projects which are relatively insensitive to schedule delays may be better candidates for this delivery method. For CMR projects, these values indicate that increasing the initial budget of a may have a positive impact on overall schedule certainty, even though this positive impact is not guaranteed.

Results of the multiple regression simulation model supported these findings and provided additional insights into the relationship between preconstruction services and project final cost. The DBB model was able to provide accurate estimates of final costs with and without including the final duration of the project, as was expected due to the lack of significant correlation between cost and duration variables from the initial analysis. The CMR model was less accurate in predicting final cost than the DBB model, but each configuration of the variables was able to return predictions at greater than 90% confidence. The inclusion of preconstruction cost as a dependent variable slightly reduced the accuracy of the model predictions but dropping the duration variable from the regression slightly improved results (from r^2 value 0.90995 to 0.911). This drop in accuracy is consistent with common pricing practices associated with preconstruction services where general contractors offer a lump sum amount that rarely comes close to offsetting the real hourly cost of the professional services they provide because they view preconstruction services as an investment in being able to negotiate the price of construction and preconstruction services fees are typically less than 0.5% of total cost (Gransberg and Carlisle 2008). The model demonstrates that while cost of preconstruction services impacts the final cost of the project, its impact is limited.

4.4 Conclusions

Final cost can be predicted with at least 90% confidence for both DBB and CMR projects provided the values for the initial cost and duration of the project, and the cost of preconstruction services for CMR projects. Contrary to assertions in existing literature, CMR does not appear to outperform DBB in controlling project cost growth, but it does provide a greater level of schedule certainty. Lower correlation between cost and schedule duration values in DBB than CMR provides an indicator that CMR may provide greater control over the final schedule. The contradiction regarding cost performance raises an important question: if CMR doesn't provide a better vehicle to reduce schedule growth over DBB, then what value do public university owners recognize in CMR, that is not recognized in the literature, causes it to continue to be a preferred delivery method?

4.4.1 Limitations

Limitations to this study are primarily associated with the source and quality of project data used in the model. Results of this study were drawn from project databases assembled by the main author and three other researchers' prior work. During the analysis of the data, assumptions were made about the similarity of contracting methods utilized among the multiple public agencies represented in the data, which included the Naval Facilities Command that utilizes both traditional low-bid DBB and an alternative version that includes some best value selection criteria that evaluate the qualifications of the bidders. There were twice as many DBB projects as CMR projects in the sample which may have been a source of the higher confidence levels in prediction results for both analyses. As a result, the authors consider these results to be emerging trends that would benefit from 1) cleaning and improving the project data in the model and 2) incorporating more CMR projects so that the dataset is more similar.

5.0 Quantifying the Value of Owner-Directed Project Scope Growth in Construction Manager-at-Risk Delivered Public University Capital Projects

Gransberg, N.J. and Maraqa, S., "Leveraging the Value of Project Scope Growth through Construction Manager-at-Risk Delivery of Public University Capital Improvement Projects," *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, 2022, 14(1): 04521042. To be presented at the American Society of Civil Engineers' Construction Institute and Construction Research Council Joint Conference, Arlington, VA, March 9th-12th, 2022.

5.1 Synopsis

When capital improvement project final costs exceed the costs of initial estimates, the overrun is assumed to be an indication of poor performance. However, when the project owner adds scope at any point after the initial estimate, the value of the project is enhanced, even though the numbers are interpreted in a negative light. This paper explores the idea that construction manager-at-risk (CMR) delivery provides a level of contractual flexibility that is not available in traditional design-bid-build (DBB) contracts, and as such, lends itself to projects where additional funding may become available after contract award and facilitate its efficient use in a manner not available in DBB delivered projects. The paper reviews the cost performance of 166 CMR and DBB projects completed by 23 American public universities valued at over $3B, collected from 2018 to 2019. The study that found cost growth on university CMR projects was greater than similar DBB projects, contradicting the conclusions of most of the literature on CMR. It reports the analysis of a second sample of 86 projects, which individually compared DBB projects matched to similar CMR projects finding that CMR project design fee efficiency was double that in DBB. The first contribution is providing an objective metric to differentiate between owner-driven scope cost growth and cost growth due to other reasons, and secondly, posits that the contractual flexibility inherent to CMR project delivery adds value for money by allowing a university to expeditiously obligate new sources of funding, such as donations.

5.2 Introduction

This study compares the relative cost performance of Construction Manager-at-Risk (CMR) and Design-Bid-Build (DBB) projects completed in the public sector higher education construction market, with a specific focus on design fee efficiency. As public owners, universities' capital improvement program funding sources typically include a percentage of non-tax funding that comes from charitable donations made by private entities. Because these funds are voluntary, it is difficult to forecast when they will become available and may fund anywhere from minor remodels to construction of new major facilities. As a result, the ability to add scope to an existing contract in an efficient manner to utilize new funding becomes an important aspect of a university capital improvement program.

5.2.1 Research Objectives

This paper explores the following research questions related to project cost certainty:

1. Does utilizing CMR change (increase or decrease) project cost certainty when compared to DBB?
2. Is there a difference in design fee efficiency between CMR and DBB projects?
3. If there is a difference in design fee efficiency, what is the probable cause of this difference?

5.3 Research Methodology: Contract Collaboration Clause Synchronization Analysis

CMR contracts have the feature of mandating an improved level of collaboration between the designer and the general contractor through each party's contracts with the owner, which maintain the same lines of contractual privity as found in DBB contracts. This feature is absent in DBB contracts and present in Design Build (DB). However, collaboration is enforced by the subcontracts internal to the DB entity. It has been theorized that contracts which are synchronized with respect to expectations for collaboration, improve the likelihood that the owner will receive the intended expected benefits of CMR project delivery (Gransberg and Gransberg 2019The legal foundation for contractually required collaboration is the doctrine of "Good Faith and Fair Dealing," which essentially forms "a general assumption of the law of contracts, that people will act in good faith and deal fairly without breaking their word, using shifty means to avoid obligations or denying what the other party obviously understood" (Hill and Hill 2007). Lahdenperä (2012) found that "express good faith" contract clauses that seek to regulate the relationships between the parties are effective in providing a framework upon which the interpersonal relationships that create actual collaboration can be realized.

To test this assertion in the public higher education CMR context, CMR contracts used by the University of Oklahoma and the State of Colorado Department of Education were evaluated. To provide a more global assessment, American Institute of Architect's (AIA) 2019 standard form contracts for CMR, was also included.

5.3.1 AIA Standard Form Contracts

Many public universities base their CMR contracts on the AIA standard form contracts for CMR delivered projects (AIA B133-2019 and AIA A133-2019). These contracts incorporate multiple clauses throughout the agreements establishing the form of collaboration expected between the designer and general contractor. There are many similarities between these CMR contracts and the AIA's standard form contracts for DBB delivered projects from a cursory review, which may indicate that AIA CMR contracts utilized DBB contracts as the base from which they were written. For example, in paragraph, §2.2 Relationship of the Parties of the general contractor's agreement establishes the owner's expectations for the general contractor to cooperate with the designer and reads as follows:

> *"The Construction Manager accepts the relationship of trust and confidence established by this Agreement and covenants with the Owner to cooperate with the Architect and exercise the Construction Manager's skill and judgement in furthering the interests of the Owner to furnish efficient construction administration, management services, and supervision, to furnish at all times an adequate, supply of workers and materials; and to perform the Work in an expeditious and economical manner consistent with the Owner's interests. The Owner agrees to furnish or approve, in a timely manner, information required by the Construction Manager and to make payments to the Construction Manager in accordance with the requirements of the Contract Documents."*

The architect's agreement also contains a paragraph in Article 2 §2.3 that references the Construction Manager's contract and includes an exculpatory clause reliving the designer of responsibility for the general contractor's actions. It reads as follows:

> *"The Architect shall provide its services in conjunction with the services of a Construction Manager as described in the agreement identified in Section 1.1.5. The Architect shall not be responsible for actions taken by the Construction Manager."*

The clause in the general contractor's agreement consists of seven lines of text whereas the clause in the designer's agreement consists of two lines of text. The phrase "covenants with the Owner to cooperate with" is only present in the general contractor's contract. The word "cooperate" is only present once in the designer's contract (§6.4) and speaks to the owner's duty to cooperate with the designer. The exculpatory language present in the designer's agreement is absent in the general contractor's agreement in Article 2. The architect's contract (AIA B133-2019) mentions the Construction Manager 131 times and the general contractor's contract (AIA A133-2019) mentions the Architect 84 times. A count of common phrases showed an incidence of 41 times in the designer's agreement and 36 times in the general contractor's agreement for a combined total of 77 incidences. Of the 23 phrases analyzed, 11 occur more often for the general contractor than the architect and 11 occur more often for the architect. The three most common sets of phrases were "shall provide/furnish" (10 times; 3 A/E & 7 GC), "shall prepare/collect" (10 times; 4 A/E & 6 GC), and "shall advise/recommend/consult with" (9 times; 2 A/E & 7 GC). The phrase "to cooperate with/cooperation" appears once and only in the general contractor's agreement. These phrases are present roughly twice as often in the general contractor's agreement than in the architect's which may be interpreted as placing the onus for building project team collaboration on the general contractor, which appears to be validated by a specifically titled paragraph outlining the relationship of the parties, only present in the general contractor's agreement. The phrases "reasonably prompt/promptly/promptness" occur seven times, 6 times in the designer's agreement and once in the general contractors, which may be interpreted as a recognition that the designer's production of construction documents and responses to requests for information have an impact on the project construction schedule. In aggregate, this textual analysis appears to embrace the traditional concepts of roles for the designer and general contractor, with collaboration being viewed as primarily the general contractor's responsibility.

5.3.2 University of Oklahoma Contracts

The University of Oklahoma (OU) has utilized CMR project delivery since the early 2000's, being an early implementor soon after legislation was passed to allow its use in projects (61 OK Stat § 61-202.1). OU utilizes a heavily modified version of the AIA standard form CMR contract that makes multiple improvements regarding expectations for collaboration. The two contracts analyzed came from an academic building project constructed in 2016. The architect's agreement has a three-paragraph article titled "The Project Construction Manager" that consists of 18 lines of text and 241 words. Paragraph 8. (a) reads as follows:

> *"The Architect shall cooperate with the Construction Manager with respect to any duties, obligations, and responsibilities of the Construction Manager including those set forth in the Agreement for At Risk Construction Management Services executed by and between the Owner and the Construction Manager. The Architect's duty of cooperation shall include, but shall not be limited to, the duty of providing information to the Construction Manager including those documents identified in Paragraph 14 hereinbelow; the duty of meeting and consulting with the Construction Manager concerning any matter relating to the Project; and the duty of working with the Construction Manager with respect to any inspection, testing, or analyses of any work performed on the Project;"*

The following paragraph goes on to establish that the duties of the designer do not alter any of the general contractor's responsibilities. The final sentence is compelling in its effective description of the roles and relationship between the designer and general contractor:

> *"It is expressly acknowledged and agreed that the duties of the Architect to the Owner are independent of, and are not diminished by, any duties of the Construction Manager to the Owner."*

The general contractor's agreement has a similar four-paragraph article titled "The Project Architect" that consists of 24 lines of text and 306 words. Paragraph 9. (a) is like the architect's Paragraph 8. (a) and contains the same language, with direction to cooperate with the designer, be familiar with their agreement. The difference between this and Article 8. of the designer's agreement are two sentences in the second and third paragraphs that direct the general contractor to review and study all documents prepared by the designer and comply with them to protect the owner's interests. These two additional sentences read as follows:

> *"The Construction Manager shall carefully review and be familiar with the Agreement for Architectural Services between Owner and Architect. … b) The Construction Manager shall review and study any and all analyses, reports, and other similar documents prepared by the Architect and furnished to the Construction Manager, and the Construction Manager shall incorporate and comply with any recommendations or proposals contained therein if necessary to protect the interest of the Owner and if authorized by the Owner in writing;"*

Paragraph 9. (c) has the same language as Paragraph 8. (b) in the architect's agreement. The architect's contract (University of Oklahoma 2015) mentions the Construction Manager 79 times and the general contractor's contract (University of Oklahoma 2016) mentions the Architect 115 times. A count of common phrases showed an incidence of 43 times in the designer's agreement and 76 times in the general contractor's agreement for a combined total of 119 incidences. Of the 23 phrases analyzed, 14 occur more often for the general contractor than the architect and five occur more often for the architect. The three most common sets of phrases were "shall advise/recommend/consult with" (17 times; 3 A/E & 14 GC), "shall provide/furnish" (15 times; 3 A/E & 12 GC), and "shall prepare/collect" (4 times; 7 A/E & 6 GC). The phrase "to cooperate with/cooperation" appears five times, three times in the architect's agreement and twice in the general contractor's agreement. The two most common phrases occur roughly four times as often and the third phrase less than twice as many times as often in the general contractor's agreement, indicating that most of the responsibility in developing the collaborative relationship between the architect and general contractor is on the general contractor. The presence of highly synchronized articles dedicated to each party's duties to collaborate are present in each agreement is an improvement over the AIA standard form contracts.

5.2.3 State of Colorado Contracts

The University of Colorado and Colorado State University utilize standard form contracts for CMR, referred to as Construction Manager/General Contractor (CM/GC) provided by the State Architect's Office (State of Colorado 2019, State of Colorado 2021) operating under the legislative statutes governing Integrated Project Delivery (CO Rev Stat § 24-93-101) and do not appear to be based on the AIA standard form contracts. The history behind the development of these contracts was not readily available, however they appear to have been written from the ground up for this delivery method. Each contract has similar paragraphs setting the owner's expectations for collaboration between the designer and general contractor, much like the articles present in the University of Oklahoma's contracts. These paragraphs are located at the beginning of Article 1. Performance of Work and share the same paragraph number, 1.1.2. The architect's Paragraph 1.1.2 consists of 16 lines of text and 198 words. The general contractor's Paragraph 1.1.2 consists of 19 lines of text and 223 words. The architect's paragraph reads as follows:

> *"In the performance of the professional services, the Architect/Engineer acknowledges that time is critical for Project delivery and that portions of the work shall have their design completed as separate Bid Packages and ready for construction before other portions of the work are fully designed. It is further recognized that this accelerated approach to construction utilizing the services of an Architect/Engineer and a Construction Manager/General Contractor is a unique concept and that its feasibility requires maximum cooperation between all parties. It is also recognized that the services to be rendered by the Construction Manager and the interrelationships and coordinative aspects thereof are not traditional. The Architect/Engineer has, however, reviewed the Construction Manager Contract and accepts the terms thereof as expressing a workable concept. In furtherance thereof, in the event there appears to be a duplication, overlap, or conflict of responsibility or duties between the Architect/Engineer and the Construction Manager, or an absence of designation, the question shall be submitted to the Principal Representative for determination. The Architect/Engineer shall abide by*

the decision of the Principal Representative provided it does not require the performance of services beyond what was reasonably contemplated and accepted by the Architect/Engineer as its responsibility."

The general contractor's paragraph adds a single sentence at the end regarding claims for increases to the project scope:

"If the Construction Manager claims any increase in the Work arises by virtue of such a decision."

The architect's contract (State of Colorado 2019) mentions the Construction Manager 151 times and the general contractor's contract (State of Colorado 2021) mentions the Architect 73 times. A count of common phrases showed an incidence of 89 times in the designer's agreement and 50 times in the general contractor's agreement for a combined total of 139 incidences. Of the 23 phrases analyzed, 13 occur more often for the architect than the general contractor and five occur more often for the general contractor. The three most common sets of phrases were "shall review" (23 times; 15 A/E & 8 GC), "shall prove/furnish/furnished" (16 times; 9 A/E, 7 CM), and "shall advise/recommend/consult with" (15 times; 9 A/E & 6 GC). The phrase "to cooperate with/cooperation" appears eight times, four times equally in each agreement. The two most common phrases occur slightly more than or close to twice as many times as often in the architect's agreement than in the general contractors, which is the opposite of both the AIA and OU agreements. This indicates that the State of Colorado more evenly expects both parties to hold responsibility for developing project team collaboration, with slightly more responsibility on the architect's part. This attitude expressed through the language of these agreements is an excellent example of synchronization that should be replicated and employed by other public owners to enable CMR projects to experience greater levels of collaboration between the designer and general contractor. Table 5.1 provides the details of the content analysis for all three contract sets.

Table 5.1 Content Analysis of Relational Phrases in Selected CMR Contracts

Phrase(s)	Incidence of Occurrence by Contract						
	A/E	CM	A/E	CM	A/E	CM	Totals
	AIA B133-2019	AIA A133-2019	OU AE CMR	OU CM CMR	SC 5.2 AE CMGC	SC 6.5 CMGC	
"shall advise and consult with", "in consultation with", "shall advise", "shall make recommendations", "shall recommend"	2	7	3	14	9	6	41
"shall provide", "shall furnish",	3	7	3	12	9	7	41
"shall review"	4	0	8	2	15	8	37
"shall prepare", "shall collect"	4	6	4	7	8	0	29
"shall schedule and conduct [meetings] with", "meet with", "shall attend meetings [and/or conferences]"	5	4	2	6	4	3	24
"prompt", "promptly", "reasonable promptness"	6	1	3	6	6	1	23
"shall promptly report", "shall promptly notify", "shall notify", "shall identify and report", "to identify"	0	3	2	2	11	2	20
"shall submit"	2	0	4	9	0	3	18
"shall assist", "assistance"	3	1	2	0	9	3	18
"to cooperate with", "cooperation"	0	1	3	2	4	4	14
"shall obtain approval", "with approval of", "for approval"	0	1	3	7	3	0	14
"shall exercise reasonable care", "reasonable opinon", "reasonable	0	1	2	0	5	4	12
"shall acknowledge", "acknowledges"	1	0	3	2	2	1	9
"shall coordinate", "in coordination with"	3	1	0	1	1	0	6
"mutually", "shall be mutually resovled", "jointly"	0	0	0	1	1	3	5
"shall reconcile"	1	1	0	1	0	2	5
"shall work together with", "shall work	1	1	0	1	0	1	4
"shall participate"	1	0	0	1	1	1	4
"shall consider", "consideration"	2	0	0	1	0	0	3
"shal present"	2	0	0	0	1	0	3
"shall be entitled to rely upon"	1	0	1	0	0	0	2
"shall deliver to"	0	1	0	1	0	0	2
"shall provide leadership"	0	0	0	0	0	1	1
A/E & CM SubTotals:	41	36	43	76	89	50	335
Synchonization Phrase Incidence Totals:	77		119		139		

5.4 Research Methodology: Shadow Projects Analysis

The methodology consisted of three steps. The first was data collection, cleaning, and population database assembly. The second step involved pairing CMR projects with similar DBB projects so that individual performance between the two delivery methods can be measured. This process is a variant of case-based reasoning commonly termed "shadow projects" and found to be valuable in previous project delivery method research (Craggs et. al 2008, Dongo et al. 2014, FHWA 2018). The final step involved data analysis to statistically compare university project scope change using three primary measures: construction cost growth; design cost growth; and cost growth from the owner's initial estimate. The metrics were used to test the following hypotheses:

- Ho1: University CMR projects experience less construction cost growth than DBB projects.
- Ho2: University CMR projects experience less design cost growth than DBB projects.
- Ho3: University CMR projects experience less cost growth from the owner's initial estimate than DBB projects.

5.4.1 Data Collection and Database Development

Project data was collected from public universities in Alabama, California, Colorado, Kansas, Oklahoma, Missouri, North Dakota, and Texas between 2018 and 2019. The projects used in this analysis were extracted from a database of capital projects that consists of 256 CMR projects and 278 DBB projects. The base project data was collected directly from public university capital projects management organizations that responded to email requests then augmented by publicly available data found on the internet. Publicly available project data was extracted from design services and construction services contracts, estimates, capital project reports for university governing boards, and publicly posted cost data on university websites. Universities were selected based on an internet screening search that identified institutions that use CMR. Table 5.2 shows the institutions represented in the final database, which was reduced to 67 CMR projects and 99 DBB projects (189 CMR & 179 DBB removed for insufficiency).

Table 5.2 Research Project Participant Universities

Participant University	**CMR Projects**		**DBB Projects**	
	#	**Total Cost**	**#**	**Total Cost**
Auburn University	0	$0	19	$368,829,142
Cal Poly Pomona	1	$81,912,914	0	$0
Colorado State	3	$263,876,234	4	$182,700,000
North Dakota State University	5	$81,853,579	21	$140,124,362
Texas A&M System Schools				
TAMU - College Station	13	$292,538,752	6	$47,564,672
TAMU - Commerce	1	$28,116,512	0	$0
TAMU - Corpus Christi	1	$324,963,941	1	$6,009,626
TAMU - Galveston	1	$28,200,000	0	$0
TAMU - Health Science Center (Houston)	1	$103,800,000	0	$0
TAMU - International	3	$38,177,865	1	$12,494,023
TAMU - Kingsville	3	$26,024,720	0	$0
Prairie View A&M University	1	$14,280,254	0	$0
Tarleton State University	4	$125,360,657	3	$42,780,762
TAMU - Texarkana	0	$0	1	$20,546,246
TAMU - Texas Extension Service	0	$0	1	$16,496,724
TAMU - Texas Transportation Institute	0	$0	1	$18,727,663
West Texas A&M University	2	$37,416,933	0	$0
University of Colorado System Schools				
CU Boulder	6	$266,380,900	13	$20,398,386
CU Colorado Springs	3	$75,900,000	10	$17,362,007
University of Houston	0	$0	5	$59,381,026
University of Oklahoma	14	$157,091,114	10	$18,520,069
University of Texas System Schools				
UT Austin	1	$69,400,000	1	$2,600,000
UT Dallas	4	$191,239,872	2	$41,857,267
Subtotals	67	$2,206,534,247	99	$1,016,391,975

Data types collected for the database and their definitions are as follows:

- University Name
- Project Type – Projects were sorted as either New Construction or Renovation projects.
- Project Subtype – Projects were sorted into 7 subtype categories: Academic, Administrative, Athletics, Utilities, Health Sciences, Housing, Paving.
- Project Size (Square Feet)
- Contract Type (CMR/DBB)
- Total Project Cost ($) – Includes design, construction, administration, and all other project related costs incurred by the owner after the project has been completed and accepted.
- Initial Estimated Cost ($) – This is the earliest available project cost estimate produced by either the owner or designer for project planning and funding.
- Total Construction Cost ($) – This is the construction cost of the project as established by the contract for construction services (DBB projects) or the establishment of a GMP (CMR projects) necessary for the owner to issue the notice to proceed.
- Final Construction Cost ($) – This is the sum of the Total Construction Cost plus the cost of additional scope added to the contract by change order(s).
- Initial Contract Design Fees ($) – This is the cost of design fees established in the professional services contract issued to the project designer.
- Final Design Fees ($) – This is the sum of the Initial Contract Design Fees plus the cost of additional scope added to the contract by change order(s).

5.4.2 Data Missingness

Data collected directly from university capital projects staff was complete and consisted of 77 DBB projects and 29 CMR projects, with the exception of the University of Houston which did not provide project data in the requested format on 5 DBB projects (and were eliminated from the data set). Data collected from internet searches of publicly available projects, 22 DBB projects and 38 CMR projects, lacked some of the collected datapoints found in project data obtained directly from the source. This lack of complete project datapoints, also known as *missingness*, necessitated the use of a nonparametric machine learning method to impute the missing datapoints. Datapoint missingness for project data collected via the internet is found in Table 5.3. Only three data types had a missingness of greater than 50%: Project Size, Initial Contract Design Fees, and Final Contract Design Fees. Data gathered directly from university staffs provided sufficient information to impute representative values for the missing internet data using machine learning as explained in the subsequent paragraphs.

Table 5.3 Percentages of Missing Data for Publicly Available Projects over the Internet by Contract Type

Data Type	**DBB**	**CMR**
Project	0.0%	0.0%
Project Type	0.0%	0.0%
Project Subtype	0.0%	0.0%
Project Size (SF)	63.0%	56.1%
Contract Type	0.0%	2.4%
Total Project Cost	37.0%	12.2%
Initial Estimated Construction Budget	7.4%	14.6%
Total Construction Contract Cost	3.7%	26.8%
Final Construction Cost	40.7%	43.9%
Initial Contract Design Fees	100.0%	75.6%
Final Design Fees	100.0%	100.0%
Percent Total Data Missing	41.9%	34.9%

5.4.3 Random Forests Machine Learning Imputation Methodology

Data imputation tools are effective ways to fill missing datapoints in a dataset where there is sufficient complete data to reasonably impute from. Missing datapoint values were imputed using a nonparametric machine learning algorithm known as Random Forests programed in Python programming language. This method generates synthetic data from a distribution of observed data and is good at handling multiple variable types and measuring dissimilarity between variables by weighing the contribution of each variable in the model by its dependence to other variables (Shi & Horvath, 2006). The Random Forests algorithm is a tree-based ensemble method using randomized decision trees which considers nonlinearities and interactions between the variables while constructing decision trees (Lin et al. 2017) which typically have low bias and high variance. Resultant accuracy is improved by increasing the number of decision trees within the algorithm using bootstrap aggregation of multiple regression trees to reduce the risk of overfitting (Brownlee 2016, Cutler et al. 2017, Lin et al. 2017). Random Forests is an extension of an ensemble method known as Bootstrap Aggregation (also termed "Bagging") that combines multiple algorithm predictions to increase prediction accuracy by reducing variance in decision trees produced by classification and regression (CART) (Brownlee 2016). Random sub-samples of the dataset are produced and used to train a CART model, after which an average prediction is calculated using new data. Random Forests limits the CART learning algorithm to a random sample of features to search, typically the square root of the number of input variables, when finding the optimal split point in a decision tree, preventing decision trees from becoming overly correlated by a small selection of very strong predictors. Variable importance is determined by calculating the drop in error at each variable split point and averaging the sum across all decision trees where the larger the drop in error, the greater the importance of the input variable (Brownlee 2016). This algorithm was appealing due to its ability to impute missing values, reduce computational time, allow for parallel data processing, provide integral estimation of generalization error, weighting of classes to resolve unbalanced data, measuring variable importance, and the detection of outliers (Cutler et al. 2017). Random Forests is also considered more robust in dealing with label noise, an issue affecting classification accuracy stemming from the data quality of training instances within inductive learning models (Saffari et al. 2009, Zhu & Wu 2004).

5.4.3.1 Random Forests Data Imputation Procedure

The first step in the initial database development was to categorize and clean the data by matching data types to categories and encoding data into numerical variables to identify missing values. Many of the Project Type observations that were either missing or classified as a less frequent categorical type were collapsed into an "Other" category, reducing total variable types. Later, these missing Project Type values were manually categorized. Other category types, such as Project Name, Project Size, etc. were dropped from the dataset prior to analysis. Variables were then checked for missing values, sorted by percentage of missing values, and compared. Projects with complete data were split into 80% training and 20% test sets, randomly by percentage, to generate the Random Forests model. Missing values in the public data were then imputed with the Random Forests model and inspected for major outliers. The sample standard deviation was calculated for each data type for the complete dataset and the imputed public dataset, then compared. The imputed standard deviation was improved for all data types except CMR Initial Design Fees, which was 4% larger than in the same variable in the complete data set.

5.4.4 Shadow Project Assignment

Each CMR project in the dataset was matched with its most similar DBB shadow project. Traditional metrics of measuring project performance typically only compare project performance after the design is complete, which does not account for the influence of non-construction events that occur during planning and design (Konchar and Sanvido 1998; Col Debella and Ries 2006). The use of shadow projects is an established technique in construction research (Dongo et al. 2014) to control for the inevitable differences between projects resulting from regional market variances, labor availability, material cost variability, weather effects, etc. that render assumptions of normality within a dataset invalid. Using shadow projects allows the researcher to construct a sample with data that are closer to the assumption of normality than would otherwise be observed in the population. CMR and DBB projects were matched using the criteria proposed by Dongo et al. (2014) in descending priority:

1. Similarity in Initial Estimate Cost
2. Similarity in Project Type
3. Similarity in Project Subtype

This logic permits a comparison in trajectories of similar projects from the earliest point in the design available in the given data and compute their relative performance to construction completion. In this case, the dataset contained more DBB projects than CMR projects, so 43 CMR projects were selected and matched with the 43 most similar DBB projects, according to the criteria, for a total of 86 projects. The imputed dataset was sorted by Initial Cost Estimate, then by Project Type, and finally by Project Subtype. In the case where a CMR project had more than one DBB project that satisfied each criterion, the project with the closest Initial Estimate Cost was selected. For CMR projects where only two criteria were satisfied, the project with the closest Initial Estimate Cost was selected. The breakdown of Project Type and Project Subtype for the 86 sample projects were as follows in Table 5.4:

Table 5.4 Shadow Project Data Sample Statistics

	Project Type		Project Subtype						
	New Construction	Renovation	Academic	Admin	Athletic	Utilities	Health Science	Housing	Paving
CMR	19	24	24	4	10	2	2	1	0
DBB	20	23	24	3	6	3	1	5	1

5.4.5 Shadow Project Analysis

Analysis of the shadow project database measured 1) calculating project performance with traditional metrics and 2) calculating design fee efficiency using a comparison of construction scope dollars to design fee dollars.

5.4.5.1 Project Performance Analysis

The following performance metrics (Equations 5.1, 5.2 and 5.3) were calculated for each project in the sample:

Equation 5.1 Cost Growth (%) from Initial Estimate

$$Cost\ Growth_{from\ Estimate} = \frac{Final\ Construction\ Cost - Initial\ Estimate}{Initial\ Estimate} x\ 100$$

Equation 5.2 Cost Growth (%) from Construction Contract Award

$$Cost\ Growth_{from\ Contract} = \frac{Final\ Construction\ Cost - Total\ Construction\ Cost}{Total\ Construction\ Cost} x\ 100$$

Equation 5.3 Cost Growth (%) from Design Contract Award

$$Cost\ Growth_{Design\ Fees} = \frac{Final\ Design\ Fees - Initial\ Contract\ Design\ Fees}{Initial\ Contract\ Design\ Fees} x\ 100$$

Measures of central tendency were calculated for the CMR projects and DBB projects separately and then compared (See Table 5.5). Additionally, the total value for each contract type was summed, and the total value of projects in the data sample was summed.

Table 5.5 Project Performance Statistics

		Cost Growth - Estimate	Cost Growth - Contract	Cost Growth - Design
DBB	**MEAN**	-8.00%	4.90%	11.30%
	MEDIAN	1.30%	3.60%	10.90%
	STANDARD DEV	29.50%	6.50%	13.60%
	DBB VALUE	$735,023,057		
CMR	**MEAN**	5.00%	9.10%	10.40%
	MEDIAN	5.00%	5.50%	15.00%
	STANDARD DEV	35.40%	16.90%	83.10%
	CMR VALUE	$808,726,828		
CMR - DBB Difference	**MEAN**	13.00%	4.20%	-1.00%
	MEDIAN	3.70%	1.90%	4.10%
	STANDARD DEV	5.90%	10.40%	69.50%
	TOTAL VALUE	$1,543,749,885		

Results of the analysis seemed to contradict Ho1, Ho2, and Ho3 as well as the general findings in the literature that CMR has been shown to improve cost certainty when compared to similar DBB projects (West et al. 2012; Molenaar et al. 1999, Touran 2006). For the sample analyzed in this paper, however, construction cost growth in CMR projects was roughly twice of that observed in DBB projects. This is consistent with a study by Carpenter and Bausman (2016) that attributed similar outcomes to a combination of conditions in the public higher education construction market. The study found that project cost performance is impacted by scope changes directed by influential internal stakeholders, quality standards that are higher than comparable commercial projects, and resistance toward adopting the institutional culture necessary to utilize alternative project delivery methods (Carpenter and Bausman 2016) and leads one to infer that university capital project performance should not be compared directly to similar project performance in other market sectors.

5.4.5.2 Design Fee Efficiency Analysis

These results required that additional analysis be conducted to understand the analysis results of the shadow projects sample. These results showed that CMR projects experience roughly twice the cost growth as comparable DBB projects, which leads one to question CMR's continued use in this market segment. One possible explanation is that CMR delivery facilitates both changes and additions to project scope in a manner that add perceived value. A new metric was developed to compare cost growth between construction costs (C$) and design fee costs (D$) to provide some insight into the relative value of each delivery method. Inspiration for this metric loosely came from the concept of Value for Money. Value for Money is often expressed as a ratio of benefits and costs that consider the efficiency and effectiveness of the application of resources to end goal attainment (Glendinning 1988). The following ratios (Equations 5.4, 5.5, and 5.6) were calculated for each project in the sample:

Equation 5.4 Construction ($): Design ($) Initial Estimate

$$Construction\ \$: Design\$_{Initial} = \frac{Initial\ Construction\ Estimate\ Cost}{Initial\ Design\ Fees}$$

Equation 5.5 Construction ($): Design ($) Contract Award

$$Construction\ \$: Design\$_{Contract} = \frac{Total\ Construction\ Cost}{Initial\ Design\ Fees}$$

Equation 5.6 Construction ($): Design ($) Final Construction Cost

$$Construction\ \$: Design\$_{Final} = \frac{Final\ Construction\ Cost}{Final\ Design\ Fees}$$

The C$:D$ ratio expresses the value of the construction scope developed per unit of design expenditure and is intended to measure the efficiency of design fees according to project phase. The resulting ratio is a means to quantify much design effort must be expended to produce the final constructed design solution. Thus, if the final design for a constructed feature work is produced for the originally estimated design fee, it can be said that the design effort was highly efficient. On the other hand, if a myriad of revisions, changes, and/or additions are made before the documents are released for construction, then the cost of the design should be higher than the original fee and reflected in the data as design cost growth. Hence, as the C$:D$ ratio increases, the efficiency of the expended design effort increases as well. C$:D$ ratios were calculated for the 86-shadow project sets in the sample population and measures of central tendency are shown in Table 5.6:

Table 5.6 Design Fee Efficiency Ratios

		C$:D$ - Initial	C$:D$ - Contract	C$:D$ - Final
DBB	**MEAN**	14.75	0.08	0.09
	MEDIAN	14.66	0.08	0.08
	STANDARD DEV	3.88	0.04	0.04
CMR	**MEAN**	16.28	0.09	0.11
	MEDIAN	11.51	0.08	0.09
	STANDARD DEV	18.42	0.05	0.14
CMR - DBB Difference	**MEAN**	1.53	0.01	0.02
	MEDIAN	-3.16	0.01	0.01
	STANDARD DEV	14.54	0.01	-0.03

The results of this analysis demonstrated that design fees were significantly more efficient during the design process for both CMR and DBB projects in the sample, with the difference between CMR and DBB projects being negligible. However, as this analysis compared design fee efficiency over the entire life of the project did not compare construction dollars spent in change orders to the design fees change orders necessitated by owner-driven scope change. One final C$:D$ ratio was calculated to compare post-award change order dollars to change order dollars using the following equation:

Equation 5.7 Construction ($): Design ($) Post-Award Changes

$$Construction\ \$: Design\$_{Changes} = \frac{Final\ Construction\ Cost - \ Initial\ Construction\ Estimate\ Cost}{Final\ Design\ Fees\ -\ Initial\ Design\ Fees}$$

To differentiate between owner-directed scope growth and scope creep due to other issues, a secondary analysis of a subset that contained only projects that experienced both construction and design growth to focus the measurement of the differences between CMR and DBB projects. The analysis was necessary for three reasons:

1. Projects that did not experience construction cost growth could not be measured with this metric,
2. Projects that did not experience design fee cost growth even though they may have experienced construction cost growth may be attributed to contractor errors which would not require additional design work to be completed by the designer, or
3. Cost growth without design fee growth may be attributed to the designer errors and omissions, which would also not require additional design fees to be paid.

Thus, refining the analysis permitted the analyst to identify those projects that experienced cost growth where the design fee increase can be attributed to owner-driven scope growth. This removed 13 CMR projects and 10 DBB projects from the previous sample. The results of this analysis are in the table below (see Table 5.7):

Table 5.7 Change Order Design Efficiency Ratios

		C$:D$ - Change
DBB	MEAN	8.48
	MEDIAN	4.42
	STANDARD DEV	9.96
CMR	MEAN	14.87
	MEDIAN	8.43
	STANDARD DEV	20.83
CMR - DBB Difference	MEAN	6.39
	MEDIAN	4.01
	STANDARD DEV	10.87

5.5 Results

Construction cost growth in CMR projects was roughly twice of that observed in the DBB shadow projects leads one to infer that the universities in the sample are, contrary to conventional wisdom, availing themselves of beneficial cost growth due to owner-directed additions. Being able to efficiently obligate funding that becomes available from unexpected donors or at fiscal year-end maximizes the efficient use of available capital and adds value for money to a university's capital improvement program. Thus, the C$:D$ ratio provides an objective measure of this benefit.

5.5.1 Results of Traditional Metrics Analysis

CMR project delivery also appears to provide the owner with the ability to efficiently add new scope to the project after the GMP has been agreed. The analysis shows that CMR projects tended to experience more cost growth (about 4% more on average) throughout the design and construction phases than comparable DBB projects did. Design fee growth rates in CMR-delivered projects were quite similar in DBB projects, about 10% and 11% respectively, although median design fee growth for CMR projects was about 4% greater than DBB-delivered projects and the standard deviation for CMR was almost eight times as large as in DBB. If CMR and DBB delivery methods were judged only by the traditional project performance metric of cost growth, the DBB projects outperformed the CMR projects within this sample. When viewed through a cost certainty lens, it appears that the DBB projects realized roughly half as much overall cost variability as the CMR projects with the standard deviations for construction phase cost and design fee growth at 10.4% and 69.5% greater than in DBB. However, classic metrics do not differentiate between owner-directed cost growth and cost growth due to other issues like differing site conditions, force majeure, design errors and omissions, etc. Despite this difference in cost performance, the widespread of application of CMR project delivery within the public higher education market indicates that there are other perceived benefits in utilizing this delivery method that cannot be captured by using strictly traditional project performance metrics like cost and schedule growth.

5.5.2 Post-Award Change Design Fee Efficiency in CMR

Analysis of design fees employed in post-award changes was telling. CMR design dollars were able to generate almost twice as much post-award construction scope as the same dollars would using DBB. The standard deviation was also roughly twice as large in CMR versus DBB, which means that not all post-award CMR changes in the sample were executed as efficiently as the mean and median values, but also some were appreciably more efficient as well.

5.5.3 Improved Cooperation and Collaboration

The analysis showed that for owner-directed changes in CMR projects, design dollars are roughly twice as efficient as those spent for change orders in DBB projects. One explanation is the collaborative relationship between the owner, designer, and general contractor established in the CMR contract that makes the coordination of changes less confrontational than those in DBB projects. CMR contracts for the designer and general contractor enable the owner to require both parties to cooperate and collaborate as expected which can improve project team integration, reducing the level of contention in dealing with scope changes during construction, as demonstrated earlier in this paper. Contracts where the collaborative language is well synchronized between the designer and general contractor provide the legal groundwork to induce collaboration during design and construction. Sophisticated owners that can expand their project administration paradigm beyond traditional methods to embrace the unique capabilities and ground rules of CMR stand to gain more from its employment. The analysis of post-award change design fee efficiency seems to indicate that the level of synchronization may play a role in how efficiently design fees are expended in this phase.

5.5.4 Negotiated Versus Fixed Construction Price

A second possible explanation for greater design fee efficiency in construction phase scope growth regards making changes to DBB contracts after the construction price has been fixed. In CMR, the construction price is negotiated, rather than competitively bid, the scope of work is not fixed until the guaranteed maximum price (GMP) is established. Some universities negotiate a lump sum GMP to cover the entire project scope and may or may not convert this to a lump sum at some point in the project. Other universities negotiate a series of GMPs for each work package as the design progresses. This enables expeditious owner directed scope increases to accommodate funding that may not have been obligated or available when the general contractor's preconstruction services contract was executed. I In many cases this capacity in CMR contracts may obviate the need to request permission from a funding authority to utilize the newly available funding to enhance a previously approved capital project.

5.5.5 Incentives and Reduced Transaction Costs

The literature shows that two other factors of the GMP negotiation process influence the behavior of the contractor during negotiations. First, most CMR contracts contain provisions that allows the owner to terminate the preconstruction services contract and reprocure using DBB if a mutually agreed GMP cannot be established, which places the onus on the contractor to settle with the owner rather than lose the opportunity to construct the project (Cox et al. 2011; West et al. 2012). Secondly, Molenaar et al. (2009) found that contractors interviewed in the study emphasized that CMR gave them an opportunity to enhance their competitiveness on future CMR projects with the given owner by doing a good job on the current project. One of the study's conclusions was that "future work was the most highly valued incentive for construction contractors in CMR." Thus, the flexibility to minimize the transaction costs associated with owner-directed scope increases is a benefit that has not been recognized in previous project delivery research.

5.6 Conclusions

Of the 86 projects analyzed from the national sample of 534 projects, 22 projects did not experience cost growth (13 CMR/9 DBB). 50 projects experienced cost growth of 10% or more (28 CMR/22DBB). The CMR delivered projects, in both mean and median values, experienced more cost growth from the initial estimate and from the GMP than comparable DBB delivered projects in the sample. In fact, the DBB projects, on average, experienced -8% cost growth from the initial estimate and only 4.9% cost growth from the contract to completion. These results, when interpreted through the lens of conventional project performance metrics, appear to demonstrate greater cost certainty in the sample of DBB delivered projects than the comparable sample of CMR delivered projects. This came as somewhat of a surprise to the authors, as much of the literature comparing CMR project delivery to DBB project delivery has shown that CMR delivered projects tend to outperform DBB projects regarding cost certainty (Pocock et al. 1996;

Konchar and Sanvido 1998; Korkmaz et al. 2010) with the exception of public-school projects (Rojas and Kell 2008; Carpenter and Bausman 2016). One should note, however, that the focus of the projects analyzed in this paper were restricted to capital projects completed by public universities, which is a unique market segment within the construction industry.

Two primary causes for project cost growth are 1) errors and omissions in the plans and specs caused by the designer or 2) owner-driven scope growth. Owners have Spearin Doctrine liability which warrants the completeness of plans and specifications provided to the general contractor which have been developed by the designer, hence any errors and omissions within the project documents are the owner's liability if discovered, which can contribute to project cost growth through contractor generated change order requests. Conversely, owners may decide to add scope to a project after the project documents have been completed, or as design work packages are completed, at their discretion, which contributes to project cost growth. Conventional project performance metrics fail to differentiate between these two modes of construction cost growth, inadvertently combining all owner-driven scope growth with the designer's errors and omissions-driven scope growth. Design fees expended for post-GMP/construction services contract scope growth are roughly twice as efficient in CMR projects when compared to comparable DBB projects. This is most likely attributable to a combination of documented benefits derived from the CMR delivery method, specifically 1) the general contractor is included as a partner in the design process through a professional services contract (preconstruction services) to improve the constructability of the design, 2) CMR has been shown to improve the relationships within the project team through increased collaboration which seems to reduce transaction costs of post-award change orders, and 3) providing real time pricing of project scope while the scope is being developed. Measuring design fee efficiency using construction dollars-to-design dollars ratios provides project managers with a new tool that allows them to quantify previously unmeasured benefits of employing CMR project contracts to efficiently add scope to projects, to the benefit of the owner.

5.6.1 Limitations

The C$:D$ design fee efficiency metric is a novel concept that provides an analytical tool where there was no tool previously. However, it is only one tool in the project managers' tool kit and caution should be taken when the calculated efficiency ratio is significantly higher than average to prevent erroneous results. Further investigation into the contract change history of the project in question would be warranted to validate the calculated ratio. Possible sources of error could result from 1) projects where the design contract value is increased due to reimbursable expenses that are not a result of owner-driven scope additions, 2) projects where the designer has errors and/or omissions in the documents and the owner decides it is in their best interest to pay for the additional cost of redesign resulting in a contract modification for the designer and additional scope for the builder, or 3) other circumstances that could provide positive indicators that are not validated by the project history.

5.6.2 Next Steps

Further research should investigate whether the owner's ability to add scope to a CMR project after the GMP, without the limitations imposed by DBB project delivery, is a perceived benefit of utilizing CMR project delivery within the public higher education construction market. Textual analysis of a larger collection of CMR contracts may provide useful examples of contract language that can be incorporated to improve synchronization between the designer and general contractor’s agreements, specifically its role in post-award scope changes. Additionally, further study is required to determine if the C$:D$ ratio can be generalized as a measure of design fee efficiency for CMR projects outside the public university sector. Additionally, it would be beneficial to either 1) replace the imputed data in the shadow projects dataset with actuals and re-run the analysis or 2) assemble a new comparable set of project data to analyze and compare with the initial analysis. Further development of this design fee efficiency metric is needed to provide robust, reliable guidelines for employing it as an analytical tool for capital projects.

5.6.3 Acknowledgements

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6.0 Best Practices in Delivering Public University Capital Projects with Construction Manager-at-Risk

Gransberg, N. and Pittenger, D. (2021). “Best Practices for Delivering Public University Capital Projects with Construction Manager-at-Risk.”

6.1 Paper Synopsis

Validation of the research was conducted through a content analysis of external RFQs and RFPs, a survey of public universities capital projects staffs, and an exploration of three successful projects from the database that appeared to have been poorly managed according to traditional project performance metrics of cost and schedule growth. The validation process disproved one of the research hypotheses and strongly supported the remaining ones and provides insights into the perceptions of CMR delivery by owner’s representatives and ways that project teams have successfully delivered complex projects that met owner and end user goals.

6.2 Research Methodology

This study employed qualitative research methods to accomplish 1) construct validation and 2) internal and external findings validation. Construct validation was conducted through literature review of papers addressing the use of CMR in public projects exploring causes of scope growth, owner perspectives on adding new scope to existing CMR projects, and the impact of collaboration, project team integration, and early contractor involvement. Internal validation was conducted through 1) surveying capital projects staff at participant universities which had provided project data for the project database compiled as a part of this research project and 2) a case study analysis of three CMR-delivered projects. External validation was conducted 1) by including capital projects staff from other non-participant public universities in the same survey and 2) content analysis of RFPs and RFQs for CMR-delivered public education-sector projects that had not been included in earlier analyses. The purpose of this multimethod research was to achieve "data envelopment" thru triangulating the findings of each method by approaching the research questions posed from multiple directions (Williams 2003).

6.3 RFQ/RFP Content Analysis

RFQs and RFPs for CMR projects were collected by publicly available internet search, resulting in the collection of 44 individual procurement documents. Content analysis produced a count, by document, of the number of incidences that an RFQ/RFP addressed a selection of 95 criteria common to these types of documents. Common criteria were organized into the following groups:

1. Administrative and Cost Data
2. Type of Procurement Process
3. Submittal Requirements
4. Interview Process and Requirements
5. Method of Award
6. Preconstruction Services Included

Consolidated counts for criteria in each category were assembled, sorted, and analyzed. Results of this analysis provided an insight into 1) characteristics of general contractors that are perceived as indicators of competence and 2) common patterns in the methodologies of public university owners in procuring general contractors for CMR delivered projects. A combination of visual inspection and OCR tools were employed to reduce the content of each document into a summarized scope and numerical count of the presence of common criteria.

6.4 RFQ/RFP Content Analysis Results

This collection of RFQs and RFPs issued by public universities and educational institutions ranged in date from 2002 up to 2019 and had total value of more than $950 million. The 86% of documents came from public universities with the remaining 14% coming from public educational institutions such as community colleges or public-school districts. 55% of institutions utilized an RFP-only procurement process, followed by 30% which used an RFQ-only process. Only 5 organizations used a two-step RFQ + RFP process. 68% of institutions utilize a shortlisting procedure prior to award. These data can be found in Table 6.1.

Table 6.1 Administrative, Cost, and Procurement Data

Project Budgets (Millions)			**Procurement Process**	**% of Tot**	**Count**
Range		$1.1 - $131.7	RFQ	30%	13
Mean		$24.94	RFP	55%	24
Median		$12.50	RFQ+RFP	11%	5
Organization	**% of Tot**	**Count**	LOI	0%	0
University	86%	38	Other	5%	2
Other Educational Institution	14%	6	**Shortlist Procedure**	**% of Tot**	**Count**
Total		**44**	Yes	64%	28
			No	36%	16

An analysis of proposal submittal requirements can identify the level of importance certain selection criteria are to an owner and, where there is a high level of commonality across owners, can identify which common criteria that are considered important in general (Table 6.2). Owners use the RFP submittal requirements to manage risk associated with procuring the general contractor by asking for proof of applicable experience, staff qualifications, management style and associated plans, cost of proposed fees, financial state of the proposer, and history of any negative events that could disqualify the proposer from the selection. The criteria with the highest prevalence were a requirement to provide references from past projects (82%) followed by two requirements for providing past project experience in CMR (77%) and related projects (73%). When considered in aggregate, the most important factors these owners were interested in were being able to select a reputable firm (references) that was competent to deliver a specific type of project (related experience) using CMR project delivery (CMR experience). In other words, these owners wanted to select a general contractor that has already learned how to deliver a project using CMR on somebody else's dime. The next five most important criteria consist of various plans and the general contractor's organization, ranging from 59% to 61% of all documents in the sample. The remaining submittal requirements present in over 50% of the sample are a history of claims and litigation (59%), qualifications of the project manager (55%) and superintendent (52%), and proof of adequate bonding capacity (52%). Management plans provide an insight into the way a general contractor approaches the work and an opportunity to assess their level of sophistication and construction expertise, which owners in this represented sample consider to be highly important in selecting a best-qualified contractor. This provides support to conclusions in Chapter 6 which posits that project change can be incorporated more efficiently into CMR projects than with DBB as a function of improved cooperation and collaboration between the general contractor and the designer. An effective method of evaluating a general contractors potential for cooperative and collaborative behavior is an analysis of their management plans which should clearly identify the ways in which they intend to integrate with the designer of record and owners' staffs.

It is of particular interest to note that pricing requirements were not present in more than half of the RFQs and RFPs analyzed. Pricing submittal requirements included proposed preconstruction services fee (48%), proposed construction fee (36%), proposed general conditions fee (14%), proposed post-construction services fee (9%), and rates for self-performed work (7%). This shows the most owners do not consider pricing as an important criterion for selecting the best qualified general contractor. This provides support to lessons learned from case study analysis in Chapter 2 recommending that owners, when using a best value/qualifications-based selection, the agency should not assign so much weight to the price evaluation criteria that is overwhelms the ability to select the best qualified contractor. When taken together with heavy emphasis on selecting the best-qualified contractor, these statistics provide support to conclusions drawn from the Utah, Kansas, and Oregon project case studies in Chapter 2 which found that owners have the potential to mitigate project risk more effectively when they have the ability to negotiate the cost of construction with a well-qualified contractor, sharing the risk for the work rather than optimizing for low cost and attempting to shed the risk onto the low bidder. This also supports conclusions from Chapter 6 that explained the increased efficiency in design fee expenditures for post-award growth flowing from the ability to negotiate project costs and share construction risk with the project team.

Table 6.2 Proposal Submittal Requirements and Content Provided

Submittal Requirements	**Category**	**%**	**#**	**Submittal Requirements**	**Category**	**%**	**#**
References from Past Projects	Experience	82%	36	Quals - Quality Manager	Qualifications	39%	17
CMR Project Experience	Experience	77%	34	LEED Certification Plan	Management	36%	16
Related Project Experience (non-CMR)	Experience	73%	32	Proposed Construction Fee	Pricing	36%	16
Quality Management Plan	Management	61%	27	DBE Plan	Management	34%	15
Safety Management Plan	Management	61%	27	Other Key Project Plans	Management	32%	14
Schedule Control Plan	Management	61%	27	Current Workload	Capacity	25%	11
Organizational Structure/Chart	Management	59%	26	Preliminary Project Schedule	Scheduling	23%	10
Subcontracting Plan	Management	59%	26	List of Proposed Subcontractors	Management	23%	10
Claim History and Litigation	Neg. History	59%	26	Quals - Team	Qualifications	18%	8
Quals - Project Manager	Qualifications	55%	24	Default History	Neg. History	16%	7
Quals - General Superintendent	Qualifications	52%	23	Proposed Self-Performed Work	Management	14%	6
Proof of Adequate Bonding Capacity	Capacity	52%	23	Proposed General Conditions Fee	Pricing	14%	6
Quals - Estimator/Scheduler	Qualifications	48%	21	Claim Reduction/Resolution, Dispute Resolution Plan(s)	Management	14%	6
Cost Budget Control Plan	Management	48%	21	Construction Traffic Control Plan	Management	11%	5
Proposed Preconstruction Services Fee	Pricing	48%	21	Proposed Post-Construction Services Fee (Profit)	Pricing	9%	4
Quals -Other Key Personnel	Qualifications	45%	20	Rates for Self-Performed Work	Pricing	7%	3
Quals - Preconstruction Manager	Qualifications	41%	18	Analysis of Construction Budget	Cost Estimating	5%	2
RFQ/RFP Content Provided		**%**	**#**	Quals = Qualifications; DBE = Disadvantaged Business Enterprise;			
Preliminary Plans/Specifications		48%	21	LEED = Leadership in Energy and Environmental Design			
Quality Management Roles and Responsibilities		41%	18	CMR = Constructin Manager-at-Risk			
Design Criteria Checklists		25%	11				

6.5 Survey Research Methodology

A 14-question survey (Addendum B) was submitted to capital projects personnel employed at 32 public universities in 17 states where legislation currently allowed CMR project delivery using cloud-based platform (Survey Monkey). The goal was to receive a minimum of 20 responses, with a target response rate of at least 10%, necessitated sending surveys to more than 200 individuals. Most universities maintain a limited professional staff to oversee capital projects delivery, typically less than 20 employees, of which roughly half are directly involved in project management. The University of Oklahoma and the University of Kansas, for example, both maintain a staff of 16 (3 executive administrators, 6 project managers, and 7 support staff), of which 9 employees each would be the idea target to respond. Larger universities and statewide university systems may have additional staff whereas smaller institutions may only have 2 or 3 full time employees, relying on design and construction management subcontractors to provide professional planning and oversight. Construction projects used in the project database were gathered from 23 universities, so it seemed reasonable to expect at least 1 response from each school to the survey, however, web scraping provided limited results for university staff contacts, so additional schools within each region were selected as proxies. Most of these additional universities had been contacted during the data collection phase for the project database and included in Table 6.3. 27 responses were received out of 228 requests, of which 23 were fully responsive, reaching the 10% target response rate.

Table 6.3 Targeted Public Universities

Montana State University	University of Alabama
New Mexico State University	University of Georgia
Oklahoma State University	University of Kansas
Oregon State University	University of Missouri
Tarleton State University	University of Montana
Texas Tech University	University of Nebraska

The survey consisted of three sets of questions 1) 6 multiple choice questions focused on the project development and design phases, 2) 7 multiple choice questions on experiences on recently completed projects, and 3) an open-ended textual response question asking if there was anything respondents would like to add. The questions were developed with results of prior research conducted comparing DBB and CMR project delivery methods in public university capital projects with a view to validate their findings (Addendum B). Demographic information was limited to the respondent's university and their role of which there were 12 executives and 11 non-executive staff from universities in Arkansas, Colorado, Georgia, Kansas, Oklahoma, New Mexico, and Texas. This fortuitous split between executive and non-executive staff allowed further analysis to compare the delta in perceptions between the two in the subsequent analysis.

Response data was organized and consolidated to enable an effective analysis, covered in the next section.

6.6 Survey Research Analysis

Consolidated results were sorted by question-response, by respondent organizational role, and by affiliated university. Respondent organizational roles were consolidated into two categories: Executive/Director and Project Staff. Minor inconsistencies carried over from the online survey platform were corrected and unnecessary data was deleted, such as date-time alphanumeric strings, etc., and finally visually inspected for missing datapoints or obvious transcription errors. Responses were converted into numerical values then percentages of total responses, by question. These values were consolidated into a new table with a summarization of each survey question by questions set with its related research objective hypothesis. Free text comments from the final question were preserved in a separate worksheet. A final quality control inspection was conducted comparing the tabulated results with the raw output from the survey platform. Question responses were then compared with their related hypothesis to determine if it was disproved or validated. Tabulated results and free text comments were finally reviewed to identify any unexpected results.

6.7 Survey Research Results

Responses to the survey questionnaire were received over a period of six months (March to August 2021) with 23 fully complete responses. Respondent roles/job titles were broken down into two groups: Director/Executive (12 respondents) or Project & Support Staff (11 respondents). A further breakdown of Project & Support Staff can be found in Table 6.4 and a breakdown of organizational role by affiliated university can be found in Table 6.5

Table 6.4 Breakdown of Respondent Organizational Roles

Organizational Role	**Count**
Director/Executive	12
Capital Projects Staff	
Project Manager/Construction Administrator	6
Designer (Architect/Engineer/Interior Design/etc.)	4
Accounting/Finance/Contract Specialist	1
Total	23

Table 6.5 Respondent University Breakdown by Organizational Role

Organizational Role	**Exec**	**Staff**
Colorado State University	0	1
North Dakota State University	0	1
Oklahoma State University	2	0
Oregon State University	1	0
University of Arkansas	3	0
University of Colorado	1	4
University of Georgia	3	0
University of Kansas	0	1
University of New Mexico	1	0
University of Oklahoma	0	4
University of Texas	1	0
Totals	**12**	**11**

Responses to questions one through six are shown in Table 6.6. Responses to the second question were as expected, indicating that CMR projects regularly experienced owner-driven scope growth at respondent universities, as was shown in Section 3.0 where post-award design fee cost growth had a median value of 15%. Responses to the third question were a surprise, with 91% of respondents indicating that a typical owner-driven scope change experienced in a CMR project would not necessitate a second procurement if the delivery method were DBB. This disproved Research Hypothesis 3a which posited that CMR-delivered projects allow owners to incorporate scope changes that would otherwise require a second procurement if the project was delivered under a DBB contract model. Responses to questions four through six overwhelmingly favored CMR over DBB delivery for projects with increasing complexity especially if additional funds could potential become available during design or construction phases.

Table 6.6 Responses to Survey Questions 1 to 6

General Questions:	**Yes**	**Exec/PM**	**No**	**Exec/PM**
1. CMR authorized at institution?	100%	23/0	0%	0/0
2. Owner-driven Scope added regularly in CMR projects? ***(Hypothesis 3)***	83%	9/10	17%	3/1
3. Typical Owner-driven scope growth in CMR require re-procurement in DBB? ***(Hypothesis 3a)***	9%	2/0	91%	10/11
Preferred Delivery Method for:	**DBB**	**Exec/PM**	**CMR**	**Exec/PM**
4. University 3rd party stakeholders involved in determining scope ***(Hypothesis 4)***	17%	1/3	83%	11/8
5. Complicated site ***(Hypothesis 4)***	13%	0/3	87%	12/8
6. Additional project funds could become available during design/construction ***(Hypothesis 3,4)***	9%	0/2	91%	12/9

Responses to question seven (Table 6.7) favored CMR delivery with 74% of respondents reported working relationships on recent projects as “good” and 0% as “poor” whereas responses to DBB projects reported 57% as “good” and 22% as “poor”. These responses are indicative of 1) the value of qualifications-based selection (QBS) where the criteria other than cost alone are employed to procure the best-qualified general contractor and 2) the impact that increased project team integration and collaboration may play due to contractual relationships established between the project parties during the preconstruction phase. It should be noted that, given a larger survey sample size, there could be executives that report recent CMR working relationships as "poor". Executive responses to this question for CMR unanimously selected "good" indicating that leadership is much more likely to view working relationships in CMR-delivered projects positively compared to project staff who were more evenly split between "good" (5 responses) and "neutral" (6 responses) positions. The difference in response distribution for DBB working relationships was less pronounced for executives who were more likely to rate them as "poor" (4 responses) or "neutral" (3 responses) than "good" (5 responses) whereas project staff were more likely to rate them as "good" (8 responses) versus "neutral" (4 responses) or "poor" (1 response). Further investigation into the cause of this split in perceptions would be worthwhile.

Table 6.7 Responses to Questions 7 to 9

<u>Recent Project Experiences:</u>		**Good**	**Exec/PM**	**Neutral**	**Exec/PM**	**Poor**	**Exec/PM**
7. Working relationships with designer and general contractor? ***(Hypotheses 1,4, & 5)***	DBB	57%	5/8	22%	3/2	22%	4/1
	CMR	74%	12/5	26%	0/6	0%	0/0
<u>Typical Scope Change by Phase:</u>		**DBB**	**Exec/PM**	**CMR**	**Exec/PM**	**Same**	**Exec/PM**
8. More changes during design/preconstruction? ***(Hypotheses 2&4)***		17%	2/2	48%	7/4	35%	3/5
9. More changes during construction? ***(Hypotheses 2 & 4)***		48%	7/4	17%	1/3	35%	4/4

Responses to questions eight and nine (Table 6.8) asked which delivery method tended to see more changes during the design/preconstruction phase or the construction phase. The responses were almost mirror opposites of each other with CMR tending to see more scope changes during design/preconstruction and DBB during construction. These responses correlate with the way that project scope is developed in both delivery methods: CMR allows for collaborative scope development versus the scope being developed exclusively by the owner and designer in DBB. Scope growth is an inevitable function of the owner figuring out exactly what it needs from a project to meet its goals and expectations for the finished facility. This is strongly supported in the literature, reviewed both here in this and previous chapters. Scope change is more efficiently incorporated into a project before the actual construction commences, ideally before a lump sum price for the work is agreed to as this provides a greater opportunity for the general contractor to take advantage of economies of scale in procuring material, equipment, and labor. Late scope changes typically come at a higher per unit cost resulting from the additional coordination and administrative effort required of the general contractor to secure additional construction forces and logistics to accommodate the increased scope. These responses seem to indicate that CMR delivery provides a better vehicle to efficiently incorporate owner-driven scope changes into the project prior to commencing the work.

Table 6.8 Responses to Questions 10 and 11

Owner-Driven Scope Change by University 3rd Parties:	**Every Project**	**Exec/PM**	**Routinely**	**Exec/PM**	**Occasionally**	**Exec/PM**
10. After design contract awarded? ***(Hypothesis 3)***	39%	7/2	43%	2/8	17%	3/1
11. After construction contract awarded? ***(Hypothesis 3)***	9%	2/0	43%	4/6	48%	6/5

Questions ten and eleven sought to gauge how typical scope changes driven by the owner's 3rd university clients (end users, administration representatives, facilities engineering, maintenance, college deans, etc.) occur after the design services contract is awarded and then after the construction services contract is awarded (Table 6.9). 43% of respondents indicated that university 3rd parties drove scope change routinely in both design and construction phases. The overall trend for 3rd party scope was more likely to occur during the design phase than the construction phase, but it is important to note that 0% of respondents indicated that these 3rd parties “never” drove scope change in either phase. These results indicate that university 3rd parties can be expected to regularly drive scope changes on projects both during design and construction. This can be highly disruptive to a project and cause negative impacts to both the budget and schedule if they are not well-managed. Responses to question four indicate a preference for CMR project delivery when 3rd parties are expected to play a significant role in developing the project scope, which also correlates with a primary theme from interviews conducted in Chapter 4 where expectations management was expressed as a critical function for the parties of the project team to control scope change and additions responsibly to keep projects on track. It is the owner’s responsibility to ensure that a sufficient amount of 3rd party requirements is incorporated into the scope early enough in the design so that subsequent discovery and incorporation of new scope requirements do not negatively impact the project team’s ability to successfully complete the project. Similarly, the designer’s responsibility is to be forthright and honest with the owner about the potential impact of newly added scope to a project so that expectations for what the general contractor will have to build are realistic both in cost and time impacts. These responsibilities are directly supported by the general contractor who provides priced options for the owner and designer to be able to make well-informed decisions from. CMR project delivery provides the lines of communication between these parties to enable these processes and open-books accounting to provide detailed, accurate cost estimates as quotes that can be reviewed and issued as change orders. Responses to question twelve confirmed that CMR is the preferred delivery method to incorporate late changes caused by the owner and/or 3rd parties with 74% indicating they favored CMR.

Table 6.9 Responses to Question 12

Preferred Delivery Method for:	DBB	Exec/PM	CMR	Exec/PM	Same	Exec/PM
12. Incorporate late scope changes caused by Owner/3rd parties ***(Hypothesis 3&4)***	4%	0/1	74%	11/6	22%	1/4

Question thirteen was intended to determine whether university capital projects staff recognized the ability to add owner-driven scope as a benefit of CMR project delivery. A little more than half of the respondents (Table 6.10) indicated in the positive, with twice as many executives selecting "yes" as project staff (8 executives/4 staff). The remainder of respondents were closely split between "no" and "no opinion". The largest number of executive responses were "yes", and the largest number of staff responses were "no opinion". The strong response to this question lends credence to the assertion that CMR delivery provides an effective contractual vehicle to incorporate late changes efficiently even though this benefit has not been previously identified in the literature.

Table 6.10 Responses to Question 13

Recognition:	Yes	Exec/PM	No	Exec/PM	No Opinion	Exec/PM
13. Ability to add owner-driven scope a benefit if CMR? ***(Hypothesis 3&4)***	52%	8/4	22%	3/2	26%	1/5

The final question of the survey was posed as a free-text, open-ended invitation to provide any additional information that respondents thought would be important to communicate. Nine respondents provided additional comments (Addendum C), which could be categorized into the following categories:

1. Local policies governing the use of CMR delivery (1 executive comment/4 staff comments):

- *By statue, we are allowed to use CM@R on projects with a total project cost over $5M. Between $1M and $5M we are required to use DBB.* (Director/Executive)
- *Projects have a funding cap that cannot be exceeded regardless of requests for added scope.* (Project Manager)
- *Historically we have not pursued DBB on large projects, but that has begun to shift as it has been felt that a lot of scope was evaporating in CMR deliveries.* (Architect/Campus Planner/Design Phase Manager)
- *CMR is typically an option on larger projects as it allows the contractor to have more control of the subcontracts. DBB is used for the smaller (typically no larger than 5 million, always under 1 million) project and added scope is not usually an issue on these. CMR must get approval from the state to be used as a construction method, DBB does not need such approval. The university always tries to carry a 5% contingency not only for unforeseen conditions but for scope changes as well, no matter the delivery method.* (Project Manager/Construction Administrator)

2. Benefits and positive outcomes for CMR delivered projects (4 executive comments)
    - *CMR is consistently a better approach. The overall experience is better, quality of work is superior, and at the end of the day, the overall cost is usually the same or similar and the project completion is usually quicker with CMR.* (Director/Executive)
    - *Costs that appear to be 'saved' during DBB usually turn out to equal the CMR original cost or exceed it.* (Director/Executive)
    - *CMR has proven to be a very valuable tool when used on major capital projects over the past 17-plus years.* (Director/Executive)

- *Over the last decade we have migrated to Target Value Design Build Lump Sum and Design Build with GMP project delivery and acquisition strategies using internal staff to develop the RFP and Design Criteria Documents. We have metrics associate with our now completed design build projects have outperformed both DBB and CMR in terms of schedule, cost/GSF and completed project quality.* (University Architect)
- *CMR costs less to build a project.* (Director/Executive)

Executive comments mirrored the functional roles that executives fulfill for their organizations being focused on identifying and implementing forward-looking solutions to meet current and future needs of their organizations and clients. Their comments provided insight into their experiences with and perception of CMR project delivery in public university capital projects.

Staff comments, similarly, mirrored their functional roles, being focused on the implementation of organizational policies and procedures, engaged in the real daily work of managing complex projects with hard budgetary and schedule constraints, responsible for being good stewards of taxpayer and donor generated funds to construct the quality facilities that will satisfy end-user needs and requirements for years to come. Their comments shared insights into how their universities selected project delivery methods, the effect of funding caps on scope changes, and lessons learned and trends in CMR as well as other project delivery methods.

6.8 Project Case Studies

The following section discusses a selection of successful projects included in this study that appear to have failed, according to traditional project performance metrics. Two of these projects were nominated for the Associated General Contractors' ACE awards in the year of their completion (Addenda D & E) and all three achieved LEED certification.

6.8.1 Five Partners Place Office Building, University of Oklahoma

The 5 Partners Place building is a $27 million, four-story, 100,000 square foot LEED certified commercial office building was programmed and developed in the late 2010's and built between 2012 and 2017 to provide space for several existing south campus tenants to move into larger spaces and to accommodate a major federal client with very specific construction criteria to be met, which drove the delivery method selection to be CMR. These factors contributed to the lengthy construction time and the quantity of change orders as unfinished spaces were leased and built out. This project provides a good example of how CMR delivery provides an effective way to deliver complex, underfunded projects where the scope is not fully developed by the time that construction needs to begin.

6.8.1.1 OU Research Campus Development CMR History

The University of Oklahoma began developing a research campus office park south of the main campus starting in the early 2000's that eventually resulted in nine total buildings: five tenant-finished office space Partners Place buildings, the National Weather Center building, the Radar Innovations Laboratory building, and the two Stephenson Center research buildings of which all but one was built using CMR project delivery. The first CMR delivered project on the

OU campus was the 1 Partners Place building, completed in 2003 by Lippert Brothers Construction, Inc. (LBI) and designed by The McKinney Partnership Architects (TMP). This project team was very successful at delivering this first CMR project which resulted in the delivery method's adoption by the university's Architectural & Engineering Services division which utilized CMR deliver for larger, complex projects that would benefit from early contractor involvement and integration into the design team. These two firms won contracts for and built four of the five Partners Place buildings, culminating with 5 Partners Place. They had developed an excellent working relationship over the previous 15 years and had successfully delivered multiple commercial building projects for the university.

6.8.1.2 Project Contract History

Development for the 5 Partners Place building began in 2010 as the popularity of existing office space on the research campus had created a need for another building. TMP was selected as the designer of record in November of 2010 on a percentage of construction fee (7.75%) plus a $65,000 lump sum to secure LEED certification and reimbursable expenses with a 10% markup for a sum of $1,731,250. The initial estimated budget for construction was $21.5 million and had not changed in the 18 intervening months when the general contractor was brought in under a preconstruction services contract in June of 2012 for a lump sum of $47,000. The project scope was refined and developed over the next five months to accommodate five tenants that had committed to leasing space in the building, planning for the remaining unfinished space to have all the building infrastructure necessary installed in it, and conducting at-cost value engineering to bring the project into the budget. LBI submitted a GMP to the university of $24 million, of which $2.24 million was owner contingency, $14.9 million was allocated to the building core and shell, $3 million allocated to finishing out spaces with tenant commitments, and $2 million allocated to future tenant space infrastructure.

LBI was issued eight change orders that increased the construction cost by $1.7 million, of which most was devoted to tenant finish outs for newly leased spaces and a combination of owner and tenant requested changes. TMP was issued ten contract modifications increasing their design fees by $228,000, half were pass through payments to the commissioning agent and the other half were dedicated to tenant build out and tenant/owner change requests. Construction on the building core and shell began in November of 2012 and substantial completion was granted in December of 2014. Six of the eight change orders issued to the general contractor occurred after they had been granted substantial completion, with the two largest for finishing out tenant spaces on the first and fourth floors.

6.8.1.3 Tenant Abandonment

OU Real Estate had lined up a tenant who committed to move into a significant portion of the fourth floor of the building, contributing funds to customize the finish out their future 9,100 square foot space. TMP fully designed the space for them and worked to extensively redesign it to reduce the cost to the tenant. This design work was being done at-risk in expectation of receiving a contract modification to cover the cost of the design. The university had exercised an option in the contract to preposition $72,600 of materials to accelerate the build out, which was expected to cost around $546,000. Soon thereafter the tenant decided they would be occupying the space and walked away. It is incredibly common in CMR delivered projects for designers and general contractors to provide services to an owner before they receive an official contract for the work which can place them in a difficult position from time to time when the funding fails to be secured. This kind of behavior communicates the level of trust that these firms place in owner and each other to share the risk so that they can all share the reward. TMP requested a contract modification to help cover the lost design effort associated with the tenant abandonment of the 4th floor spaces but reduced their fee by 20% as recognition that the owner had suffered from the event as well. A contract modification was issued to TMP in May of 2015 for the redesign for a lump sum of $26,208 and the work on the building continued. This kind of event can be devastating if the project team is poorly integrated and lacks trust in each other, especially for design firms which lack the financial depth and robustness as the owner and general contractor. Fortunately, TMP and OU had a longstanding relationship of mutual respect and the project survived. This event is a good example of how to maintain trust and collaboration in a CMR delivered project by sharing risk across the project team.

6.8.1.4 Bureau of Land Management Delayed Occupancy

The largest tenant at 5 Partners if the Bureau of Land Management (BLM) Oklahoma Field Office, which occupies over 14,000 square feet and more than half of the first floor and portions of the second floor with their Wild Horse and Burro Program staff, moving into the space in October of 2016, almost two years after the building core and shell were substantially complete. One of the university's primary motivations for building 5 Partners Place was the hope that the Bureau of Land Management would occupy the office space as they were looking to move the regional office out of their facilities in Tulsa. This remained a closely held secret for several years however, steps were taken in the design phase to provide the necessary infrastructure to make the building an attractive choice for the agency, adding reinforced floors for record stack rooms and additional conduit sleeves for power and data runs to the parking lot.

In May of 2014 the university capital projects staff were notified that the space would need a wet lab to potentially accommodate US Geological Survey employees that might be officing with the BLM. A contract modification was issued to the designer to design the lab who worked with the general contractor to adjust the layout and infrastructure in the space so that the lab could be built if the BLM decided to move in. The project proceeded with construction and completion of the building core and shell. TMP worked with the university real estate office, beginning in June of 2015, to put together test-fit feasibility plans based on details of BLM's expressed requirements. In late January of 2016, the lease agreement with BLM was imminent, so the university directed the designer to complete the design for the build out of the first and second floor areas, which was all done at-risk until a contract modification was issued in June of 2016 to pay for the previous 12 months of design effort and subsequent construction administration of the work. TMP's at-risk proactive engagement with the real estate office, the General Services Administration, and the BLM provided the continuity necessary to successfully design and construct the facilities to meet every stakeholder's needs over a relatively compressed timeline once the decision to move was made.

LBI had maintained a reduced staff on site to work through tenant finish outs, warranty work, and minor changes associated with the building being incrementally occupied, which over time was reduced to a junior assistant superintendent who maintained an office onsite and continued to meet regularly meet with the campus capital projects staff and designer to keep abreast of future work. Over the summer and fall of 2015, LBI increased their participation with TMP in pricing the BLM tenant build-out and began to organize for a late-spring/early-summer construction start date. The scope of the change order required selective demolition and relocation of existing mechanical and electrical infrastructure, installing partition walls, casework, doors, signage, a secured entrance, and fenced parking area. LBI was able to involve key trade subcontractors that had been brought under contract for the building core and shell in early 2016 to collaboratively develop their work packages enabling the general contractor to efficiently remobilize on site and begin work that summer. The BLM set their move-in date to the first of October 2016 to coincide with the expiration of their current lease on facilities in Tulsa, which meant that substantial completion had to be accomplished before the end of September. LBI began the work in early August under a verbal agreement, receiving a change order for the scope of the work on August 31st and receiving substantial completion for the office spaces less than one month later, on September 29th, allowing the BLM to move in on time. The general contractor took another month after the interior work was completed to finish constructing the parking lot gates and fence. Phasing the work to accomplish owner and tenant goals for move-in mitigated the financial risk associated with delays, additional leasing cost for the BLM and lost revenue for the university real estate, in a compressed timeline. Additionally, completing the work in two months reduced the cost of general conditions associated with the change order and provided a more efficient delivery of the construction scope.

6.8.1.5 Owner Representative Continuity Disruptions

Continuity in the members of a project team is crucial to the success of the project as many of the collectively developed decisions made by the owner, designer, and general contractor over the lifespan of the project often are not written down or fully captured in meeting minutes, email conversations, and official documentation and, even if it were so, is a big ask for a new team member to get up to speed on. The university had four different project managers on this project, the first one oversaw the planning and programming of the project and the commencement of construction but left the organization halfway through the building core and shell build. The second project manager took over during the middle of the build and oversaw its completion and tenant changes until he retired in the summer of 2015. The third project manager took over in mid-2015 and oversaw the remaining tenant change orders and the initiation of the after the BLM design work before handing of the project to a fourth project manager in early 2016 and stayed on the project until it was finally closed out in 2017. The owner's role in setting project goals, identifying key success factors, making decisions, and providing leadership to the project team can be a difficult endeavor yet these functions provide the authority and direction needed to successfully complete construction projects. Discontinuity in project leadership can cripple a project due to differences in communication and management styles, even if outgoing and incoming representatives are competent, experienced, and conduct a good handover of project documents. The 5 Partners Place project experienced this disruption three times in the project and yet was able to deliver the project successfully and efficiently relying on the strong relationships between the designer and general contractor who carried the project over the finish line. The relationship between TMP and LBI was the keystone to completing this project successfully, their initiative in proactively engaging with third party stakeholders and willingness to begin work on a verbal agreement mitigated the disruption from the constant changes in the owner's project leadership.

6.8.1.6 Performance Metrics

The 5 Partners Place Building project has mixed performance according to traditional metrics. The project construction cost grew 9% from the early estimate but only 8% from the GMP to completion, which would be typically considered an acceptable amount of cost growth as many university systems have a 10% cap on change orders before the project requires a special authorization to exceed this limit. Design fee cost growth was 18%, according to the contract modifications, however TMP coordinated the payment $103,141 for the commissioning agent as a pass-through fee without any markup, which is unusual for projects on the OU campus given that the capital projects staff typically bring the commissioning agent under a direct contract with the owner. Given the discontinuity of project leadership, TMP volunteered to coordinate the commissioning and handle their payment at zero cost. Considering these irregularities, the actual design fee cost growth was only 7%, adding $125,000 to the initial contract. Schedule growth for the project, however, was 44%. The initial project schedule was planned for 584 days of construction but tool a total of 783 days due to the extended lease-out of the tenant office spaces and delay associated with moving the BLM into the building. This project experienced a steady stream of owner-driven scope change over the life of the project which was managed well because of project team integration between the designer and general contractor. Design fee efficiency for post award changes had a C$:D$ value of $13.32, which is well above the mean value of $8.48 for DBB project post award scope changes. Considering the deleterious effect of inconsistent owner's representation, this efficiency ratio for developing construction scope illustrates an excellent example of how CMR delivery enables a more efficient incorporation of scope changes than found in DBB delivery. Had the owner chosen to deliver this building project under DBB contracts would have theoretically reduced the capacity to develop the amount of additional scope from $1,663,6190 to between $552,000 to $1,111,500, which very well could have impacted the ability to move in the BLM, which cost $893,000. Conversely, the theoretical cost for the owner to pay for the necessary scope additions under DBB delivery would have had an additional design cost of between $71,000 to $252,000. This additional design cost would have to be either passed onto the tenant or would have pushed the design fees over the 10% change order cap, requiring the capital projects staff to go back to the board of regents to ask for more money. Finally, the C$:D$ value is a concrete quantification of the quality of integration in the project team, specifically between the designer and the general contractor.

6.8.1.7 Lessons Learned

This project provides several useful lessons learned. A highly integrated design and construction team that has a well-established relationship of trust and confidence in each other has the potential to deliver a complex project successfully meeting the owner's key success factors despite discontinuity in the owner's project leadership. The value of the relationship established between a designer and general contractor is difficult to quantify in theory but is simple to observe in practice. Selecting the best qualified designer and general contractor is more important on non-standard projects that have increased levels of complexity and risk associated with the impact of 3rd party stakeholders, both internal and external to the university, that are highly involved in developing the scope of the work and whose satisfaction is necessary to meet the owner's key success factors for the project. Finally, a highly qualified CMR project team has the potential to carry a complex project to successful completion and efficiently incorporate scope changes and additions even when the owner's project management is in flux. This project provides strong support to the conclusions from research conducted in Chapters 2, 3, and 6:

1. CMR project delivery provides greater contractual flexibility to incorporate owner-directed and late scope changes to capital projects on public universities. (Hypothesis 3).

CMR delivery provided an effective vehicle to build a tenant finished office building capable of being utilized prior to every space being completed and allowed the late finish out of a large section of the building (14,000 square feet) for a federal agency with a range of specialized requirements to satisfy federal regulations for occupancy.

2. Contractual language governing the relationship between the designer and the general contractor should be well-synchronized (Hypothesis 5).

   Contract documents utilized were well synchronized providing an enforceable baseline expectation for collaborative behavior. The well-established professional relationship between the designer and the general contractor was given the latitude to provide a greater level of service to the owner, 3rd party stakeholders, and tenants despite disruptions from changes to the owner's project team.

3. CMR project delivery provides the opportunity to incorporate owner-driven scope changes more efficiently than DBB providing greater value for money to the owner (Hypotheses 1, 3 & 4).

   The relative quality of project team integration can be measured by the C$:D$.

   $C\$:D\$_{Change} = \$13.32$

   Post-GMP Construction Scope Change = $1,663,610

   Design Fee for Owner Driven Scope Change = $124,913

   Theoretical Cost of DBB Design Fee Scope Change = $71K to $252K

   Theoretical DBB Scope Change Capacity Reduction = $604K to $1.1M

6.8.2 Biotechnology Building E-Wing Addition, University of Colorado Boulder

The Jennie Smoly Caruthers Biotechnology Building's E-Wing is an award-winning, certified LEED Platinum, 57,500 square foot teaching and research laboratory addition to the Jennie Smoly Caruthers Biotechnology Building located on the University of Colorado at Boulder's (CU Boulder) east campus and hosts undergraduate, graduate, and industry biotechnology research, housing the university's BioFrontiers Institute and private industry partner companies (CU Boulder 2021). Industry tenants include, at the time of this writing, Agilent Technologies, Arpeggio Biosciences, Edgewise Therapeutics, Double Helix, VitriVax, and Wavi. Special research campuses are a common feature on many major public universities with strong research programs that provide tenant office space and access to advanced research facilities to private industry partners that intend to partner with on-campus research staff and students. The project received awards from both the Engineering News Record (Best Higher Education/Research Project – Merit) and the Associated General Contractors (ACE Award Best Building Project – General Contractor $10-$40 million) (AP Construction 2021). This section will explore how CMR project delivery provided the vehicle need to complete this complex project.

6.8.2.1 Project Contract History

Capital projects staff for CU Boulder delivered this project using standard form CM/GC contracts developed by the State Architect of Colorado's office, which contain an excellent example of highly synchronized preconstruction and design contract language. The designer was awarded their initial contract in January of 2015 and received six cost additive amendments and a final deductive amendment that provided a credit back to the owner. The general contractor was awarded the contract for preconstruction services in March of 2015 and received five cost additive amendments, nine zero cost amendments, and one deductive amendment returning a credit back to the owner. Full details are shown in Table 6.11

Table 6.11 CU Boulder E-Wing Design and Construction Contract History

DOR: HDR Architecture, Inc.			CMR: Adolfson & Peterson Construction						
Contract	**Date**	**Sum**	**Contract**	**Date**	**Precon Fee**	**Const. Services Fee**	**General Conditions Fee**	**Direct Cost of Work**	**Total**
Original	27-Jan-15	$2,670,290	Original	5-Mar-15	$75,000	$0	$0	$0	$75,000
Mod 1	25-Jan-16	$199,043	Mod 1	25-Feb-16	$41,536	$612,500	$1,210,631	$10,903,082	$22,767,749
Mod 2	27-Apr-16	$5,520	Mod 2	23-May-16	$2,263	$18,243	$85,621	$2,602,832	$2,708,959
Mod 3	14-Jul-16	$5,800	Mod 3	28-Sep-16	$0	$0	$0	$0	$0
			Mod 4	15-Nov-16	$0	$0	$0	$0	$0
Mod 4	3-Jan-17	$41,886	Mod 5	5-Jan-17	$0	$0	$0	$0	$0
			Mod 6	23-Mar-17	$13,140	$105,897	$462,765	$3,418,198	$4,000,000
			Mod 7	5-May-17	$0	$0	$0	$0	$0
			Mod 8	7-Jul-17	$0	$0	$0	$0	$0
			Mod 9	26-Jul-17	$560	$11,716	$0	$138,707	$150,983
Mod 5	24-Jul-17	$79,260	Mod 10	31-Aug-17	$23,788	$191,710	$665,428	$7,159,462	$8,040,388
Mod 6	4-Oct-17	$3,060	Mod 11	19-Dec-17	$0	$0	$0	$0	$0
			Mod 12	16-Apr-18	$0	$0	$0	$0	$0
			Mod 13	23-Sep-18	$0	$0	$0	$0	$0
			Mod 14	31-Oct-18	$0	$0	$0	$0	$0
Mod 7	19-Dec-18	-$11,099	Mod 15	8-Feb-19	$0	$0	$0	-$418,550	-$418,550
Total		**$2,993,760**	**Totals**		**$156,287**	**$940,066**	**$2,424,445**	**$33,803,731**	**$37,324,529**

6.8.2.2 Project Financing History

The Jennie Smoly Caruthers Biotechnology Building was originally developed in 2005 as a three-phase project due to funding limitations with only sufficient state funding to complete the first phase. The project was rescoped to take advantage of cash funding internal to the campus, descoping the state-funded portion of the project and utilizing $148 million to complete the first two project phases which constructed the four-story building shell consisting of an auditorium and four wings. The university received a $15 million grant from the National Institutes of

Health which completed a portion of the buildout and finish for several laboratories, offices, and accessory spaces. The state subsequently authorized $6 million in state funding to complete the interior buildout and an additional $4 million in cash to design and begin construction on the E-Wing. The university received an additional authorization of $15 million in state funds and $13.2 million in cash to expend during the 2015-2016 fiscal year, bringing the total appropriation of funds to $32,266,168. The university requested, in June of 2017, an additional $10.9 million in supplemental funding to an "*insufficient construction labor force in the region, an unfavorable bidding climate for outfitting highly technical teaching and research laboratories, and a ten-year delay in the project's initial construction schedule*" (CU Boulder 2017) bringing the total cost to $43,169,753. It is important to note that the amount of funds allocated to a project cover design and construction costs as well as owner costs associated with developing, administering, furnishing, and operating the facility so they do not track straight between costs expended as payments to the builder and designer.

6.8.2.3 Phasing an Underfunded Project

The university had developed programming requirements for the new addition at an estimated value of roughly $38 million moving forward with obtaining approval from their board of regents. The designer was selecting in late 2014 with contract award to HDR Architects, Inc. in January of 2015, prior to having obtained full funding for the project. A review of the May 2015 University of Colorado Board of Regents Capital Construction Subcommittee meeting minutes (Capital Construction Subcommittee 2015) showed that only $10 million had been appropriated, with the State of Colorado committing to allocate a total of $21 million to the project with responsibility for the remaining $17 million assigned to the university. This is a common feature in the long work of financing public university capital projects where funds are committed from various agencies, by issuing debt instruments, and fundraising among donors. The facilities construction staff at CU Boulder recognized the need for specialized construction expertise to be able to successfully deliver this project concurrently as additional funding was secured. They quickly followed up the design services award by selecting a general contractor only a month later, awarding the preconstruction services contract to Adolfson and Peterson Construction. They were able to work closely with the designer to phase the project around the owner's financial constraints by breaking down the scope into the base contract work that consisted of a four-story building core and shell plus the academic programing spaces for the first phase and individual labs within the addition into separate work packages as priced alternates to the base contract that were completed in the second and third phase. This allowed the project team to begin preliminary investigative work in the spring of 2015 by the owner issuing a series of notices to proceed (NTP) with fixed not to exceed (NTE) limits and substantial completion and final acceptance dates for each phase. An NTP was issued in December of 2015 for prework vibrations monitoring, required by building tenant researchers that were conducting experiments with rats and needed to determine if the construction work would affect the study, which was continued during the length of the project (AP Construction 2021). The third NTP was issued in January 2016 to mobilize for construction. The project schedule, provided in the first contract modification issued which also established the GMP, showed that preconstruction activities began in March of 2015 and planned to be complete in August of 2016, running concurrently with construction for a full seven months starting in February of 2016, aligned with the university's academic calendar (Table 6.12). Subsequent work packages for laboratory facilities, an elevator, landscaping, and site furnishing and were priced as seven alternates to the base contract and executed by change order if funding became available to cover the work. Eventually, the university was able to raise the remaining funds needed to complete the building which included a $2 million donation from John and Anna Sie, the founder of Starz Entertainment and longtime CU Boulder philanthropists (Knoss 2017). Phase 1 occupancy for the building core and shell was substantially complete on April 24th and final completion was achieved on May 11th. Phase 2 occupancy for the second-floor laboratories was granted in September of 2017 while Phase 3 work continued on the ground and 1st floor offices and laboratory spaces for the next year. This strategy of using “planned” change orders should be considered a best practice for delivering partially funded, complex projects.

Table 6.12 E-Wing 95% CDs Schedule Work Packages – Contract Amendment #2

Work Packages - 95% CD Schedule	**Start Date**	**Finish Date**
Preconstruction Services Activities	2-Mar-15	11-Aug-16
Site Mobilization	8-Feb-16	9-Mar-16
Demolition	15-Feb-16	6-Oct-15
Early Sitework	16-Mar-16	18-May-06
Foundations & Substructure	23-Mar-16	31-May-16
Superstructure	18-May-16	9-Sep-16
Exterior Envelope	21-Jul-16	23-Dec-16
Roofing	30-Aug-16	11-Nov-16
Core and Shell + Academic Space	13-May-16	7-Feb-17
Elevator	30-Aug-16	5-Dec-16
Final Site Development	17-Oct-16	21-Apr-17
Final Inspections	4-Nov-16	20-Feb-17
Closeout	4-Jan-17	21-Feb-17

6.8.2.4 Strategic Subcontractor Buyout and Design-Assist Roles

The general contractor brought on subcontractor trades strategically utilizing a phased buyout of the project scope by bringing on key trades in design-assist roles for developing and pricing work packages around the available funding. AP sought out competent subcontractors that had experience working on the Boulder campus and were familiar with the university’s construction administration processes including several that had worked on the original building project. This enabled the general contractor to efficiently accomplish as much work as was financially feasible and to have established relationships with subcontractors that allowed for portions of the work to be delayed until finding was procured and then collaboratively escalated. This process allowed the general contractor to remain mobilized onsite after the core and shell plus academic space phase was completed and flow directly into finishing out the various lab spaces, avoiding the cost and impact of multiple mobilizations.

6.8.2.5 Mockups and BIM Modeling Accelerate Approvals

The E-Wing project contained several nonstandard features of work that required extra effort to receive timely approvals. The building envelope's architectural appearance was a critical success factor for the owner who expected the addition to blend seamlessly with the existing building and match the architectural context of the campus. Universities with distinctive architectural styles rely heavily upon their capital projects staff to maintain the consistency in finished to renovations and new buildings. For example, the University of Oklahoma's architectural style is called Cherokee Gothic and consists of brick and architectural cast stone exterior finishes accented with gothic flourishes that match the early buildings erected on the campus in the late 1890's and early 1900's. CU Boulder's self-named architectural style is referred to as University of Colorado Style and is characterized by sandstone walls, tile roofs, limestone trim, and black metal accents (CU Boulder 2018). AP constructed six different mockups to select the brick blends and grout pigments that best matched the existing building's envelope which had weathered over the years since it was built changing the colors of the original brick blend and grout. This mockup process should be considered a best practice for commercial building work in this market segment.

The general contractor developed a coordinated BIM model for the addition over the course of the preconstruction services phase that enabled the project to deconflict building systems, phase work to reduce the impact to ongoing operations in the building, and as tool to assist permitting with the campus authority holding jurisdiction. An example provided in their AGC award submission (AP Construction 2021) was a dance floor being installed above a mechanical chase. Flooring is not typically installed above mechanical chases but campus maintenance staff had requested the local for its ease of access The contractor recognizing the importance of satisfying facilities management's concerns and goals for the project, so it was incorporated into the BIM model which was used to guide final reviews for each floor with facilities management to ensure that concerns about servicing equipment and any final modifications could be incorporated.

6.8.2.6 Performance Metrics

The project's initial schedule for a 358-day project duration grew to a total of 928 days by completion because of the integrated approach the project team took to phasing the work to meet funding availability. According to traditional schedule growth metrics, this project saw 159% growth in duration, which could be considered a major failure in project management if the context of the growth was not well understood. The construction cost grew 31% from the initial estimate and 39% from the GMP with design cost growing by 16%. These metrics could also be interpreted negatively as a sign of poor scope definition and mismanagement if the context of the project were not understood. Design fee efficiency ratios provide an easily understood assessment of the quality of project team integration expressed as the efficiency of incorporating owner-driven scope changes into the project. The C$:D$ $_{Change}$ value for this project was $34.82, the dollar amount of construction scope that every additional dollar of design fee added to the project produced. DBB C$:D$ $_{Change}$ ratios calculated in Chapter 5 varied between an average of $4.42 and a median of $8.48. The project team for the E-Wing project was able to produce between four and eight times as much construction scope as could be expected in a comparable DBB-delivered project. If this project had been delivered effectively under a DBB delivery, the amount of construction scope added post-award could have theoretically been reduced by $11M to $12.7M due to the delivery method. If the university had been adamant about constructing the full scope in the additions, it could have theoretically increased the over cost of the project by $1.3 million to $2.9 million in addition design fees to obtain it. The $2 million Sie Foundation donation was just enough to carry the project over the finish line, to put things in perspective.

6.8.2.7 Lessons Learned

This C$:D$ ratio strongly supports Hypotheses 1, 3, and 4 and clearly demonstrates the value of CMR delivery for complex projects that would benefit from known advantages (shown in Table 1.11) 1) QBS selection of the general contractor, 2) continuous budget control, 3) construction and design team integration, 4) more ability to handle changes in design and scope and would be considered a highly successful project from the owner's standpoint by being able to deliver the full scope of the project in a cost-effective manner providing more value for the funding allocated to the project. This project provides strong support to the conclusions from research conducted in Chapters 2, 3, and 6:

4. Select the general contractor as early as possible in the design phase to maximize the potential benefits of CMR delivery (Hypothesis 1 & 4).

   Early contractor involvement enables the owner to make design decisions with more complete information with accurate pricing and understanding constructability issues

5. Contractual language governing the relationship between the designer and the general contractor should be well-synchronized (Hypothesis 5).

   Contract documents utilized were highly synchronized providing an enforceable baseline expectation for collaborative behavior.

6. CMR project delivery provides the opportunity to incorporate owner-driven scope changes more efficiently than DBB providing greater value for money to the owner (Hypotheses 1, 3 & 4).

   $C\$:D\$_{\text{Change}}$ = $32.82

   Post-GMP Construction Scope Change = $14,556,780

   Design Fee for Owner Driven Scope Change = $418,062

   Theoretical Cost of DBB Design Fee Scope Change = $1.3M to $2.9M

   Theoretical DBB Scope Change Capacity Reduction = $11M to $12.7M

6.8.3 Multipurpose Stadium, Colorado State University

The capital projects staff at Colorado State University were one of the earliest supporters of this research project and provided an incredibly useful set of projects that were critical to this research. When the campus architect, Mike Rush, handed over the dataset of their projects he pointed out that the largest project of the group looked like it was a failure by traditional project performance metrics for schedule and cost growth (Table 7.8), but it was considered an incredibly successful project. The key to its success was found in the CMR project delivery method which set the right conditions for the project team to incorporate new scope funded by late donations to the project after construction had commenced. This section will provide a brief overview of the project and how it provides a source of validation to previously identified research findings.

6.8.3.1 Contract History

Canvas Stadium is a 727,000 square foot, LEED Silver multipurpose facility opened in 2018 in the heart of the main campus of Colorado State University in Fort Collins, Colorado financed entirely by private donations and bond sales (CSU 2020). Fundraising began for the new stadium began in 2013 to replace the existing 32,500-seat stadium with a larger 41,000-seat stadium to help in recruiting out-of-state athletes and students (Wall Street Journal 2013) with construction commencing in May of 2015 and completion of the stadium portion of the building occurring in August of 2017 in time to play the first NCAA football game of the season. The original planned to cost for the stadium in 2012 was between $150-160 million for construction costs and an overall project budget of $243 million for approximately 670,000 square feet of space (RFP 2012) with the plan to be built in 20 months, beginning construction in October of 2014 and completion by May of 2016. The construction cost estimate was reduced to $125 million by October 2014 resulting from fund raising difficulties, which appeared to have cause a year's delay in the construction start. This cost was adjusted upwards to $195 million for construction, $220 million for the total project, in November of 2014 prior to seeking and receiving approval from the university's board of governors' approval during the first week of that December (CBS Denver 2014). The stadium project was delivered using standard form CMR contracts awarded to Populous, a major multinational sports and entertainment facilities designer out of Kansas City that partnered with ME Engineers out of Denver, in April of 2012 (Populous 2012) and then with M.A. Mortenson Company, a major American general contracting company headquartered in Minnesota in October of 2013 (American City Business Journals 2013). The State of Colorado refers to CMR as CM/GC for both horizontal and vertical construction. The university retained an owner's representative firm, Icon Venue Group, which was brought on to develop a preliminary feasibility study (Armbrister 2012).

6.8.3.2 Early Contractor Involvement

Mortenson was brought on board early enough in the project's design phase, in September of 2013, that they were able to provide a wide range of preconstruction services to the owner. The RFP for preconstruction services listed several specific services expected but left it open for the general contractor to be able to propose additional services that the owner may have not contemplated at the time of writing this procurement document. Specified preconstruction services in the RFP can be found in Table 6.13. The university architect put special emphasis on their expectations for project team integration using words like "cooperatively", "collaboratively", and "collectively" in key sections throughout the RFP. The following quotation was taken from the "Preconstruction Phase Services" subsection under the "Scope of

Services" section, and it does an excellent job of characterizing the expected tone of relationships between the project team parties (emphasis added):

> *"Furthermore, specific studies to understand cost implications of particular design solutions and/or material selections will be required throughout the Preconstruction Phase. It is currently anticipated that Contractor will be required to establish the GMP based on partially complete Construction Documents. At any time that the Contractor's estimate exceeds the Fixed Limit of Construction Cost, the Contractor will be required to participate in value engineering with the Project Manager, Architect, and Owner to collaboratively bring the design of the Project within such budget."*

Expectations must be established up front in CMR delivered projects to gain the opportunity for reaping the numerous potential benefits of this delivery method (Chapter 4.3.2) which should at least be done by writing them into the contract documents.

Table 6.13 Preconstruction Services Listed the CSU Stadium CM/GC RFP

Preconstruction Services		
General	Work cooperatively with the PM, Architect, and Owner	
	Constructability Reviews	
	Preconstruction Planning	
	Other Services as Reasonably Requested by Owner	
Cost	Cost Estimating Expectations:	
		Best Value
		Cost Certainty
		Meet Fixed Limit of Construction Cost
		Show Fees & General Conditions
	Cost Estimates	
		Conceptual Design Documents
		Schematic Design 50%
		Schematic Design 100%
		Design Development 50%
		Design Development 100%
		Construction Documents 50% - GMP
		Fees & General Conditions
	Collaborative Value Engineering to stay in the Budget	
	Show Access to Actual Market Pricing (Est & VE)	
		Provide Cost for Trade Subs to Assist in Est's & VE
Schedule	Scheduling	
		GMP Date
		Meet Project Schedule
	Specific Studies to Understand:	
		Cost Implications
		Materials Selection

6.8.3.3 Additional Non-RFP Preconstruction Services

Mortenson provided additional preconstruction services to the university that were not specified in the RFP. They provided assistance with public outreach to opposition groups that had coalesced in the Fort Collins community over concerns from churches and private citizens about construction impacts, game day traffic, and many that desired to save or renovate the existing stadium which was roughly three miles off campus. The general contractor the university in communicating project goals and expectations while an intergovernmental agreement was prepared between Colorado State and the City of Fort Collins which direct the formation of a “Stadium Advisory Group” which consisted of nine jointly appointed members that included business owners, community leaders, a pastor, two retired CSU faculty, and the county director of natural resources. This group served as an interface between the university, the city of Fort Collins, and the community while also overseeing the use of a “Good Neighbor Fund” established to mitigate impacts established by the university that promised to pay in $37,000 a year and fundraise for a $750,000 endowment (Henry 2015). Mortenson’s team participation and leadership in this preconstruction activity helped the project team keep the design schedule moving forward.

Mortenson’s preconstruction team used Populous’ design models to develop a 4D Building Information Model (BIM). BIM integrates schedules, material costs, logistical plans and simulations, submittal data, with building models produced by the designer of record. The general contractor used the 4D BIM model to mitigate schedule risk by synchronizing the model with the schedule. Mortenson used the BIM synchronization software called Syncho PRO to tie elements of the 3D model with their associated schedule activities in the Primavera P6 schedule and vice versa, linking schedule activities with 3D content into a common filetype (AGC 2017). This technique allowed the general contractor to evaluate proposed changes and modifications to the project with better information to understand potential impacts to the schedule, budget, and workflow. Mortenson established a monthly update to the synchronized 4D model as a forecasting tool to plan out the upcoming month’s work which was incorporated into the phasing plan and communicated to trade partners, the contractor’s internal staff, the designer, and the owner providing a visual representation of where the project needed to be in four weeks. This was especially helpful in developing the work plans associated with the radial grid system employed in the building's structure which was more complex due to long cantilevers supporting upper bowl seating. Logistical planning simulations were run in the model to develop the site logistics plan, sequencing of cranes and critical lifts with the installation of cast-in-place concrete, precast stadia seating, and structural steel erection (AGC 2017). 4D BIM provides a good visualization tool that can improve project communication and understanding by clarifying complex activities into a visual model that is simple to understand, reducing decision-making time and improving the quality of decisions made. A good example in this project was how concurrent work within the same area of the building was planned. The project schedule planned for concurrent work to occur on an upper concourse level (CMU block walls, roofing and mechanical equipment) and the elevated hard-lid soffit system being installed above it that precluded the use of traditional scaffolding. This drove the decision to use a suspended scaffolding system which was work was simulated and planned in the 4D model with the structural engineer and the scaffolding subcontractor, allowing an efficient installation that avoided making modification to the steel structure, mitigating potential negative impacts on the project schedule from the change (AGC 2017).

The general contractor is incentivized in CMR to help the designer prioritize efforts to produce complete documents for early work packages and to reduce potential delays in getting them released for construction. Every week that the design is delayed is one week less that the contractor has to complete the project and they are the ones who will be held liable if substantial completion dates are missed. Early schedule goals to begin work in 2014 and be finished by the summer of 2016 had been pushed due to fundraising and community opposition, so streamlining the design process became a critical goal to achieve the current project schedule. Work officially began at the end of the spring semester in May of 2015. Supporting preparatory work had to be completed over the summer with the first excavation on the stadium site occurring October of 2015. Being able to have the stadium open in time for the Fall 2017 NCAA football season was a driving concern. This kind of schedule constraint is commonplace in public university construction projects, attempting to reduce disruptions on campus during the regular school year by maximizing production over the summer and various holiday periods so that facilities can be substantially complete to open in time for students to return to campus, attend scheduled events, etc. In revenue generating facilities like stadiums, having them open in time for their regular competitive seasons is typically critical to the university having the financial capacity to make payments on construction financing (loans, municipal bonds, etc.). Missing scheduled payments hurts an institution's credit rating and can negatively impact their ability to issue debt to fund future work.

6.8.3.4 Collaborative Scope Definition and Refining

Mortenson brought a decision-making tool to the project team that was used to work through all the decisions that had to be made throughout the design and construction of the project, which was called the "Cost/Scope Alignment Tool" or CSAM (AGC 2017). They used this tool to help the owner define and refine the project scope that employed a matrix to visualize impacts that various design options had on project cost, schedule, and quality by sorting through the university's "wish list" to move forward on implementing options that provided the most value. Part of the function of this decision support matrix was to focus decision-making on identifying scope and solutions that would provide the 1) best possible facility, 2) meet project cost and schedule goals, and 3) serve the university and end-user needs into the distant future.

The project scope had limited the multi-purpose programming aspects of the new stadium to athletics team support facilities, retail space, and game day operations with vague references to the aspect of community-use. In a February 2015 report reviewing design phase progress, the gross square footage of the building (excluding the game field) was a total of 636,527. The main focus for programing was located under the western concourse and contained the majority of square footage allocated; the eastern concourse plans appeared to be limited to enclosing the space under the concourse.

6.8.3.5 Performance Metrics

This project initially was planned on a 423-day construction schedule that ultimately took 809 days to complete, experiencing schedule growth of 91.25%. Construction cost at award was $172,083,882 and grew 14.41% to $196,882,358 by project completion. Construction cost growth from the initial estimate was less, however, growing 10.38% from $178,361,837 by project completion. Design fee cost growth was lower than construction cost growth, growing 9.86% from $11,879,270 at contract award to $13,050,014 at completion. These cost growth performance metrics would not appear to be out of the ordinary, however 91.25% schedule growth would raise a red flag.

6.8.3.6 Incorporating Late Scope Additions with Donations

Construction operations began on the stadium project in May of 2015 while a series of donors began to make commitments to add roughly $28 million to the project: an anonymous donation of $20 million to name the field in honor Sonny Lubick, a $3.5 million donation by alumnus Michael Smith to fund the construction of a new alumni center in the stadium, and a

$4.3 million donation by the New Belgium Brewing Company to fund a named hospitality area (a bar) in the north endzone (Phifer 2016) which was announced in April of 2016. The project team, in June of 2015, prepared plans and estimates to add an additional 82,000 square feet of programing under the east concourse consisting of 20,000 GSF for the alumni center, 11,000 GSF for a new student advising center, and the remaining 51,000 GSF dedicated to a mix of circulation space, classrooms, academic offices, and mechanical space for a total of $18,500 that would also enable the project to achieve LEED Silver certification (CSU 2015). Mortenson was well-positioned to provide priced options to the owner and designer to assist in making better programming and configuration decisions that could be easily converted into executed change orders. As subsequent donations came in, including the late donation from New Belgium Brewery in the spring of 2016, these established relationships and lines of trust and communication forged out of several years of integration from design through construction ensured that Colorado State University efficiently incorporated new project scope while reducing disruptive impacts to the project trades labor force. This project added $24,798,476 of construction scope after the GMP as agreed to but only paid an additional $1,170,744 in design fees for these changes which shows that the university was able to get $21.18 of construction scope for every design fee dollar spent on owner-driven scope changes. The mean and median C$:D$ values for DBB post award changes are $4.42 and $8.48 (Chapter 6). If this project had been delivered using DBB, using the DBB $C\$:D\$_{Change}$, the Colorado State University would theoretically have had to reduce the amount of construction scope added to the project between $14.9 million to $19 million. To put this into perspective, the new alumni center donation was $3.5 million and the endzone bar donation was $4.3 million and would have likely required both a significant descoping in other programming that was added to the east concourse post award and a reduction in the finishes and programming for those two additions. On the other hand, if the university had been adamant about adding the additional programming, the design fees to accomplish these owner-driven scope additions could have theoretically cost an additional $1.8 million to $4.4 million.

6.8.3.7 Lessons Learned

There are three primary lessons that can be drawn from the stadium project at Colorado State University, a highly successful CMR-delivery public university project, that support Research Hypotheses 1, 3, 4, and 5. This project was procured using standard form CM/GC contracts provided by the Colorado State Architect's Office which were shown to have a high level of synchronization between the general contractor's preconstruction services agreement and the designer's design services agreement (Chapter 4) which provided the contractual environment within the project team to enable a effective integration and collaboration. Hypothesis 3 claims that CMR delivery provides greater contractual flexibility for incorporating owner-directed and late scope changes, scope changes on this project were both late and owner-driven yet were effectively incorporated into the project. Hypothesis 4, on a similar train of logic, states that CMR project delivery provides greater efficiency incorporating changes than DBB due to project team integration (owner, designer, general contractor). The general contractor's contribution to the project in CMR can be oversized, providing constructability reviews, developing 4D models to support both designers and trade subcontractors, and producing priced options with actual quotes that can be readily converted into change orders accelerates the decision-making process for the owner. Hypothesis 5 posits that the "quality of contractual language synchronization between the designer and general contractor directly impacts… project team integration," which is clearly demonstrated here. The high level of trust and integration provided the requisite lines of communication and intentional collaboration to efficiently incorporate roughly $25 million of owner-driven scope with a $C\$:D\$_{Change}$ value of $21.18, with roughly four times more efficiency than under DBB project delivery. Efficient change scope generation allows the general contractor to provide a greater value of betterments as project funds which would have gone to the designer in additional fees are invested into the project itself, which generates more value to the owner, their end-users, clients, and 3rd parties than would have been realized under a DBB delivery model. This provides strong support for Hypothesis 1 that CMR project delivery provides greater value for money to the public university owner than would be realized under DBB delivery. The project example demonstrates clear support for many of the findings and conclusions found in Chapters 2, 3, 4, and 6:

1. Select the general contractor as early as possible in the design phase to maximize the potential benefits of CMR delivery (Hypothesis 1 & 4).

   Early contractor involvement enables the owner to make design decisions with more complete information with accurate pricing and understanding constructability issues

2. Contractual language governing the relationship between the designer and the general contractor should be well-synchronized (Hypothesis 5).

   Contract documents utilized were highly synchronized providing an enforceable baseline expectation for collaborative behavior.

3. CMR project delivery provides the opportunity to incorporate owner-driven scope changes more efficiently than DBB providing greater value for money to the owner (Hypotheses 1, 3 & 4).

   $C\$:D\$_{Change} = \$21.18$

Post-GMP Construction Scope Change = $24.8M

Design Fee for Owner Driven Scope Change = $1.17M

Theoretical Cost of DBB Design Fee Scope Change = $2.9M to $5.6M

Theoretical DBB Scope Change Capacity Reduction = $14.9M to $19.6M

6.9 Quantifying Value for Money in CMR Project Delivery

Quantifying value is a complex undertaking that attempts to associate some sort of measurement to a concept that is a combination of objective fact and subjective perception. Recognizing these limitations, it seems worthwhile to propose a simple metric for assessing the theoretical value for money realized on CMR delivered public university capital projects that measures the difference in the design capacity to incorporate owner-driven scope changes as compared to a DBB delivery model, expressed as a range of dollar values as illustrated in the following equations. Please note that the upper and lower limit equations are based on the skewness from the calculation of C$:D$ values derived from the shadow projects analysis in Chapter 6 and are directly applicable to these projects as part of this study. Should this calculation be applied to other project data, these values should be recalculated and adjusted based upon their skewness.

Equation 6.1 Value for Money – CMR ($)

$$VfM_{CMR}(\$) = [VfM_{CMR\ Upper\ Limit}(\$): VfM_{CMR\ Lower\ Limit}(\$)]$$

Where,

Equation 6.2 Value for Money – CMR ($) Lower Limit

$$VfM_{CMR\ Lower\ Limit}(\$) = \Delta Construction\ Cost_{Post\ Award}\ (\$) - Change\ Capacity, DBB_{Mean}\ (\$)$$

And,

Equation 6.3 Value for Money – CMR ($) Upper Limit

$$VfM_{CMR\ Upper\ Limit}(\$) = \Delta Construction\ Cost_{Post\ Award}\ (\$) - Change\ Capacity, DBB_{Median}\ (\$)$$

Where,

Equation 6.4 Mean Change Capacity of DBB ($)

$$Change\ Capacity\ DBB_{Mean}(\$) = \Delta Design\ Fees_{Change}(\$) x\ Mean\ C\$: D\$_{Change\ (DBB)}$$

And,

Equation 6.5 Median Change Capacity of DBB ($)

$$Change\ Capacity, DBB_{Median}(\$) = \Delta Design\ Fees_{Change}(\$)\ x\ Median\ C\$: D\$_{Change\ (DBB)}$$

And,

Equation 6.6 Post Award Construction Cost Change ($)

$$\Delta Construction\ Cost_{Post\ Award}\ (\$) = Construction\ Cost_{Final}\ (\$) - Construction\ Cost_{GMP}(\$)$$

And,

Equation 6.7 Post Award Design Fee Cost Change ($)

$$\Delta Design\ Fees_{Change}(\$) = Design\ Fees_{Final}(\$) - Design\ Fees_{Init.Contract}\ (\$)$$

For example, the calculation for the multipurpose stadium at Colorado State University would be as follows:

$$Construction\ Cost_{Final}\ (\$) = \$196{,}882{,}358$$

$$Construction\ Cost_{GMP}(\$) = \$172{,}083{,}882$$

$$Design\ Fees_{Final}(\$) = \$13{,}050{,}014$$

$$Design\ Fees_{Init.Contract}\ (\$) = \$11{,}879{,}270$$

The mean and median C$:D$ values for DBB delivery were calculated in Chapter 6:

$$Mean\ C\$: D\$_{Change\ (DBB)} = \$8.48$$

$$Median\ C\$: D\$_{Change\ (DBB)} = \$4.42$$

Calculate the values of design fee change and post-award construction change:

$$\Delta Construction\ Cost_{Post\ Award}\ (\$) = \$196{,}882{,}358 - \$172{,}083{,}882 = \$24{,}798{,}476$$

$$\Delta Design\ Fees_{Change}(\$) = \$13{,}050{,}014 - \$11{,}879{,}270 = \$1{,}170{,}744$$

Calculate median and mean DBB change capacity based off the value for design fee change:

$$Change\ Capacity\ DBB_{Mean}(\$) = \$1{,}170{,}744\ x\ \$8{,}48 = \$9{,}927{,}909$$

$$Change\ Capacity, DBB_{Median}(\$) = \$1{,}170{,}744 \text{ x } \$4.42 = \$5{,}174{,}689$$

Calculate upper and lower limits:

$$VfM_{CMR\ Upper\ Limit}(\$) = \$24{,}798{,}476 - \$5{,}174{,}689 = \$19{,}623{,}787$$

$$VfM_{CMR\ Lower\ Limit}(\$) = \$24{,}798{,}476 - \$9{,}927{,}909 = \$14{,}870{,}567$$

Therefore, for the multipurpose stadium,

$$VfM_{CMR}(\$) = [\$19{,}623{,}787: \$14{,}870{,}567]$$

6.10 Conclusions and Recommendations

CMR provides public university owners with the contractual vehicle to successfully deliver complex projects, realistically align project scope with project financing and other owner/3rd party constraints, add scope to an on-going project more efficiently that in DBB providing greater value for money to the owner as the final scope of the project is fully defined. This has been quantified by measuring design fee efficiency comparing the dollar value of construction scope developed for the change order to design change dollars expended, providing a novel tool to understand the beneficial impact of 1) the contractually-established relationships between the designer and general contractor, 2) integration and collaboration among the project team, and 3) contractual flexibility to proceed with necessary work on verbal agreements for projects that appear to perform poorly according to traditional performance metrics of schedule and cost growth from award but are successful projects according to the owners and end-users. Owners have an opportunity to maximize the potential benefits available in CMR delivery on good candidate projects by employing the following best practices.

6.10.1 Best Practice 1: Synchronize Design and Preconstruction Contracts

Contract language in the designer's agreement for design services must be well-synchronized with the general contractor's preconstruction services agreement. This means that where the general contractor has a duty to the designer in their agreement, the designer's agreement should reflect their duty toward to general contractor for the clause in their agreement.

6.10.1 Best Practice 2: Select the General Contractor ASAP

Select the general contractor as early as possible in the design to maximize the potential benefits of integrating them into the project team. Early integration provides time to develop healthy professional relationships between each party of the project team and allows the general contractor to better understand the context of major project decisions. Early integration also allows the owner and designer to make major scope decisions with more complete pricing, materials selection, preferred means and methods, labor and equipment availability, logistical considerations, and constructability information.

6.10.3 Best Practice 3: Use CMR to Phase Construction on Partially Funded Projects

Partially funded, complex projects that need to begin construction prior to securing full funding that could benefit from a phased construction strategy should consider utilizing CMR delivery where the general contractor and designer collaboratively develop the scope into stand-alone work packages aligned with owner financial constraints, treated as "planned change orders" to the base contractor for the project.

6.10.4 Best Practice 4: Supplement Traditional Performance Metrics on CMR Projects

Traditional project performance metrics for cost and schedule growth may not provide an accurate assessment of the delivery of CMR projects constructed by public university owners in the United States. Measuring the efficiency of design fees expended for owner driven scope changes provides a tool evaluate 1) the relative quality of integration and collaborative behavior in the project team and 2) quantify the relative value for money received by the owner from employing CMR project delivery.

6.11 Limitations

This research project was specifically focused on comparing CMR and DBB project delivery on public university project in the United States of America, which is a unique, albeit significant, sector of the American construction industry which demonstrated several unique characteristics that drive decision making that may not be applicable in other related segments of the construction industry.

The first major limitation of this study is that projects included in the database did not include any from New England states nor any CMR projects from Deep South states, Auburn University provided 22 DBB projects, so regional variations in the way CMR is employed may not have been addressed for those states.

The second major limitation of this study is that development of the project database required missing data value imputation. The quality of the imputed data was considered sufficiently robust for the analysis but could be improved by being updated with actual values, which was not attainable over the period the research. Random Forests imputation provides a better method of imputing missing project data values than early techniques and has proven its utility in this study, among others, and should be considered by other construction engineering research scholars to assist in developing statistically significant data sets, with a fully appreciation of its limitations.

The third limitation is in the computation of value for money, proposed in the previous section. This calculation should be used an indicator to assess the relative value received by an owner from CMR delivery on a project that benefited from the ability to fully develop the final scope concurrent with construction activities. It is a relative value that is useful for understanding the impact of project team integration, trust, and collaborative behavior on a complex project, however it should not be considered definitive.

6.12 Contributions

This research study provides several direct contributions to the existing body of knowledge within the discipline of construction engineering, construction research, construction project management, and alternative project delivery.

The first contribution is that, for capital projects on public universities, the value of CMR delivery is not in its ability to reduce cost growth but the capacity to efficiently incorporate new owner-driven scope requirements identified after the design has commenced and as the project shifts into construction. CMR project delivery does not appear to reduce project cost growth in public university capital projects. This is supported by research focused on education sector construction yet contradicts a significant portion of the literature on CMR delivery in general.

The second contribution is to provide a novel metric (C$:D$) to evaluate the relative efficiency that CMR delivered projects incorporate scope change by comparing the dollar value of new construction scope to the dollar value of additional post-award design fees, which are typically only given to designers for owner-driven scope change. The C$:D$ metric can be used to evaluate CMR projects that appear to be performing poorly according to traditional cost and schedule growth metrics but may be providing a more efficient vehicle to deliver complex, partially funded, and/or phased construction projects in an easily understand manner. This metric provides a tool for capital projects staff to accurately communicate project status and success with university leadership, governing boards, and stakeholders with a vested interest in the efficient use of funds.

The third contribution is providing a technique to evaluate the synchronization of contract clauses between design services and preconstruction services contracts for CMR delivered projects where a greater level of synchronization provides the contractual basis for maximizing the potential benefits of cooperation and collaborative behavior between the designer and general contractor.

The fourth contribution is a demonstration how machine learning can be leveraged in construction research. This project provides several modern machine learning tools that can be employed by construction researchers to improve the rigor of statistical analysis of historical project data, specifically the use of Multiple Regression models and the Random Forests algorithm as a technique to impute missing data more accurately. Research in construction engineering requires the application of both qualitative and quantitative research methods as every construction project is essentially unique. This makes it difficult to assume normality of any database of projects, even two projects with the same plans, specifications, owner, designer, and general contractor will be unique due to variations in the weather, market forces, availability of labor, etc. Additionally, assembling statistically significant databases of projects is challenging as private owners and general contractors tend to view historical data as being proprietary and access to project data from public owners may require the onerous and expensive approach of utilizing the Freedom of Information Act. Therefore, being able to develop complete databases with incomplete data that is assembled by a combination of voluntary provision, internet searches, and other open-source techniques is a critical tool in the toolkit of any construction researcher.

The fifth contribution is a method of quantifying the value for money in dollars of construction change scope that owners have received on projects that have benefited from efficient incorporation of owner-driven scope change with CMR as compared to the potential of a theoretical delivery of the same project under DBB.

6.13 Recommendations for Future Research

CMR delivery of public university capital projects would benefit from additional research primarily in three areas:

1. An extended analysis of contractual clause synchronization between design services and preconstruction services contracts that includes additional standard form contracts (AGC Consensus Docs, CMAA Standard Contracts, etc.) as well as proprietary contracts used by public universities outside of the scope of this project may provide new insights and examples of effective contractual language that can be synthesized into best practices may contribute to improving the quality of existing CMR contract documents.
2. The public university capital project database would benefit from several improvements. First, imputed data points should be replaced with actual data and compared to evaluate the effectiveness of Random Forests data imputation. Second, additional projects should be added for other public universities in different geographical areas than covered under the scope of this project to validate conclusions and identify regional idiosyncrasies inherent to this market segment. Third, the multiple regression model simulation should be rerun using final data and additional project data to refine levels of correlation between cost and schedule variables and to explore the effects of preconstruction services fees on final cost and final schedule.
3. A research study to fully develop the proposed value for money in CMR calculation would provide rigor to this proposed technique and improve its usefulness.

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Addendum A – Informal Interview Protocol

Interview Protocol – Preconstruction Services Research Question

Interviewer: ________________________ Date: _________________________________
Interviewee: _______________________ Organization: ___________________________

Introduction & Consent

Thank you for making time to allow for this interview! You were selected based upon your experience in the construction industry and position within your organization. The focus of this research project is to better comprehend how contracting parties in construction projects define their roles and responsibilities during preconstruction, within the Construction Manager-at-Risk delivered project. In order to allow me to take accurate notes, I would like to audio record our conversation today and transcribe portions of it, after which, the audio recording will be deleted. Is that ok with you? Once my research is complete, I would be happy to share my findings with you, if you wish.

Eligibility

1. Would you define your employer as an Owner, Architect, or Construction Manager?
2. What is your position at your company/firm/organization?
3. How many years have you worked in the commercial construction industry in Oklahoma and North Texas?
4. How many years have you worked in the construction industry?
5. How many Construction Manager-at-Risk delivered projects have you participated in? (5 minimum)
    a. PROBE: (If answer is 3 or 4 CMR) How many negotiated bid/qualifications based selection project have you participated in?
6. Briefly describe your role and responsibilities at your company/firm/organization.

Participation

1. How often would you say that your company/firm seeks projects procured under Construction Manager-at-Risk (CMR) contracts?
    a. PROBE: How many CMR delivered projects does your company/firm engage in a typical year?
    b. PROBE: Do you have a preference for project delivery method?

2. Have you participated in preconstruction activities as part of a CMR contracted project within the last two years?
    a. PROBE: What was the rough scope of the project(s)?
    b. PROBE: Would you say these are typical projects for your company/firm?
    c. PROBE: What was your role?

Definition

3. How would you describe the (Choose One to match interviewee) Owner's/Architect's/CM's role during preconstruction activities?
    a. PROBE: What sort of specific responsibilities do you have?

4. What would you say the most important preconstruction activity is for a project?
    a. PROBE: What would you say makes it important?
    b. PROBE: Can you think of any other ones that important as well?

5. Thinking on your top preconstruction activity, what are the outcomes you believe it should provide the project?

    a. PROBE: How often have you seen these outcomes realized?
    b. PROBE: What do you think contributed to that?

6. Thinking about the (Choose one – not interviewee) Owner/Architect/CM, what would you say are their role is during preconstruction activities?
    a. PROBE: What would you consider to be their primary responsibilities?
    b. PROBE: In your opinion, how well do they seem to understand these responsibilities?
    c. PROBE: Has this ever impacted your company's/firm's contribution to the scope of work, either positively or negatively?

7. Thinking about the (Choose remaining one) Owner/Architect/CM, what would you say are their role is during preconstruction activities?
    a. PROBE: What would you consider to be their primary responsibilities?
    b. PROBE: In your opinion, how well do they seem to understand these responsibilities?
    c. PROBE: Has this ever impacted your company's/firm's contribution to the scope of work, either positively or negatively?

Communication & Collaboration

8. In your experience, how well do the (Choose two – opposite of interviewee) Owner/Architect/CM coordinate with and support your company's/firm's/organization's responsibilities during preconstruction activities?
    a. PROBE: In your experience, does one of them typically perform better than the other?
    b. PROBE: Can you give an example of project where preconstruction went particularly well?
    c. PROBE: Can you give an example of project where preconstruction went particularly poorly?

9. Do your contracts typically stipulate collaboration between your company/firm and the Architect and CM?
    a. PROBE: What are some of the more common stipulations that you see?
    b. PROBE: How do these stipulations affect your interaction with the Architect and CM?

Lessons Learned

10. We're almost done here, I'd like you to pause for a second and consider this. If you were able to change anything about the relationship between your company/firm/organization and the (Choose opposite two) Owner/Architect/CM in regards to preconstruction activities, what would it be?

11. Is there anything else you consider important, or salient, to the topic that we haven't already discussed?

12. Thank you so much for your time!

Addendum B – Informal Interview Transcripts

1. Construction Manager Interview

The first interview was conducted with a senior project manager for a major regional construction management company. He had 16 years of construction management experience in the commercial construction, six of which had been at his current company and holds a Bachelor of Science in Construction Management. His role as a senior project manager places him in responsibility over multiple projects where he was responsible for overseeing preconstruction services, managing project finances, liaising with the Owner's representatives and the Architect, and the delegation of authority to field office personnel for the day-to-day management of subcontractors. His recent projects include multimillion dollar higher education mixed-use, housing, and commercial hotels. His company operates primarily as a Construction Manager-General Contractor (CMGC), preferring to secure projects with negotiated bids, although they do seek out a small number of hard bid projects from time to time.

Architect's Responsibilities

The interviewee was asked to describe the responsibilities of the Architect as it related to preconstruction activities within a CMR contract with the following question:

INTERVIEWER: [T]hinking about the Architect, what would you say are their responsibilities for preconstruction?

CM: My big thing from them is ***that they're communicating with the Owner*** and ***being realistic of what they're going to deliver***. Of course there's always the back and forth between the general contractor and the Architect. The last project I did, being a design build, my relationship with the Architect was incredible. It was not only beneficial to each other but to the project and to the Owner, because of that relationship. You know, that's not every project but I believe that ***the Architect has responsibility going back to managing expectations and understanding***. I'm doing a hotel, my next project is a hotel, I've got a 688-page design criteria for the specific brand of hotel. In that you have minimum design standards, for example like [the university] has, basic design standards for buildings, whatever. So, when we're going through [preconstruction] ***I'm expecting that Architect is designing to the minimum standard*** and that's what the expectation is. So, if we're on the same page, say we're looking at finishes, and I'm having this discussion with the Architect in my pricing and I'm pricing $6 per square foot tile and he says, "Well no, no, no, this is what we've normally done and this is $10-12 per square foot." So now, what happens? You go in front of the Owner and say, "My estimate is based on $6 per square foot and this guy's wanting to give you $12 per square foot and you have the money for $8 per square foot." So where is that open communication at? The last thing you want to do is this – here's what happens a majority of the time – ***the Architect draws something, we get it, we price it, most of the time it is way over budget, and then everybody points fingers at us*** and goes, "Well, you need to get this in line." When I go back to the Architect and I say, "Ok Mr. Architect, we need a less expensive product." The Owner has to go, "Ok, I understand that." I keep saying that [we have] finite resources and if you have that communication you can give that look you want for the price, it's just going to take some communication between the parties, that's all.

INTERVIEWER: So why do you think that happens?

CM: ***I think what we're saying really is, you've got champagne tastes on a beer budget. What I think needs happen very first, up front is [to ask] what is my budget? That's what needs to be established.*** Now, if there are standards that a client has, we need to address those. That's key. I don't believe in getting a set of plans, working up an estimate, presenting it to an Owner and had [having them say], "Well, this is way too much." If you could have told us how much you had, that could have gotten back to the Architect to draw something within the budget, because that's what it comes down to. You want to satisfy your client but you also what to make sure it's on budget. Those conversations are never fun to have.

INTERVIEWER: [chuckle] They are necessary though.

CM: They are very necessary to have. We all want to satisfy our client, that is correct, I agree 100%. That's why you're hiring me, but I also need to be honest with you about what you're looking at you can't afford. So, what can we do to get you the look that you want for, the program you want, within your budget? So, there's going to have to be some give and take.

Owner Responsibilities

The interviewee was asked to describe the responsibilities of the Owner, as it related to preconstruction activities within a CMR contract with the following question:

INTERVIEWER: Absolutely. So, what would you say are the Owner's responsibilities during preconstruction?

CM: ***The best thing that an Owner can do is to talk about what their vision of the project is with the Construction Manager and the Architect in the room*** and establishing – a lot of times it's "siloed" – there's a lot of conversation with the Architect that we're not privy to. ***It's like we get ganged up on when you come back with a budget because Architects do not traditionally have a good idea about budgets.*** They design things and have no idea what it costs in the real world. So, I think the conversation comes with all parties involved. Now relating that, saying here's what I'm looking for, there's a lot of smart people that can go and solve these problems. ***When it's siloed and you don't have all the information or you're not part of the discussion it makes it very difficult to try and satisfy a client.***

INTERVIEWER: Yeah, you know, absolutely. So, has that ever impacted your company's contribution to the scope of work, either positively or negatively?

CM: Yeah, it has. *It's more of, you know it's difficult when a client wants to come in, you know, four months from opening and says, "I want to put a hot tub on the second floor."* And you go, "OK, there's a lot of work that's going to go into this." They say, "Whoa, whoa, whoa, that's way too much." *And you say, "Well this is what it's going to cost."* ***And they're like, "Well, you know, the Architect told me it would be like half of that."*** *And the smart ass in me wants to say, "Well have the Architect build it for you for half the cost."* [laughter] So you have to set that expectation and working in the successful projects I've had, the Owner is coming up with these changes, I'm discussing it with the Architect like, "Hey man, this costs X amount a square foot, how much do they have?" ***It goes back to the relationship. A successful project is where you are not adversaries but allies. So, I can call and have that honest talking with my Architect and he can have the same thing and call me and ask and bounce ideas off of me with the goal being that we're trying to satisfy our client.***

2. Owner's Representative Interview

The second interview was conducted with an Owner's representative project manager from the capital projects unit for a major higher education institution. He had 25 years of experience, primarily in commercial construction, as an Architect, of which the last three years has been as an Owner's representative and holds a Master of Science in Architecture. His recent experience included a 75,000 square foot commercial higher education building procured using CMR as well as various remodel projects. His organization procures and manages capital construction projects that range from $75,000 to $100+ million which are typically procured using CMR contracts with negotiated preconstruction services. Recently, his organization decided to hard bid a handful of projects as test cases due to negative outcomes associated with some high profile CMR projects. He was responsible for predesign project development with the Owner-end user, selection of the Architect and CM, project finances including payment of the Architect and CM, coordination of meetings and collaboration between contracting parties, review of project documents including plans, specifications and submittals, approval of changes, and the general oversight of the project from concept to completion.

Architect's Responsibilities

The interviewee was asked to describe the responsibilities of the Architect as it related to preconstruction activities within a CMR contract with the following question:

INTERVIEWER: So, thinking about the Architect's role in the preconstruction period, what are their primary responsibilities? [pause] What do you expect for them to provide to you and to the CM?

OWNER: ***Almost the same thing for all the phases: clear documentation, clear documents. One of the things that's happened with CM is that there's been a lack of quality control once you get to construction documents, just to answer your precon[struction] question. It is a problem, since the Architect is working with a CM, working through details and ways to do things.*** I don't think they button up their CD's [construction documents] as tightly as they used to, but that's not the only reason, it's not taught as well as it once was taught. I think software has caused a problem in construction documents, but I think that's just a big problem in the industry is poor construction documents.

INTERVIEWER: So, what you're saying, you'd expect to see in a hard bid scenario a more complete, or better finished, set of documents as opposed to what you typically see in your CM projects?

OWNER: Certainly, now they still go and get bid out, to the subcontractors, so they still have to be solid documents, but it's a little bit looser.

INTERVIEWER: In your opinion, how well do they seem to understand these responsibilities?

OWNER: ***Hmmm… the ones we've been dealing with recently have understood it well.***

INTERVIEWER: Has this had an impact, either positively or negatively on your projects?

OWNER: Mostly positive, [Architecture Firm] has done a good job. My background was almost all hard bid projects as an Architect so my knowledge is limited to only a few projects that were CM-at-Risk. So I've learned a lot over these last couple of years

Owner Responsibilities

The interviewee was asked to describe the responsibilities of the Owner, as it related to preconstruction activities within a CMR contract with the following question:

INTERVIEWER: So how would you describe the Owner's role during preconstruction activities?

OWNER: Hmmm… [pausing to thinking] ***A lot of it is weighing the options when you're looking at "We can only afford this much." Then, you're talking to the end users, which in this case is the [university department]… and helping them determine "Hey we need this, we need that, we gotta have this, we can live without that." Making sure that those needs end up reflected in the documents that are being estimated.*** Does that sort of make sense?

INTERVIEWER: Yeah, yeah, you really … kind of serving as a middleman in that way. So, dealing with the expectations of the end users.

OWNER: Oh yeah! ***Managing them and making sure that they don't think they're going to get more than they are, so that they're not disappointed later. But then also, seeing what the needs are for the university and what's really critical to have a successful program.***

INTERVIEWER: Kind of adding that extra layer of realism to the design, to the, to the project…

OWNER: I don't know if realism is the word, but…

INTERVIEWER: I guess "realistic" is a better term…

OWNER: Um, yeah, and ***prioritizing the options.***

3. Architect Interview

The third interview was conducted with the director/senior project manager for a local Architectural design firm. He had over 40 years of experience in the construction industry and holds a Bachelor of Science in Architecture. His recent experience included both private and public commercial construction projects primarily procured under negotiated bids using CMR and Design-Build project delivery methods. His role includes responsibility for securing new work, execution of the design, coordination of technical consultants, the Owner, design team and Construction Manager, typically for the duration of his projects up to the one-year warranty. Projects discussed ranged in scope from $300,000 renovation to a $30 million commercial office building.

Architect's Responsibilities

The interviewee was asked to describe the responsibilities of the Architect as it related to preconstruction activities within a CMR contract with the following question:

INTERVIEWER: How would you describe the Architect's role during Pre-Construction Activities?

ARCHITECT: Man, that is a great question. ***As my experience has been, it's varied.*** I think it has a lot to do with who is really leading the project, whether you're in a CMAR or any other relationship, contractual relationship, short of Design-Build where the contractor is going to hire us directly. ***It gets a little grey ….and a little nebulous in terms of the responsibilities, based upon the experience and the capabilities of the contractor, in my opinion.*** We have worked on a project that was about $30 million with ***a national sized CM, at risk, and they drove the process from the very beginning***. I think it was highly technical project, they had lots of experience there, and my contributions during preconstruction [chuckling] were fairly minimal. We kind of doped out what the building needed to be in terms of square footage, size, arrangement, and they contributed from day 1 on the, "Are you sure about this structurally? Are you sure about this mechanically? Are you sure about this from where we're worried about procurement and equipment?" On the flip side of that, we've had CMAR's on projects that were smaller, in scale. One project that comes to mind that's about $11 million, office building type project and in that we were definitely more in the lead, "This is what we want in terms of materials, can you price it?" and they were more reactionary. We've had varying input and varying results in terms of the preconstruction services. I think the biggest thing they can contribute, or that they did contribute, is constructability and cost. Along with constructability comes scheduling. The $30 million project I was talking about was definitely about some elements with very long lead times and those procurement was clearly identified up front as what were, kind of going to be our choke points. Do you want us to procure it for now or do you want us to bring it later? You know, those kinds of discussions I definitely feel that the Architects are normally not that privy to and can't really contribute to. To kind of answer your question though, I've had varying kinds of successes and varying kinds of roles. I think the biggest thing is, I've always felt about a CMAR, but sit around and collaborate together and depending on what all of our team needs are this is what we need to do to contribute to that. So, if I need to contribute more on the initial front end, in terms of site plan, layout, sizes in terms of structural, civil, I can do that. Or if it's more along the lines of just initially, just kind of, how big, how wide, how tall, I can do that as well. To me, it's much more of a CMAR-type, and Design-Build is a little similar, where we can kind of define our roles from the git-go and so long as it's clearly defined, one can kind of go about their business and work together towards it and not necessarily in a hard-bid, traditional design bid build.

Owner Responsibilities

The interviewee was asked to describe the responsibilities of the Owner, as it related to preconstruction activities within a CMR contract with the following question:

INTERVIEWER: Thinking about the Owner, how would you describe their responsibilities for Pre-Construction Activities?

ARCHITECT: Wow, that *is* a great question. I think a lot has to do with the Owner's mindset. It's my opinion that the Owner should be *very* engaged during the preconstruction process. ***The Owner sets the tone, in my opinion.*** If they are actively involved form the git-go and can contribute and kind of build that collaborative atmosphere, I think that any project, no matter if it's compressed in time or challenged in money or whatever issue may be challenging that project, that project will be a success. I think that if the Owner is engaged, especially as it comes to the preconstruction side, can understand cost issues, can understand scheduling issues, the ramifications of decisions, the project will succeed. End of story. ***I do think that most Owners have in their mind that, "I've hired you all to do this, I've already got a full time job and that's what I need to do, I need to respond to you."*** So, depending on how big the riffs are, how big the challenges are, I think that approach is not very successful. If we're going to go build, if we sat down and said I'm going to go build a 10,000 square foot, metal shop for handful of trucks or cars, the Owner doesn't really need to be involved too much. The cost is going to be identified immediately, there's not going to be any risks, you know that's pretty straight forward stuff. The more challenging the project may be, for any reason, the cost, the schedule, the use, that's when I feel that the Owner needs to be part of the process and be engaged every step of the way, because nothing an affect the project worse than having a backup. When you've gone down the road in a certain direction but now we're going to shift to a different direction, that's when it causes confusion. ***I think the Owner has a key, critical role and when you boil it all down, the Owner sets the tone for how this is going to go.*** If you're engaged in it, we're going to make it, and if you're standoffish, there's some risk! Then I think that onus switches over to the Architect more, and it's the CMAR, it's kind of more on the Architect and the contractor to work together to solve it so that they can *propose* to the Owner, here's our unified, semi-unified answer. We hope you like it. [laughing]

INTERVIEWER: In your experience, ***how well do most Owners seem to understand their responsibilities?***

ARCHITECT: ***Outside the university, nobody.*** [laugher] I think it has a lot to do with the staff. If you have people that can kind of help you navigate the process, then the Owner is represented and represented well. We have a couple of projects in the recent past, they're relative small, I think they're like $2 million, and the Owner would… appear… at meetings and then wouldn't really contribute very much more than approvals and it, uh, went ok. But I don't think it, uh, there wasn't very much in terms of decision making, other than yes and no, so, because they have other things to do. And I fully understand that and there's times when I want to engage you on this deal, but on the flip side of that… um, you've got other things to do. [chuckles]

INTERVIEWER: I guess sometimes that just the situation that you're in, if they don't have a fully developed staff or they're not super savvy…

ARCHITECT: Yep, that's exactly right. I personally, have never been accused of keeping my Owner or my client informed, but I certainly have been accused of over informing them! [laughter]

INTERVIEWER: I think I'd prefer the latter to the former! [laughter]

ARCHITECT: [laughter] You know, on our private projects, we solicit some input from the Owners, how'd we do on the project? You know, do want us for your next project? Do you want this project manager assigned to you? And I've received some comments like, "[Architect's name] really sends us a lot of stuff…"

ADDENDUM C – Validation Survey Questions and Summary of Results

1. Does your university permit the use of Construction Manager-at-Risk or Construction Manager-General Contractor project delivery for capital projects?
    a. Yes 22/96% 12 Exec/ 10 PM
    b. No 0/0%
    c. Yes, but it is rarely used 1/4% 1 Exec/ 0 PM

2. In your experience, does your university tend to add owner-driven scope to CMR or CM/GC delivered projects on a regular basis?
    a. Yes 19/83% 9 Exec/ 10 PM
    b. No 4/17% 3 Exec/ 1 PM

3. In your experience, would owner-driven scope growth that is added to typical CMR or CM/GC deliver projects by change order require a re-procurement if the project were delivered under a DBB contract?
    a. Yes 2/9% 2 Exec/ 0 PM
    b. No 21/91% 10 Exec/ 11 PM

4. If you knew that 3rd party stakeholders within the University would be heavily involved in the decision-making regarding a project's final scope, which delivery method would generally be considered a better fit?
    a. DBB 4/17% 1 Exec/ 3 PM
    b. CMR 19/83% 11 Exec/ 8 PM

5. If you knew that a project had a complicated site (multiple subsurface utilities coordination, constricted site, significant student/traffic disruption, historical renovation, etc.), which delivery method would generally be a better fit?
    a. DBB 3/13% 0 Exec/ 3 PM
    b. CMR 20/87% 12 Exec/ 8 PM

6. If you knew that additional funding could potentially become available during either the design or construction phase of a project that would permit an increase the overall scope of a project, which delivery method would generally be a better fit?

    a. DBB 2/9% 0 Exec/ 2 PM
    b. CMR 21/91% 12 Exec/ 9 PM

Thinking of RECENTLY completed projects at your university, please answer the following questions:

7. Rate the university project teams' working relationships with the contractor and designer working on the project.
   - i. DBB: Poor 5/22% 4 Exec/ 1 PM
     Neutral 5/22% 3 Exec/ 2 PM
     Good 13/57% 5 Exec/ 8 PM
   - ii. CMR: Poor 0/0% 0 Exec/ 0 PM
     Neutral 6/26% 0 Exec/ 6 PM
     Good 17/74% 12 Exec/ 5 PM
8. Which project delivery method tended to experience more changes during the design/preconstruction phase?
   - i. DBB: 4/17% 2 Exec/ 2 PM
   - ii. CMR: 11/48% 7 Exec/ 4 PM
   - iii. No difference 8/35% 3 Exec/ 5 PM

9. Which project delivery method tended to experience more change orders during construction?
   - i. DBB: 11/48% 7 Exec/ 4 PM
   - ii. CMR: 4/17% 1 Exec/ 3 PM
   - iii. No difference 8/35% 4 Exec/ 4 Exec

10. How often do 3rd party stakeholders (building occupants, college deans, campus groups, administrative departments, etc.) drive changes to project scope *after the **design** contract has been awarded*?
    - i. Never 0/0% 0 Exec/ 0 PM
    - ii. Occasionally 4/17% 3 Exec/ 1 PM
    - iii. Routinely 10/43% 2 Exec/ 8 PM
    - iv. On every project 9/39% 7 Exec/ 2 PM

11. How often do 3rd party stakeholders (building occupants, college deans, campus groups, administrative departments, etc.) drive changes to project scope *after the **construction** contract has been awarded*?
    - i. Never 0/0% 0 Exec/ 0 PM
    - ii. Occasionally 11/48% 6 Exec/ 5 PM
    - iii. Routinely 10/43% 4 Exec/ 6 PM
    - iv. On every project 2/9% 2 Exec/ 0 PM

12. In which project delivery method is it easier to incorporate ***late** changes to the scope* that were caused by the owner or 3rd party stakeholders?
    - a. DBB 1/4% 0 Exec/ 1 PM
    - b. CMR 17/74% 11 Exec/ 6 PM
    - c. Same 5/22% 1 Exec/ 4 PM

13. Do you consider the ability to add owner-driven scope to a benefit of CMR?
    a. Yes 12/52% 8 Exec/ 4 PM
    b. No 5/22% 3 Exec/ 2 PM
    c. No opinion 6/26% 1 Exec/ 5 PM

14. Is there any additional information that you would like us to know about? (Open-ended responses listed below with respondent role/job title)

<u>Directors/Executives</u>

- By statue, we are allowed to use CM@R on projects with a total project cost over $5M. Between $1M and $5M we are required to use DBB. (Director/Executive)

- CMR is consistently a better approach. The overall experience is better, quality of work is superior, and at the end of the day, the overall cost is usually the same or similar and the project completion is usually quicker with CMR. (Director/Executive)

- Over the last decade we have migrated to Target Value Design Build Lump Sum and Design Build with GMP project delivery and acquisition strategies using internal staff to develop the RFP and Design Criteria Documents. We have metrics associate with our now completed design build projects have outperformed both DBB and CMR in terms of schedule, cost/GSF and completed project quality. (University Architect)

- Costs that appear to be 'saved' during DBB usually turn out to equal the CMR original cost or exceed it. (Director/Executive)

- CMR has proven to be a very valuable tool when used on major capital projects over the past 17-plus years. (Director/Executive)

- CMR costs less to build a project. (Director/Executive)

<u>Project Management and Support Staff</u>

- Historically we have not pursued DBB on large projects, but that has begun to shift as it has been felt that a lot of scope was evaporating in CMR deliveries. (Architect/Campus Planner/Design Phase Manager)

- CMR is typically an option on larger projects as it allows the contractor to have more control of the subcontracts. DBB is used for the smaller (typically no larger than 5 million, always under 1 million) project and added scope is not usually an issue on these. CMR must get approval from the state to be used as a construction method, DBB does not need such approval. The university always tries to carry a 5% contingency not only for unforeseen conditions but for scope changes as well, no matter the delivery method. (Project Manager/Construction Administrator)

- Projects have a funding cap that cannot be exceeded regardless of requests for added scope. (Project Manager)

Construction Manager-at-Risk Scope Certainty Survey

Consent Form

Online Consent to Participate in Research

Would you like to be involved in research at the University of Oklahoma?

I am Nils Gransberg, Doctoral Candidate from the Gallogly College of Engineering and I invite you to participate in my research project entitled “CMR Scope Certainty Survey”. This research is being conducted online. You were selected as a possible participant because of your role in designing, planning, and administering public university capital construction projects at a university that is authorized to utilize Construction Manager-at-Risk (CMR), also referred to as Construction Manager/General Contractor (CM/GC). You must be at least 18 years of age to participate in this study.

Please read this document and contact me to ask any questions that you may have BEFORE agreeing to take part in my research.

What is the purpose of this research? The purpose of this survey is to validate research findings related to the use and benefits of CMR project delivery in public higher education industry capital projects. This study investigated the performance of 166 capital projects delivered using Design-Bid-Build and CMR at 23 public universities in the United States.

How many participants will be in this research? Not more than 100 people will take part in this research.

What will I be asked to do? If you agree to be in this research, you will be asked to complete a 13 question, multiple choice survey related to your views and perceptions of project delivery methods employed at your university.

How long will this take? Your participation will take approximately 5 to 7 minutes.

What are the risks and/or benefits if I participate? There are no risks from being in this research. This research has the potential to benefit American public universities by improving project procurement and administration practices as related to alternative project delivery methods.

Will I be compensated for participating? You will not be reimbursed for your time and participation in this research.

Who will see my information? In research reports, there will be no information that will make it possible to identify you. Research records will be stored securely and only approved researchers and the OU Institutional Review Board will have access to the records.

Data are collected via an online platform not hosted by OU that has its own privacy and security policies for keeping your information confidential. Please note no assurance can be made as to the use of the data you provide for purposes other than this research.

What will happen to my data in the future?

After removing all identifiers, we might share your data with other researchers or use it in future research without obtaining additional consent from you.

Do I have to participate? No. If you do not participate, you will not be penalized or lose benefits or services unrelated to the research. If you decide to participate, you don’t have to answer any question and can stop participating at any time.

Who do I contact with questions, concerns or complaints? If you have questions, concerns or complaints about the research, contact me at nils.gransberg@ou.edu or cell 405-570-3393. My faculty advisor is Dr. Dominque Pittenger, PhD you can reach at dominquep@ou.edu.

You can also contact the University of Oklahoma – Norman Campus Institutional Review Board (OU-NC IRB) at 405-325-8110 or irb@ou.edu if you have questions about your rights as a research participant, concerns, or complaints about the research and wish to talk to someone other than the researcher(s) or if you cannot reach the researcher(s).

IRB Number: 13233

* 1. Please print this document for your records. By providing information to the researcher(s), I am agreeing to participate in this research.

- [ ] I agree to participate.
- [ ] I do not want to participate.

Construction Manager-at-Risk Scope Certainty Survey

General Questions

* 2. What university do you work for?

* 3. What is your role/job title? (Check all that apply)

- [ ] Director/Executive
- [ ] Project Manager
- [ ] Construction Administrator/Project Engineer
- [ ] Accounting/Finance
- [ ] Designer (Architect/Engineer/Interior Design/etc.)
- [ ] Construction Inspector
- [ ] Code Official
- [ ] Contract Specialist
- [ ] Other (please specify)

* 4. Does your university permit the use of Construction Manager-at-Risk or Construction Manager-General Contractor project delivery for capital projects?

- ○ Yes
- ○ No
- ○ Yes, but it is rarely used

* 5. In your experience, does your university tend to add owner-driven scope to CMR or CM/GC delivered projects on a regular basis?

- ○ Yes
- ○ No

* 6. In your experience, would owner-driven scope growth that is added to typical CMR or CM/GC deliver projects by change order require a re-procurement if the project were delivered under a DBB contract?

- ○ Yes
- ○ No

* 7. If you knew that 3rd party stakeholders within the University would be heavily involved in the decision-making regarding a project's final scope, which delivery method would generally be considered a better fit?

- DBB
- CMR

* 8. If you knew that a project had a complicated site (multiple subsurface utilities coordination, constricted site, significant student/traffic disruption, historical renovation, etc.), which delivery method would generally be a better fit?

- DBB
- CMR

* 9. If you knew that additional funding could potentially become available during either the design or construction phase of a project that would permit an increase the overall scope of a project, which delivery method would generally be a better fit?

- DBB
- CMR

Construction Manager-at-Risk Scope Certainty Survey

Recently Completed Projects Questions

Thinking of RECENTLY completed projects at your university, please answer the following questions:

* 10. Rate the university project teams' working relationships with the contractor and designer working on the project.

	Poor	Neutral	Good
DBB	◯	◯	◯
CMR	◯	◯	◯

* 11. Which project delivery method tended to experience more changes during the design/preconstruction phase?

◯ DBB

◯ CMR

◯ No Difference

* 12. Which project delivery method tended to experience more change orders during construction?

◯ DBB:

◯ CMR:

◯ No difference

* 13. How often do 3rd party stakeholders (building occupants, college deans, campus groups, administrative departments, etc.) drive changes to project scope after **the design contract** has been awarded?

◯ Never

◯ Occasionally

◯ Routinely

◯ On every project

* 14. How often do 3rd party stakeholders (building occupants, college deans, campus groups, administrative departments, etc.) drive changes to project scope after **the construction contract** has been awarded?

◯ Never

◯ Occasionally

◯ Routinely

◯ On every project

* 15. In which project delivery method is it easier to incorporate late changes to the scope that were caused by the owner or 3rd party stakeholders?

- DBB
- CMR
- Same

* 16. Do you consider the ability to add owner-driven scope to a benefit of CMR?

- Yes
- No
- No opinion

17. Is there any additional information that you would like us to know about?

Construction Manager-at-Risk Scope Certainty Survey

Thank you for participating in this research! If you have any further comments or questions, feel free to contact Nils Gransberg at nils.gransberg@ou.edu or cell 405-570-3393.

Addendum D - AGC Award Submission E-Wing Addition CUB

University of Colorado Boulder Jennie Smoly Caruthers Biotechnology Building E-Wing Addition and Renovation

Adolfson & Peterson Construction

Keri Burson: kburson@a-p.com; 303-363-7101

9. Best Building Project – General Contractor ($10-$40 Million)

Why this project should win an ACE Award and why this project is unique

Building on a busy, occupied campus presents challenges for any construction project. However, at the University of Colorado Boulder – a 600-acre campus with 33,246 students – the Jennie Smoly Caruthers Biotechnology Building E-Wing Addition and Renovation project was unlike any other, requiring strict construction protocols and unique innovations to build and renovate without making noise or vibration.

The jobsite was sandwiched between the Laboratory for Atmospheric and Space Physics, Prentup Field and Potts Field, requiring construction activities to be coordinated around the schedules of CU's soccer, track and field and skiing teams in addition to the academic and research facilities. This limited scheduling construction work for weekends and off-hour work. The addition had to be built with the building fully operational, connecting to a 330,000-sf facility containing numerous biochemical labs and vivariums which could not be moved or disturbed. These highly-sensitive labs – which included live animals, million-dollar investment research, dangerous chemicals and work by Nobel Prize-winning scientists – were required to remain fully functional and running 24-7. Being an addition, these labs and learning environments were extremely close to where construction had to occur. Exterior windows of the existing structure became interior windows, resulting in no buffer zone for work.

The project required removing an entire side of the existing 3-story structure and rebuilding a 57,500-sf new addition. Connecting and tying into the current structure required precise engineering expertise to match up each floor elevation, restructure room layouts, which bridged old and new rooms, and connect to the existing main stairway and hallway which were permanent parts of the old building. 73 vertical feet of brick was removed from the exterior

Adolfson and Peterson Construction. (2021). University of Colorado Boulder Jennie Smoly Caruthers Building E-Wing. Adolfson and Peterson Construction (Website). (n.d.). Retrieved October 29, 2021, from https://www.a-p.com/projects/university-of-colorado-boulder-jennie-smoly-caruthers-biotechnology-building-e-wing-addition-and-renovation.

façade, leaving only 5 inches of studs and 1 layer of drywall between construction and labs conducting million-dollar research.

Excellence in Project Execution and Management/Team Approach:

Coordinating with the University, the team organized town hall meetings on campus with lab users, campus facility management and neighboring campus entities. Current project information, upcoming activities, logistics and questions were all addressed. The meetings also gave facility users a personal connection with the construction management team and an opportunity to address their concerns. During construction, weekly prepared dashboard communications were customized to the project and handed out to the project stakeholders.

The team also included both the physics and athletic departments in their meeting and communications. They prepared public communications and 4-week look ahead schedules for the CU website. For example, when the team needed to build their crane in the parking lot, a phased logistical plan was sent out to the user groups months in advanced and coordinated around their activities for least impact to parking. Even with the best planning, unexpected issues came up, such as the team providing a portable restroom for the band during a Grateful Dead concert. The band paid their gratitude in T-shirts to the construction team.

Because testing and research functionality was needed 24 hours a day inside the facility, utility shutdowns were not possible. Pre-planning was essential in preconstruction and included numerous MEP investigations. To tie electrical and mechanical into the existing utilities, the team created a detailed communication and M.O.P. or needed major outages. The work was conducted during the least disruptive time periods between 1 and 5 am, requiring special scheduling challenges for construction. Most importantly was the communication with the University and lab managers to properly prep for the outages – preparations which took 3 months to implement and had to run flawlessly.

The team had nine seismic vibration monitors (one on every floor and two in sensitive labs) to monitor any disturbances during construction. These were linked to the phones of both the construction team and the client’s facilities management team, alerting them of any potential problems. A baseline was set before construction began to create a known vibration threshold. The construction team built thermal and acoustical walls between spaces to lessen disruptions caused by construction. Besides when initially tested, the monitors never went off, which reflects the diligence of the construction crews to not impact the client's valuable research.

Solutions of Special Projects:

The project was underfunded from the beginning with the University only having $25.6M approved and a design of a $37M addition. With the lacking funds, the team had to find a way to make the project still go. Even though the awarded contract was CM/GC, the preconstruction team acted in a design-build fashion with the architect to phase and estimate with CU's budget constraints. The team broke the labs out into a separate work package which maintained state compliance by providing academic spaces in phase I. Phase I construction was able to then start.

AP provided 18 full estimates and countless smaller pricing exercises and had full team involvement during preconstruction for a seamless transition to construction. AP also had a team member who worked as an Estimator in preconstruction and shifted to Assistant Project Manager during construction, providing the client and team a continuous thread of budget management. Subcontractors were brought on through a strategically phased buyout process in design-assist roles and alternates were crafted around what funds were available, repricing pieces to accommodate escalation after a year delay. AP targeted subcontractors that had campus experience and understood CU's standards, including subcontractors who originally built the Jennie Smoly Caruthers Biotechnology Building.

The team worked diligently with CU on funding for the entire building and was able to avoid demobilizing after the core and shell was done and continue the lab TI work in two additional phases. At the end of the project, unused contingency was leftover on the project and AP was able to return those funds to CU.

Construction Innovations/State-of-the-Art Advancement:

Construction practices put into place were proven scientifically evident, reflecting the uniqueness of this project. Research in the labs used live rats—animals whose natural cycles of defecation, feeding and sleeping were closely monitored by researchers. The labs measured cortisol levels continually before and during construction, measuring stress or any abnormalities caused by construction activity. No indication of stress was found and thus the labs had scientific data that construction did not impede their live animal experiments.

CU has its own authorities of jurisdiction so the team didn't need to go to the state or city for permitting and inspections. The team understood the importance of ensuring these individuals were satisfied with the work performed, each having their own requirements – often which were not standard requests. For instance, a dance floor was put into the mechanical chase, where usually flooring isn't installed, at the request of the building's maintenance management for ease of accessibility. These personnel were deeply involved in the project since they were responsible for maintaining the equipment and structure once construction was over. Once BIM coordination was complete, the AP team invited the CU Facility Management Team to participate in the final BIM fly-throughs of each floor in order to make any final modifications for access concerns by the individuals that would be servicing the equipment.

Even though the team had information for materials ordered on the original structure, the look and colors of the materials had since changed. Six different brick mockups were created to obtain a grout that matched the existing structure due to the fading from sun and wind (image 1).

In addition to the unused contingency AP was able to return to CU, the project finished $500,000 under budget.

Environmental/Safety:

The project finished without any lost-time incidents on an occupied campus and facility.

Above safety training and standards common to the industry and AP, this project took an increased approach to harassment prevention because of the large amount of people on campus. All personnel onsite were trained and instructed on what was considered appropriate interaction with students, staff and community members.

AP implemented a badging system to easily identify all workers and put security measurements in place to enter the site. Field management communicated with subcontractor crews about how the project is a high-profile project to the University and the safety concerns on the busy campus. Background checks were required for all workers involved in the project. Because of the significant pedestrian traffic on campus, it was imperative for the team to coordinate signage and wayfinding with the University to properly redirect students and staff.

On-time delivery coordination was imperative for the limited laydown site, so the team rented a parking lot a quarter mile down the road and trucked materials and personnel back and forth. This area allowed for parking and storage when just-in-time deliveries weren't feasible. To maximize efficiency, daily huddles were conducted with the Foreman before work began each day to coordinate the offsite staging and deliveries.

Excellence in Client Service and/or Contribution to Community:

The project was committed to sustainable design principles and is pending LEED Gold Certification. The addition is fitted out with sustainable heating, cooling, water treatment, and material selections to reduce the structure's carbon footprint. The addition was designed to have an efficient footprint that is intelligently sited and features windows and shading devices that maximize the interior natural light while minimizing solar glare.

The addition was painstakingly designed to not look like an addition, while meticulously being reinvented to improve on everything that the 360,000-sf original structure left to be desired. To anyone walking by, the precise location where the finished addition attaches to the existing structure at the new side entrance is inconspicuous. Success of the project is reflected by the seamless transition from old to new.

"I have been involved with a fair number of construction projects on campus over the years, and it is one thing to build a stand-alone building, and quite another to build a building with people connected directly to the construction site. Our many researchers perform sensitive and sophisticated experiments and were very concerned that noise, vibration, power/utilities issues, and the like, would pose significant problems. We wanted the space, but at what sacrifice? Well, the AP team was amazing. They were great at communicating the construction schedule, they accommodated all our requests (ok, some demands!), were hugely flexible, and did all that in a professional and courteous way. They all went that extra mile to make sure we got what we needed, and, remarkably, were always so pleasant about it! Truly impressive!" – Lee Silbert, Director of Operations at Biofrontiers Institute, University of Colorado Boulder


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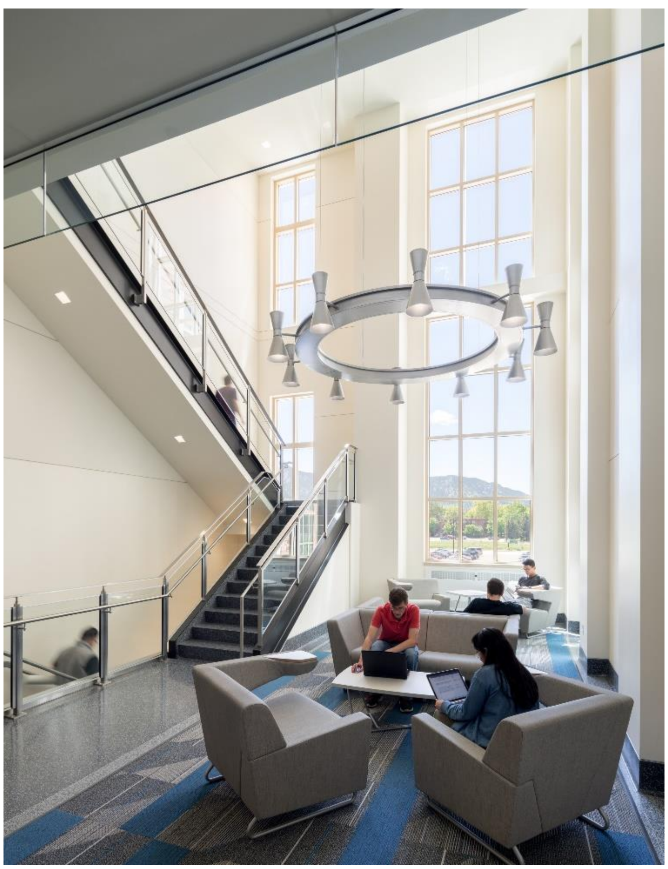



SUPPLY AIR

2017 AGC ACE Awards

Colorado State University On-Campus Stadium

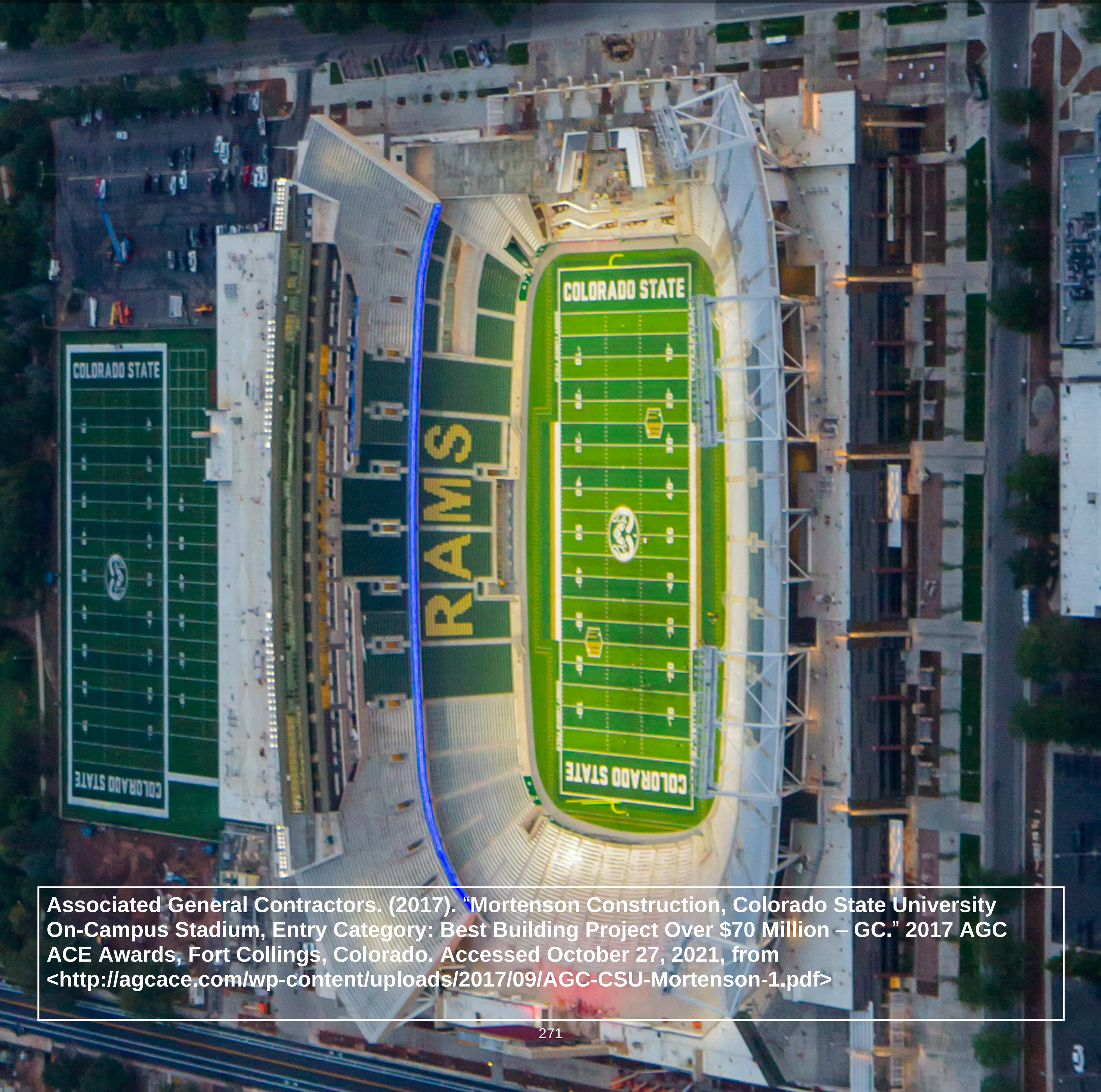
Fort Collins, Colorado

Entry Category: Best Building Project Over $70 Million - GC

Mortenson construction

"We probably built the best stadium in America."

Joe Parker, Athletic Director, Colorado State University



Associated General Contractors. (2017). "Mortenson Construction, Colorado State University On-Campus Stadium, Entry Category: Best Building Project Over $70 Million – GC." 2017 AGC ACE Awards, Fort Collings, Colorado. Accessed October 27, 2021, from <http://agcace.com/wp-content/uploads/2017/09/AGC-CSU-Mortenson-1.pdf>

COMING HOME

After nearly 50 years playing off campus, Colorado State University has brought athletic competition back to the University's core with its new, multi-purpose, 41,000-capacity, On-Campus Stadium. The stadium enhances existing game day traditions while creating new excitement for athletes, students, fans, the Fort Collins-area community and the state of Colorado.

The project is part of an overall commitment in excellence across the institution, including investments in ensuring student success and an outstanding student experience, in faculty and staff, and athletics. CSU's campus has witnessed a transformation in the past several years, with a $1.5 billion investment in facilities and infrastructure.

The On-Campus Stadium will be used year-round. It is not only the home of CSU football administration offices, training and team locker rooms, but also home to 80,000 square feet of space for alumni, academics and student advising. Open for business less than two years after groundbreaking, this Mortenson-built facility includes:

- 36,000 seats
- 11,600 square foot stadium club
- 112 concession sale points
- 22 luxury suites and 40+ loge boxes
- a new alumni association center
- a center for advising and student achievement
- a hall of champions
- six additional retail locations

The open north end zone consists of two large grand staircases on either side of the New Belgium Porch. The open concept integrates amenities and offers an intimate view of the game, accomplishing CSU's goal

Transforming design to reality.

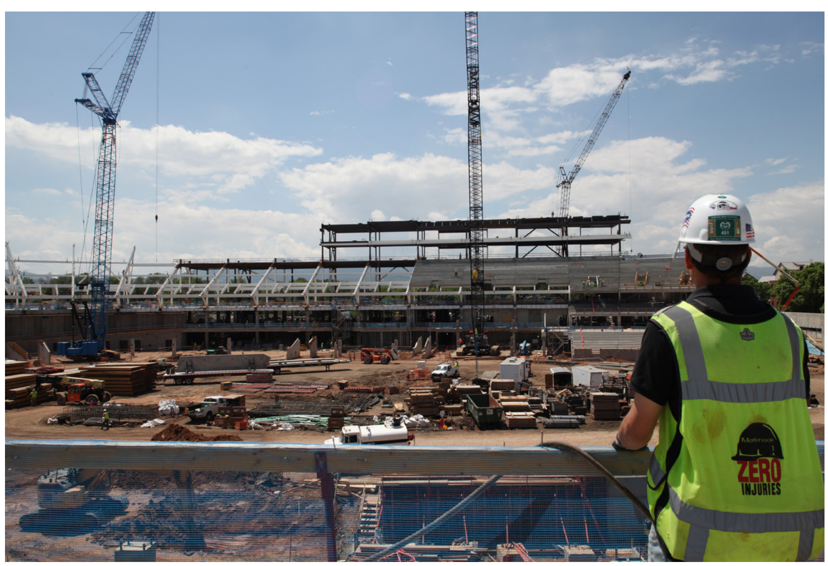
of fan game involvement. This design allows fans to arrive to a single 300-level concourse with continuous connection to the game and back to campus.

ENSURING DELIVERY OF THE BEST PRODUCT MEETING COST AND SCHEDULE

Project site and campus context February '16, five months after groundbreaking.

Throughout the process of bringing a stadium on campus, the owner and project team faced many challenges. Opposition to the project came from those who wanted to save the existing Hughes Stadium, campus neighbors who worried about the impact of construction and traffic on game days, and others concerned about the impact of such a large project being built right in the middle of a 586-acre campus. Community outreach and stakeholder input became helped streamline the process. An open communication approach by everyone on the team was crucial to developing trust and overcoming the challenges of delivering the stadium in less than two years.

Well-coordinated preconstruction efforts became particularly crucial to achieving this goal. One of the many tools employed by the project team was the development of Mortenson's CSAM: the Cost/Scope Alignment Matrix. This tool was frequently used and referred to as the team worked through myriad decisions that were required of the owner.



An eye on progress as of June 2016.

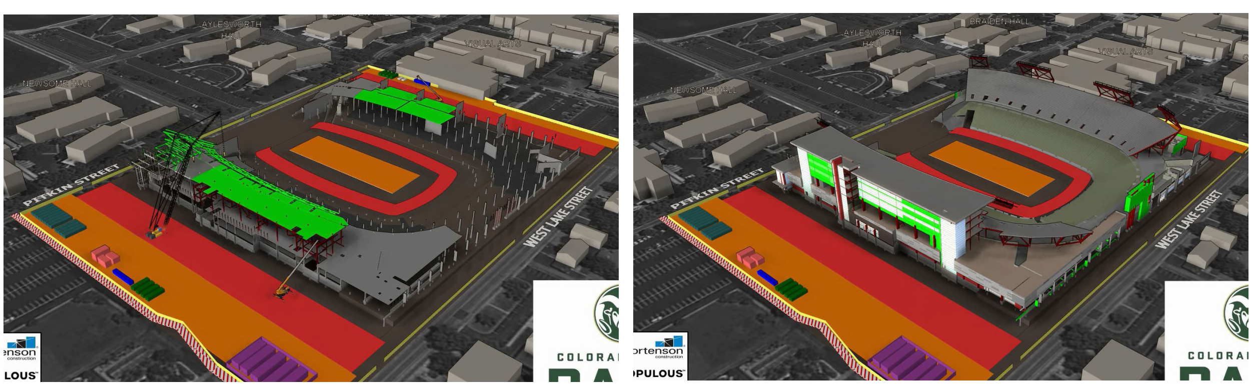
This matrix helped the team clearly see the cost, schedule and quality impacts of the various options that the owner had to sort through. The ultimate goal of the project team in utilizing this matrix was to deliver the best possible facility that would meet owner goals within the project's budget and schedule constraints while serving the University's and the community's needs well into the future. The team started with a "wish list"that the design and construction team reviewed with the owner, allowing them to sort through the options and implement the ones that provided the most value, along with the including owner's "must haves".

LEVERAGING BIM TO ACHIEVE QUALITY AND SCHEDULE DEMANDS

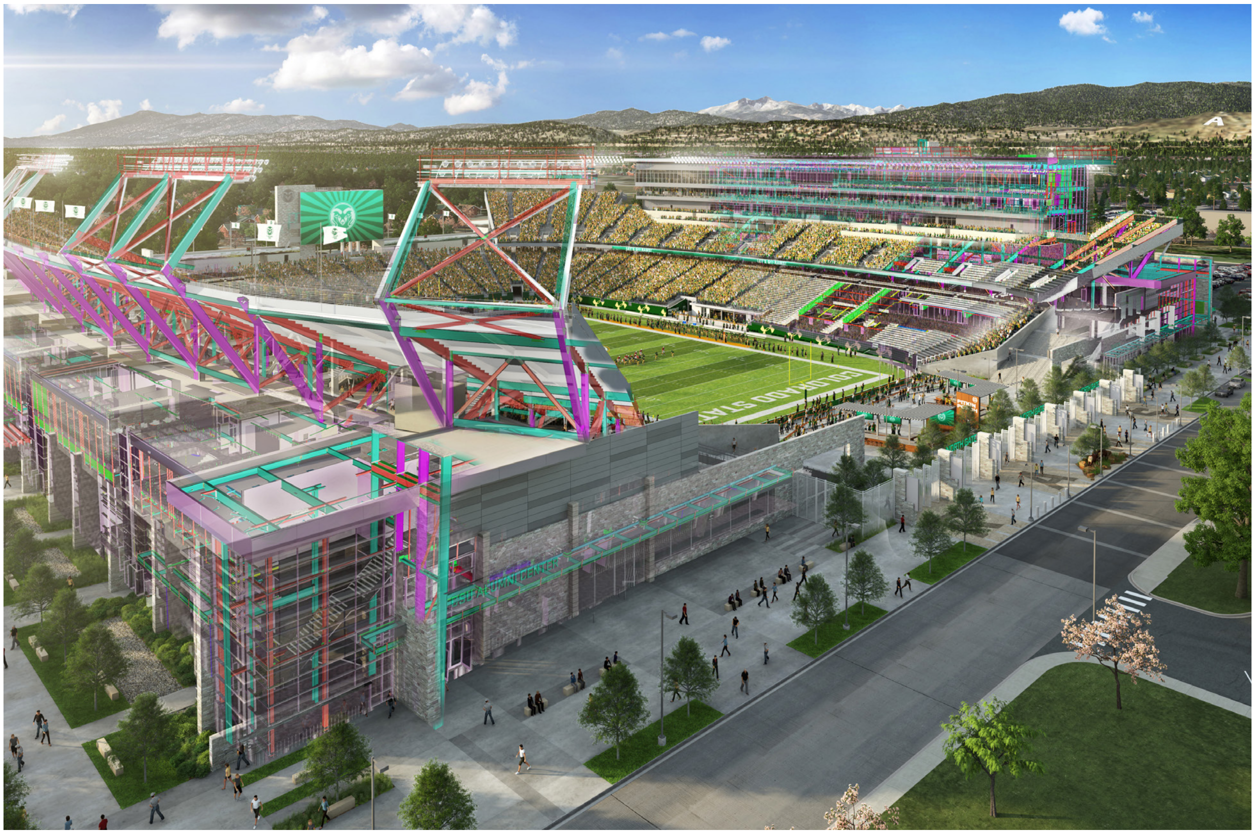
With a deliverable date looming less than two years out, the construction team mitigated the schedule challenges through the use of 4D modeling and the use of mock-ups to ensure constructibility of all of the details. The team used Populous' design models as the basis for the 4D development. By exporting critical 3D elements such as structural and enclosure objects to a common file type and then tying those elements to activities from the P6 schedule using the software Synchro PRO, the team successfully linked 3D content and activities from the schedule to properly evaluate any modifications or proposed changes.

The team developed a workflow and each month the 4D model was used to forecast what the stadium was going to look like at the end of the month. This model state was then incorporated into phase plans which were posted in all the jobsite trailers and conference rooms. This process helped ensure that the entire project team had an idea of what the progress would look like at the end of each month.

The 4D modeling was done from start to finish and helped identify issues before they became problems, especially during the structure phase. The stadium's radial grid system required a more technical approach than a typical building and the steel framing that supports the upper bowl seating includes long cantilevers.   The model showed everything from how cranes were sequenced to site logistics that may affect the structure, including steel, precast stadia seating and cast-in-place concrete.



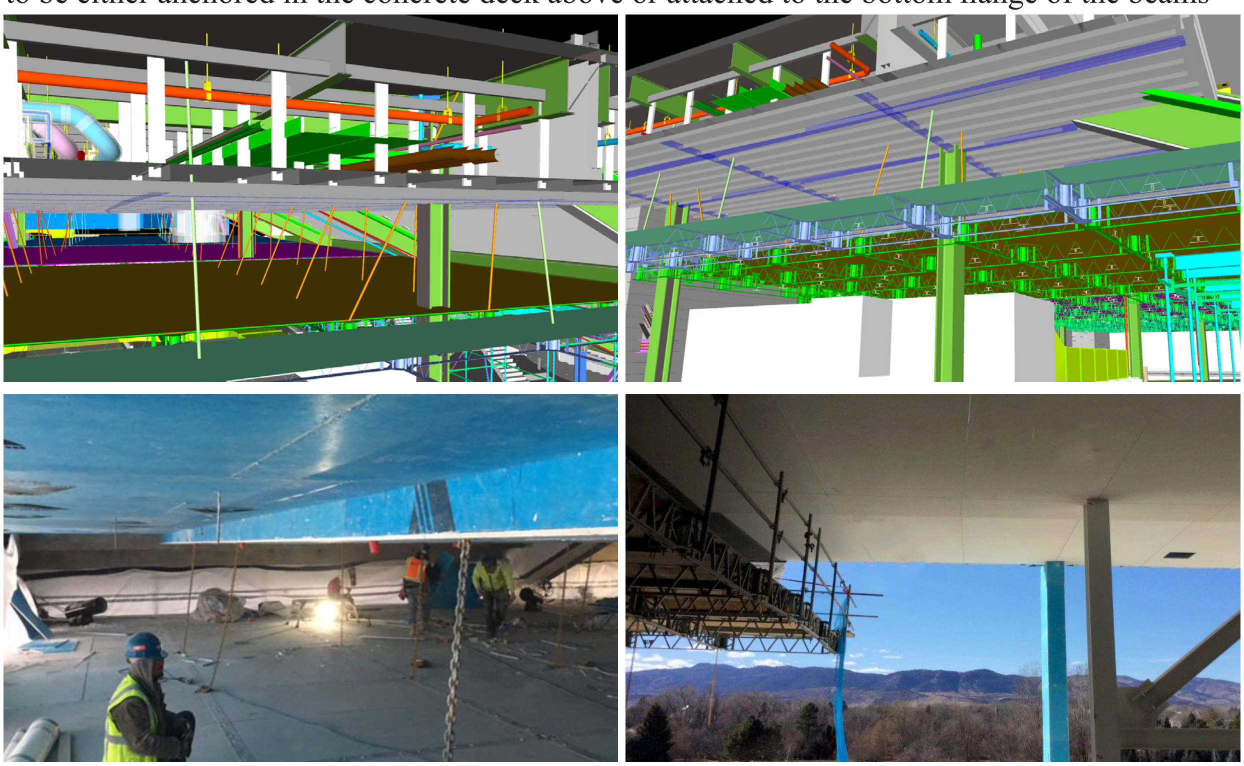
Screen shots of the animated 4D that was a powerful planning and logistics tool.



An image from the model in context with a photo of the completed stadium.

One of the areas that was particularly challenging was the coordination of concurrent work on and above the concourse level (Level 300). Intensive pre-planning was required to manage the work that had to occur to complete the concession areas while other trades had to build the soffit beneath Level 500 of the tower. Freestanding CMU walls, a roofing system, and large mechanical equipment had to be installed on the concourse on Level 300 concurrent with the installation of a 25,000-square-foot framed Direct Applied Finishing System (DAFS), a hard lid soffit system with stucco finish. This meant that traditional scaffolding could not be erected to execute this work without negatively impacting trade partner access and the overall schedule. The team implemented a hanging scaffolding system beneath the Level 500 tower that allowed various trade partners to finish their work on the soffit from the leading edge of the platform. This "Quikdeck" system, traditionally used for performing work beneath bridges, was assembled and disassembled from north to south in eight-foot sections as the work progressed and was completed. This eliminated the need for shoring, allowing the freestanding concourse concessions to be completed without interruption.

Pre-planning for this scenario occurred early in the project and involved Mortenson's Integrated Construction Coordination team to get the system incorporated into the overall 3D model. This model coordination was key because the Quikdeck system was suspended by hangers that need to be either anchored in the concrete deck above or attached to the bottom flange of the beams



Screen shots from the model showing the Quikdeck System and the system in action.

above. After developing an initial Quikdeck layout that minimized attachment points to the structure, it was determined that the resulting lateral loads on the typical floor beams would be unacceptable. To address this issue, the structural engineer, Martin/Martin, provided guidelines for hanging the system directly from the slab, with allowable loads for various slab areas and anchor spacings. Using this information, the scaffold trade partner, Safeway Scaffolding, was able to reconfigure the Quickdeck layout to avoid any modifications to the steel floor structure by attaching the slab on deck. Thus, the project team was able to efficiently coordinate a hanging and coring effort while accommodating the installation of MEP systems on the floor above (i.e. installation of bathroom fixtures and food service equipment), allowing crews to progress with work in a safe and minimally congested manner.

A LABOR OF LOVE FOR THE PROJECT TEAM

More than a dozen Mortenson CSU alumni worked on CSU's On-Campus Stadium.

Although the stadium is one of many important new buildings the CSU campus has seen over the years, it was particularly important to the Mortenson team and its trade partners. With nearly 100 CSU graduates that are Team Members at Mortenson, the pride felt for the Green and Gold within the organization is strong. More than a dozen Mortenson CSU alumni directly worked on the project, including one Team Member who had a truly unique perspective: Former CSU Ram football team member and Mortenson Project Engineer Cameron Moss. Cam made his desire to be part of this project known. "For the most part, I just let them tell me where I'm going, but I definitely let them know this was somewhere I'd like to be," he said.

His involvement as a project engineer is special to the school and its renowned construction management program. "I think it's exactly that. It's a unique combination of having a former student-athlete now working for Mortenson, getting a chance to do something historical in his career and early in his career," said CSU athletic director Joe Parker in an interview with the Loveland Reporter-Herald. In addition to Cam and the many other Mortenson CSU alumni Team Members who worked directly on the job, there were many others who supported efforts. There were also dozens of CSU grads from our trade and design partners who worked on this project. All told more than 1.75 million craft hours went into the delivery of this state-of-the art facility.

THE END RESULT

The excitement on campus is palpable as the Rams football team is off to a winning start in the new stadium. Fans visiting the stadium during a recent open house were left with “jaws dropping” and gushed about the quality of the construction. At a media tour held just before the official opening, Joe Parker stated, “we probably built the best stadium in America.”