CITC GLOBAL
Construction in the 21st Century
11th International Conference (CITC-11)
September 9-11, 2019, London, UK

Springer
SPRINGER NATURE

Building Commissioning: Do Cost Benefits Outweigh the Initial Investment for U.S. Army Corp of Engineers?

Amber Lanphere[1], Scott Kramer[1], and April Simons[1]

[1] Auburn University
krameswe@auburn.edu

Abstract. The research conducted in this study explored the various building commissioning processes currently implemented at the U.S. Army Corps of Engineers for building construction projects in order to determine if the benefits and cost avoidance outweigh the initial cost investment. Over recent years, the USACE has been experiencing some challenges with meeting scheduled beneficial occupancy dates (BOD) on several military construction projects. These issues have led to investigation and analysis efforts in order to determine the root cause for not meeting scheduled BODs. Many of the identified root causes could have been mitigated or eliminated early in the project if building commissioning had been properly implemented and administered with a qualified Commissioning Authority (CxA). This research study includes recommendations for implementing a consolidated, technically sound and detailed building commissioning specification. This should help reduce the cost of building commissioning by eliminating overlapping requirements.

Keywords: USACE, Building Commissioning, Cost, Specifications.

1 Introduction

Building commissioning, in the most basic terms, is a process which ensures the building owner receives the quality and functionality of the building that is expected and required. Most federal government agencies, including the Department of Defense (DoD), General Services Administration (GSA), National Aeronautics and Space Administration (NASA), Department of Veterans Affairs, Department of Energy, and Department of State, require building commissioning as part of their building construction contracts and their specific requirements are documented in the Whole Building Design Guide. This research paper focuses primarily on Department of Defense building commissioning practices and costs for projects contracted and administered by the U.S. Army Corps of Engineers (USACE). According to the current U.S. Census Bureau [1], estimated federal construction expenditures in calendar year 2017 will be approximately $247 billion. With building commissioning costs currently ranging from .5% to 2.25% of construction costs, the federal government will spend approximately $1 billion to $5.5 billion in building commissioning costs [2]. This is a substantial price to pay for a requirement that may seem unnecessary or duplicative to the outside observer. By the definition of building commissioning, an outside observer

may feel that a building owner should receive the quality and functionality of the building they are procuring without having to pay an additional cost for building commissioning. Historical evidence suggests, however, that the building owners are consistently not receiving what they expected or required upon occupancy of their building. They experience malfunctioning equipment, missing equipment, lack of operation and maintenance documentation, lack of spare parts or knowledge of how to acquire spare parts, equipment that isn't installed or integrated properly, and equipment interoperability issues. This can lead to increased energy costs, increased life safety risks, decreased personnel productivity, increased cost for contract modifications and re-work, increased life cycle cost, decreased building operational life, and increased operation and maintenance costs [3]. The causes of the deficiencies listed above are most often not evident, even to the subject matter experts. They are discovered and eliminated by a systematic, methodical approach that prepares and tests the whole system, rather than individual components or subsystems. If appropriate review and issue resolution techniques are not implemented during the design and construction phases of a project, acceptance testing will most likely fail resulting in schedule delays and significant additional costs. This research paper will analyze the building commissioning processes and procedures utilized within USACE building construction projects and determine if they are being performed as intended and whether the value added correlates with the cost of building commissioning.

2 Background

Historically, federal government agencies have treated commissioning as a requirement that applies strictly to mechanical, specifically heating, ventilation and air conditioning (HVAC), systems which is conducted when the mechanical systems undergo testing and balancing (TAB). The U.S. Army Corps of Engineers was the first federal agency to develop commissioning HVAC (Cx) guide specifications in 1993, followed by HVAC Cx procedures in 1994. The American Society of Heating, Refrigerating, & Air Conditioning Engineers (ASHRAE) published Guideline 1-1996: The HVAC Cx Process in 1996 and by 1998, numerous federal government agencies have begun incorporating HVAC Cx requirements in building construction projects. The Leadership in Energy and Environmental Design (LEED) organization first incorporated HVAC Cx as a LEED criteria in 1998. Between 1998 and 2005, numerous organizations, private and public, began incorporating HVAC Cx requirements in building construction projects. Commissioning industry groups began forming and certification qualification programs for Commissioning Authorities were developed.

ASHRAE published Guideline 0: The Cx Process in 2005, which was the next major release in the commissioning industry. ASHRAE Guideline 0: The Cx Process introduced the concept of total building commissioning, thus, shifting the focus from strictly HVAC systems. With the publication of the Energy Policy Act of 2005, Energy and Independence Security Act of 2007, and Executive Order (EO) 13693, federal agencies were mandated to "lead by example, promoting sustainable federal buildings through environmentally-sound, economically-sound and fiscally-sound design,

construction, and operating decisions." [4]. In response to this mandate, the DoD published the Unified Facilities Criteria (UFC) 4-030-01 Sustainable Development was on 21 December 2007, which was superseded numerous times until the latest version UFC 1-200-02 High Performance and Sustainable Building Requirements was published on 01 December 2016. This UFC is applicable to "all planning, design and construction, renovation, repair, operations and maintenance, and affixed equipment installation in new and existing buildings, regardless of funding source, that results in DoD real property assets." [4]. The UFC 1-200-02 includes building commissioning as an integral part of the design and construction of buildings; therefore, emphasizing the inclusion of building commissioning requirements into the design and construction plans and specifications. In order to ensure design and construction specifications include the building commissioning requirements, the DoD developed the Division 01 – General Requirements, Section 01 91 00.15 Total Building Commissioning Unified Facilities Guide Specifications (UFGS) and the latest version was published in May 2016. The U.S. Army Corps of Engineers tailors the Total Building Commissioning UFGS as a minimum and includes it in the combined set of specifications for every new building construction project.

3 Purpose of the Study

The purpose of this study was to explore the various building commissioning processes currently implemented at the U.S. Army Corps of Engineers on new building construction projects and determine if the cost benefits outweigh the initial cost investment. The U.S. Army Corps of Engineers currently utilizes various combinations of the following specifications in all new building construction projects: 01 91 00.15 Total Building Commissioning UFGS as discussed previously, LEED Fundamental Commissioning and Verification, LEED Enhanced Commissioning, and a new custom USACE Tulsa District specification titled Section 01 91 00.15 10 Mechanical/Building Control Systems Integrator. In a recently awarded design-build construction project, all four of these specifications were included in the request for proposals (RFP). The RFP included a separate Contract Line Item Number (CLIN) in the pricing schedule for each of these requirements to be priced separately as CLINs 0008, 0009, 0010, and 0011 as shown in Figure 1 [5]. Even though three of these are included as "options" in the RFP, a combination of these options were actually awarded for the project. This paper will define, in very broad terms, the scope of each of these specifications while exploring possible overlap or redundancies in the requirements. The paper will cite some recent bids received for these requirements, recently awarded costs, and potential cost avoidance by incorporating these requirements.

4 Rationale for the Study

The U.S. Army Corps of Engineers (USACE) has traditionally had a reputation for being a world class construction agency. The USACE has a long and rich history with many military and civil works customers and sponsors. Over recent years, the USACE

has been experiencing some challenges with meeting scheduled beneficial occupancy dates (BOD) on several military construction projects. These issues have led to investigation and analysis efforts in order to determine the root cause for not meeting scheduled BODs. Many of the identified root causes could have been mitigated or eliminated early in the project if building commissioning had been properly implemented and administered with a qualified Commissioning Authority (CxA).

PRICING SCHEDULE

CLIN No.	Description	Quantity	Unit	Unit Price	Amount
	BASE PROPOSAL				
0001	Design Costs · Except as listed separately	1	Job	XXX	$_____
0002	Design Costs – Comprehensive Interior Design (CID) (Note 11)	1	Job	XXX	$_____
	Subtotal Design Costs (CLINS 0001 – 0002 Inclusive)				$_____
0003	Non-Design Costs Except as listed separately	1	Job	XXX	$_____
0004	Non-Design Costs – Comprehensive Interior Design (CID) (Note 11)	1	Job	XXX	$_____
	Subtotal Non-Design Costs (CLINS 0003 – 0004 Inclusive)				$_____
0005	Construction Costs Except as Listed Separately	1	Job	XXX	$_____
0006	As-built Drawings	1	Job	XXX	$_____35,000
0007	O&M Manuals	1	Job	XXX	$_____60,000
0008	Provide Fundamental Commissioning	1	Job	XXX	$_____
	Subtotal Construction Costs (CLINS 0005 – 0008 Inclusive)				$_____
	TOTAL BASE PROPOSAL (CLINS 0001 – 0008)				$_____
	OPTIONS				
0009	Option 1 – Provide Enhanced Commissioning	1	Job	XXX	$_____
0010	Option 2 – Provide Total Building Commissioning	1	Job	XXX	$_____
0011	Option 3 – Provide Mechanical/ Building Control Systems Integrator	1	Job	XXX	$_____
0012	Option 4 - Provide Asbestos Survey	1	Job	XXX	$_____
0013	Option 5 – Lead-Based Paint Abatement	150	SF	$_____	$_____
0014	Option 6 – Asbestos Abatement	273,520	SF	$_____	$_____
0015	Option 7 – Provide Furnishings (FF&E) from CID	1	Job	$_____	$_____
	TOTAL OPTIONS (CLINS 0009 – 0015)				$_____

Figure 1: Design-Build Construction Project Pricing Schedule.

5 Research Design

The research begins with exploring the various processes involved in new building construction commissioning and identifying which processes are included or excluded in the four building commissioning specifications currently utilized by USACE: 01 91 00.15 Total Building Commissioning UFGS, LEED Fundamental Commissioning and Verification, LEED Enhanced Commissioning, and a new custom USACE Tulsa District specification known as Section 01 91 00.15 10 Mechanical/Building Control

Systems Integrator. The flowchart shown in Figure 2 illustrates the processes involved in building commissioning as defined in ASHRAE 0-2013 [6]. ASHRAE 0-2013, ASHRAE 189.1-2014 and ASHRAE 202-2013 are the most commonly used industry standards for building commissioning and are the standards referenced in USACE policies and regulations. As shown in Figure 2, the building commissioning process is comprised of many activities that could be discussed at length, but is beyond the scope of this research.

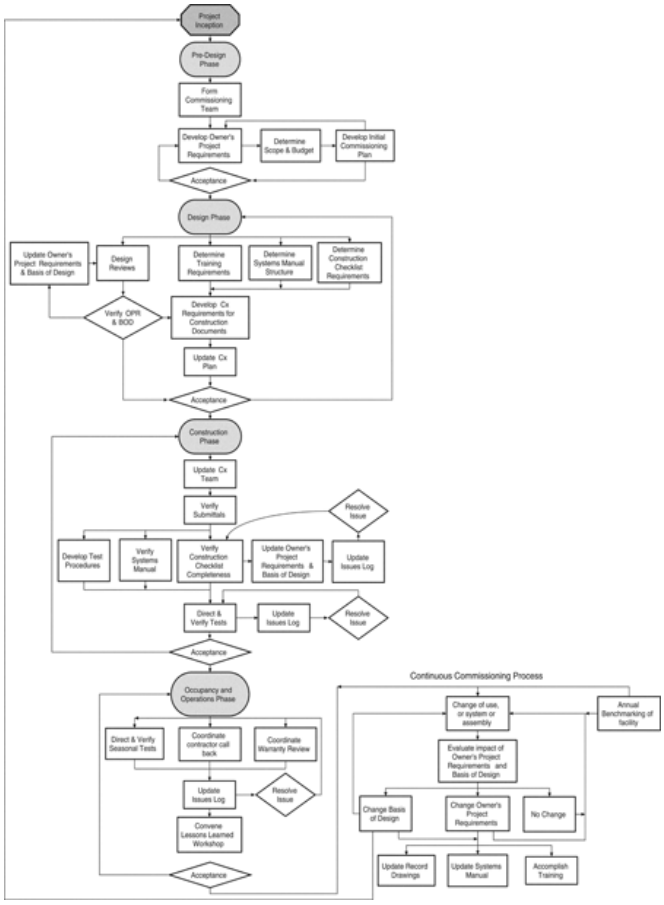

Figure 2: ASHRAE 0-2013 Commissioning Process Flowchart.

This research paper will focus on one example project for illustration purposes, but will need to be researched further due to factors that vary from project to project. These factors include specific knowledge within the product development team (PDT) related to building commissioning activities, building commissioning processes, building commissioning criteria, and building commissioning policies; qualifications of the specifications writers; and thoroughness of the specifications quality review. The research will begin by examining each of the four USACE building commissioning specifications individually.

Beginning with the 01 91 00.15 Total Building Commissioning UFGS, the research reveals that the unmodified language in the specification is closely tied to the ASHRAE 202-2013 Commissioning Process for Buildings and Systems. The requirements in the 01 91 00.15 UFGS essentially further define the processes for the activities shown in Figure 2 [7]. These requirements may be tailored to project specific requirements by utilizing the SpecsIntact software. The language in the specification is considerably broad; therefore, requires technical writers and engineers to include additional details based on technical knowledge of the project requirements. The technical writers and engineers should have knowledge of the building commissioning project requirements, as well as applicable policies, criteria and guidance. This section within the specifications affords USACE the opportunity to really define the building commissioning requirements in as much detail as possible. This UFGS undoubtedly should be included in every USACE building construction project as it is necessary to incorporate the Unified Facilities Criteria (UFC) 1-200-02 High Performance and Sustainable Building Requirements [4]. The Unified Facilities Criteria (UFC) 1-200-02 High Performance and Sustainable Building Requirements is one of the most important and commonly used UFC when discussing building commissioning, sustainable design and development, and third party certification [4].

Following the 01 91 00.15 UGFS, the research progressed to the LEED Fundamental Commissioning and Verification requirement. This requirement originated around 2001 due to the initiatives in sustainable design and development (SDD) as discussed in the Unified Facilities Criteria (UFC) 1-200-02 High Performance and Sustainable Building Requirements [4]. As part of SDD, military construction projects were required to achieve LEED certification, as well as other LEED credits. LEED certification requires Fundamental Commissioning and Verification as illustrated in Figure 3 [8]. On 17 January 2017, the Department of the Army issued the Sustainable Design and Development Policy Update Memorandum [9]. This memorandum supersedes any SDD policy that was issued prior to 17 January 2017. The overarching SDD requirements referenced in the memorandum are derived from ASHRAE 189.1-2014. The criteria outlined in ASHRAE 189.1-2014 aren't dependent on an overall third party certification from organizations such as the U.S. Green Building Council; therefore don't require LEED certification [10]. Therefore, based on current guidance, the LEED Fundamental Commissioning and Verification is no longer required by policy or regulation. Additionally, the Engineering and Construction Bulletin 2016-30 Air Force Sustainability Guidance for Third Party Certification issued on 21 December 2016 states "All new AF projects, not previously registered under LEED version 2009 by the registration close date of 31 October 2016, will register with USGBC or GBI for DoD specific GPC certification, regardless of funding source, for the following design and construction activities occurring on permanent Active AF Installations in the United States and its territories (in accordance with the current UFC 1-200-02, Table 1-1, updated 1 December 2016): (1) All new buildings larger than 5,000 SF, with construction cost greater than $3M.

(2) All renovations to an existing building greater than 5,000 SF, with construction cost greater than $3M and 50% Estimated Replacement Cost (ERC) [11]. The current UFC 1-200-02 High Performance and Sustainable Building Requirements encompasses

the DoD third party certification requirements. The third party certification process has been streamlined and tailored to meet the needs of the DoD by utilizing the High Performance and Sustainable Building (HPSB) Guiding Principles. Projects that conform to the requirements of the UFC 1-200-02 High Performance and Sustainable Building Requirements are considered compliant with the HPSB Guiding Principles [4]. The DoD agency specific HPSB compliance checklists can be found in Paragraph 4-2.1 of the UFC. The DoD agency will register for third party certification through the Green Building Initiative (GBI) by utilizing the GBI Guiding Principles Compliance for New Construction Process Guide [11]. If the LEED Fundamental Commissioning and Verification requirement were still enforced; however, the 01 91 00.15 Total Building Commissioning UFGS contains the requirements needed to meet the LEED Fundamental Commissioning and Verification requirement with very minor adjustments to the language. Due to the similarities between 01 91 00.15 Total Building Commissioning UFGS and LEED Fundamental Commissioning and Verification requirements, the DoD should not be paying separate and distinct costs for the requirements. This is in direct conflict with CLIN 0008 on the pricing schedule shown in Figure 1.

The next building commissioning requirement researched was the Enhanced Commissioning requirement. As shown in Figure 3, Enhanced Commissioning is a LEED credit worth 6 points. The Enhanced Commissioning requirement builds upon the Fundamental Commissioning and Verification requirement. Figure 4 illustrates the differences between Fundamental Commissioning and Verification and Enhanced Commissioning [13]. According to the latest Engineering & Construction Bulletin (ECB) 2015-6 Total Building Commissioning Process for USACE Projects, "Prior directives mandated enhanced commissioning and identified select projects to earn LEED Enhanced Commissioning credit EAc3. LEED EAc3 is no longer mandated per SDD Policy Update. Current policy requires meeting Total Building Commissioning requirements per ASHRAE 189.1-2011 as opposed to LEED EAc3 (Reference h and i). Project Delivery Teams are not required but are encouraged to pursue achieving LEED EAc3 when possible" [14]. Based on this current information, the DoD could implement the building commissioning best practices shown in Figure 4 into the 01 91 00.15 Total Building Commissioning UFGS and shouldn't incur additional cost.

LEED for New Construction and Major Renovations (v4)

		POSSIBLE: 1
Credit	Integrative process	1

LOCATION & TRANSPORTATION		POSSIBLE: 16
Credit	LEED for Neighborhood Development location	16
Credit	Sensitive land protection	1
Credit	High priority site	2
Credit	Surrounding density and diverse uses	5
Credit	Access to quality transit	5
Credit	Bicycle facilities	1
Credit	Reduced parking footprint	1
Credit	Green vehicles	1

SUSTAINABLE SITES		POSSIBLE: 10
Prereq	Construction activity pollution prevention	REQUIRED
Credit	Site assessment	1
Credit	Site development - protect or restore habitat	2
Credit	Open space	1
Credit	Rainwater management	3
Credit	Heat island reduction	2
Credit	Light pollution reduction	1

WATER EFFICIENCY		POSSIBLE: 11
Prereq	Outdoor water use reduction	REQUIRED
Prereq	Indoor water use reduction	REQUIRED
Prereq	Building-level water metering	REQUIRED
Credit	Outdoor water use reduction	2
Credit	Indoor water use reduction	6
Credit	Cooling tower water use	2
Credit	Water metering	1

ENERGY & ATMOSPHERE		POSSIBLE: 33
Prereq	Fundamental commissioning and verification	REQUIRED
Prereq	Minimum energy performance	REQUIRED
Prereq	Building-level energy metering	REQUIRED
Prereq	Fundamental refrigerant management	REQUIRED
Credit	Enhanced commissioning	6
Credit	Optimize energy performance	18
Credit	Advanced energy metering	1
Credit	Demand response	2
Credit	Renewable energy production	3
Credit	Enhanced refrigerant management	1
Credit	Green power and carbon offsets	2

MATERIAL & RESOURCES	
Prereq	Storage and collection of recyclables
Prereq	Construction and demolition waste ma
Credit	Building life-cycle impact reduction
Credit	Building product disclosure and optim declarations
Credit	Building product disclosure and optim
Credit	Building product disclosure and optim
Credit	Construction and demolition waste ma

INDOOR ENVIRONMENTAL QUALITY	
Prereq	Minimum IAQ performance
Prereq	Environmental tobacco smoke control
Credit	Enhanced IAQ strategies
Credit	Low-emitting materials
Credit	Construction IAQ management plan
Credit	IAQ assessment
Credit	Thermal comfort
Credit	Interior lighting
Credit	Daylight
Credit	Quality views
Credit	Acoustic performance

INNOVATION	
Credit	Innovation
Credit	LEED Accredited Professional

REGIONAL PRIORITY	
Credit	Regional priority

TOTAL	
40-49 Points CERTIFIED	50-59 Points SILVER

Figure 3: LEED v4 Scorecard for New Construction and Major Renovations.

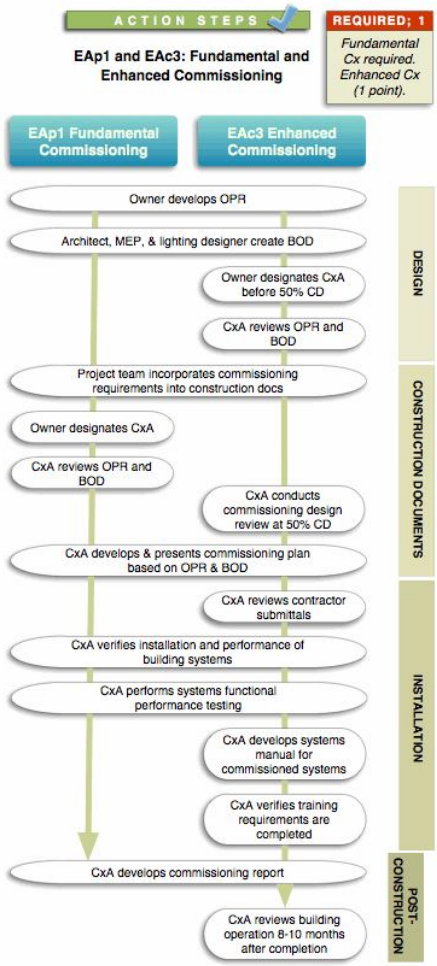

Figure 4: Fundamental Commissioning and Verification vs. Enhanced Commissioning.

The final USACE building commissioning specification researched was the new Section 01 91 00.15 10 Mechanical/Building Control Systems Integrator specification unique to the Tulsa District. This new specification is currently being implemented in a couple of projects as a preliminary study. This specification was created to address specific mechanical, primarily HVAC, system commissioning challenges. The primary architect for the specification is the Ft. Sill Area Office Engineer, Rick West, P.E. The HVAC system commissioning challenges cited by Mr. West included: "Untimely selection/submittal of major equipment items; Major equipment components often procured from multiple manufacturers/vendors (e.g. not "Plug & Play"); Absence of defined control modes over the full range of system operation (dead zones); Operational sequences/integration points on equipment with packaged controls not fully

defined/detailed; Integration of Dedicated Outside Air Units (DOAU's) w/bldg DDC controls is especially problematic." [15]. In an effort to mitigate or eliminate these challenges, the Section 01 91 00.15 10 Mechanical/Building Control Systems Integrator specification includes the language shown in Figure 5. Because this specification was so recently developed, it is impractical to quantitatively measure cost vs. benefits or potential cost avoidance. The pricing for this specification; however, is shown in Table 1.

1.4 CONTRACTUAL EMPLOYMENT REQUIREMENT

The Mechanical/Building Control Systems Integrator, hereafter referred to as the "Integrator", shall be hired by the prime Contractor and work directly for the Government. All documents, notes, requirement, comments, etc. that are generated by the Integrator shall be provided to the Government with a courtesy copy furnished to the Contractor.

1.5 MECHANICAL/BUILDING CONTROL SYSTEMS INTEGRATOR JOB DESCRIPTION AND FUNCTIONS

The Integrator shall report directly to the person designated by the Contracting Officer's Representative.

Integrator's activities include direct digital control (DDC) and HVAC and building equipment controls systems engineering, integration, programming, and active integration of systems, equipment, processes and controls from multiple HVAC and mechanical equipment manufacturers both during design processes (review and coordination) and all phases of facility construction. Work activities include assessing designed and installed systems and equipment for controls, working issues and providing remediation, design and installation fixes and troubleshooting of same systems. Work activities require an individual possessing traits of decisiveness, initiative, tact, mechanical and systems and equipment experience, judgment, integrity, dependability, and the ability to communicate in a technically credible manner to customers, suppliers, controls contractors and engineers. The Integrator must also possess exemplary working and safety habits.

The Integrator shall provide (at minimum) the services, actions, equipment, reports, etc. as required by the related Mechanical/Building Controls Systems Integrator Checklist (Appendix A) located at the end of this section.

Figure 5: Excerpt from Section 01 91 00.15 10 Mechanical/Building Control Systems Integrator Specification.

6 Data Analysis

The actual cost data for this analysis was pulled from two sample projects within USACE. The data presented in table 1 represents the cost of the four building commissioning specifications currently utilized within USACE [16]. Company A and B correlate to the sample project which has been discussed throughout this research paper and correlates to the pricing schedule shown in Figure 1. Company C, Company D, Company E, Company F, Company G, Company H and Company I all correlate to a second sample project for which the Fundamental Commissioning and Enhanced Commissioning specifications or CLINs weren't included as part of the project scope. Additional building commissioning cost data does exist; however, will require close

coordination with the contractors that bid on the items. The building commissioning cost data is frequently buried within other CLINs such as the Construction CLIN, and the contractor doesn't provide a breakout of the cost within the Construction CLIN. The data presented in Table 2 represents the cost of the four building commissioning specifications currently utilized within USACE [16] as a percentage of the overall project price proposed by the various companies.

Some of the salient points within the Table 1 and Table 2 data includes: the range of costs and percentages of each CLIN, the average cost and percentage of each CLIN, and the median cost and percentage of each CLIN. Another key data point includes the assumed value or weight the contractor is placing on each of these building commissioning CLINs. Company A assumes higher costs for all the CLINs in general, but associates very little cost with the Enhanced Commissioning CLIN. Company B doesn't appear to understand the requirements in these CLINs very well, as they are pricing the Enhanced Commissioning CLIN and the Total Building Commissioning CLIN at the same price. Additionally, Company B has a significantly lower Mechanical/Building Control System Integrator CLIN cost than all the other companies. In general, the majority of the companies are placing a higher cost on the Mechanical/Building Control Systems Integrator CLIN than on the Total Building Commissioning CLIN.

The individual building commissioning CLIN cost percentages presented in Table 2 all fall within the higher end (2.25%) of the expected building commissioning building commissioning costs, according to U.S. General Services Administration [2]. Several of the individual building commissioning CLIN costs are below the expected low end of the range (0.5%). The data presented in Table 2 totals, however, all (except Company A) fall within the range of 0.5% to 2.25% as cited by the U.S. General Services Administration [2]. More than likely, these CLINs would not all be awarded at the same time, as Figure 1 illustrates that three of the CLINs were options. The total row just illustrates the worst case scenario if all the CLINs were awarded.

According to the U.S. Department of Energy, "the recognized rule-of-thumb used in the construction industry to estimate return on investment is a $3 savings for each $1 spent on commissioning. (More complex facilities such as laboratories and hospitals may have greater return on investment ranging from $3 to $11 for each dollar spent." (2017). The U.S. Department of Energy also provides building commissioning estimated costs per square foot for various facility complexities as shown in Figure 6.

	Company A	Company B	Company C	Company D	Company E	Company F	Company G	Company H	Company I	Range	Average	Median
Fundamental Commissioning	$230,000.00	$90,000.00								$140,000.00	$160,000.00	$160,000.00
Enhanced Commissioning	$10,817.00	$40,000.00								$29,183.00	$25,408.50	$25,408.50
Total Building Commissioning	$343,032.00	$40,000.00	$45,026.00	$31,945.00	$30,000.00	$25,000.00	$65,300.00	$75,500.00	$60,989.33	$318,032.00	$79,643.59	$45,026.00
Mechanical/Building Control Systems Integrator	$270,353.00	$22,000.00	$58,000.00	$69,398.00	$70,740.00	$78,000.00	$45,600.00	$71,445.00	$77,764.18	$248,353.00	$84,811.13	$70,740.00
Total	$854,202.00	$192,000.00	$103,026.00	$101,343.00	$100,740.00	$103,000.00	$110,900.00	$146,945.00	$138,753.51			

Table 1: Building Commissioning Pricing for Sample Projects.

	Company A	Company B	Company C	Company D	Company E	Company F	Company G	Company H	Company I	Range	Average	Median
Fundamental Commissioning	0.63%	0.19%								0.43%	0.41%	0.41%
Enhanced Commissioning	0.03%	0.09%								0.06%	0.06%	0.06%
Total Building Commissioning	0.94%	0.09%	0.34%	0.23%	0.22%	0.18%	0.50%	0.56%	0.36%	0.85%	0.38%	0.34%
Mechanical/Building Control Systems Integrator	0.74%	0.05%	0.44%	0.51%	0.53%	0.57%	0.35%	0.53%	0.56%	0.69%	0.47%	0.53%
Total	2.33%	0.41%	0.78%	0.74%	0.75%	0.75%	0.85%	1.09%	0.92%			

Table 2: Building Commissioning Pricing as a Percentage of Total Project Price for Sample Projects.

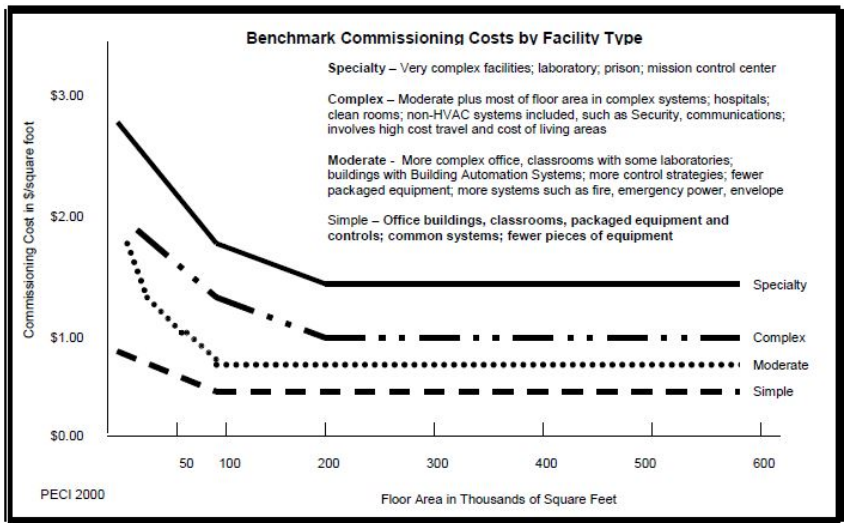

Figure 6: Building Commissioning Estimated Costs per Square Foot for Various Facility Complexities.

7 Conclusions & Future Research

According to the U.S. Department of Energy [17], "the recognized rule-of-thumb used in the construction industry to estimate return on investment is a $3 savings for each $1 spent on commissioning. (More complex facilities such as laboratories and hospitals may have greater return on investment ranging from $3 to $11 for each dollar spent." Theoretically, USACE should be receiving the cited return on investment. Historically, it isn't evident whether USACE is realizing any benefits or cost avoidance by implementing building commissioning standards. However, in talking with one of our primary building commissioning authorities, they noted that many deficiencies discovered early in the project design or construction could have resulted in significant cost modifications and schedule delays had they not been discovered early in the project schedule. The USACE will continue to collect qualitative data on projects requiring building commissioning, and analyze the data to determine cost avoidance and benefits. The building commissioning pricing received from contractors, or investment cost,

appears to be within the expected ranges. The sample size is prohibitively limited in order to infer any definitive cost conclusions, and research should continue to collect building commissioning cost data.

In general, it appears that USACE needs to consolidate the building commissioning specifications into the Section 01 91 00.15 Total Building Commissioning UFGS, add technical details to the Section 01 91 00.15 Total Building Commissioning UFGS and implement a thorough quality review of the Section 01 91 00.15 Total Building Commissioning UFGS for every RFP. Additionally, the USACE field offices should be well versed on the requirements in the Section 01 91 00.15 Total Building Commissioning UFGS and the Section 01 91 00.15 10 Mechanical/Building Control Systems Integrator specification in order to properly inspect and manage the work. The contractors must be held accountable for meeting the specification requirements; otherwise, any cost benefits or cost avoidance will be diminished. The USACE designers should also include more rigor in reviewing design plans specifications and raise concerns early in the design phase. Research should also continue for the Section 01 91 00.15 10 Mechanical/Building Control Systems Integrator specification. Deliverables as a result of this specification should be reviewed and documented for further analysis. USACE should continue to document BOD schedule delays and analyze and document the root causes.

8 References

1. U.S. Census Bureau. (2017). *Value of Construction Put in Place at a Glance.* Retrieved from https://www.census.gov/construction/c30/c30index.html
2. U.S. General Services Administration. (2017). *Commissioning Agent Cost.* Retrieved from https://www.gsa.gov/portal/content/101959
3. Grondzik, W. T. (2009). *Principles of Building Commissioning.* Hoboken, New Jersey: John Wiley & Sons Inc.
4. U.S. Department of Defense. (Dec 2016). *Unified Facilities Criteria (UFC) 1-200-02 High Performance and Sustainable Building Requirements.* Retrieved from https://www.wbdg.org/FFC/DOD/UFC/ufc_1_200_02_2016.pdf
5. U.S. Army Corps of Engineers. (2016). *Sample Project 2-Phase Design-Build Request for Proposal: Phase 2 of 2.* Retrieved from U.S. Army Corps of Engineers internal files
6. American Society of Heating, Refrigerating, and Air-Conditioning Engineers. (2013). *ASHRAE Guideline 0-2013 The Commissioning Process.* Retrieved from https://www.ashrae.org/resources--publications/bookstore/commissioning-essentials
7. U.S. Department of Defense. (May 2016). *Unified Facilities Guide Specifications (UFGS) 01 91 00.15 Total Building Commissioning.* Retrieved from https://wbdg.org/ffc/dod/unified-facilities-guide-specifications-ufgs/ufgs-01-91-00-15
8. U.S. Green Building Council. (2015). *LEED v4 Scorecard for New Construction and Major Renovations.* Retrieved from https://www.usgbc.org/credits

9. U.S. Army. (2017). *Sustainable Design and Development Policy Update Memorandum.* Retrieved from https://www.wbdg.org/FFC/ARMYCOE/POLICY/Army_SDD_Policy_Update_2017.pdf
10. American Society of Heating, Refrigerating, and Air-Conditioning Engineers. (2014). *ASHRAE Standard 189.1-2014 Standard for the Design of High Performance Green Buildings.* Retrieved from https://www.ashrae.org/resources--publications/bookstore/standard-189-1
11. U.S. Army Corps of Engineers. (Dec 2016). *Air Force Sustainability Guidance for Third Party Certification.* Retrieved from https://www.wbdg.org/FFC/ARMYCOE/COEECB/ecb_2016_30.pdf
12. Green Building Initiative. (2017). *GBI Guiding Principles Compliance for New Construction Process Guide – (DoD)*. Retrieved from http://www.wbdg.org/FFC/AF/POLICY/GBI_Guiding_Principles_Compliance_NC_DoD_Process_Guide.pdf
13. Bowman, S. (2013). *NC-v2.2 EAp1: Fundamental Commissioning of the Building Energy Systems.* Retrieved from http://www.leeduser.com/credit/nc-v2.2/eap1#bev-tab
14. U.S. Army Corps of Engineers. (2015). *Engineering and Construction Bulletin No. 2015-6 Total Building Commissioning Process for USACE Projects.* Retrieved from https://www.wbdg.org/FFC/ARMYCOE/COEECB/ecb_2015_6.pdf
15. West P.E., R. (2016). *FSAO/Military Design Partnering Session*. Retrieved from U.S. Army Corps of Engineers internal files
16. U.S. Army Corps of Engineers. (Sep 2016). *Sample Project Proposals.* Retrieved from U.S. Army Corps of Engineers internal files
17. U.S. Department of Energy. (2017). *Commissioning for Federal Facilities.* Retrieved from https://energy.gov/sites/prod/files/2014/07/f17/commissioning_fed_facilities.pdf