Total Building Commissioning: Case Study of the U.S. District Courthouse in Salt Lake City, Utah, USA

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Abstract
Principles and procedures of Total Building Commissioning (C_x) are presented as a case study of the U.S. District Courthouse, which is being constructed in Salt Lake City, Utah, USA, as a design-bid-build project. This 10-story building has a floor area of approximately 357,000 gross square feet and has an estimated construction cost of $177 million. The construction is to be completed in July 2014. This case study focuses on commissioning of several systems during the design phase, and partial commissioning of the envelope system, which was the only system available for performance testing during the early stage of construction. Findings and conclusions are presented regarding performance enhancements of several systems attributable to commissioning during the design phase, and performance testing of the envelope system during the early construction stage.

1. Introduction

Most buildings, if not commissioned, tend to operate ineffectively in meeting the owner's functional requirements, and typically consume excessive amounts of energy [1, 2]. During the past 10 years, commissioning guidelines and standards have been developed for specific operating systems such as HVAC and building enclosures [3, 4]. Additionally, criteria and procedures have been developed for Total Building Commissioning (C_x) to evaluate the integrated performance of building systems, including the site, envelope, HVAC, lighting, electrical, plumbing, and fire and smoke control systems [2, 5].

To assure a high standard of excellence, the Public Buildings Service (PBS) of the U.S. General Services Administration (GSA) requires a C_x Process for quality delivery in new construction and facility modernization [2, 6]. It is a process for achieving, validating, and documenting that the performance of the total building and its systems meets the design intent and requirements of the owner.

C_x is being implemented for the design and construction of the new U.S. District Courthouse in Salt Lake City, Utah, USA. This project has been selected as a "case study" as it exemplifies many of the issues that must be overcome to achieve a successful C_x. At the current stage of this design-bid-build project, specific commissioning procedures have been conducted during the design phase, but testing during construction has been limited to performance evaluation of the envelope system.

This paper describes the commissioning procedures that are being implemented for this project, and presents initial findings and conclusions.

2. Case Study: U.S. District Courthouse in Salt Lake City

Design for the new U.S. District Courthouse in Salt Lake City, Utah began approximately 10 years ago. In 2010, the U.S. General Services Administration (GSA) was authorized by Congress to proceed with $177 million for construction of this project. Construction began in January of 2011 and is expected to be completed in July of 2014. The new building is located on a site directly adjacent to the west of the existing Frank E. Moss Courthouse, which has exceeded its original design capacity from both a space and security perspective.

The new 10-story courthouse is designed to serve seven district and three magistrate courtrooms, fourteen chambers for judges, spaces for the U.S. Marshals Service and the U.S. Probation offices, and to provide office support spaces on all floors. Two floors below grade are designed to provide parking and building support space, including mechanical and electrical equipment rooms. A penthouse has been designed to provide support space for mechanical equipment. The building will have approximately 357,000 gross square feet of floor area, 33,088 square feet of roofing and 147,485 square feet of unitized, glazed curtain wall.

The new courthouse was designed in accordance with the *PBS Facilities Standards P100-2005* [6] and the 2007 *U.S. Court Design Guide* [7]. It has also been designed to achieve "gold certification" in accordance with Leadership in Energy and Environmental Design (LEED®) [8], which, through its requirement for commissioning, is intended to verify that the building has been designed and built using strategies aimed at improving overall performance compared to a baseline design.

3. Case Study: Total Building Commissioning Process

The commissioning process adapted by GSA for the Salt Lake City Courthouse, shown in Fig. 1, incorporates goals for commissioning during four phases of the project: 1) development of the Owner's Project Requirements (OPR); 2) the design phase, which includes schematic design through development of construction documents; 3) the construction phase; and 4) the post-occupancy phase. This case study addresses phases 1, 2 and the early construction stage of phase 3. Evaluation of the commissioning for the remaining construction and post-occupancy phases will be reported in a subsequent paper.

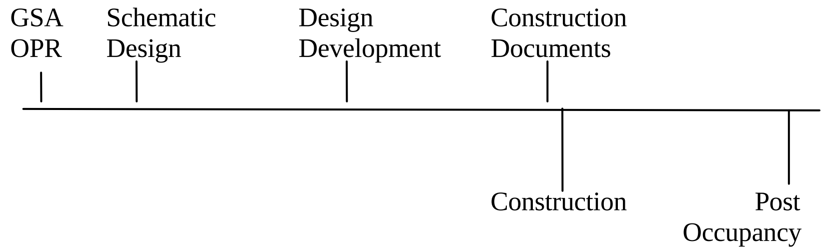

Fig. 1 – Total Building Commissioning Process from inception to completion

A. Owner's Project Requirements (OPR)

Although GSA selected a design-bid-build method of delivery for this project, the OPR is still under development. Currently, the OPR comprises five major system categories that are being commissioned. Examples of these systems, sub-systems, assemblies and components are shown in Table 1. Fire-alarm, security, communications, and vertical transportation systems are not shown in Table 1 as they will be commissioned separately by PBS and were not included in C_x scope of work. Moreover, only commissioning of the Courtyard Fountain in Cagegory 1 was included in the C_x scope of work.

Table 1. System categories and examples of sub-systems, components and assemblies for commissioning in the new U.S. Courthouse in Salt Lake City, based on the C_x Scope of Work.

Category	System	Sub-systems	Components and Assemblies
1	Site and Land Use	a) Irrigation b) Storm Water Management c) Courtyard Fountain d) Site Lighting	• Filtration, water treatment
2	Material Resources	a) Foundation b) Envelope	• Curtain walls, opaque walls, doors, roofing
3	Energy Consumption	a) HVAC b) Electrical Power	• Chillers, boilers, pumps, fan and air distribution system, piping system, and control systems • Switchgear, transformers, emergency generators, motor control centers, distribution panels,

			exterior and interior lighting
4	Hot and Cold Water Distribution Systems	a) Potable (domestic) water b) Non-potable water c) Sanitary	• Pumps, filters • Cooling tower, make up water, humidification, pumps, and heating and cooling coils • Drainage and vent piping
5	Indoor Environmental Quality (Pre- and Post-occupancy)	a) Air quality delivered by air handling units b) Acoustics c) Thermal conditions in occupied spaces d) Lighting conditions in occupied spaces	• Filters, demand control ventilation • Sound transmission through walls, reberation times in courtrooms • Air distribution, control system • Fixture layout, dimming and daylight control, occupancy sensors

This case study focuses on system categories 2 – 5 in Table 1. Figure 2 shows a flowchart, which exemplifies the design and construction processes in this project for the progression of commissioning the envelope (i.e., enclosure), the mechanical, electrical, plumbing (MEP), and the control systems. The OPR and commissioning procedures for post-occupancy performance have not yet been determined.

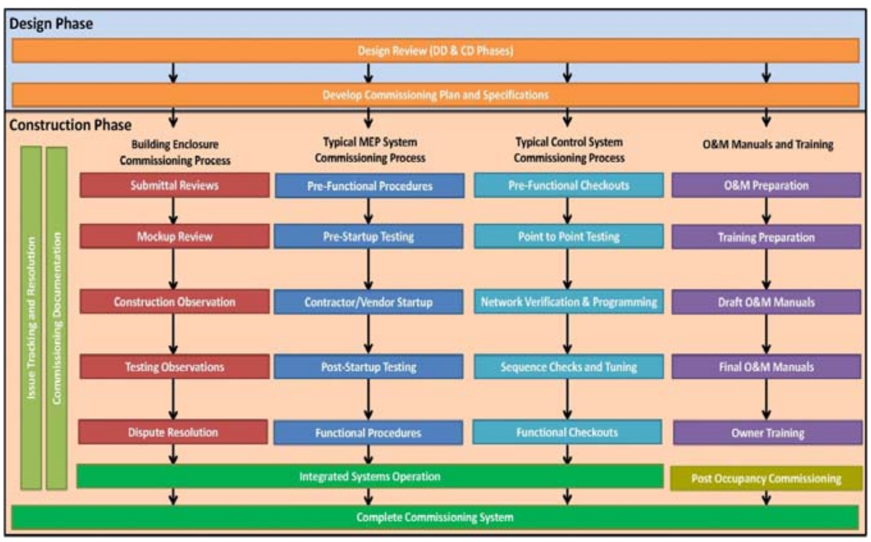

Figure 2. Flowchart for commissioning the enclosure, MEP, and control systems.

B. Design Stage Commissioning Activities

Commissioning of the “Design Review Deliverables” was conducted by the Commissioning Agent (C_xA), based on formal submissions made by the design team. During schematic design, design development, and preparation of construction documents (Fig. 1), the submittals were reviewed with regard to: 1) the Basis of Design (BOD); and 2) the Owner’s Project Requirements (OPR):

1) The building enclosure, MEP and control systems (see Fig. 2), which were shown on the design drawings and further defined in the technical specifications, were reviewed. Comments by the C_xA were provided to the design team with recommended revisions for incorporation into their drawings and specifications.
2) Project meetings were conducted with the project team (designers, contractors, owners representatives) to review and discuss the C_x comments and recommendations regarding the design details and specifications.
3) As determined necessary by the C_xA and owners representative, additional building commissioning specifications were prepared to augment requirements in other technical sections.
4) The C_xA organized and facilitated a Controls Integration Meeting.
5) After each of the review periods, the C_xA submitted to the owners’ representative a package of “Administrative Deliverables” that included:
    a) The Design Issues Log
    b) A set of Commissioning Schedule Milestones for integration by design and construction team
    c) A Commissioning Plan Outline
    d) The Commissioning Plan updates.

C. Early Construction Commissioning Activities

1) The early stage of construction included site preparation; routing of underground utilities for water, sewer, electrical power, and natural gas; construction of the foundation, below-grade garage, above-grade structural members; and construction of the enclosure including opaque walls, curtain walls, and roofing. Commissioning of early construction stage activities included:
    a) Submittal Reviews were performed and recommendations were provided on key building enclosure and MEP shop drawing submittals including:
        - Below-grade waterproofing

- Exterior door and windows
- Curtain wall
- Roofing
- HVAC and control systems
- Electrical power and lighting systems
- Plumbing systems.

b) Reviews of the envelope system were conducted by observation of mockup construction for compliance with the project documents and approved shop drawings. As described below, observations of mockup construction and recommendations were used to inform the development of an installation checklist for field quality control by the general contractor.

c) Installation checklists were developed for the major components and assemblies of the building enclosure, MEP and control systems, which are to be used during the C_x construction observation activities.

d) Observations of the on-site building enclosure construction were conducted to assess compliance with the project documents.
   - Following the site visits, field reports were issued that contained observations and recommended actions for the design and construction team.
   - While on-site, the C_xA met with the contractor and design team to assist in resolving detailing issues.

2) Envelope Performance Testing:
The C_xA observed laboratory and field mockup testing of the envelope system for compliance with the project documents and the approved shop drawings.

a) Laboratory Testing – Curtain wall performance testing at two off-site testing locations were observed to verify system performance with the project requirements.

b) Field Testing – On-site testing of curtain walls was observed. Testing of exterior doors and windows, and roof flood testing to verify performance with the project requirements has not yet been conducted.

4. Findings from Design Reviews and Early Construction Field Testing

Information was provided by GSA and the C_xA to the design and construciton team regarding recommendations to be incoporated into the design and construction of various systems for Total Building Commissioning (C_x).

For this case study, which focuses on the envelope and MEP system performance, the following enhancements resulted:

- OPR criteria for commissioning the systems were incorporated into the drawings and specifications, which enabled coordination between the building designers, contractors, and the C_xA.
- Point to point locations for the sensor-controller-controlled devices for the HVAC control system were identified on the drawings at the request of the C_xA. These points will be helpful in the latter stages of C_x.
- Pre-functional and functional performance requirements were determined in the early stages of design for various components and systems such as chillers, boilers, pumps, air handling units, ductwork, switchgear, transformers, emergency generators, and the building automation and control system (BACS).
- For the envelope system, water leakage and air infiltration criteria were incorporated into project drawings and specifications. The methods of testing to verify compliance with water leakage criteria, but not air infiltration criteria, were also defined in the C_x requirements.
- The C_xA reviews of the design documentation resulted in recommendations to the design team for cost-effective performance enhancements to the lighting, acoustic, HVAC systems, and the expected reduction in energy consumption related to recommended modifications to the envelope system.

A. Mock-up Tests for the Envelope System

At the observed stage of construction, performance testing of the MEP systems was premature, but the envelope system was available for mock-up and field testing. Two sets of mock-up tests were conducted.

1) On August 23, 2011, fabrication of the unitized curtain wall panels was observed by the C_xA, with specific concern for seals that would be concealed when the mock-up is constructed. Findings indicated that some voids were found in the sealant application; these were repaired before the units were assembled and shipped. Quality control logs were reviewed but no physical testing was conducted.
2) On September 9, 2011, a mock-up of the envelope was observed by the C_xA, with particular focus on the quality of the splice joints and terminations of the curtain wall assembly. Findings indicated that the assemblies were constructed in accordance with the

approved mock-up shop drawings, with minor discrepancies. Results from these observations were used to inform installation checklist development for field quality control.

B. On-site Test Method for Envelope System

Water leakage testing was conducted in accordance with ASTM E 1105-00 (Re-Approved 2008) [9]. The OPR and procedures for air leakage testing had not been determined and air leakage testing has not been conducted.

C. On-site Test Procedure for Water Leakage

1) On May 23, 2012, a static pressure water penetration test was performed at one location on a portion of the aluminum curtain wall system, including a 90 degree outside corner condition, as shown in Fig. 3. The size of the test area was 14 feet wide and 8 feet high. Six test specimen sites were located within this area as shown in Fig. 4.

Figure 3. View of test specimen area from the exterior.

View of test sp

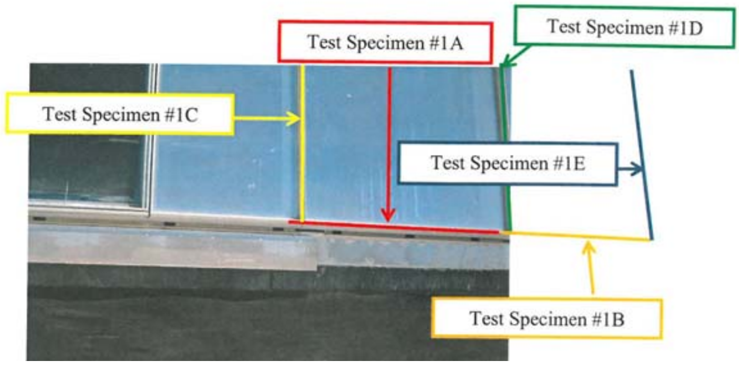

Figure 4. Location of Test Specimens in Test Section shown in Fig. 3.

2) The perimeter of the test chamber was attached and sealed to the interior faces of the horizontal and vertical mullions surrounding the glazing at the top and sides and to the concrete floor slab at the bottom of the section shown in Fig. 3.
   a) The test chamber was equipped with a centrifugal blower/vacuum pump, air flow meter, and a pressure sensing device to maintain the desired air pressure differential across the assembly. Water penetration tests were conducted at 8.0 psf air pressure differential while simultaneously spraying water onto the exterior face of the assembly at the required rate of 5 gallons of water per hour per square foot.
   b) During testing, the interior face of the test area was inspected for water leakage. Testing continued for 15 minutes

D. Performance Criteria for Water Leakage

1) Water leakage was defined as penetration of water beyond a plane parallel to the glazing intersecting the innermost projection of the test specimen, not including interior trim and hardware, under the specified conditions of air pressure difference across the specimen.
2) According to the test protocol, no water leakage was to be observed at the interface of the test area after 15 minutes of the water challenge.

E. Water Leakage Test Results

The results of the water leakage testing are summarized in Table 2.

Table 2. Summary of Water Leakage Test 1.

Specimen	Observation	Remediation	Final Result
1A	Leakage at two locations	Additional Sealant installed	Pass
1B	No water leakage		Pass
1C	No water leakage		Pass
1D	No water leakage		Pass
1E	No water leakage		Pass

5. Conclusions

1) Successful Total Building Commissioning (C_x) is highly dependent on the clarity and timeliness of the criteria and procedures that are defined in the Owner's Project Requirements (OPR). The 10-year gap from start of initial design to start of construction was an impediment to the C_x process in this case study.
2) C_x is more than a design process. Commissioning of the physical systems to pre-set criteria at the onset and duration of construction is critical to successful building performance.
3) Credible qualitative and quantitative evaluation and testing early in the construction process informs the design-construction team and enables improved quality control during and after construction.

References

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[2] U.S. General Services Administration. 2005. The *Building Commissioning Guide*. Public Buildings Service, Office of the Chief Architect, April 2005.

[3] ASHRAE Guideline 1.1-2007: *HVAC&R Technical Requirements for the Commissioning Process*.

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[7] *U.S. Courts Design Guide*. 2007. U.S. Department of Commerce, Accession Number PB-97-152466.

[8] U.S. Green Building Council. 2005. *LEED® for New Construction and Major Renovations*, version 2.2.

[9] ASTM E 1105-00 (Re-Approved 2008), *Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors and Curtain Walls, by Uniform or Cyclic Static Air Pressure Difference* (Uniform static air pressure difference was employed during these tests).