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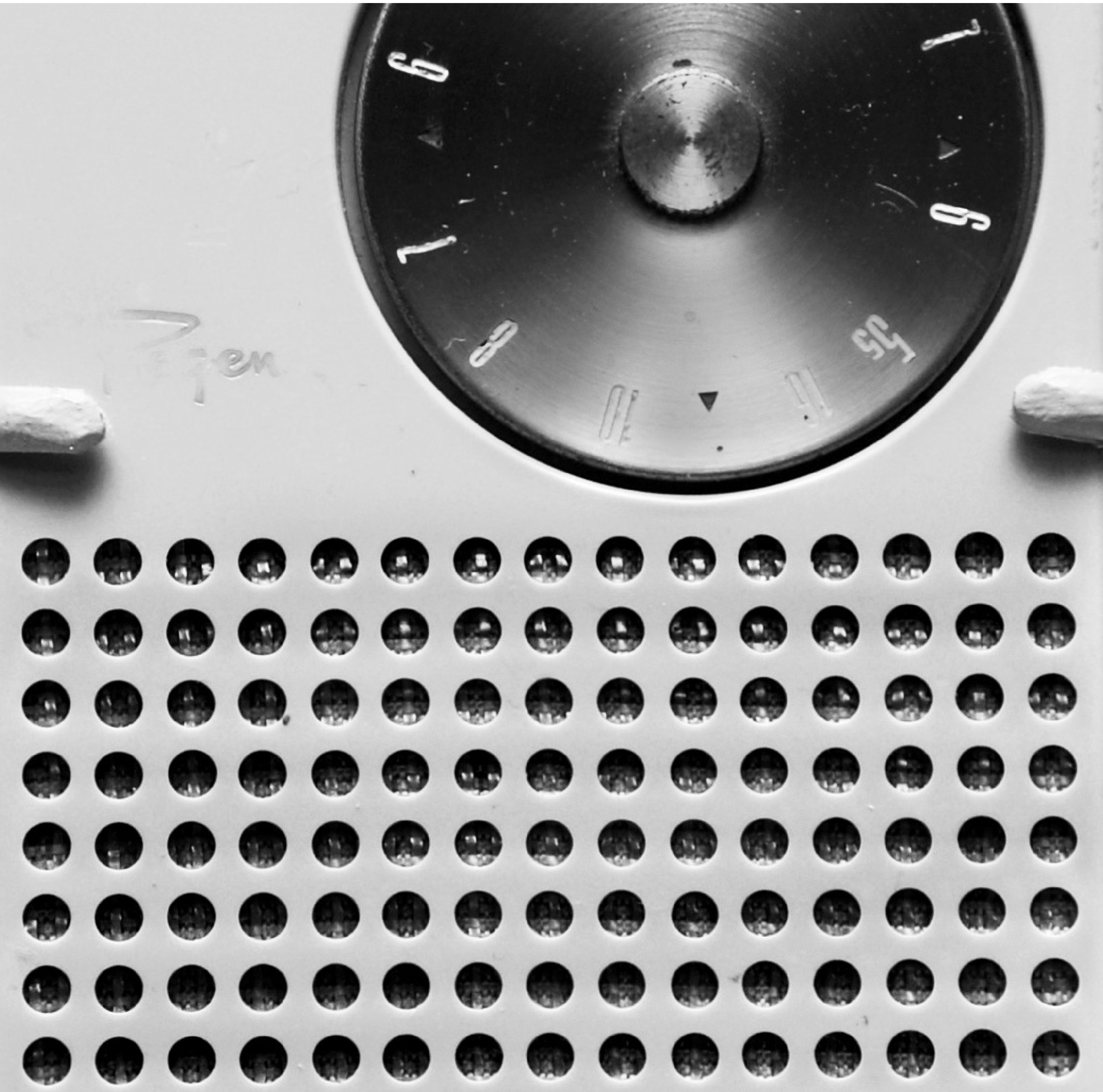

01.
BUILDING COMMISSIONING: STRATEGIES, CRITERIA AND APPLICATIONS

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ABSTRACT
Building performance monitoring has a great potential to reduce energy usage through improved operation and maintenance. Enhanced functioning, lower energy costs, better indoor air quality and overall design satisfaction are some of the key benefits. However, in order to achieve these goals, successful transfer of design intent is required through all stages of design process and operation.

This paper discusses building commissioning, particularly focusing on capturing design intent throughout the project lifecycle. Building commissioning requires that users and facility managers fully understand design intentions, as well as interactions with prescribed building systems. Design representations and knowledge transfer become crucial in that aspect. Cost-implications, benefits, and roles of agents are discussed. Tools and applications aimed at facilitating the process are presented.

1.0 INTRODUCTION
Architecture, as a practice, relies on descriptions and representations of physical objects before their actual existence. Evaluation is necessary in order to compare the difference between the expected and achieved results. However that is a fairly complex procedure due to the discrepancies between building as a conception and building as a physical object. Isolated measurements with discrete objectives are the current typical method for evaluation, but the future goal is the persistent improvement of quality through continuous evaluation[1]. In order to achieve this goal, several prerequisites must be satisfied:

- Evaluation must be done systematically.
- Evaluation data must be organized and kept in a format usable for future use.
- Continuity of information must be present during different phases of a building's lifecycle.

Contribution from buildings toward global energy consumption is currently 40 percent[2]. Most of the energy usage in building is associated with building systems, particularly for the operation of heating, ventilation and air conditioning (HVAC) systems, which on average consume about 50 percent of building energy[3]. Evaluation of building systems and their performance is critical for reduced energy consumption.

Building commissioning is an important new area that promotes evaluation during several stages of the design process as well as operation and maintenance. Building commissioning has been made a prerequisite for Leadership in Energy and Environmental Design (LEED®) project delivery and certification, which has greatly increased awareness about this process. Projects following LEED guidelines are required to perform post-occupancy commissioning and additional points can be achieved by introducing comprehensive commissioning earlier in the design process.

Primary objective of commissioning is to evaluate building systems and verify design intent. During the early stages of the design, the commissioning process should be focused on balanced relationships between owner's requirements and design functionalities addressing these requirements. During the construction process, commissioning is focused on ensuring that the building agrees with the design specifications and intended functionalities. During the operation phase, the primary objective is to measure and verify that building performance is following design specifications. Continuous commissioning is also being advocated as a successful method for real-time monitoring and adjusting building performance based on operational requirements[4].

This paper is structured as follows: initially, cost-implications are briefly discussed to introduce benefits and associated costs. Methodologies for capturing design intent are discussed as well as roles of different agents during the process. Tools and applications, developed to assist documentation and the process, are lastly presented.

2.0 COST-IMPACT

Integration of building systems and their interdependencies in operation require coordination in design, construction and operation. Failure or deficiency of one component may influence the overall system affecting energy efficiency. Benefits of incorporating commissioning include energy and non-energy impacts and should be accounted for when assessing initial cost of commissioning process versus gained benefits over the building's lifecycle. Energy benefits are primarily associated with decreased operating costs, while non-energy benefits include improved indoor air quality, system reliability, building operation and maintenance and improved occupant comfort[5].

Recent study on cost-effectiveness of the building commissioning process has found that for new buildings, median commissioning costs are $1.00/SF, ranging from $0.49 to $1.69, depending on the size of the facility[6]. Median percentage of the total construction cost is 0.6%, ranging from 0.3% to 0.9%. Median payback time for the initial cost is 4.8 years, ranging from 1.2 years to 16.6 years, depending on the facility size, initial cost and energy savings.

Relative costs, energy savings and projected payback time also depend on the building type. Energy intensive facilities, such as laboratories, hospitals and higher education facilities tend to have larger energy savings associated with the commissioning process as well as lower average payback time. Commercial facilities, such as offices and retail, also have lower payback time.

3.0 STRATEGIES AND CRITERIA: PERFORMANCE METRICS

Commissioning originated in the naval industry, where constructed ships were tested for flaws and deficiencies prior to joining fleets. In the building industry, commissioning was adopted during the 1970s as a method for testing functionality of building systems and equipment prior to occupancy. Reasons for adoption were that advanced technologies and sophisticated building systems were implemented, requiring that all building systems functioned properly. American Society of Heating Refrigeration and Air-Conditioning Engineers (ASHRAE) initiated development of guidelines for building commissioning of HVAC systems in 1984, with the intent to develop a process framework for evaluating systems prior to occupation. The resulting document, revised in 1996 and 2007, defines commissioning as the process of ensuring that HVAC systems are designed, installed, functionally tested and operable in conformity with the design intent and owner's requirements[7]. ASHRAE developed a guideline for the overall commissioning process in 2005, which provides direction for evaluation of design and systems in new buildings, such as fire and life safety, roofing systems, HVAC, electrical distribution and emergency power, controls and communications systems. The commissioning process, according to this guideline, is defined as a "quality-oriented process for achieving, verifying and documenting that the performance of the facilities, systems and assemblies meets defined objectives and criteria"[8].

Documents essential for building commissioning are Design Intent, Basis of Design and Commissioning Plan[9]. Design Intent captures owner's requirements and should provide metrics and measurable objectives that can be utilized to develop Basis of Design functionalities. Clearly defined performance criteria for temperature levels, lighting, internal air quality and energy consumption are recommended. Commissioning Plan identifies the organizational structure of the process during different design phases and should identify roles of different agents. It is a communication tool between the owner and the commissioning authority, outlining the planning and scheduling of evaluations and tests.

Design Intent should capture operational goals by stating an objective, strategy and associated quantitative performance metrics. Objectives are qualitative statements reflecting desired performance and metrics are variables that can be utilized to measure objectives. Strategies are ways for implementation in the design. Performance metrics should be measurable, have a clear definition and boundaries of the measurements and indicate progress toward operational goals[10].

Capturing and preserving this information across the lifecycle of the building ensures that:

- Participants in the project can clearly document desired performance objectives during initial planning
- Evaluations of the proposed designed options are supported and the decision making process relies on evaluation results
- Evaluations are shared among the design agents
- Commissioning process is well supported and cost-effective
- Performance measurement and verification are supported in a structured manner.

Example of this method is presented in Figure 1. Owner's goal requiring an energy-efficient building should be utilized to develop performance objectives, such as “Minimizing Lighting Load” or “Minimizing Heating Load”. These goals are the basis for developing design strategies as well as performance metrics when applicable.

Multiple qualitative goals can be expressed for energy efficiency, environmental impact and overall functionality. From the qualitative goals, implementation strategies can be developed to address particular goals by the actual design. Performance metrics, expressed in quantitative manner, can be utilized to set objectives that can be predicted, tested, measured, verified and monitored during the building lifecycle.

4.0 IMPLEMENTATIONS: PROCESS AND ROLES OF AGENTS

Commissioning process is initiated by the owner and the methodology depends on the time when Commissioning Authority is introduced in the overall design process. Post-construction commissioning is a one-time evaluation of building systems that occurs prior to occupation. Improved methodology is commissioning during several stages of the design process, which indicates that Commissioning Authority is involved from the early start. The last form is continuous commissioning, which monitors performance through a form of Building Energy Management System (BEMS). Table 1 summarizes characteristics and properties of these different types.

Roles of agents depend on the utilized type of process. There are similarities in the overall structure, however, the amount of involvement highly depends when the Commissioning Authority is introduced. In the case of post-construction commissioning, Design Intent Documentation (DID) is developed by the owner with input from the design team and consultants as well as facility managers and occupants. During the design phase, the architect develops Basis of Design (BOD) documentation that should respond to DID and owner’s requirements. Commissioning Authority is usually introduced close to the end of construction phase where commissioning plan and schedule should be prepared. These documents are used as a basis for testing procedures, which are performed prior to occupation. Design projects that are seeking LEED certification must perform this basic process, but the involvement of the Commissioning Authority should begin at the design development phase since review of DID and BOD is required. Commissioning Authority prepares final reports, which outlines test procedures, data reports and records for LEED documentation.

Comprehensive commissioning involves Commissioning Authority from the pre-design phase and requires enhanced collaboration and communication between

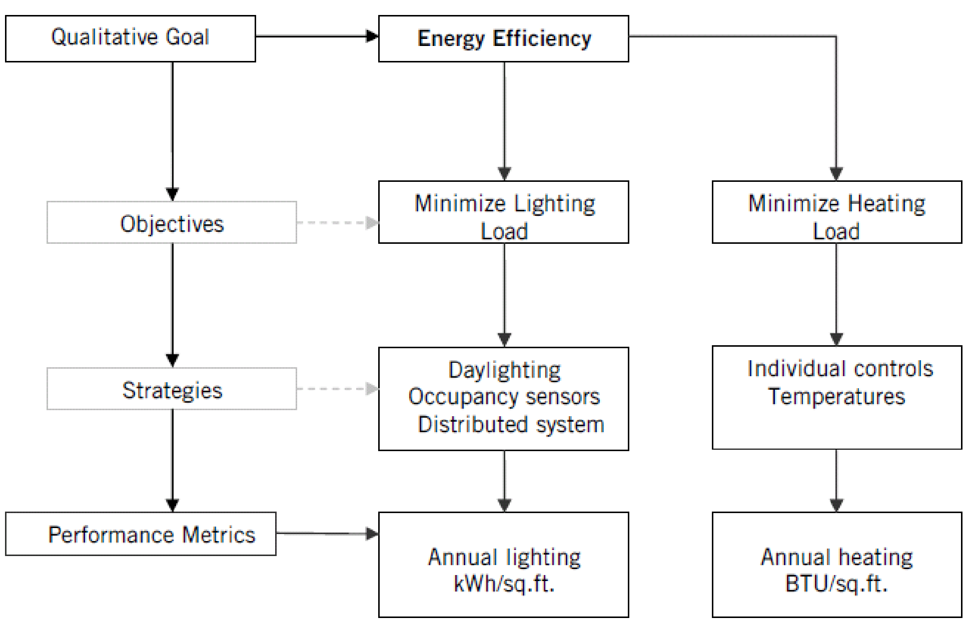

Figure 1: Method for capturing design intent through establishment of objectives, strategies and performance metrics.

agents. Table 2 presents matrix of roles and responsibilities during pre-design and design stages of the process while Table 3 shows construction and occupancy/operation phase. Dependencies between procedures are indicated. Additional commissioning for LEED requires reviews during design developments and construction documentation as well as operation manual and post-occupancy testing.

The benefits of comprehensive commissioning is that collaboration from the earliest stages of the design as well as reviews during design development and construction documentation result in early detection of flaws and issues. Due to the growing complexity of building design and systems, energy savings are obtainable through optimal control, early detection and correction of faults and enhanced equipment performance.

5.0 TOOLS AND APPLICATIONS

There are several existing tools and applications developed for assisting in capturing design intent and documentation of the commissioning process.

Lawrence Berkeley National Laboratory developed a database tool that provides a structured approach for recording Design Intent based on operational goals, objectives, strategies and metrics[11]. The major advantage for using this tool is that owners and designers can plan, monitor and verify that the requirements are being met during each stage of the design process and Commissioning Authority, facility managers and future owners can understand the building, its systems and the intended operation. This is usually owner-driven process; however, collaborative involvement of all involved agents is beneficial. Area included in this application are general requirements; mechanical for ventilation systems, chiller plants and heating plants; electrical for lighting system, distribution system, and renewable sources; process for loads and operation and maintenance. Documentation templates for LEED projects are included in the application.

California Commissioning Collaborative (CCC) provides tools and resources to assist commissioning process for building owners and commissioning authority[12]. Useful templates include planning documents, such as scope of work, commissioning plan, log and systems manual. For example, guidelines for setting up the Design Intent include set of questions that should lead the process, such as the functional type of the facility and its

Table 1: Commissioning process types and characteristics.

TYPE	CHARACTERISTIC
Post-Construction	Applies to small and medium scale buildings. Involves one time checks and testing of building systems after construction. Performed by Commissioning Authority who may be part of Owner's or Construction Organization.
LEED Prerequisite E1	Involves one time checks and testing of building systems, but should begin at the design development phase. Commissioning Authority must review Design Intent documentation and Basis of Design.
Comprehensive	Applies to medium to large scale buildings. Begins early in the project. Requires independent Commissioning Authority. Requires design development review. Testing and verification performed after construction. Reports and operation manuals needed.
LEED Credit E 3	Similar to comprehensive commissioning process. Requires design development review, review of construction documentation, and submittals. Operation manual and post-occupancy commissioning are required.
Continuous	Requires constant monitoring of building performance during operation.Involves automatic or manual measures of energy usage and system performance and comparison to final Design Intent metrics. Involves functional performance testing during construction, and fault detection and diagnostics during operation.

	Owner	CA	Design Team					Consultant	Contractors		Specialists		Building Operators		
	Owner, Owner's Representative	*Commissioning Authority*	*Architect*	*Structural Engineer*	*Mechanical Engineer*	*Electrical Engineer*	*Interior Design Professional*	*Consultants*	*General Contractor*	*Subcontractors*	*Indoor Air Quality Specialist*	*Acoustic Specialist*	*Facility Manager*	*Facility Engineer*	*Occupants*
PRE-DESIGN															
Design Intent Documentation (DID)	P	R	I	I	I	I	I	I					I	I	I
Allocation	P	U	U	U	U	U	U						I	I	
Commissioning plan	A	P	I	I	I	I							I	I	I
Log and report	R	P	U	U	U	U		I	U	U					
Acceptance and commissioning process report	R	P	U	U	U	U		U	U	U			U	U	
DESIGN															
DID Update	A	P	I	I	I	I		I			I		I	I	I
DID-Schematic design phase	A	P	I	I	I	I		I			I	I	I	I	I
DID-Design development phase	A	P	I	I	I	I					I		I	I	I
DID-Construction documentation phase	A	P	I	I	I	I		I			I		I	I	I
Basis of Design (BOD)	A	R	P	I	I	I					I		I	I	I
BOD-Schematic design phase	A	R	P	I	I	I					I	I	I	I	I
BOD-Design development phase	A	P	I	I	I	I		I			I		I	I	I
BOD-Construction documentation phase	A	P	I	I	I	I		I			I		I	I	I
Updated commissioning plan	R	P	U		I	I		U					I	I	
Construction specifications for commissioning	R	P	U					I	U	U			U	U	
Systems manual outline	A	P	I	I	I	I							U	U	
Commissioning-Focused design review	A	P	U	U	U	U						I	I	I	I
Log and report	A	P	U	U	U	U		I	U	U		I	I	I	I
Acceptance and commissioning process report	A	P	U	U	U	U		I				I	I	I	I

Key

	P	Provided by
	A	Approved by
	R	Reviewed by
	I	Input from
	U	Used by

Table 2: Roles and dependencies between agents during comprehensive commissioning process (pre-design and design)[13].

	Owner	CA	Design Team					Consultant	Contractors		Specialists		Building Operators		
	Owner, Owner's Representative	*Commissioning Authority*	*Architect*	*Structural Engineer*	*Mechanical Engineer*	*Electrical Engineer*	*Interior Design Professional*	*Consultants*	*General Contractor*	*Subcontractors*	*Indoor Air Quality Specialist*	*Acoustic Specialist*	*Facility Manager*	*Facility Engineer*	*Occupants*
CONSTRUCTION															
Pre-bid commissioning briefing	R	R	I					I				I	I		
Commissioning plan and inspection checklists update	R	U	I		I	I		I	U	U		I	I		
Pre-construction commissioning process briefing	A	P	I					I	U	U		I	I		
Submittal review comments	R	P	I		I			I	U	U		I	I		
Commissioning schedule	R	P	I					I	U	U		I	I		
Test procedures	A	P	I		I	I		I	U	U	I	I	I		
Test data reports	A	P	I					I			I		I		
Commissioning meeting record	A	P	R					R	U	U	R	R	R	R	
Site visit record	A	P	R					R	R	U	R	R	R	R	
Training plans	R	R	I		I	I		I	U	U	I		A	R	
Construction phase commissioning process report	A	R	I					I	U	U	I		R	R	
Systems manual update	A	P	I		I	I		I	I	I	I		R	R	
Log and report	R	P	U					I	U	U	I		I	I	
BOD update	R	P	P			I		I	U	U	I		I	I	
Construction phase acceptance and commissioning process report	A	P	R					I	U	U	I		I	I	
OCCUPANCY AND OPERATION															
DID Compliance update	A	P	R					I	R	I	I		A	R	
Testing record	A	P	R						R		I		A	R	
Acceptance and commissioning process report	A	P	R						U	U	I		A	R	
System manual update	A	P	I		I	I			I	I			A	R	

Key

P	Provided by
A	Approved by
R	Reviewed by
I	Input from
U	Used by

Table 3: Roles and dependencies between agents during comprehensive commissioning process (construction and occupancy/operation)[13].

requirements, types of equipments, occupant comfort and thermal conditions and methods for operational benchmarking.

Energy Design Resources (EDR) hosts a web-based application Commissioning Assistant, useful for providing project-specific information to the design teams[14]. Basic functions include evaluation of the probable commissioning cost, identification of the scope and development of documents, Design Intent and Basis of Design documentation, commissioning specifications, sequence of operations as well as training plan and systems manual.

6.0 CONCLUSION

This paper reviews commissioning process with particular focus on strategies and criteria for capturing performance-based metrics. Cost-implications, benefits and roles of different agents are discussed. Transfer of qualitative goals to implementation strategies and subsequently to performance metrics is presented as a methodology for capturing design intent. Multiple qualitative goals can be expressed for energy efficiency, environmental impact and overall functionality. Implementation strategies can be developed from qualitative goals, addressing specific areas of design. Performance metrics, expressed in quantitative manner, can be utilized to set objectives for predicting, testing, measuring, verifying and monitoring performance across the building's lifecycle.

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