# LINKING BUILDING COMMISSIONING AND OPERATIONS AND MAINTENANCE TOWARDS AN EMBEDDED COMMISSIONING PRACTICE

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ABSTRACT

Building Commissioning (BC) is a powerful, cost-effective strategy to verify that facilities perform as intended, and have fewer performance problems and reduced repair cost. BC's fundamental aim has been to ensure that all building systems, mechanical as well as structural, electrical, egress and the like, operate optimally and efficiently. However, communication between BC and the Operations and Maintenance (O&M) phase, or the other building phases for that matter, is difficult, at best. The vast amount of data captured during these phases of the facility life-cycle is neither accessible to other stakeholders nor are they part of the facilities long term data history. Where as there are many potential benefits of connecting BC and O&M processes, the O&M personnel do not provide feedback to building designers or engineers either. These benefits include improved facility performance, greater user satisfaction, less costly maintenance and upkeep, energy conservation, and improvement of facility information systems. In this paper, based on interviews with experts in the field, we survey the characteristics of these fields of practice and propose a strategy for an integrated BC, O&M application environment.

INTRODUCTION

The principal objective of this paper is to develop an approach that bridges Building Commissioning (BC) with Operations and Maintenance (O&M) in order to provide a more effective decision support environment for life-cycle facility management.

A closer look at the manual operations of facility maintenance reveals three key modes of operation: *corrective, preventative* and *predictive*. Corrective maintenance is also known as the "run-to-failure" mode, which is reactive, time consuming and costly. Preventative maintenance involves pre-scheduled service in order to prevent failure before it happens and extend the useful life of systems and equipment. Predictive maintenance, on the other hand, is proactive but is based on the actual condition of equipment. While it saves on cost of parts, it is a more costly and impractical approach (Akın, et.al., 2004a).

Some aspects of BC overlap with the continuous monitoring of facilities. Re-commissioning or retro-commissioning processes retest previously commissioned or pre-existing systems using the same original checklists and verification test procedures used during BC, on a regular basis (Luskay, et.al., 2003). These involve performance tests and inspections conducted regularly or initiated by a malfunctioning system, a change in occupancy or functionality. However, these processes do not supply persistent data to monitor long-term behavior of systems and equipment either.

Automated monitoring of facility performance is a new area of application that can potentially link BC and O&M (Eastman, 1999). One of the promising areas of development, Building Energy Management Systems (BEMS), is in energy conservation (Piette, et.al., 1996). BEMS are computer-based centralized systems that help manage, control and monitor particular engineering services. BEMS assisted facility monitoring approaches make use of a fault detection and diagnosis tool (FDD). Yet, this approach also fails to capture the entire BC process, such as inspections (Akın, et.al., 2004b).

In our research, we adopt the Embedded Commissioning (EC) approach combining some of the manual processes with the automated decision support strategies. The objective of EC is to embed the BC philosophy into the entire facility life-cycle by facilitating data exchange and availability in all stages of design delivery and facility operation. It combines the continuous monitoring by BEMS with the more direct control over systems by periodic re-commissioning. It provides ongoing embedded commissioning by integrating scheduled maintenance with continuous systems verification; and retains persistent information of the monitoring results and maintenance activities and makes this information available to the operators and commissioners.

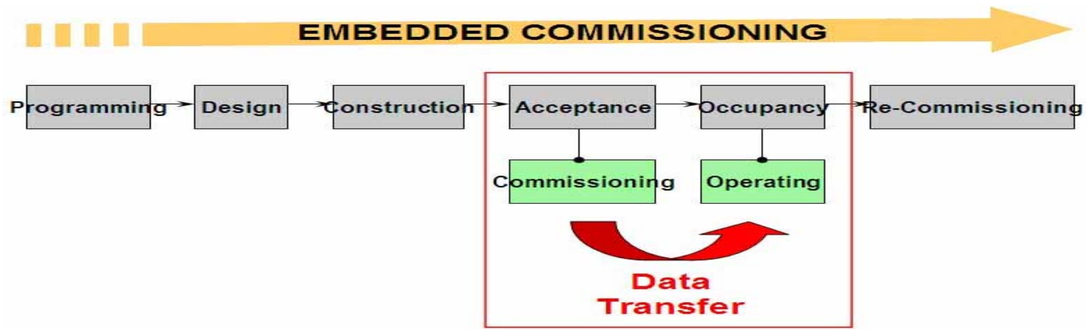


*Figure 1. Our data transfer focus area in the context of the entire Embedded Commissioning process*

In this particular paper, we explore the interaction between the acceptance and occupancy stages of the building life-cycle (Figure 1). Before embarking on the particulars of this task, we decided to survey the field and learn more about the dynamics of BC and how it may logically interact with the O&M world.

## INTERVIEWS

In the context of our ongoing research on building commissioning over the course of the last two years, we conducted interviews with seven different experts in the field. These included members of commissioning delivery firms, academics, owner's representatives, and design engineers (Table 1). Our findings can be classified under five headings: business side of BC, scope of BC, documents of BC, standardization of BC products and processes, and automation of BC.

### Business side of BC

Our structured interview with the experts indicates two significant aspects of the business side of BC: the need for commissioning and the composition of the commissioning team.

#### *Need for BC*

The primary motivation for the BC sector is that the verification of the system is a natural part of building delivery. If architects and engineers designed the right system and "the mechanical contractor did his job right," then all of the systems would work right. This is all that matters, yet it does not always happen. The golden rule of providing budget, schedule, and quality is partially fulfilled (Piette, et.al., 1996). For the most part, the industry has learned to prioritize budget and schedule, while guaranteeing quality is a hit and miss affair [Table 1, int-3].

*Table 1. Experts Interviewed* (to protect confidentiality names of experts are not cited)

| | |
|---|---|
| int-1: | Mechanical Engineer, Ebert-Ingenieure GdbR mbH, Hanauer Strasse 85, München, October 17, 2005 (Paris), duration of meeting: 120 minutes |
| int-2: | Mechanical Engineer and Researcher, Technology Expert, CANMET Energy Technology Center, National Resources, Canada, October 19, 2005 (Paris), duration of meeting: 45 minutes |
| int-3: | Mechanical Engineer and Project Manager, Sebasta Blomberg, Boston, MA, March 3, 2003 (Pittsburgh), duration of meeting: 60 minutes |
| int-4: | Architect and Project Manager, Carnegie Mellon University, February 5, 2003, duration of meeting: 45 minutes |
| int-5: | Professor of Architecture, College of Architecture, Art, Planning, University of Cincinnati, February 14 2003, duration of meeting: 120 minutes |
| int-6: | Mechanical Engineer, LLI Technologies Inc, Pittsburgh, PA , January 8, 2003, duration of meeting: 250 minutes |
| int-7: | Professor and Researcher, Carnegie Mellon University, February 18, 2003, duration of meeting: 45 minutes |

There is increased demand for BC. Not all of the motivation can be placed at the door step of delivery of quality. Some of this demand arises from emerging practices like LEED [Table 1, int-4], increased sense of security in particular with the federal government facilities [Table 1, int-3], and increased performance demands in the building industry, whether it is in new hi-tech construction or the booming retrofit and renovation sector [Table 1, int-3]. Today the mechanical systems have to talk to the fire alarm system which needs coordination with the structural system and the sprinkler system [Table 1, int-3]. Furthermore, pressures placed by the ever present energy conservation demands lead to a growing re- or retro-commissioning movement.

Who is filling this void created by this emerging sector? Contractors, designers, manufacturers, and new specialists are all gearing up to the challenge. The existing business sector is trying to improve the bottom line by readjusting their conventional packages and including BC into their standard service sets. Whether as part of the conventional practice or as a third-party specialty, BC has become commonplace in large mechanical practices leading to multi-million in volume of business, and tens of specialists in each office [Table 1, int-3].

*Structure of the BC Team*

The BC practice essentially belongs to mechanical engineering. [Table 1, int-7] BC teams are typically led by mechanical engineers but also have other engineers' and equipment specialists' participation [Table 1, int-6]. The driving factors are both possession of knowledge of the field as well as authority to instill confidence in the service receiver (ASRAE, 1996).

There are potential hazards. As in any emerging field there are wannabes who can detract from a smooth professional development. The other more immediate difficulty is the perceived and actual infringement of the third party [Table 1, int-6] on the turf of one of the original parties: the design engineer. In this picture, there is real room for resentment. More often than not, design engineers are asked to design with minimal fees. They design, supervise, and validate in the usual way, using tools like the punch-list. However, these designers see additional fees go to third party engineers who not only cut into their fees, but add inadvertent insult to injury by scrutinizing the work [Table 1, int-4]. In reality, the strongest players in the sector are the design engineers who have the experience to make a significant impact in BC [Table 1, int-3].

Mechanical vendors and contractors also play an important role in commissioning due to the operations and maintenance phase of validation and verification of system performance in buildings. They are indispensable in the preparation of the training manuals and conducting the training with facilities staff [Table 1, int-6].

Outside of the US, in Germany for instance, the BC industry is motivated by warranty agreements and government commissions [Table 1, int-1]. While re-commissioning and Continuous Commissioning™ are not common, they can be required under special contracts.

<u>Scope of BC</u>

The experts we interviewed brought up two different areas of scope: design intent and programming phase and post commissioning phase.

*Design Intent and Programming Phase*

There is unanimity among practitioners that BC starts with the design intent document at the facility programming phase. Unfortunately, this is rarely what happens. Often the factors that motivate BC arrive through the back door (LEED certification, performance problems, design difficulties), well after the initial programming is completed. In most cases, the most rudimentary form of early BC is conducted just as a part of facility programming, including, defining criteria and simple regulation and guidelines for the commissioning plan [Table 1, int-1].

In post-construction commissioning, the design intent document is somewhat distant to the immediate goal of BC, which is compliance. The BC authority verifies that what is built matches what is designed. They schedule, measure and record data, as well as contribute to the balancing and bid-tracking process [Table 1, int-7]. The typical design intent document, on the other hand, specifies why and how a building should be designed. There are at least two consequences of this apparent gap between the intent and commissioning documents.

One is to use BC as a one time verification task, in which the intent document plays an indirect role if at all [Table 1, int-2, Table 1, int-3]. This approach is further justified by the fact that design intent is volatile and is seldom unchanged even at the time of initial occupancy. The other approach is to see BC as a continuous process in which the intent document is integral. In fact, BC starts during the composition of the intent document [Table 1, int-6]. This approach also entails validation. It is not sufficient to verify that the construction matches the design specification but that it also fulfils the performance specified in the intent document [Table 1, int-3]. This approach projects the same sort of validation effort into the future, requiring that the O&M operations also serve relevant performance measures [Table 1, int-3].

*Post Commissioning*

BC is increasingly seen as a segue-way to monitoring the life-cycle performance of a building (Akın, et.al., 2004b). Based on verification and validation goals, commissioning deliverers use the design objectives as the criteria through which appropriate test are done to continuously insure effective performance. These tests have to comply with the bid documents and O&M manuals, even if they have to be reconfigured [Table 1, int-3]. Once the building is occupied, the least predictable and controllable factor, the occupant, is introduced into the process. There is no guarantee, for instance, that the users would not, willfully or inadvertently, tamper with the settings of the HVAC system [Table 1, int-7]. All of these factors conspire to cause significant differences between the pre-construction and post-construction phases of BC [Table 1, int-6].

BC is most prevalent in the commercial and institutional sectors [Table 1, int-2]. LEED certification has been the driving force for many institutional buildings while performance warranties have been the impetus for commercial applications [Table 1, int-4]. The bulk of current BC work is still devoted, however, to older buildings, in their equipment adjustment and energy performance improvements that do not involve LEED or warranty issues [Table 1, int-7].

Automated systems can help work out the wrinkles at the seams of such continuous approaches to BC (Turkaslan, et.al., 2005a). They can, at a minimum, ease the data transition points between people and commissioning tools and techniques [Table 1, int-7].

We also observed significant differences in the international scene, in which European practice is often limited to the warranty periods of buildings, while in the US it is more widely and sporadically applied as a function of market demand [Table 1, int-1].

BC Documents

Since BC is a relatively new phase in the building delivery process, its standards for documentation are still evolving [Table 1, int-6]. While this is clearly a current shortcoming, it also provides an opportunity for those who are interested in developing new standards before some of the ineffective and ad hoc activities are legitimized through habit of practice (ISO, 2003).

This concern points to several key documentation stages on which to concentrate. The undisputed starting point appears to be the design intent document which establishes the basis of the project [Table 1, int-3, Table 1, int-6]. Another critical document developed in the early stages, is the commissioning plan, which is specialized in the BC task [Table 1, int-3]. The next key document set is the contract or bid documents which specify the entire systems as designed [Table 1, int-1]. In the design of mechanical systems, simulations also play an important role. Simulations, if properly documented, can become effective guidelines for the commissioned performance of a building [Table 1, int-1]. Once the construction is completed the documents that become critical are the punch-lists [Table 1, int-3], test protocols [Table 1, int-5, Table 1, int-6], and the as-built drawings, specifications, and all approved shop drawings and other submittals [Table 1, int-6, Table 1, int-7]. Post-construction BC concludes with the final commissioning report [Table 1, int-3]. There is usually a follow-up "re-commissioning" report which augments the first one. Depending on the local and national practices, this may be done to complete the seasonal tests to fulfill work contracts or warranty periods.

LEED certification requires the BC process but also introduces other (environmental) criteria to be satisfied. The LEED documentation usually provides a good supplement to the commissioning report [Table 1, int-4]. The final report is the culmination of interim reports which is finally certified by a mechanical engineer. The commissioning report is followed by the O&M manuals [Table 1, int-6] and training documentation [Table 1, int-3] towards the maintenance and upkeep of the facility. While the vendors and contractors provide these documents, contractually they are expected from BC providers.

It is obvious that one of the most difficult challenges here is to have consistent data management across different documentation phases (Wang, et.al., 2004). Tracking information to its origins and finding changes and their rationale is often critical and very difficult to do effectively. In practice, there are many document-seams [Table 1, int-3]. Often practice adapts to these inefficiencies as mere inconveniences, however, improved applications and data tracking procedures can help [Table 1, int-1] and are sorely needed.

Standardization of BC Products and Processes

One of the most difficult topics in a fresh and evolving area of practice is standardization. There is often little enthusiasm for it, not to mention less than a compelling justification. On the other hand, there are very few standards regarding procedures, equipment, and documentation [Table 1, int-6, Table 1, int-7]. Even establishing a standard test procedure for the airflow unit can be challenging. How a unit should perform is determined differently from engineer to engineer [Table 1, int-3]. Sometimes, what needs to be commissioned is not clear; and everything cannot be tested, even if there are appropriate test procedures [Table 1, int-6].

Some building types and clients bring with them standards that must be met. Most government facilities which have volume or criticality fall into this category: defense department buildings [Table 1, int-3], VA hospitals [Table 1, int-5], NIH facilities, and so on. Universal design is an area in which clear goals are established towards global standards for accessibility. Even with supporting legislation, the details of testing and verification in this area are difficult to standardize. BC, a far more technical performance issue with broad demands on a diverse set of constituents, is even more difficult a target [Table 1, int-5].

Firms that are specialized have developed their own standard procedures that incorporate tasks by others, such as the mechanical vendors. They establish priorities and protocols that serve their clients and specialization areas best [Table 1, int-4, Table 1, int-6]. In the absence of standard data transfer tools from one stage of the process to the next, manual methods of data mapping are used, such as assignment of unique identifiers to equipment [Table 1, int-6]. Also, other players, contractors, vendors and design engineers can be pulled into the process on an as needed basis [Table 1, int-6].

The danger exists that the needs of the BC practice field are too diverse to make standardization of data and protocols a reality (Turkaslan, et.al., 2005b). Viewing the field as a collage of diverse practices, it is easy to imagine how a "universal" data representation, for instance, could be deemed unworkable [Table 1, int-3]. What works for a commercial client on a suburban site in the Mid-West commissioned for LEED purposes, for instance, would be very different from that for a Pentagon facility.

Automation of BC

Currently, the most generalized and common applications in the field are supported by general purpose AEC applications such as ArchiBUS [Table 1, int-5], IFC Compatible platforms like ArchiCAD and AutoCAD, and of course the multi-purpose systems like spreadsheets and data base support applications (Access) [Table 1, int-6]. These applications are not BC-specific and leave a lot of unfulfilled opportunities for the digitization of BC practice.

One of the most immediate opportunities is in data handling: collecting, storing, organizing, reporting and managing for BC purposes [Table 1, int-1]. Data resulting from standardized test procedures invoked manually or automatically can be stored in a database [Table 1, int-2].

The next frontier is the processing of the data to perform standard verification and diagnostic tasks (Wang, et.al., 2004, Turkaslan, et.al., 2005). Reasoning systems can even help with analysis of HVAC components and systems, identifying faults, diagnosing, and evaluating for potential energy efficiency improvements. Detailed and comprehensive reports can be produced [Table 1, int-2]. BEMS applications represent a significant step in this direction. It is used to optimize the performance of complex systems to help operations staff diagnose and tune systems. A challenge is to make it easier to obtain and use relevant data from the BEMS system for the benefit of an expanded user base [Table 1, int-1, Table 1, int-2]. Another area of significant application is the use of simulation software to define desirable performance data, particularly in the area of energy, which include tools like *MATLAB*, *Energy Plus*, and *Transis* [Table 1, int-1].

Interface with users is another area of potential development. Measurements, comparisons with design specifications, and recording actual readings are normally entered by hand. There is room for improvement here through the use of sensors, hand held devices, data interpretation and display, and intelligent applications [Table 1, int-7]. Visualization software, for instance, is one of the breakthrough application areas that can covert even the digitally challenged users to automation [Table 1, int-1]. Usually, the goal of using visualization is to intuitively and easily observe operation patterns, for example, the performance data from pumps, valves and dampers [Table 1, int-1]. Augmented reality applications can also help compare specifications to actual field data in order to determine differences and diagnose problems [Table 1, int-7].

Designing and building software applications is the least of the challenges facing automation. Acceptance of such tools in the field is a more difficult end. Not all field and back-office staff is comfortable with the idea of delegating their tasks to new software systems [Table 1, int-3]. This is so even in the HVAC area where we find the most sophisticated operators [Table 1, int-7].

## EXPERT'S LESSONS ABOUT BC

The lessons we learned from these interviews and the accompanying case study information (http://www.ce.cmu.edu/~BC/), which we collected from a number of these interviewees, provide the basis of a set of guidelines, outlined below, for expanding BC into the O&M realm.

BC is an emerging and critical phase of the building delivery process which promises to improve performance of buildings, particularly in the area of energy use. If these potential benefits are to be realized, however, several professional practice obstacles need to be overcome, including spheres of influence and conflict between designers and commissioning agents, efficient data encoding and exchange, and resistance to change, especially in standardization and automation.

BC is a diverse and non-standard area of practice which benefits both from its reach (impacting key areas like LEED, energy conservation and occupant satisfaction in buildings) as well as suffers from its volatility (retro-commissioning, stealth-commissioning, pseudo-commissioning, and so on.) Yet, the case for standardization has not been fully made even among those who stand to benefit from it, not to mention those who can deliver standardization.

Due to "cooperative" work structure that exists between building commissioning agents and those responsible for facility delivery, BC agents often foster good personal contacts with those parties whose work they evaluate (design engineers) and monitor (contractors). As a result, most commissioning authorities prefer to keep errors and fixes off of the books, particularly if the mechanical contractors are cooperative in remedying the situation and if LEED certification is necessary. Record keeping is usually limited to instances when the contractors and the commissioning authority are in conflict or intended as a punitive-retaliatory act. While this certainly sounds like an oversimplification (even to us), most commissioning documents we examined show a very small number of actual fixes. We labeled this practice "Stealth Commissioning."

This sort of cooperative relationship is usually extended to design engineers as well. We found that at least one instance, in which what appeared to be a design error leading to major equipment failure has been classified as "normal oversight" by the commissioning authority. In reality, it would have been very difficult to predict this failure mode without actually testing the extreme conditions by implementing them. This would have lead to a destructive form of commissioning. It is certainly justified to avoid this kind of "Extreme Commissioning" tests. More sophisticated simulation techniques, however, can be used to predict if and when catastrophic results can be expected.

We anticipate that the case for automation will be made through such interventions including the routine testing and diagnosis of performance. New and emerging applications including simulation, BEMS, and visualization tools are expected to have a positive impact on this trend.

In the following sections, we will build upon this view of the manual BC practice envisioning a digital BC world in which availability of accurate and efficiently accessed data would be ubiquitous. Through this approach, we will paint a picture in which these challenges of the conventional BC processes would be reformulated into opportunities for integrating it with O&M.

## INTEGRATION OF BC AND O&M

The initial challenge in integrating BC and O&M is to enable the flow of data between these two domains. The next challenge is to design an integrated digital tool that can facilitate flow of data between the key components of the complex web of design delivery and facility operation tasks.

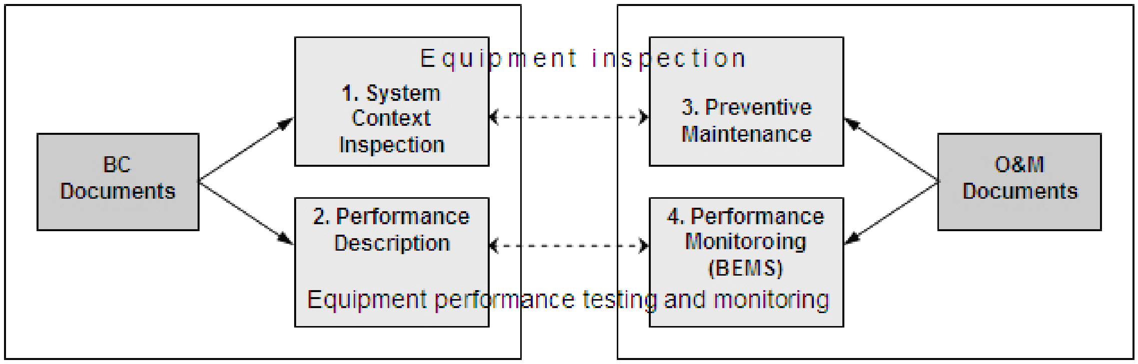


*Figure 2. Mapping the BC and O&M Data and Process Models*

Data Compatibility for Integration

We conducted a simple test in assessing whether data used in the BC process resembles that which is useful during later stages. For this comparison, we use the commissioning documents and O&M manuals and procedures of the New House residence hall at Carnegie Mellon University. The BC documents that can potentially feed into the O&M process include the system context inspection and performance description forms. These correspond to the preventative maintenance and performance monitoring (BEMS) formats in the O&M phase (Figure 2).

In order to bridge the two processes, we can find compatibility and data exchange in the *equipment inspection* area, which includes a match of the "system context inspection" against "preventative maintenance;" (top row in Figure 2) and the *equipment performance testing and monitoring* area, which matches "performance description" against "performance monitoring," or BEMS (bottom row in Figure 2).

| Equipment Performance Testing and Monitoring | | Equipment Inspections | |
|---|---|---|---|
| **BC MODEL- 2. Performance Description** | **O&M MODEL - 4. Performance Monitoring (BEMS)** | **BC MODEL – 1. System Context Inspection** | **O&M MODEL – 3. Predictive Maintenance** |
| **Heating Coil** | | | |
| air_flow | airFlowRate | is_fins_bent | - |
| entering_air_temp_dry | enteringAirTemp | is_fin_spacing_as_specified | - |
| leaving_air_temp_dry | leavingAirTemp | is_row_no_as_specified | - |
| face_velocity | - | is_inlet_ductwork_attached | - |
| - | waterFlowRate | is_outlet_ductwork_attached | - |
| - | enteringWaterTemp | - | is_obstructed |
| - | leavingWaterTemp | - | is_leaking |
| - | valvePosition | - | is_dirty |
| | | - | has_corrosion |
| | | - | is_dampers_OK |
| | | - | is_bypass_damper_motors_OK |
| | | - | drain_pan |
| **Hot Water** | | | |
| entering_water_temp | enteringWaterTemp | | |
| leaving_water_temp | leavingWaterTemp | | |
| water_flow_rate | waterFlowRate | | |
| water_pressure_drop | - | | |
| coil_capacity (n) | - | | |
| air_pressure_drop | - | | |
| **Steam** | | | |
| inlet_duct_size (n) | - | is_conden_piping_attached | - |
| outlet_duct_size (n) | | is_steam_piping_attached | - |
| entering_steam_pressure | enteringSteamPressure | | |
| steam_connection_size (n) | - | | |
| condensate_size (n) | - | | |
| - | steamTemperature | | |

*Figure 3. Correspondence of Inspection and Performance Testing Attributes in BC and O&M Models*

The next question of interest was whether there was sufficient compatibility between these data formats, namely the attributes and values used in measuring and monitoring these pieces of equipment. To test this idea, we dug deeper into the New House data. In Figure 3, we illustrate three pieces of equipment and the compatibility of the types of descriptors (inspection and performance testing attributes and values) they have: Heating Coil, Hot Water, Steam systems.

Where there are entries on the same row there is matching data. Where there are no entries on either side or the columns, there is no compatible data. The lighter font is used for attributes that have fixed values and do not need continuous tracking. Based on this limited test we observe that interoperability between BC and O&M processes is feasible and potentially productive. Immediate benefits would be in the areas of data accuracy and efficiency of data access. By automatically supporting the flow of data back and fourth between the two processes, errors due to manual data re-encoding and data interpretation would be reduced. Furthermore, the process of automatically transferring data that is compatible can considerably reduce the time of completing data needed in either process.

Automating the Integration and BC and O&M Data

In considering this issue, we first created a map of all of the design delivery and facility operation tasks, of which we could get possession. Then we laid them out in relation to each other, identifying the automation tools that would be required to generate the O&M decision support tool from all of the pre-existing processes, tools, and documents (Figure 4).

We organized these along columns that represent the phases of the design delivery and facility operation domain: programming, design, construction, commissioning, and operating. The integration of manual processes into the domain of an automated decision tool requires considerably more work and is usually a one time task of formal modeling that can render the future references to the manual documents unnecessary. Whereas the integration with automated tools would afford the comfort of working in a homogeneous domain of representation and would likely require continuous use of these tools over time. Therefore we organized Figure 4 in two rows each corresponding to the manual processes and the automated ones, respectively.

This map of the design delivery and facility operation domain clearly points to the area into which we need to focus our attention: the digital operations manual. We propose to build a software environment that will be able to take all of the appropriate input from the other tools and processes – requirement specifications, maintenance operations, and building management systems (BEMS and the like) – and produce, semi-automatically, a digital facility operations manual. We envision this software environment to enable facility operators to take maximum advantage of all data and information available on the facility, to maintain a robust data base, to access this information at the office as well as in the field, to work with greater speed and accuracy in conducting the business of facility operations.

Feasibility of Automation

Not all of the aspects of the design delivery and facility operation domain can be automated. These include:

- equipment inspections
- development of equipment checklists (semi)
- preventive and corrective maintenance (manual)
- develop issues log (semi)

This still leaves a great deal of work that needs to be done in order to create a usable and feasible digital environment.

- functional performance testing and measurements
- ensuring proper ventilation and IAQ at all times
- maintaining proper set points -- temperature and pressure
- ensuring proper sequence of operations
- identify malfunctioning sensors, valves and dampers and ensure proper installation
- data collection, analysis, and interpretation of results (FDD)

## CONCLUSIONS

This paper has reviewed the professional practice of BC with the intent of identifying challenges and opportunities for digitally integrating it with the downstream tasks of facility operations. We found that there are many obstacles to the full and accurate documentation of the BC process and the flow of information from this phase to downstream tasks without information loss. On the other hand, a closer view of the details of the data its attributes and values indicates that the integration of these phases of building delivery and operations are not only feasible but also useful. Through the seamless flow of data between these phases, we anticipate that not only the O&M Phase but also the BC phase will also become faster and more accurate.

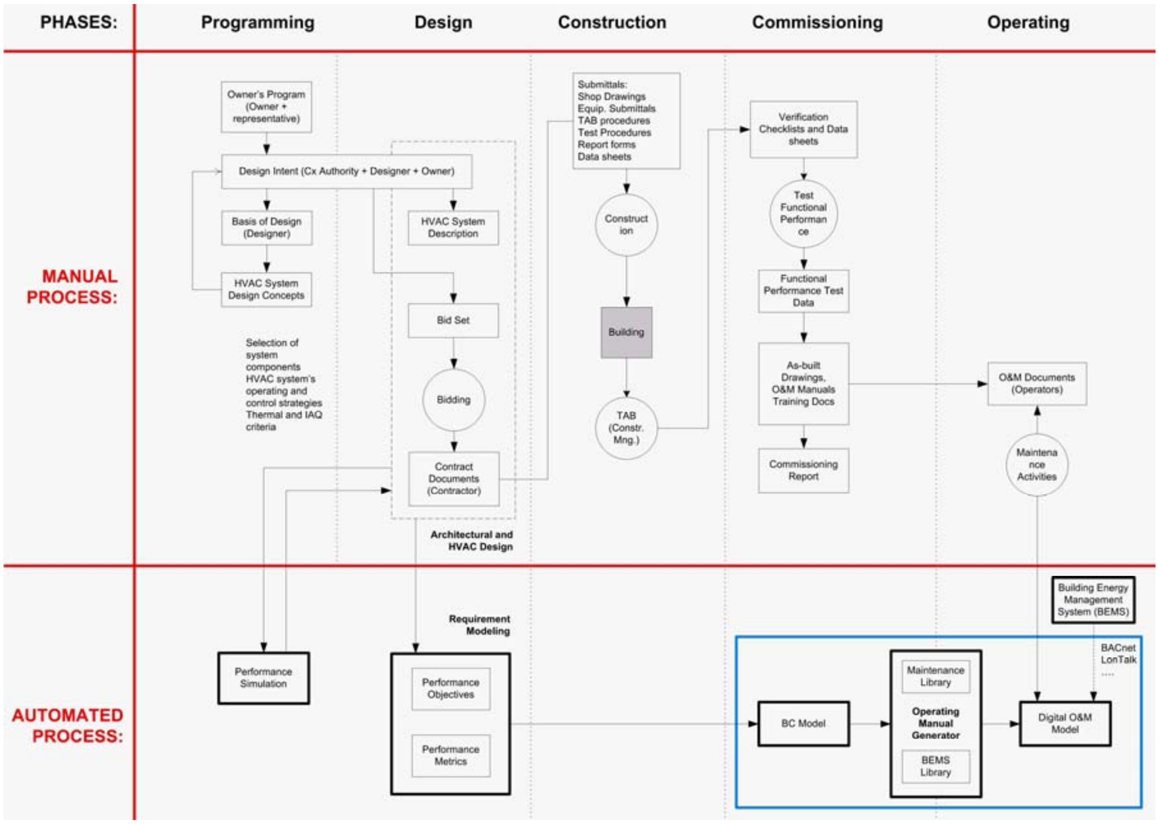


*Figure 4. Interactivity of manual and digital processes in the design delivery and facility operation domain as a context for the integrated BC and O&M processes.*

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