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Cheryl Chi, Disney Research China, People's Republic of China

Mei-Yan Fan, Disney Research China, People's Republic of China

Yan-Ping Wang, Disney Research China, People's Republic of China

Helen Chen, Disney Research China, People's Republic of China

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Ashwin Mahalingam, IIT Madras, Tripp Shealy, Virginia Tech, and Nuno Gil, University of Manchester

INCENTIVIZING HIGH BUILDING PERFORMANCE: A CASE STUDY OF PERFORMANCE CONTRACTING FOR NEW CONSTRUCTION

Cheryl Chi[1], Mei-yan Fan[2], Yan-ping Wang[3], Helen Chen[4]

ABSTRACT

Buildings account for almost 40% of total energy consumption in the United State and 33% in China. The improvement of building performance and energy efficiency presents great opportunities to sustainability. Performance contacting is promoted as an approach to improve high performance of buildings by introducing performance incentives into building projects to address entrenched issues originated from the fragmentation of the Architecture, Engineering and Construction industry. However, while performance contracting for retrofit projects is gaining attraction, performance contracting for new construction is rare.

The paper reports a three-year longitudinal case study of performance contracting for new construction in Shanghai. It adopts action research methodology combining participatory observation, archival analysis and questionnaire survey. It identifies 18 major challenges at the technical, managerial, and institutional levels and maps out their inter-relationship throughout project design, construction and operation phases. A roadmap showing possible directions for initiatives are developed. The study demonstrates a methodology that synthesizes ideas, experience and knowledge from different project participants and is able to provide a holistic view of performance contracting for new construction as a collaborative approach that addresses interrelationships, multi-party interests, and trade-offs.

KEYWORDS

High Performance Buildings, Performance Contracting, Energy Efficiency, Action Research

INTRODUCTION

Buildings account for almost 40% of total energy consumption in the United State and 33% in China (Abeysinghe and Barakat 2016, Hu et al. 2016, Zhao et al. 2016), which contributes significantly to CO_2 emissions. At the same time, the Architecture, Engineering, and Construction (AEC) industry is slow in pursuing opportunities in high building performance especially energy efficiency (Eubank and Browning 2004).

[1] Senior Research Scientist, Research Integration, Disney Research China, Shanghai, China. cheryl.chi@disney.com

[2] Research Associate, Disney Research China, Shanghai, China. mei.yan.fan@disney.com

[3] Associate Research Scientist, Disney Research China, Shanghai, China. yanping.wang@disney.com

[4] Senior Researcher, Disney Research China, Shanghai, China. helen.chen@disney.com

One of the major barriers is the lack of incentives for long-term high building performance in the way buildings are typically designed, constructed and operated (Busch and Diamond 1996, Eubank and Browning 2004), resulting in gaps between the designed and actual building performance (De Wilde 2014, Hu et al. 2016). Particularly, building performance is the result of the interactions among the design of architecture and engineering systems, construction management and quality, operations and maintenance practices, and occupant uses. In typical fragmented delivery processes, the hazard of "displaced agency" (Henisz et al. 2012)—key project participants make decisions in silo with limited understanding of the impact of their decision on other disciplines in the decision-making process over the project lifecycle—significantly impact resulting building performance including energy efficiency.

Performance contracting addresses the abovementioned issue to achieve high building performance by introducing performance-based incentives into long-term contractual relationship among the owner and key project participants (e.g., designers, engineers, builders, owners, and operators) (Eubank and Browning 2004, Widjaja 2016). Performance contracting aims at motivating high performance and energy saving behaviors of these key project participants, and, ultimately, ensuring the sustainability of buildings. It is a contractual mechanism that leverages investment and expertise from specialized companies (Pacific Northwest National Laboratory et al. 2015) and incorporates integrated project delivery mechanisms (Hellmund et al. 2008) (e.g., early involvement of key project participants and collaborative organizational arrangement among them) to achieve high building performance goals. In current practices, performance contracting is mostly used on retrofit energy projects. Its application for new construction and for overall building performance (e.g., including human comfort and other functionalities) is rare (Satchwell 2010, Pacific Northwest National Laboratory et al. 2015). New construction projects present greater opportunities for achieving a high level of building performance that goes beyond incremental improvements by incorporating integrated design and available advanced technologies with high efficiency (Eubank and Browning 2004). This paper aims to develop an understanding of challenges facing performance contracting for new construction and to outline a holistic framework for its successful implementation.

BUILDING PERFORMANCE CONTRACTING

The concept that building requirements should be specified in terms of its performance and service conditions has been promoted since 1925 in the U.S. to drive a paradigm shift in the construction industry from a focus on "prescriptive means" to a focus on "desirable ends" (Foliente 2000). Performance contracting is a contractual approach built on this concept to achieve desirable outcomes through systems thinking, which is also called "outcome-based" contracting (Ng et al. 2009). It is a procurement mechanism in which service providers finance, design and build building(s) or system(s) and recoup the investment from guaranteed performance improvements, which ties service provider's compensation to the performance of the product and completely shifts the responsibility of financing, operations and maintenance (Hypko et al. 2010, Hughes and Kabiri 2013).

Performance contracting is well-established in the defense industry and manufacturing industry, and it is in various levels of development in different sectors of the construction industry (Ng et al. 2009, Hypko et al. 2010, Hughes and Kabiri 2013). Energy performance contracting is one sector showing rapid development.

The emphasis on energy performance of buildings and facilities was highlighted under the shock of the energy crises in the 1970s, which, in 1980s, was crystalized to "energy performance contracting" (Okay and Akman 2010). Energy performance contracting approach is performed by a private company, typically an energy service company, and comprised of four components: (1) turnkey service, (2) comprehensive measures, (3) project financing, and (4) energy savings guarantee (ICT International and National Association of Energy Services Companies 2007). The mechanisms under which energy performance contracting leads to high energy performance are two-fold: (1) leveraging the expertise and investment from the private sectors and (2) tying together credit risk of financing, technical risk from design, and resulting performance risk (Okay and Akman 2010, Pacific Northwest National Laboratory et al. 2015).

Recently, energy performance contracting is regaining significant attention due to global warming effects. Similar concepts are also discussed in literature as energy savings performance contracting (ESPC) (Smith 2004, Smith 2010) and energy service contracting (Sorrell 2007). Particularly, studies regarding energy performance contracting for retrofit projects are proliferating.

A collective effort by Pacific Northwest National Laboratory et al. (2015) investigates and compares the expanding market of energy performance contracting for retrofit projects in China and the U.S., and identifies practices and barriers in these markets[5]. In current practices, contract periods range from 4-8 years to more than 20 years with three options for financial mechanisms: shared savings, guaranteed savings, and outsourcing of energy management. Yik and Lee (2004) investigate the conditions and factors (such as fluctuation of electricity price) that render the energy performance contracting not viable. Lee et al. (2013) survey influential parameters influencing energy savings (e.g., weather conditions, occupancy, operating hours, thermostate set-point) and develop a simulation-based method to evaluate the energy saving shortfall for building retrofit. Xu and colleagues identify success factors of the implementation of energy performance contracting in hotel building retrofits in China (Xu et al. 2011, Xu and Chan 2013, Xu et al. 2015). The U.S. Department of Energy release a program guideline for ESPC in 2016 to advance the adoption of ESPC practices among governmental agencies (Smith et al. 2016). The guideline provides information and practices with extended definition to include savings of water use: "ESPC, or performance contracting, is a budget-neutral approach to performing building improvements that reduce energy and water use while increasing operational efficiency" (Smith et al. 2016, p.1).

In contrast, studies on energy performance contracting for new construction is still rare (Satchwell 2010, Pacific Northwest National Laboratory et al. 2015). The main challenges for new construction is that, although a theoretical financial model can be developed (Sorrell 2007), an energy performance baseline is hard to establish since

[5] The market of this type of projects is expanding: in 2011 and 2013, energy performance contracting for retrofitting was worth about $6.4 billion and $12 billion respectively in China, and about $6.3 billion and $7.6 billion respectively in the U.S.

there are no utility bills available for new construction and it is more challenging to establish the baseline based on simulation modeling (Smith 2004, Smith 2010). Similarly, there is no accurate occupancy schedule for the calculation and prediction of energy savings. In addition, long commitment time over dynamic project lifecycle processes pose real challenges and risks, such as gaps between designed and actual performance, unanticipated costs, lifetime maintenance cost and responsibility, changing requirements from the owner and user, etc. (Gruneberg et al. 2007, Almeida et al. 2010).

Despite these challenges, several organizations took initiative including the Oakland Administrative Building, North Clackamas High School in Portland, R.E. Johnson State Office in Austin, Federal Courthouse in Gulfport, and Federal Research Center at White Oak (Motegi et al. 2002, Eubank and Browning 2004, Smith 2004, Smith 2010). Although these cases share only general information and half of the studies are published when the projects are still in pre-construction stage, they document some useful practices and benefits. For instance, using computer simulation modeling to determining performance baseline can incorporate design considerations, ASHRAE 90.1 standards, and typical energy performance of current locations (Smith 2010). During the design phase, the modeling process iterates to simulate different energy conservation measures and conditions for optimization and value engineering. Typically, an energy management system is set to measure and monitor energy performance. When integrated contracting approaches are not used (like the case of North Clackamas High School and R.E. Johnson State Office), the designer cannot control construction quality and thus is unable to be held liable for actual energy performance outcome (Eubank and Browning 2004). The financing capability of individual companies in the contractual arrangement might compel a payment schedule beginning before the energy performance can be verified (Eubank and Browning 2004).

The literature review shows that performance contracting for new construction has just begun to draw academic attention. All case studies of performance contracting focusing on energy performance although there are multiple aspects of building performance including indoor air quality and thermal comfort as pointed out in the concept of “performance-based building” (Foliente 2000, Bakens et al. 2005). Scant examinations exist on challenges throughout the design, construction and operation phases. Without such longitudinal investigation, it is difficult to understand whether a specific arrangement of mechanisms under performance contracting fulfill the expectation of all project parties. A structured investigation into implementation processes beyond contractual terms is necessary for developing an in-depth understanding about why adoption of performance contracting for new construction is slow.

This paper reports a longitudinal case study in Shanghai, in which we explore the specific challenges of applying performance contracting to new construction projects. We adopt the project management framework proposed by Peter Morris (1983) to categorize the challenges we identify in the exploratory case into the technical level, managerial level and institutional level in order to differentiate the nature of the challenges. We then discuss potentially different approaches to tackle these challenges. The case study provides insights into the conditions under which performance contracting could generate the expected benefits and its adoption by new building owners could be accelerated.

RESEARCH METHODOLOGY

We conducted an exploratory case study utilizing action research, as a response to a call for "simultaneously contributing to the solution of practical problems and creating theoretical and conceptual knowledge" (Azhar et al. 2009, p.87). In our case, project participants agreed that there were uncertainties and challenges of performance contracting (Diagnosing) and they proceeded with an initial arrangement of performance contracting (Action planning). They discovered issues over the course of implementation (Action taking) and resolved issues or tried to resolve issues through discussions and workshops (Evaluating & Specifying learning) (Azhar et al. 2009). This paper reports a major evaluation and learning after two years of operation of the case building. Both action research and exploratory case studies permit researchers to navigate the phenomenon of interest in real-world settings in order to develop an understanding of the complexity and nature of the research subject (Azhar et al. 2009, Yin 2014). Action research allows researchers to further bridge the gap between academics and practice by testing theory in solving of practical problems.

Because the case of performance contracting for new construction is exploratory in nature, a single in-depth case study is useful in generating important insights that signify major issues to be addressed in this research area (Yin 2014). Except the first author, all other authors have directly participated in the case project as the owner's core team since the initiation of the case project. The first author plays a role of offering different perspectives as a means to enhance reflexivity in this type of highly engaged process research (Langley et al. 2013).

CASE BACKGROUND

The Case Project is a stand-alone 4-story office building with gross floor area 415 ㎡, located in Shanghai, China. It is a reconstruction of a typical Shanghai 1970s concrete building which was run-down and lacked original plans. The reconstruction maintains and reinforces the structure of the original building in accordance with policy requirements, and designs and installs new building systems. The design and construction began in April 2014 and we moved in the building in February 2015.

We set up the project as an experimental case of new construction performance contracting together with a performance contractor responsible for the design, installation, commissioning and operation of the building active systems (i.e., building systems that consume or generate energy, such as HVAC, lighting, security systems, air quality management etc.) for required building performance targets, with a 5-year performance contract period since the core systems commissioning completion. Under this arrangement, we aim to explore a performance contracting framework with a set of underlying mechanisms. Our goal is to incentivize the service company to guarantee high building performance, specifically energy efficiency and indoor comfort, in the most cost-effective ways possible.

DATA COLLECTION AND ANALYSIS

The study combines participatory observation, archival analysis and questionnaire survey to triangulate research results and capture a holistic view of the research subject of interest.

Participatory Observation: throughout the implementation processes, we had multiple discussions with consultants and main participants. We also interviewed key participants including the three participant authors during the operation phase with open questions such as: What did you learn from the process? What surprised you? What are the challenges?

Archival Analysis: we analyzed project documents including meeting minutes, presentations, and notes from workshops where main project participants from design through operation discussed how to modify and improve contractual agreements. Table 1 presents a list of archival data we used in analysis to identify key challenges and unexpected issues.

Table 1 Archival Data of the Case Study (September 2013-March 2017)

Data category	Description	Number
Meeting Notes	The meetings mean the case project-centric meetings from design through operation.	21
Informal Interview	Face-to-face or phone call interviews with relevant project participants with open-ended questions.	9
Workshop	Workshops at which a group of relevant project participants engaging in intensive discussion and activities on a particular subject related with the case project.	1
Operation Documentation	Documentation of practical issues found in operation and maintenance phase, and building comfort upgrades for continuous improvement.	1
Project Documentation	Performance contract, HVAC system performance report	2

We analyzed the archival data by systematic, iterative coding method. Firstly, the second author identified the sentences relevant to performance contracting for new construction from all the documents and coded them into an excel sheet as a clean data set. A total of 334 word chunks (i.e., groups of one to multiple sentences to keep intact the meaning of the dialogue) are coded. Next, two of the authors individually assigned categories of challenges to the word chunks to develop a preliminary coding scheme, and had lengthy discussion, clarification and refinement of the coding scheme, resulting in the category of challenges and their operational definitions and examples from the project documents. The second author coded the 334 word chunks again to ensure the category of challenges cover all the data. Finally, all the authors examined the coding results again to verify the categorization and definition as well as to identify and clarify their connections. Table 2 provides an example of our coding analysis extracted from the excel database.

Table 2 Example of Coding Analysis

Source	Data	Category of Challenge	Technical-Managerial-Institutional Levels
“20150811 Performance contracting strategy for new construction: case study of 624 project”	“The whole point is that not just design the building for energy performance”	Building Performance Targets	Technical Level
“624 schedule delay analysis sheet”	“Duration Variance of IBMS Sensors commissioning is 49 days, because confirmation of each sensor data point took very long by the performance contractor, setting up WebCtrl and basic user preferences”	Managerial Efforts for Project Delivery	Managerial Level
“2015-2016 informal interview for vendor selection and contract negotiation”	“China [company name] as our consultant, took initiative Built Environment Working Group for collaborating with us on integration of green building solutions, invited several market available big company incorporating many vendors, who are interested to provide the integrated building system solutions. However, the invited bidding turned out not competitive bidding for integrated building system solutions, but to be sole source for active system”	Availability of Capable Performance Contractors for New Construction	Institutional Level

Questionnaire Survey: To strengthen the validity of the identified challenges and to develop a holistic view of potential research topics and directions in the field, we conducted a survey with project decision-makers to get their assessment about these challenges. We identified a total of 16 project decision makers by discussion with our own project team and the performance contractor (as shown in Table 3) and got in touch with all of them. The survey is consisted of four questions, including:

(1) What is your role in the case project of performance contracting for new construction?

(2) Matrix questions of the level of importance (5-point Likert-scale), time of horizon for the industry to resolve each challenge and who should take lead.

(3) Please rank the Top 5 out of the 18 challenges that you think the most important to be resolved for successful implementation of performance contracting for new construction projects.

(4) Do you have any comments on specific challenges listed in the table? Are there any other challenges not identified in the table?

Table 3 Survey Respondents

Project Role	Owner	Consultants of the Owner	Performance Contractor	General Contractor	Research Partners of the Owner	Total
Number of Sent Questionnaires	4	5	5	1	1	*16*
Number of Responses	4	4	4	1	1	*14*

We received a total of 14 survey responses, with a response rate of 87.5%. In case studies, multiple methods help to improve validity of the findings (Eisenhardt 1989, Yin 2014). In our case, we are able to assess the coded challenges from all key project participants after three-year collaboration and continuous discussion over the course of project process. This greatly ensures that our results reflect a holistic view regarding the performance contracting experiment rather than the owner's view.

RESULTS

KEY CHALLENGES

A total of 18 challenges of applying performance contracting to new construction are identified and elaborated below. Table 4 shows an overview along with their operational definitions or examples for coding.

Table 4 Challenges Identified from Archival Analysis

PM Level	Categories of Challenges	Operational Definition or Examples
Technical Level	Performance Requirements of the Owner	(1) Some of the owner's requirements are immeasurable. (2) The relationship between owner's requirements and the designed performance of building systems is unclear.
	Building Performance Targets	(1) There are multiple ways based on which building performance targets can be specified including international codes, latest research outcome, or occupants' preference. (2) There are trade-offs among different performance targets (such as indoor comfort and energy performance) and some are not quantified.
	Performance Baseline for New Construction	(1) No historical data for establishing a performance baseline. (2) Difficulties of defining a performance baseline that is contractual binding. (3) There are multiple ways to define the performance baseline for new construction including building energy modeling, benchmarking and one-year operation data of the new building. (4) It is time-consuming and data-demanding to achieve relatively accurate energy modeling results in design phase.

PM Level	Categories of Challenges	Operational Definition or Examples
	Correlation Between Active and Passive Systems	(1) The relationship between the active and passive systems is unclear. (2) How to integrate technical requirements of these two types of building systems is not established.
	Post-occupancy Changes of Building Systems	(1) Changes due to new requirements of the owner, non-functional systems or upgrading of outdated technologies. (2) The changes will impact on performance monitoring and measurement.
	Performance Evaluation Planning	Performance evaluation planning includes sensors network, measured data points and time-step, and building performance display.
	Data Quality	Data availability and reliability from sensors and transmission.
	Interoperability among Simulation-Operational Models and Systems	Interoperability among Building Information Model, Building Energy Model and Building Management System need further study.
	Intelligent Building Control	(1) Intelligent building control including diagnostics tools is under development. (2) Manual operations are required to supplement it.
	System Sizing	Trade-offs among the factors that influence system sizing including the accuracy of building energy modeling, local codes and potential expansion required by the owner.
	Occupant Behavior	The impact of occupant behavior on building performance is unclear.
	Availability of Advanced Technologies	(1) Advanced technologies include green technologies, integrated building management technologies and data collection and diagnostics technologies (support data quality). (2) Integration of multiple systems and technologies is challenging.
Managerial Level	Managerial Efforts for Project Delivery and Operation	(1) Managerial efforts for integrated design. (2) Managerial efforts for construction quality. (3) Managerial efforts for efficient operation.
Institutional Level	Availability of capable Performance Contractors for New Construction	(1) Difficulties of finding qualified performance contractors for integrated building systems, active system or passive system in current market. (2) Long negotiation time and high transaction expenditure (3) The performance contractor for new construction needs to have strong financing capability
	Financial Model	(1) There is no existing financial model for the performance contracting for new construction. (2) The financial model needs to consider the interests of mutual parties. (3) Project scale impacts on the financial model to get the project financially feasible. (4) The trade-off between total cost and the value of building performance targets is unclear.
	Performance Incentive/Penalty Mechanism	(1) What incentive mechanisms encourage the vendor to pursue high building performance design in cost-efficient ways are unclear.

PM Level	Categories of Challenges	Operational Definition or Examples
		(2) When and in what conditions we need to use penalty to ensure desirable services is not defined. (3) Project scale impacts on the performance incentive/penalty structure.
	Local Legal Constraints	It's illegal to have the performance contractor to pay the utility bills for us because they are not the local legal utility suppliers.
	Contracting Strategy	How to set-up the contractual structure to allocate and mitigate the risk is under-explored in current market.

Technical Level

1. Performance Requirements of the Owner: The initial performance vision of this building is to create an energy-efficient, comfortable, healthy and environmentally friendly built-environment for the owner with visual and measurable performance. Therefore, a lengthy discussion was launched to identify what the owner's requirements meant in terms of building systems design, and translate these requirements into measurable indicators. The project team was able to define "indoor comfort" for this building in terms of relatively well-established indicators: indoor air quality, thermal comfort, and acoustics comfort.
2. Building Performance Targets: Building performance targets are contractually consequential in performance contracting. Therefore, project participants needed to know how to select reasonable targets in the local context. They knew that international codes were largely not suitable for the context of Shanghai but it was also difficult to obtain local building energy performance data of the building usage type similar to the case building to set a reasonable improvement target. In addition, trade-offs between energy performance and indoor comfort along with other qualitative requirements need to be further quantified before contractually guaranteed criteria could include multiple aspects of building performance.
3. Performance Baseline for New Construction: As mentioned in other studies, it is challenging to establish performance baseline for new construction. The owner decided to build a simulation model and develop a Guaranteed Energy Model (GEM) through validation with actual operation data. They were exploring with the GEM to figure out how to speed up the modeling efforts and scale up to larger projects. At the same time, project participants continued to discuss which way among multiple ways would motivate all project participants to pursue performance contracting for new construction.
4. Correlation between Active and Passive Systems: The performance contractor was responsible for the active system. The passive system was designed and delivered by the participants contracted directly with the owner. The performance contractor voiced concerns about how the passive system might impact the performance of the active system. But it was unclear how to evaluate this impact, even to the performance contractor themselves. This gave rise to the question: even the entire scope was contracted to one company, how, in terms of technical aspect, this company creates a design that integrates technical requirements of these two types of systems? How to provide maintenance requirements for the passive system that ensures the performance of the active system?

5. Post-occupancy Changes of Building Systems: there were incidents in which changes in the systems occurred after occupants moved in the building. They were due to evolving understanding of how the designed system actually functioned and better specified building requirements after occupants began to experience the building space. These changes created impacts on performance monitoring and measurement including how data is collected and analyzed, or performance evaluation plan.
6. Performance Evaluation Planning: after a set of performance metrics was defined, it was important to specify how these metrics could be measured over long periods accurately and reliably. The performance contractor needed to plan data collection, which includes sensors network, data points and time-steps, as well as visualization of building performance.
7. Data Quality: tightly related to the item above, the project team further defined the data quality as (1) all data required to measure performance must be reliable (i.e., within normal range), and (2) no data is missing from the sensors and transmission. The performance contractor should be required to also guarantee data quality.
8. Interoperability among Simulation-Operational Models and Systems: there existed challenges in the communication between three simulation and operational systems: building information model used for design and construction, energy simulation model used for energy performance prediction and baseline, and building management system connecting integrating data from sensor networks. A large among of information can be shared among these three systems to ensure information accuracy and completeness but it requires an overarching framework to support interoperability among them.
9. Intelligent Building Control: The performance contractor provided an intelligent building control system including remote diagnostics tools and the mechanism of sending alarm if any problem with the building system occurred. With this system, the performance contractor could provide highly responsive services while reducing the operation and maintenance cost. However, some components of the system were currently under development and the manual operations were required to supplement. It created communication load and led to waiting time when some problems with the system needed to be fixed.
10. System Sizing: several factors created uncertainties for system sizing. The owner had a potential expansion plan, which led the performance contractor to consider 20% additional capacity for future usage change. This affected equipment and system selection, which consequently affected capital cost. The system was currently running at 50% capacity. The project team also thought that the energy modeling simulation used in design may not have been accurate.
11. Occupant Behavior: there were frequent discussions regarding how occupancy and occupant behavior was very different from initially anticipated and how the difference impacted building performance and building control. Major questions included what would be variables measuring occupant behavior? What behavior impact on the energy efficiency in what way?
12. Availability of Advanced Technologies: Project team discussed how to evaluate technologies for energy-saving, sensor network, and remote diagnostics especially during the design phase no one had full knowledge about how these technologies

would actually function and how they might interact with each other. Later, project team discussed some installed technology was not functioning as intended, leading to an indoor temperature that was too low in order to maintaining reasonable indoor humidity. A change on the system that maintained both comfortable temperature and humidity increased energy use.

Managerial Level

13. Managerial Efforts for Project Delivery and Operation: in this case, local contractors and vendors lacked capability in terms of project management, planning, and quality control. The owner team played the role of holding together an integrated project organization through frequent communication and the use of building information modeling. Major managerial issues included coordination among active system, architect, and MEP system in a tight space, GC's lacking of shop drawing capability, quality mindset and construction quality control capability.

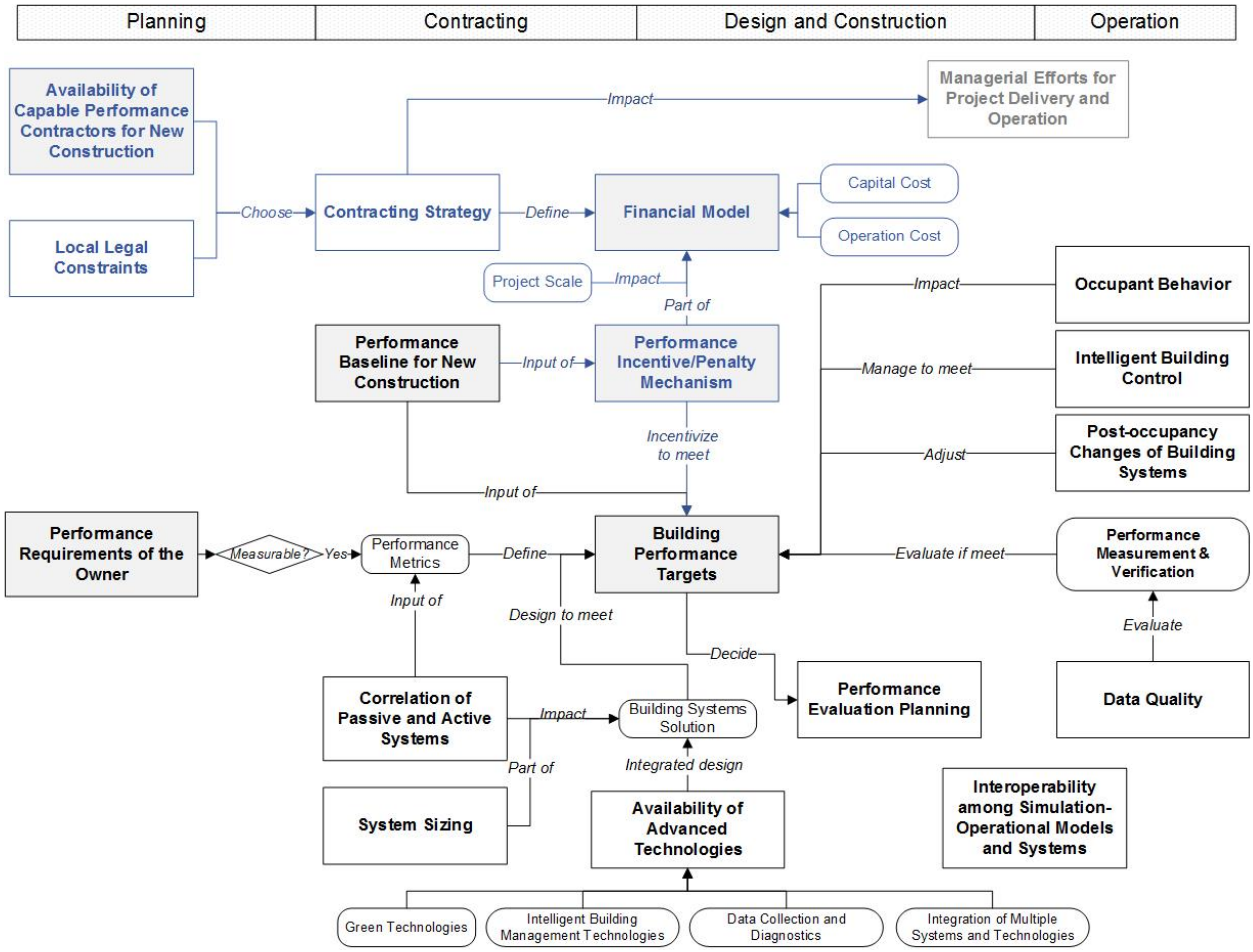
Institutional Level

14. Availability of Capable Performance Contractor for New Construction: after talking to multiple companies in the market, the owner found that few companies existed providing integrated building system solutions. Only one was interested in trying through this experimental project. Therefore, the owner had to work with this company as the sole source for the active systems. Another company showed interest in the passive systems but was unable to provide the service to sign a passive system performance contract.
15. Financial Model: there was no existing financial model in the market for the performance contracting for new construction and therefore, companies in the market perceived great uncertainties in even determining their costs of carrying out this type of projects. Frequently discussed questions included: in what conditions, with what project scales, the performance contractor could be profitable? What would be the capital costs in different financing options? What would be the profit margin attractive to service providers? What would be the appropriate range of the payment for the owner?
16. Performance Incentive/Penalty Mechanism: For typical performance contracting, incentive and penalty structure is the core of financial model and specifically focuses on what kind of behavior we would like to incentivize? How would penalties impact the relationship between the owner and the performance contractor? Discussion was around these questions: how to structure the incentive? What would be the threshold (e.g., 70% improvement compared to benchmark data of building energy consumption in Shanghai) based on which the incentive is offered? Should the cost of the system or the energy savings should be the basis in calculating the amount of incentives? How would the project team choose between applying liquidated damages vs. performance penalties? How to set up a scalable incentive structure? How to tie incentives to the desirable behaviors like right sizing of equipment?
17. Local Legal Constraints: the owner intended to structure the contract in a way that the owner paid monthly fee to the performance contractor and the performance contractor paid for the energy use. By doing so, the performance contractor had

incentive to increase energy efficiency. However, it was illegal in this market for the performance contractor to pay the utility bill.

18. Contracting Strategy: the project team had to figure out feasible procurement/packaging strategies when companies offering integrated building solutions were not available in the market. This compelled the owner to play the role of integrator of active and passive systems. Later the performance contractor raised the question: how could they be accountable for the entire system since they were not responsible for passive system and the impact of passive system on active system was unclear? This lead the project team to consider whether the performance contractor could provide specifications for passive system.

The definition of challenges above is for clear presentation. In fact, these challenges are intertwined. Figure 1 presents the relationships we captured in the conversations recorded in the archival data. For instance, in discussing the contracting strategy, the project team referred that the strategy was to a response to the problem that there was no mature market of performance contracting for new construction, a capable provider of integrated system solutions was unavailable, a financial model accepted by the industry was not available, etc. Different contracting strategies would need different management approaches including workflow and organizational roles and responsibilities. Similarly, discussions about why it was challenging to define "guaranteed improvements" that could be tied to the financial incentive and penalty revealed unclear relationship among relevant aspects of building performance, trade-offs between performance targets, interaction among different building systems, and how to develop a mutually agreed baseline. Moreover, interoperability of simulation modeling and control systems is based on detailed performance evaluation planning, knowledge of where to put data and what data is needed. This is built on well-defined performance targets, measurements and verification approaches.



Note: The top six challenges in terms of importance in the survey results are shaded with grey. The challenges at the institutional level are presented in Blue text, the challenge at the managerial level in Grey text.

Figure 1 General Relationships among the Set of Identified Challenges

SURVEY RESULTS

The key project participants were invited to evaluate the level of importance of each identified challenge with a score of from 0 to 4, representing from not important to very important. Figure 2 shows the average rated importance of each challenge, which is all above 2.00. This confirms that all of the coded challenge are critical in the case. The average of all the scores is 3.02. Among them, the top five are "Financial Model" (3.86), "Building Performance Targets" (3.86), "Managerial Efforts for Project Delivery and Operation" (3.57), "Performance Baseline for New Construction" (3.50), and "Performance Incentive/Penalty Mechanism" (3.36).

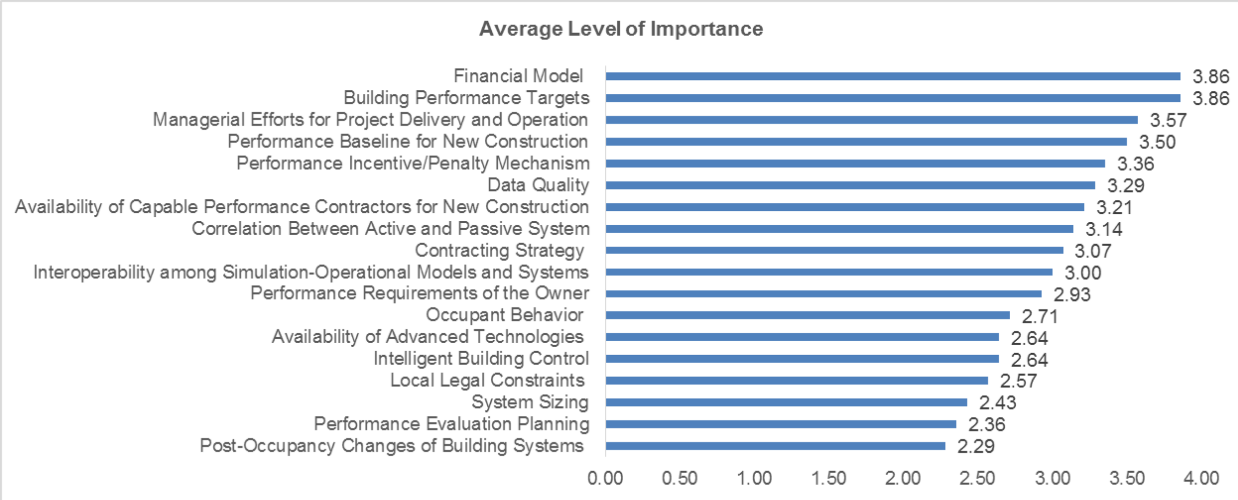


Figure 2 Average Level of Importance of Each Identified Challenge

Then the respondents were asked to rank the top five out of the 18 challenges that they think the most important to be resolved for successful implementation of performance contracting for new construction projects. A total of 15 challenges are selected and their weighted rank position are calculated. Figure 3 presents the results of the challenges with average ranking value above 1.00. They are "Building Performance Targets" (3.21), "Availability of Capable Performance Contractors for New Construction" (1.86), "Performance Baseline for New Construction" (1.50), "Financial Model" (1.50), "Performance Requirements of the Owner" (1.43), and "Performance Incentive/Penalty Mechanism" (1.21). These ranked challenges are completely aligned with the group of challenges whose average level of importance is rated over 2.93 as shown in Figure 2.

Note: (1) W=weight of ranked position (The weight of the ranked position from the first to the fifth are valued from 5 to 1 accordingly); (2) X=response count for answer choice; (3) Average ranking value= ($x_1w_1+x_2w_2+x_3w_3+x_4w_4+x_5w_5$)/Total Respondents.

Figure 3 Top Six Challenges Based on Average Ranking Value

Further examination reveals that major differences exist regarding the viewpoint of the owner group (the owner and consultants of the owner grouped) and that of the performance contractor group (performance contractor and general contractor grouped), as shown in Table 5. The owner team and the performance contractor team agree with the importance of “Building Performance Targets” (2.25 versus 3.00, respectively) and “Managerial Efforts for Project Delivery and Operation” (1.00 versus 0.80, respectively). The major difference of viewpoints exists in “Performance Requirements of the Owner” (0.25 versus 3.60 respectively) and “Availability of Capable Performance Contractors for New Construction” (3.25 versus 0.00). It is interesting to see how the owner team perceive it highly important to have capable performance contractor to offer integrated solutions while the performance contractor team perceive it highly important for the owner to provide clearly specified requirements, which implies the owner should possess knowledge about all aspects of building performance. This give rise to the question: who, in the market, should have the knowledge of how different requirements can be translated into measurable targets and how they interact?

Table 5 Comparison of Average Ranking Result of Two Groups

Categories of Challenges	**Owner Group**	**Performance Contractor Group**	***Absolute Difference***
Performance requirements of the owner	0.25	**3.60**	3.35
Availability of capable performance contractors for new construction	**3.25**	0.00	3.25
Financial model	**3.00**	**1.40**	1.60
Performance incentive/penalty mechanism	**1.50**	0.20	1.30
Post-occupancy changes of building systems	0.00	**1.00**	1.00
Data quality	0.00	**1.00**	1.00
Performance baseline for new construction	0.88	**1.80**	0.92
Contracting strategy	**1.00**	0.20	0.80
Building performance targets	**2.25**	**3.00**	0.75
Performance evaluation planning	0.00	0.60	0.60
Interoperability among simulation-operational models and systems	0.50	0.00	0.50
Local legal constraints	0.38	0.00	0.38
Occupant behavior	0.50	0.80	0.30
Managerial efforts for project delivery and operation	**1.00**	0.80	0.20
Correlation between active and passive systems	0.50	0.60	0.10
Availability of Advanced Technologies	0.00	0.00	0.00
Intelligent Building Control	0.00	0.00	0.00
System Sizing	0.00	0.00	0.00

Note: The average ranking scores no less than 1.00 are in bold.

Next, we asked the respondents, in their opinion, who should take lead to resolve each challenge. Table 6 presents the result. The respondents have highly diverse views. They only have higher consensus on that “Managerial Efforts for Project Delivery and Operation” should be resolved by private companies (71%). The rest of responses range from 7% to 57%. The resolution of eight out of the 18 challenges are perceived to be led by private companies while the resolution of six out of 18 requires collaboration among the government, private companies and research institutes. Only four challenges are voted by majority to be resolved by research institutes and one by the government. It shows that private companies were perceived to play a critical role in leading the development of this market of interest.

Table 6 Leading Actors in the Industry to Resolve Each Identified Challenge

Categories of Challenges	Government	Private Companies	Research Institutes	All Above	Private Companies and Research Institutes
Performance Requirements of the Owner	**14%**	**29%**	**0%**	**43%**	**14%**
Building Performance Targets	**7%**	**14%**	**21%**	**43%**	**14%**
Performance Baseline for New Construction	**21%**	**0%**	**21%**	**50%**	**7%**
Correlation Between Active and Passive System	0%	7%	50%	21%	21%
Post-Occupancy Changes of Building Systems	0%	43%	29%	21%	7%
Performance Evaluation Planning	0%	43%	7%	36%	14%
Data Quality	0%	36%	36%	21%	7%
Interoperability among Simulation-Operational Models and Systems	7%	21%	14%	50%	7%
Intelligent Building Control	0%	43%	21%	21%	14%
System Sizing	0%	43%	36%	14%	7%
Occupant Behavior	0%	0%	57%	29%	14%
Availability of Advanced Technologies	7%	14%	7%	57%	14%
Managerial Efforts for Project Delivery and Operation	0%	71%	0%	14%	14%
Availability of Capable Performance Contractors for New Construction	**7%**	**36%**	**0%**	**43%**	**14%**
Financial Model	**7%**	**36%**	**43%**	**0%**	**14%**
Performance Incentive/Penalty Mechanism	**0%**	**50%**	**7%**	**29%**	**14%**
Local Legal Constraints*	57%	0%	7%	21%	7%
Contracting Strategy	0%	50%	7%	29%	14%

*Note: (1) The top six ranking challenges are in bold. "All Above" means the collaboration of government, private companies and research institutes. (2) *: One respondent (7%) didn't choose any choice in this challenge. (3) The choice with biggest value (%) of each challenge are shaded in grey.*

The respondents were further asked when they think each challenge would be resolved in the industry with three choices of timescales including "1-2 Years", "3-5 Years", and "Over 5 Years", as shown in Table 7. This offers another angle assessing the timescale within which Performance Contracting for New Construction would achieve greater adoption in the industry and mapping out perceived development paths in the research area of interest. Challenges at the institutional level, although they are not within the control of project participants, are not perceived as taking longer to resolve compared to the challenges at the managerial and technical levels. Figure 4 shows the results of the challenges perceived to be resolved within the timescale of five years.

Table 7 Timescale and Development Path for the Industry to Resolve Each Identified Challenge

Categories of Challenges	Timescale Choices			*Development Path*		
	1-2 Years	**3-5 Years**	**Over 5 Years**	***1-5 years (%)***	***Average Level of Importance***	***Leading Actor (% of respondents)***
Performance Requirements of the Owner	**50%**	**50%**	0%	*100%*	*2.93*	*All Above (43%)*
Data Quality	43%	**50%**	7%	*93%*	*3.29*	*Private Companies /Research Institutes (36%)*
Intelligent Building Control	29%	**64%**	7%	*93%*	*2.64*	*Private Companies (43%)*
Post-Occupancy Changes of Building Systems	**50%**	36%	14%	*86%*	*2.29*	*Private Companies (43%)*
Performance Incentive/Penalty Mechanism	**79%**	7%	14%	*86%*	*3.36*	*Private Companies (50%)*
Performance Evaluation Planning	**64%**	14%	21%	*79%*	*2.36*	*Private Companies (43%)*
Building Performance Targets	**50%**	29%	21%	*79%*	*3.86*	*All Above (43%)*
System Sizing	**50%**	29%	21%	*79%*	*2.43*	*Private Companies (43%)*
Financial Model	**57%**	21%	21%	*79%*	*3.86*	*Research Institutes (43%)*
Contracting Strategy	**43%**	36%	21%	*79%*	*3.07*	*Private Companies (50%)*
Performance Baseline for New Construction	**36%**	**36%**	29%	*71%*	*3.50*	*All Above (50%)*
Interoperability among Simulation-Operational Models and Systems	**36%**	**36%**	29%	*71%*	*3.00*	*All Above (50%)*
Managerial Efforts for Project Delivery and Operation	29%	**43%**	29%	*71%*	*3.57*	*Private Companies (71%)*
Occupant Behavior	29%	**36%**	**36%**	*64%*	*2.71*	*Research Institutes*

						(57%)
Availability of Advanced Technologies	29%	36%	**36%**	*64%*	*2.64*	*All Above (57%)*
Availability of Capable Performance Contractors for New Construction	21%	36%	**43%**	*57%*	*3.21*	*All Above (43%)*
Correlation Between Active and Passive System	29%	21%	**50%**	*50%*	*3.14*	*Research Institutes (50%)*
Local Legal Constraints*	36%	14%	**43%**	*50%*	*2.57*	*Government (57%)*

*Note: (1) The top six ranked challenges are in bold. (2) Challenges at the institutional level are shaded with grey. (3) *: One respondent (7%) didn't choose any choice in this challenge.*

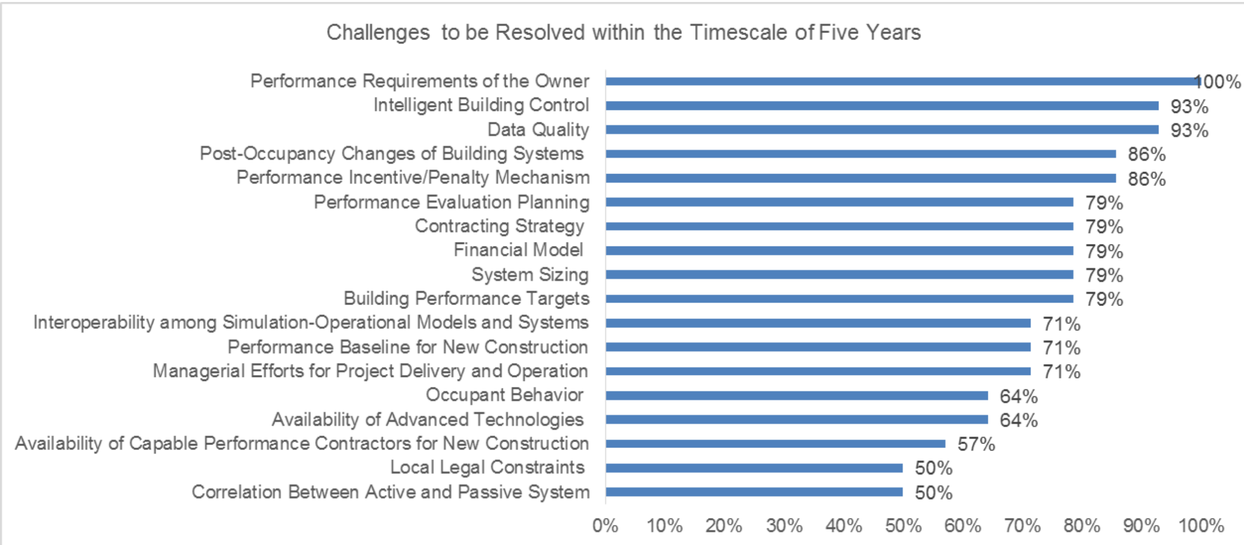


Figure 4 Challenges Perceived to be Resolved within the Timescale of Five Years

DISCUSSION

Our analysis of challenges from this in-depth case study have identified 18 challenges and their inter-relationship throughout project design, construction and operation phases. This holistic framework visualizes the complexity and dynamics of performance contracting for new construction, which might be a core barrier for its adoption. At the same time, elaboration on these challenges sheds lights on the directions and allows for assessing the timescale of resolving them.

Our categorization of challenges using Morris' project management framework help reveal that each of the technical challenges could potentially be a research subject. On the other hand, once it is resolved, the solutions could be used for all new building projects using performance contracting. More than half of our questionnaire respondents believe that these technical challenges could be resolved within 5 years. Even the challenge "correlation between active and passive system" with only 50% respondents thinking it would be resolved in 5 years, some respondents strongly believe a computational and simulation tool already exists to tackle this issue. By the time of writing the paper, the project team has greatly advanced the understanding of how energy modeling plays a role throughout the processes and that a simple, faster model meeting accuracy standards would serve the purpose of performance contracting.

While some technical challenges show promising progress, inter-relationship among the challenges seems to be left unnoticed by current academic communities. Specifically, multiple challenges are related to interaction among multiple building systems and the resulting behavior of a system combining equipment, pipelines, sensor networks, and control systems. Project participants knew this project would face challenges but learned about how difficult they were after implementation. The interdependency among various challenges makes it difficult to make a breakthrough before major challenges are all resolved. Particularly, actual operation of selected systems brought unintended surprises to all project participants and led to discussions about how designers made the choices with partial considerations of possible impacts.

This incident highlights an important challenge in performance contracting for new construction: New building construction has a high level of flexibility of selecting technologies. Many possible options and combinations of technologies and systems are open for evaluation in order to make an optimal design. How to analyze the options in enough detail at early stage to minimize future costly changes? How does the owner assess if a right performance contractor is chosen and professional choices are made among all feasible design options? These are questions that need to be answered for promoting integrated design in the construction industry.

Challenges at the managerial and institutional levels are context dependent, mostly reflecting the situation of current market. The challenges of the case categorized under the two levels might not exist in similar projects that are in other societies. For instance, how much support the local government provides for building performance improvements through policies would offer different conditions and drivers for performance contracting. Most salient example in our case would be that the availability of capable contractors having expertise of integrated project delivery in the market of China resulted in issues that are provided with a great number of best practices from the project management handbook and studies specifically focusing on integrated, relational collaboration (Hellmund et al. 2008, Smith et al. 2011, Morris et al. 2012).

Literature shows that some solutions already exist but they might require some adoption and adaptation processes before they could be feasibly used in the market of the project. Similarly, aforementioned literature of performance contracting provides theories and practices regarding financial model and incentive/penalty mechanisms. Although the literature references are mostly for retrofit projects and only focuses on energy performance, they inform us it is important to address the capital flow and to work with the financial industry and government in order to develop innovative financial products or motivating policies.

However, implementing solutions for challenges at the institutional level and managerial level require enabling factors to be in place. For instance, successful project delivery for complex, sustainable, integrated projects require professional and capable project teams, collaborative practices, business models that focus on long-term development and value human-centered design, and supportive policies. These factors drive companies (both the owner and performance contractors) willing to tackle the challenge of balancing human comfort and energy efficiency and develop capabilities accordingly.

While project participants had a relatively consistent view regarding the timescale for resolving the challenges, they had highly diverse view about who should lead. As with all knowledge-intensive endeavors such as tackling climate change or human disease, collaboration of multiple actors is needed for generating and improving solutions from scientific, technical and market innovation (Padgett and Powell 2012, Ferraro et al. 2015). This result from our survey could indicate that that any one among the government, private companies and/or research institutes has the potential to lead. More importantly, an integrator role needs to be in place to integrate these individual solutions into integrated systems and manage the complexity. What capabilities this would require is worthy of further research.

CONCLUSIONS AND IMPLICATIONS

Our three-year longitudinal, single-case study in Shanghai is one of the first study of action research in the area of performance contracting. It identifies major challenges, their relationships, and the path to developing solutions. The building is relatively small in scale and is in a market having no experience nor knowledge about performance contracting for new construction. All participants decided to use value-based performance goals instead of single purpose, energy-saving targets and were driven by experimenting and learning rather than incentives and penalties. This created a more collaborative relationship between the owner and performance contractor but the context and team dynamics might not be representative for those of typical performance contracting.

However, our case is uniquely set up as an experimental project aiming at developing solutions that are generalizable. The project team has been working side by side with researchers and consultants to examine issues and develop solutions for issues over the three years. Therefore, this case provides novel knowledge by unpacking the complexity of performance contracting for new construction. Some solutions such as the Guaranteed Energy Modeling (GEM), a methodology of developing an energy simulation model for predicting energy performance of meeting indoor comfort targets required in new construction with a reasonable level of accuracy, will be published elsewhere.

We have applied Morris' three levels of project management framework to categorize the 18 challenges of performance contracting for new construction and discussed how potential solutions and their implementation would vary due to their differences in their nature. We have mapped out the inter-relationship of all challenges during the planning, contracting, design and construction, and operation phases. By evaluating against existing literature, we have pointed out that issues related to the interactions between multiple building systems are currently most challenging but often ignored. The majority of survey respondents are optimistic about the development of this market; they expect these challenges, except the availability of capable performance contractors, to be resolved within five years. Our survey also shows that collaboration of multiple actors is needed to tackle the challenges for the market to develop. This study directly supports such collaboration by elaborating key challenges and developing a roadmap showing possible directions for initiatives. The methodology of the study, the combination of participatory observation, archival analysis and survey is relevant to the development of knowledge on the topic of interest. It presents synthesis of ideas, experience and knowledge from different project participants and is thus able to provide a holistic view of performance contracting for new construction as a collaborative approach that addresses interrelationship, multi-party interests, and trade-offs.

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