Supplementary Information for the Article:

Framework to Evaluate Quality Performance of Green Building Delivery: Construction and Operational Stage

Ayman M. Raouf and Sami G. Al-Ghamdi*

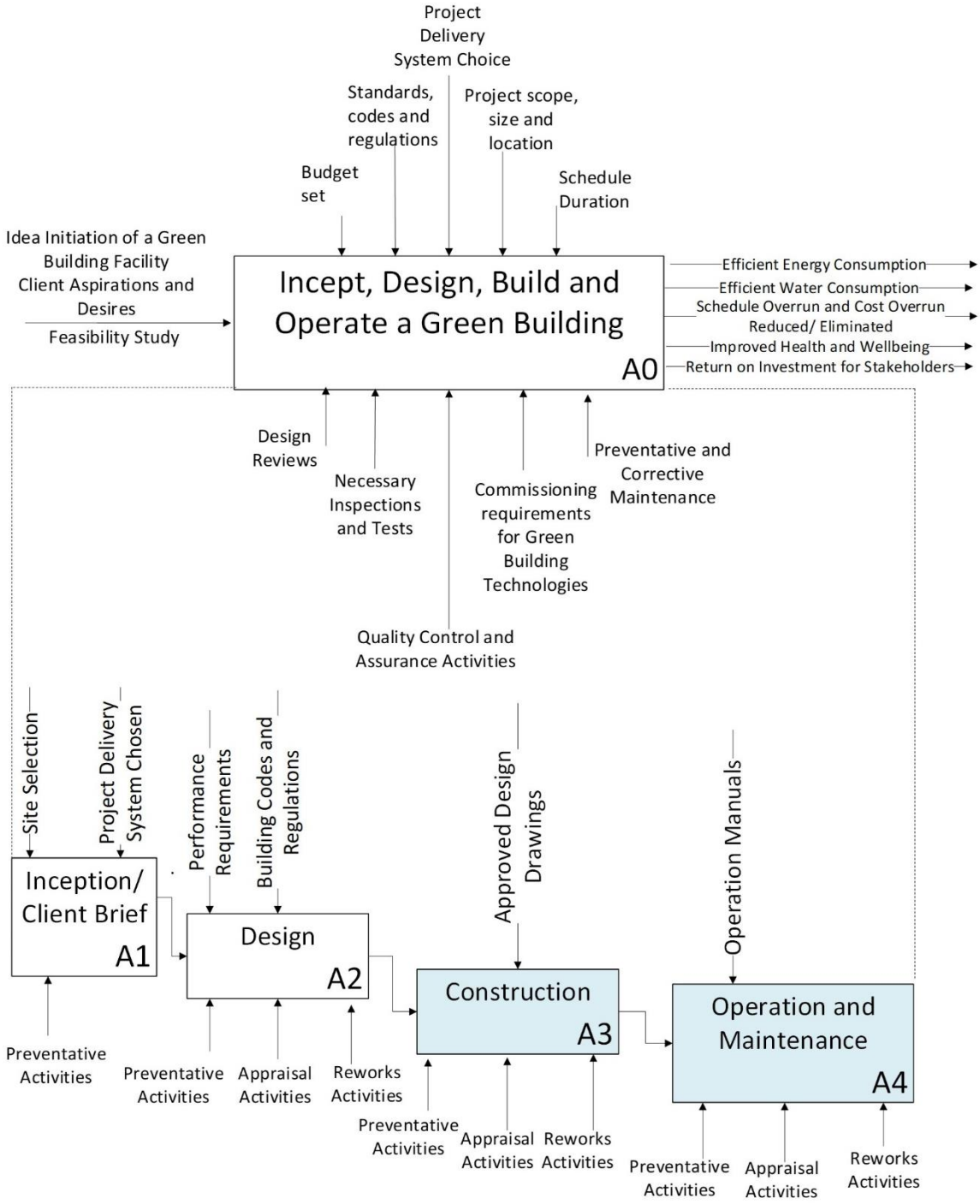
This supplementary information document reinforces the works done in the article mentioned above focusing on two sections. Section 1. Framework Details with References covers the details of the framework components including the citation sources. The Section 2 Elaborate Interview Results is an elaborate narrative of the interview participant results containing what was mentioned by the different participants. In addition, a copy of the Institutional Review Board (IRB) Letter of Approval is provided to attest that the research procedures for interacting with human matters has met the ethical requirements of the IRB. A copy of the consent form given to the participants is also provided in section 4. Interviewee Consent Form. The questions asked to the interviewers with the themes covered and purpose of the questions is also included in Section 5 Interview Questions.

* Corresponding author; Telephone: +(974) 4454 2933; Fax: +(974) 4454 0281; E-mail address: salghamdi@hbku.edu.qa

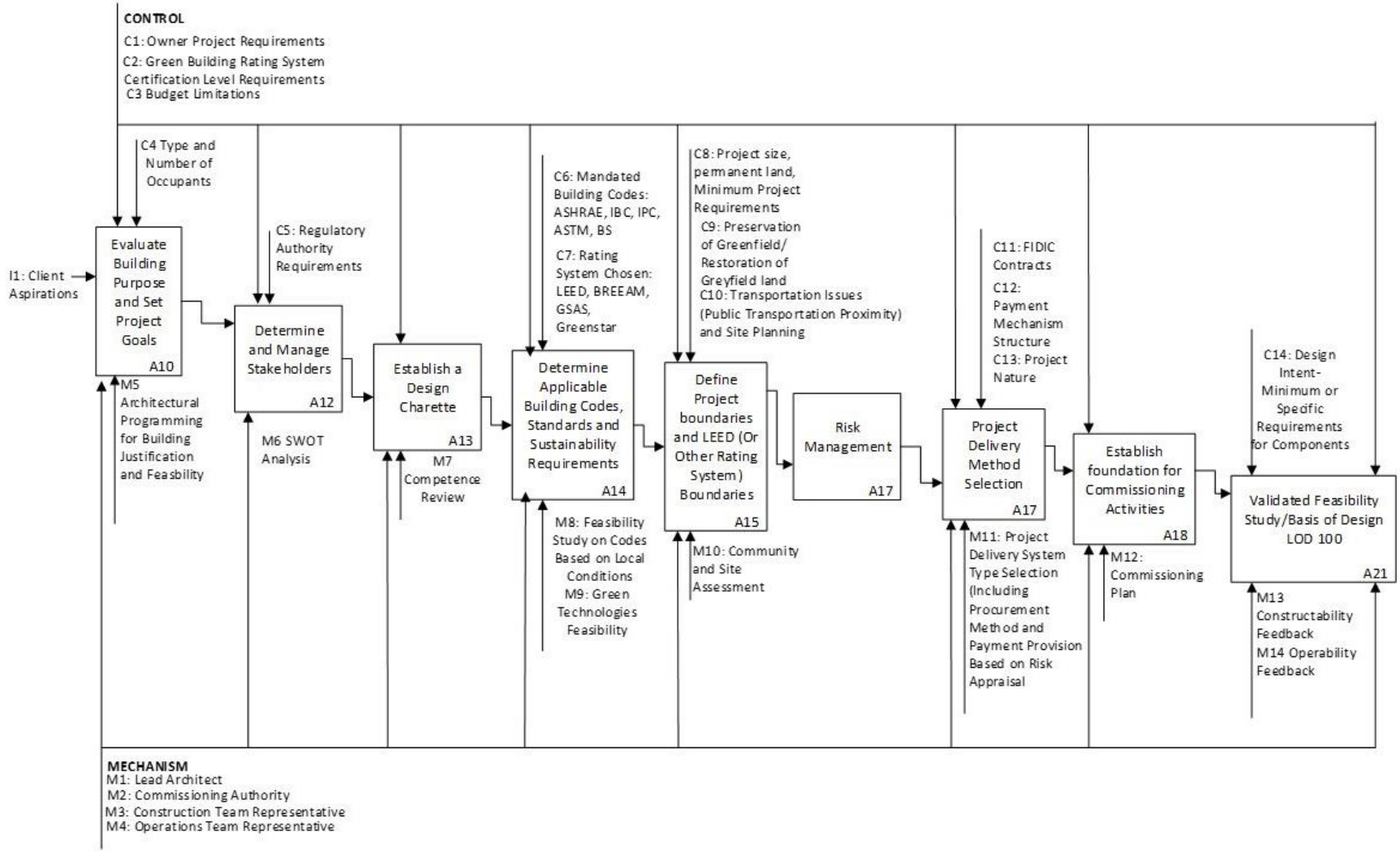
Supplementary Contents

1. Entire IFEF0 Process Model

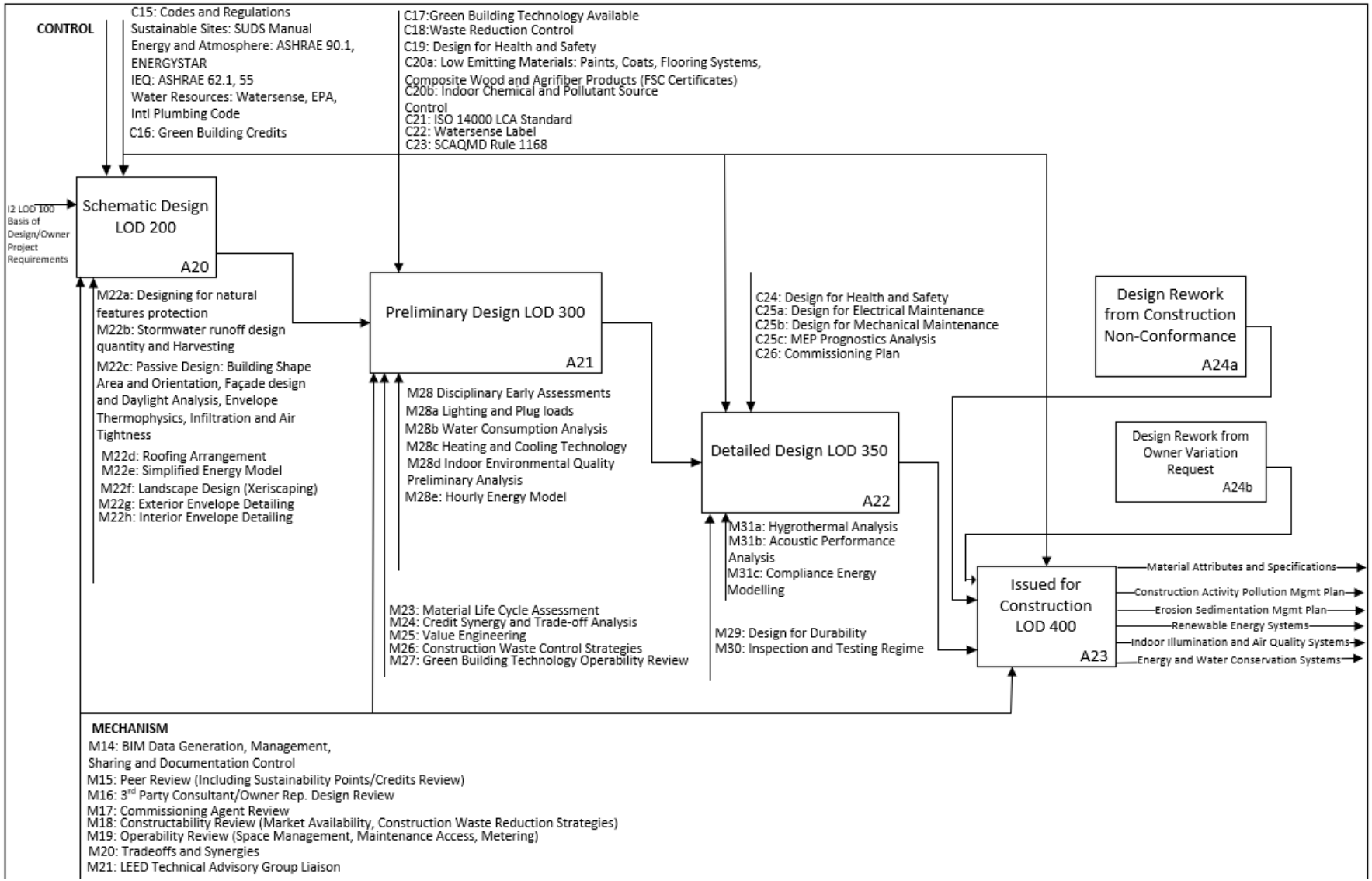
1.1 Master Node



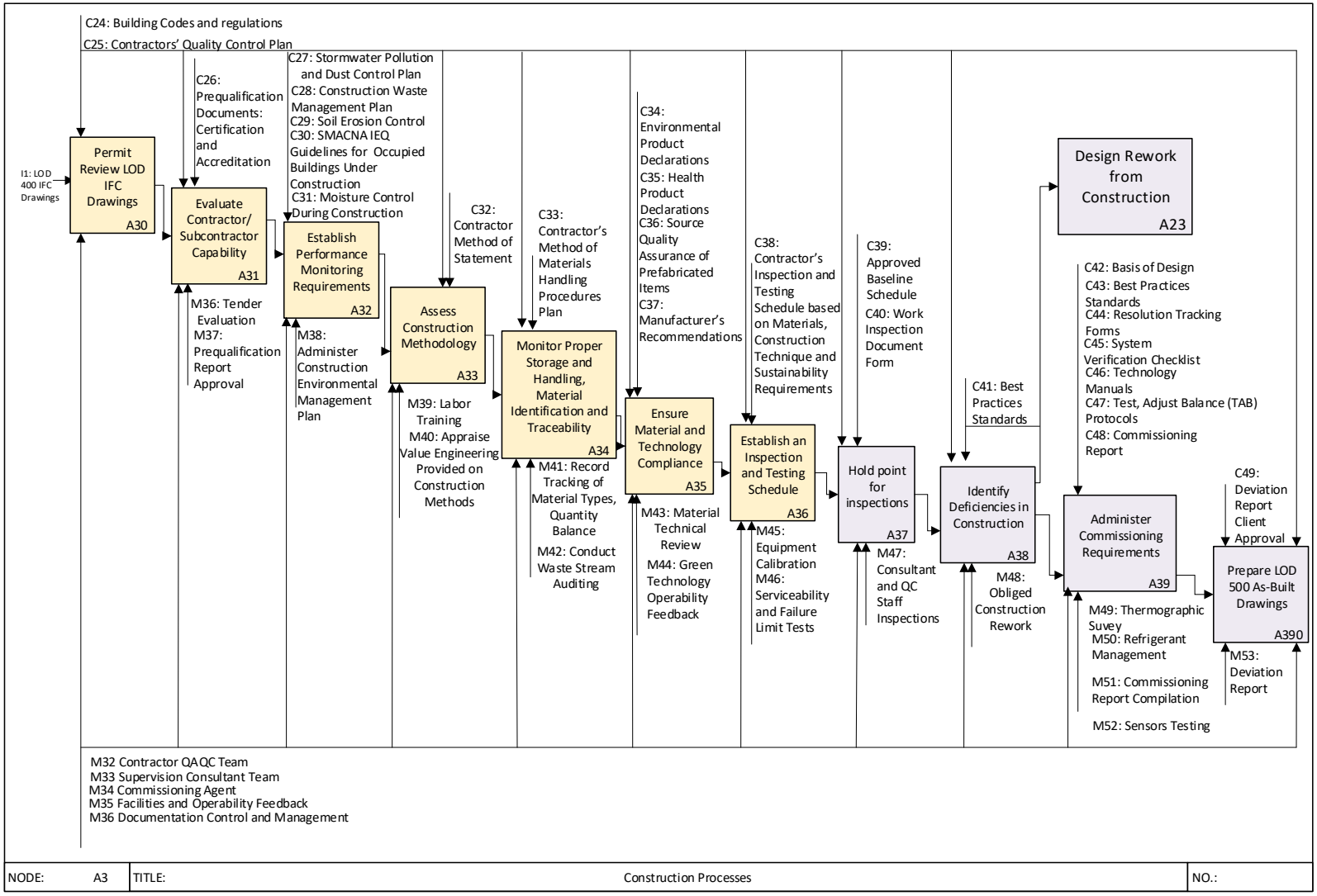
1.2 Node A1: Project Brief Node



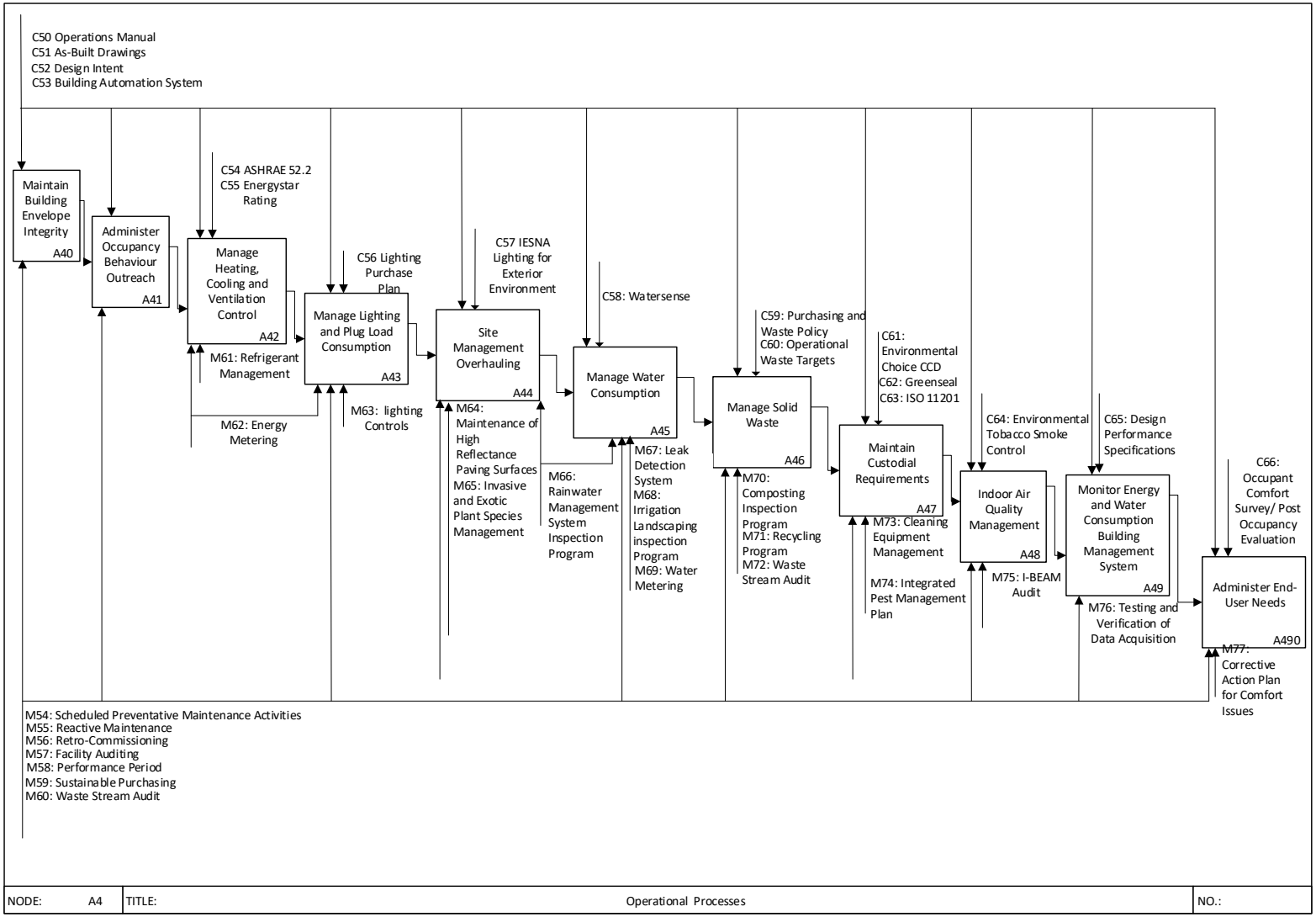
1.3 Node A2 Design Node



1.4 Node A3 Construction Node



1.5 Node A4 Operations Node



2. Framework Details with References

2.1 Node A3 Construction

Node activities A30-A36 define the pre-construction stage and A37-A390 are construction and post-construction stage. Several authors (Chan 2017; Chan 2018; Darko 2017; Hwang 2017; Love et al. 2012; Reed and Gordon 2000; Tayyab and Ajibade 2017) underpinned the need for green building technologies to complement the improved environmental and economic performance objectives of green buildings in their exploration of drivers encouraging such technologies and ways around circumventing their barriers. The multifaceted processes involved with evaluating the technologies and their interrelationship to achieve an optimized design further increases the building complexities (Tayyab and Ajibade 2017). (Tayyab and Ajibade 2017) highlighted the degree of differentiation in technological complexity for green buildings through characterizing the technologies into control systems (e.g. for HVAC, security and audio-visual control), indoor illumination systems, energy and water conservations systems, energy and water recovery systems, renewable energy systems, air quality protection systems and comfort zone temperatures control systems. Richerzhagen et al. (2008) had found that important actors (architects, developer and workers) lack the knowledge capabilities required for energy efficient technologies, which had stimulated some actors to establish training and quality management programs to improve the professionals' skills and the product quality.

Node A30: Achieve Authority Approval on LOD 400 IFC Drawings

The drawings also undergo scrutiny of the authorities to obtain permits for construction which is another review mechanism. The end-product of the design process are Construction drawings, or sometimes known as Issue for Construction drawings, which contains the details of the design after the several iterations that occur in the design process in every review stage that occurs. The 3rd party supervision consultant reviews and approves the LOD 400 IFC drawings.

Node A31: Evaluate Contractor/Subcontractor's Capability

A main contractor and subcontractors are chosen with the delegated responsibilities depending on the project delivery system chosen for the project. The contractors tendering for the project go through a prequalification review in which previous experiences, certifications and accreditations, technical and financial standing, team competences, quality control and assurance plans and commissioning plans are evaluated (ASCE 2012) (ASHRAE 2013; Kang et al. 2013).

The main contractor in Node A32 is either selected during the construction phase or is already active in the design subprocesses depending on the project delivery system followed.

Node A31: Establish Performance Monitoring Requirements

The green building consultant steers the team to establish performance monitoring requirements to measure against as the project progresses and discusses the staff, equipment and tools necessary to capture the measures. Examples include stormwater pollution, soil erosion control, construction waste management, soil erosion and sedimentation control and indoor environmental quality related measures (dust and moisture control, noise levels, thermal levels).

Construction waste monitoring includes waste stream auditing to ensure the sorting is done as per the allocated waste categorization, volume of salvaged materials retained into the construction process, ensuring the final disposal as per what was planned for in terms of reuse, recycling or special disposal for hazardous waste. Measures expected for indoor environmental quality during construction include ventilating during construction, preventing dust from accessing air handlers and ductwork through shielding, conducting air quality testing to ensure that odors and off-gases are effectively diluted with fresh air prior to occupancy (Ching and Shapiro 2014).

The constructor will have a Stormwater erosion and Sedimentation Plan that stipulates temporary and permanent measures that will be implemented in the construction phase to prevent stormwater runoff adding pollutants to the soil through temporary seeding and mulching, structural control measures (dikes, silt fences, sediment traps), stormwater management control through retention and detention ponds and low impact development techniques as well as a maintenance plan for all structures to ensure these are maintained properly (USEPA 1992).

Conventional technical requirements for quality related measures are also considered (after the project specifications were further refined following node A30) to produce checklists to check materials and construction activities against established levels of acceptability (Mahoney 2008). This also includes the commissioning testing and verification requirements for energy, indoor environmental quality and water related building components.

Node A33: Assess Construction Methodology

The construction entity provides a Method of Statement document that stipulates the procedures with descriptions of the logical sequence in executing the works (Pheng 1998). Health, safety and environmental precautions, mitigation actions and the sequencing of activities are reviewed as per the performance metrics established in

node A31 (ASCE 2012).

Node A35: Ensure Material Compliance

The team would review the materials provided by suppliers against the technical specifications set out in the project specifications and construction drawings and also determine that the materials comply with the sustainability requirements set out in the certification (LCA results attained in environmental product declaration, prioritization of materials produced in close proximity, recycled material content etc.) (USGBC 2016; Williams and Haston 1984). Prefabricated materials would also need to be quality assured prior to being brought on site with an optional surveillance from the owner (Stukhart 1989)

Node A34: Monitor Proper Storage and Handling, Material Identification and Traceability

The construction entity implements a system to identify and track the materials as well provide a suitable storage to prevent damage to the materials in site laydown area (ISO 2015). A record system will enable to analyze the amount of materials consumed and remaining to track progress of the project.

Node A36: Establish an Inspection and Testing Schedule

The inspection and testing regime established in the design stage is further revised in the construction stage with liaison of the 3rd party supervision consultant or owner representative. The frequency of testing is established in codes associated with the various building components with approval of the 3rd party supervision consultant on any deviations. An inspection and testing schedule incorporated into the construction schedule produced in Node A32 to accommodate for quality control and assurance activities as part of the construction activities. Inspections and tests conducted evaluate the integrity and workmanship of the building components. The commissioning authority is also engaged in this process to embed commissioning requirements for the energy and water components for the testing and verification procedures necessary.

Node A37: Hold Point for Inspections

As construction proceeds, the quality control and assurance team administer hold points to seize the work for the 3rd party supervision consultant to appraise the works against the approved LOD 400 construction drawings (ISO 2015). Any detection of deficiencies will seize the construction procedure until it is rectified.

Node A38: Identify Deficiencies in Construction and Sustainability Requirements

Non-conformances of the constructor revealed during the hold point or may have not been noticed during the hold point are captured and documented for rectification. This results to rework to be classified as abortive if the previous work was not compliant (ISO 2015). Rectification procedure reported first before commencing the works in a Corrective Action Plan with a budget set to execute the repairs. Situation can also be rectified through design rework to modify the design to be more practical with the construction conditions.

Node A39 Conduct Commissioning Activities during Handover Period

The commissioning agent will work with the team to appraise the building complies with the Design Intent Documents and administer that the project snag list items are completed. Green building technologies are checked against the Systems Manuals to verify the performances match to the Design Intent and project specifications. Verification tests are conducted, and the results are compiled into a commissioning report document. The proposed commissioning sequence in Node A39 covers in consecutive order: building envelope and roofing system (Scott and MacPhaul 2005), HVAC, lighting, passive and active fire protection systems, electrical and plumbing fixtures and energy and water management control systems are operating fully. After functional testing is completed, the commissioning team facilitates the training of the facilities team in equipment operations and is inducted for guidance and established timelines for recommissioning the building systems (GSA 2005).

Node A300: Prepare LOD 500 As-Built Drawings

The as-built details of the building facility is then modelling into a LOD 500 BIM model to produce As-Built drawings and are cross-compare to the construction drawings for any deviations between the drawings. Such deviations are captured on a deviation report for the owner representatives or regulatory authorities to review.

1.2 Node A4 Operations

The operational phase undergoes planned preventative maintenance checks which are proactive appraisal procedures that anticipate potential failures using vibration analysis, x-rays, acoustic systems or thermographs (Sapp 2017). Potential degradation signs are caught before they manifest into consequences that can impact the building elements' physical or functional performances (Flores-Colen et al. 2010; Madureira et al. 2017).

Also, preventative maintenance through periodic inspections, adjustments, lubrication and cleaning and performance testing intended to extend the service life of a building component(BS 2011; Sapp 2017). Failures also occur and require service repairs to restore the building components or make them more efficient through reactive maintenance. Part of the appraisal process in when previous commissioning was not done is retro-

commissioning (RCx) where a third party commissioning agent appraises the building components in complying with their design intent specifications through calibration of control system instrumentation, optimizing HVAC performances (through resetting air temperature set points, duct static pressures, air balance checks, thermostats calibration). The commissioning agent determines how the systems are designed to operate, measures their operational metrics and prioritizes a list of opportunities for improved performance (Kubba 2017).

Node A40 Maintain Building Envelope Integrity

Aggressive environments (such as humidity, extreme temperatures, salts), internal building loads and stresses as well as external insects and birds can impact the building envelope in the form of cracks, stains and fastening defects (Flores-Colen et al. 2010; Madureira et al. 2017). Consequences can result to moisture and air entrance that can cause bacteria and mold growth and intrusions permitting insect pests to enter. Regular inspections are done to maintain façade integrity to report any abnormalities and continuous cleaning of facades and protective repainting depending on the construction team's recommendations.

Node A41 Administer Occupancy Behavior Outreach

The interaction of occupants with the built environment may be inconsistent with the design intent of the building especially in terms of thermal comfort, energy and water consumption and operational waste (Geng et al. 2019). Occupants' empowerment to control of operable windows, window shading devices, thermostat levels can attribute to performance measures that designers overlooked (Schwieker et al. 2018). Occupants with consciousness towards sustainability are more forbearing to conditions that are not as ideal for indoor environmental quality and can compromise for the ultimate needs of sustainability (Deuble and de Dear 2012). Therefore, an effective outreach program that raising awareness on their impacts on energy and water usage and engages them into actions that can be done to enhance performances and a proper system in place for feedback to management.

Node A42 Manage Heating, Cooling and Ventilation Control Systems

HVAC system is frequently checked by the team for any noise issues, omittance of ozone-depleting chemicals used in the system, upholding the induced positive pressurization levels attained by the HVAC system to prevent infiltrations through cracks and apertures (Odom and DuBose 2000). Retro-commissioning is undertaken to check that the air system flow rates match the loading requirements of the designs through a process known as testing, adjusting and balancing (TAB) (USEPA 2008). In addition, to ensure effective heat transfer and reduce pressure

losses, the surfaces and filters are periodically cleaned through compressed air or dust removers for air-type equipment and water treatment and filtration for water-type equipment (USEPA 2008). Refrigerant management is done either through complete elimination or by closely monitoring that the refrigerants do not exceed a certain threshold (USGBC 2018).

Node A43 Manage Lighting and Plug Load Consumption

The operations team establishes the lighting levels that the entire building must follow with the lighting purchases complimenting the necessary luminary requirements. The lighting purchase plan also puts limitations on the mercury level that the lights exhibit. Team periodically checks the luminance levels for lighting efficiency as it will have an impact on the load consumption and lighting effectiveness (USEPA 2008). The motion detectors and photosensors are periodically checked for functioning. Submeters for electricity consumption and periodically checked and calibrated to provide accurate consumption measurements. Electricity consumption is checked against the baseline consumption amounts that the building is designed for. End-users are engaged into reducing plug loads through displaying data on electricity consumption (refer to Node A1).

Node A44 Site Management Overhauling

Any dilapidation of site materials, building components and interior furniture is reported periodically in a dilapidation survey and repaired to prevent further damages. The team would follow a Landscape Management plan that will handle integrated pest management strategies, erosion and sedimentation control for future potential construction. Strategies for the equipment to reduce noise and emissions associated is also implemented (USGBC 2018). Permeable surfaces are maintained to prevent clogging and allow for water infiltration for stormwater (EPA 2014). Physical and chemical characteristics of soils are appraised to ensure healthiness and allow for landscape vegetation.

Node A45 Manage Water Consumption (Including Process Water)

Periodic flow and pressure tests ensure that the plumbing fixtures and fittings comply to the flow and volume rates prescribed for the components. Auditing is done to capture building's existing water use by function area and determine water saving opportunities. Reviews are done on chemical concentrations of water in the cooling tower and finds ways to reduce the chemicals to reduce the need for using blowdown freshwater being used (Elliot 2019). For outdoor irrigation, soil moisture sensors are checked with the sprinkler system flows monitored.

Node A46 Manage Solid Waste

Purchasing and waste policy and operational waste targets are set in place. Waste stream audits for the ongoing waste and toxins are periodically executed to assess the amount of waste that could have been reused, recycled or composted during the regular building operations (USGBC 2018). Based on the evaluation, a baseline is deduced that will enable for opportunities for more sustainable practices for waste disposal. Arrangements for safe disposal of hazardous waste is implemented.

Node A47 Maintain Custodial Requirements

The team ensures that cleaning is done periodically with the janitorial staff inducted on any technologically sensitive equipment that require special cleaning procedures. The occupants and maintenance personnel's exposure to hazardous cleaning products is eliminated or reduced by choosing cleaning products that meet the Green Seal or Environmental Choice standards (USGBC 2018). Certain joint areas are culpable to water seeping through, and although are caulk sealed, there are requirements to re-maintain such vulnerable areas (Hassanain et al. 2015).

Node A48 Indoor Air Quality Management

Node A47 a further analysis for the measures taken by Node A40 for the building envelope to prevent mold and mildew growth (common to green buildings citation), Node A41 for proper ventilation and thermal comfort, Node A45 for solid waste to prevent accumulation of bacterial and viruses in the building and Node A46 to upkeep the building's sanitary integrity to prevent microbial infections or chemical exposure to occupants from hazardous cleaning products. The team in the event of diagnosing air quality problems can refer to architectural and mechanical drawings to collect information on pollutant pathways and driving forces associated to pinpoint the source causing the air quality problem (EPA 1991). Teams can undertake further diagnosis through air sampling to estimate occupants' exposure to any detrimental effects of poor air quality. An integrated pest management system is also set in place which includes sanitation procedures, physical barriers to prevent pest entry and structural maintenance for sealing cracks, and only when absolutely necessary to use pesticides but with proper ventilation control to prevent its spread into the building. (EPA 1991). The operations team administers a policy for environmental tobacco smoke control.

Node A49 Monitor Energy and Water Consumption Building Management Systems

Data acquisition systems are to be periodically calibrated and checked for providing hourly, monthly and annual energy and water consumption records. The centralized monitoring of the energy and water consumption of the building to produce real-time data as well as historical trends for any needs for energy and water consumption auditing. The sensors including thermostats, humidistats, pressure and temperature sensors are periodically calibrated for accurate measures (USEPA 2008)

Node A491 Administer End-User Needs

Addressing the needs of end-user for work orders and maintenance requests to be done in a timely manner to ensure the occupants are satisfied with the building itself. Some of the requests can cause for reactive maintenance to happen. A building performance is also evaluated after it has been occupied for several years through a Post Occupancy Evaluation (POE) which is a systematic process to obtain get feedback on its energy and water performance, indoor environmental quality and occupants' satisfaction (Alborz and Berardi 2015; Li et al. 2018). This has a continuous improvement benefit for the design and construction practice for the next green building project endeavor as a "lessons learnt" resource (Zimmerman and Martin 2001).

2. Elaborate Interview Results

Construction and Operations Process

For construction sustainability metrics, the participants commonly responded positively to waste management of construction and debris through dedicated coordinators that monitor segregation and conduct waste stream auditing up to the final disposal to comply with the Certificate of Final Disposal requirements. Dust control was also periodically done by contractors using TSE water contain the dust from moving vehicles. Further attainable metrics were for energy and water consumption in office buildings and in construction vehicles (through diesel consumption) and is reported and audited on a monthly basis. Indoor and outdoor environmental quality during construction however did not receive the same unanimous positive responses. P1 finds carbon dioxide and particulate matter monitoring not done by contractors because of a lack of instruments, calculators or qualified personnel to accomplish this. P13 reported that ventilation ducts are left open by contractors during construction and cause contaminations to spread across the building rooms. P9 explains the reality that construction sequencing to minimize indoor environmental quality is only thought of but is not followed because of the pressures present in the construction stage. However, P13 and P16 have made considerations for flush-out calculations to be done before and after occupancies are done and ensure the contactors meet the requirements.

Typical operational sustainability metrics such as energy, water consumption and operational waste was common by all operational participants. Process water quality in particular is measured for cooling towers which use

Treated Sewage Effluent to monitor the cycles of chemical concentration and prevent build-up of Legionella bacteria (P5 and P10). The monitoring scope between participants varied for Indoor environmental quality however with some evaluating a full spectrum of indoor gases (Volatile Organic Compounds, Particulate Matter 2.5, Carbon Monoxide and Dioxide) twice a year during peak and off-peak periods (P5, 6 and 10) whereas P7 explained it was only on done on a complaint basis. Even less frequent were the noise and light intensities (P7 and P17). P10 and P15 critiqued the metrics set in place by the green certification systems that it does consider the operational cost involved in maintaining the metrics. For example, the cost to replace LED lighting every 3 years that is not within accessible reach (high elevations or in swimming pools) is expensive to replace or in the production of electricity and potable water through renewable means is much higher than to depend on the country's networks and grids. Both participants recommended to have lifecycle cost as an operational metric to compliment the sustainability metrics.

The material approval process (in which the technical information of the material chosen is compared to the project specifications designed for) was found to be more challenging in a green building setting than a conventional project according to P9, P16 and P17. P16 explains certified wood in Qatar is more expensive and requires further documentation such as Chain of Custody numbers that after several revisions was opted out from the project. There were instances of testing facilities to validate the technical information are not readily available especially for U-values and Solar Reflective Index values. P16 bares the responsibility on the designer in specifying materials that not only attain performance but also its market availability in procurement which should be part of a constructability review. P16 states: "the designer has a responsibility in weighing down the applicability, although in principle it is fine to specify high performance, but they must assess if it is doable on site in terms of applicability and the cost to the client. Even if it is a perquisite. This is why the design process goes through several stages of concept, detailed." P9, P12 and P14 explain that material resources related green building credits can get denounced as a result of the specifications causes long lead items to be procured and also on other energy and indoor environmental quality related credits. P11 in their project of national significance appreciated this and has multiple monitoring bodies to monitor the contractors' compliance to materials even during the design stage and allowing for long lead items to be procured early on. In operations, P7, 15 and 17 confirmed that there are purchasing policies for furniture and cleaning products to comply with although P15 found the cleaning products required for green buildings were not as effective as conventional cleaning products.

Examples of potential sustainability related non-conformances happening during construction is in dewatering as reported by P1 that no lining was done for the slurry pumped from underground and left in a retention pit. Rectifying the situation led to delays to the project work. Inspecting the execution of the materials on site are also a pitfall for a contractor's nonconformance that leads to reworks when caught by the supervision consultants in particular for building envelopes such as not using aerated autoclaved concrete blocks, double-glazed glass with argon gas, e-coatings, aerated bricks. Operation-wise, P5 reported that there was a lack of refrigerant management being incorporated in the operational sustainability management plans for a fundamental reason that the chiller systems needed a refrigerant gas that although has harmful effects on the environment, but its thermodynamic efficiency was needed to achieve the required cooling loads necessary for the building. Freon gas refrigerants although are not available in the market but can still attain this but it requires an overhauling of all the condenser tubes to accommodate for the gas system when phasing out. P10 also found the current pipes are not compatible with the new recent freon gas refrigerants.

There are preventative, periodic and corrective maintenance procedures that the operational participants follow to proactively uphold the building and react to any defects that the end-users and facilities staff reports. The scheduling of the procedures is based on the manufacturers' recommendations. P5 and P6 highlighted the importance of preventative planned maintenance to prolong the accuracy of the probing devices, maintain the efficiency of MEP systems and to meet certification system credits through conducting refrigerant impact assessments and determine through periodic maintenance any leaks in the air conditioning piping. P8 is also involved with the operations team to reinstate the contractor for corrective maintenance during the Defects Liability Period.

All the operations phase participants recommended having an occupancy outreach program to promulgate sustainability information to end-users but only P6 and P17 revealed having a formal program with lectures, broadcasting with billboards and post occupancy surveys. The latter method had a mutual benefit in reinforcing sustainability principles to end-users while also obtaining information for continuous operational improvement. P15 explained how it is part of the tenancy agreement to adhere to necessary sustainability practices for waste segregation and energy and water conservation but a formal outreach system with a financial incentive to the end-users is yet to be implemented. P7's response indicates a lack of an entity taking ownership of giving out an occupancy outreach program because they find their responsibility in only providing operational data and not

engaging with the end-users directly about the data. P5 suffered from a lack of an outreach program and explains that:

"although the building was designed properly, the residents are too comfortable to their own habits with indoor temperature and water consumption control. For example, they would remove shower head aerators to have more voluminous water coming out. In addition, the strainers used in the showers for filtering the greywater were removed. The residents were less forgiving to having a slight overflow especially when removing the flow aerators. In air conditioning, the residents had access to the thermostat control to be at 21-23°C which was different from what was initially designed for".

Works Sequencing

P1, P2, P3, P12, P18 indicates that the contractor provides a Method of Statement (MoS) which declares the sequencing of works to be followed with the health, environment safety and risk concerns inherent in the work execution. A risk assessment for health, safety and environment and its impact on labor is addressed through risk mitigation measures including resequencing of works. P11 and P18 indicate that the main sequencing of works is not different from a conventional project with the only difference is incorporating in the schedule sustainability inspection requirements for air and water quality. The GSAS scores for Construction Management and it has its monitoring mechanisms. During execution there are clauses for removing dust, noise disturbance, groundwater and stormwater. P3 found that only in successful projects that the schedule sequencing included durations for inspection activities for proper green building certifications, and this depends on the knowledge and competence of the client in enforcing the schedule to be modified to contain the necessary requirements. P4 as a sustainability consultant highlights the challenge that their own independent schedule for sustainability requirement is not streamlined in their own schedule which can lead to conflicts and bypassing of sustainability related testing. P3 reveals that the flush out calculations for indoor environmental quality needed 56 days and was not complied and instead the client ended up making the flush out to 21 days and added more exhaust fans to meet the same effectiveness.

P1 and P12 explained that the scheduling is based on a construction environmental management plan (CEMP) produced before construction starts which depends on the work scope and is a live document. If there are construction risks or new construction items suddenly discovered, a new CEMP revision will reflect what is done on site. The sequencing is also influenced by the environmental impact assessment study initially done in the design and has mitigation measures formulated based on the project aspects. The aforementioned MoS gets cross-

checked against the CEMP to indicate how the work will be environmentally managed. P1 however reports that MoS does not formalize environmental concerns in the same level as health and safety and recommends more adherence to environmental requirements for a green building context. Also, P1 finds weak administration of the CEMP and perceives it as a 'Checklist documentation to attain certification".

P4 and 16 emphasize on the importance of sequencing to include inspections for insulation materials and windows to ensure the compliance of thermal resistance for the building envelope as it will have impact on the overall building energy performance. Other aspects of sequencing corroborated by P1, P12 and P14 is the sequencing for noise to reduce impact on surrounding sensitive receptors (for example schools and office buildings), dust (through weather forecasting, periodic spraying of treated sewage effluent on site and subdividing the site), and traffic management outside construction site to be more accommodating for moving equipment and materials without affecting normal traffic.

One particular activity highlighted by P12 is dewatering which needs careful sequencing as it has huge implication on the project schedule and budget which had a liaison with the design team before construction commences. The dewatering sequencing is also included in the CEMP and will depend on the nature of groundwater and its quality, foundation depth and the flowrate of the water.

Challenges of Green Building Technologies

P9 explains that the hot and humid climate in Qatar cannot depend solely on passive strategies to achieve energy and indoor environmental quality related performances and requires the conjunctive use of green building technologies to attain the necessary performances. P9 however warns against green building technologies that have not undergone committee and laboratory approvals indicating that they have been tested and tried and that it is important for the commissioning agent to review such requirements before execution.

The Building Management System (BMS) was a sensitive green building technology in which respondents P11, P13, and P16 demonstrated no lenience towards. P11 explains a case in that most of the systems were provided by a single manufacturer and even when a contractor provided a different BMS supplier with full warranties on its integrity and seamless connectivity that it was rejected by them. P13 reported on meters and submeters connected with the BMS system can suffer from short life expectancy, lack of batteries that can make up for power outages and the inability of built-in data logging. In addition, the outdoor meters were not compatible with the outside hot weather conditions.

P12 voiced a challenge in incorporating Sustainable Urban Drainage System (SUDS) technologies that are more aligned with the rainfall amounts and frequencies of temperate climates and not the arid climate of Qatar. The higher frequency of rain periods will have less contaminants accumulating in the area whereas the rare rainfall events in a desert climate has led to the environmental authorities to reject SUDS systems from the contaminants collected from roads onto the bioswales introduced. P12 explains that there should be more filters and oil interceptors embedded in the SUDS systems, but such possibilities are restricted in some cases such as parking areas.

P7 and 17 described the limitations in greywater treatment systems and rainwater harvesting systems when the building is not fully occupied to generate enough greywater or in the scarcity of rainwater received. The designers do not make correct calculations to address the system feasibility, and because of the price tag for smaller systems are expensive, designers instead opt for larger systems to cover the whole building. The tanks' filtration systems require a constant supply of water to keep them well maintained. Although there are alternatives of recirculating condensates produced from Air Handling Units into the systems, the designers are apprehensive to such innovations because such introductions are not widespread in the design practice.

P10 called out on decisions in opting for a renewable energy technology sources such as wind turbines because the feasibility study on how much is being saved for operations should not be limited to energy production but in comparing to the opportunity costs in sticking with the conventional energy sources and the associated repair and labor costs needed. Another example is in photovoltaic technologies that fall short in the storage of energy produced because the expensive batteries have a short lifetime span. Instead, P10 requires emphasis on the demand side of the energy and water consumption to be reduced before adopting supply sources. In addition, a building with a standalone Reverse Osmosis unit have a high running cost to produce $1m^3$ of water. Participant 2 corroborates this and reinforces the same idea of the high expenses in chilled water systems for each building but instead recommends having interconnectivity for a large number of buildings to connect with a particular technology.

P5 and P10 reported on the use of Treated Sewage Effluent (TSE) for cooling tower systems as a substitute for the high potable water consumed in TSE systems but there are issues of the high initial tube costs for TSE piping and the unsuitability of the TSE water parameters in containing bacteria thus making such replacement an unguaranteed technology. Instead, P10 has chosen to have a mixed TSE and potable water usage for the cooling towers.

P15 expressed a challenge from long lead items such as lighting fixtures and energy saving motors of Fan Coil Units in that their spare parts are long lead items imported from overseas and not easy to find locally. It is an issue of compatibility for the foreign Fan Coil Unit technologies and are ultimately not as effective as one would expect the motors to be. In viewing the efficacy of lighting in terms of lumens per watts, P7 finds LED less efficient compared to fluorescent lighting because the building users find the LED lighting to be dimmer leading building users to resort to normal fluorescent lighting.

Liaison between Design, Construction and Operation Teams

P3 explains that the PDS system dictates the liaison between design and construction but did not mention such for operations. For example, DB provides monitoring and feedback in design even when there is a specific green building design consultant. In other cases when projects that the design green certificate was approved and on wrong assumptions because of change of circumstances in construction, the contractor would struggle difficulties in complying with sustainability. Although DB contracts have the coordination provided between the designer and constructor according to P12 and 16, but operational coordination is difficult to achieve as the design and construction activities are happening in parallel. P10 resonated the lack of luxury to give operational feedback in district cooling technologies that were previously done and there was no mechanism set in place from the client to allow for operational feedback to the designers on necessary requirements of the operations team because of the urgency of delivering the project on time. P10 critiques the LEED Design and Construction (D+C) to be not as effective as LEED Operations and Maintenance (O+M) certification to allow for a formal operational feedback because the owner will be inclined to add technologies with high operating costs with a 24-hour active labor engagement and are not centralized to serve a cluster number of buildings. For example, a building had a wind turbine in to serve it in isolation and was not cost-effective to operate and maintain.

P14 explains the liaison done with the design team for construction waste in providing feedback for construction waste of 5% as a contingency for designers to find streams for reducing or reusing the waste in the construction practice from the materials specified in the design. Also, the construction waste that would usually get produced (e.g. cardboard material, concrete debris, glass waste) is reported to the designer to report how such materials are salvaged into factories for manufacturing form recycled materials instead of virgin raw materials. P11 as an owner representative does an extra monitoring check on the DB contractor during design through reviewing drawings and checking the materials specified comply with the performance of a 4 Star GSAS certification level.

P3, 7 and 19 had rare liaison with operations team as a sustainability consultant but appreciate the huge benefits in liaison. The facilities management by being aware on what happens in the design and construction can commence preparing a more realistic and attainable Facilities Management Plan. P7 finds that the designers do not have the efficient facility management experience to make effective spacing arrangement in the building layout that would consider aspects for waste hauling and access panel availability for maintenance. P15 views that the design team to design for LEED Gold is a difficult but attainable task and there can be an overconfidence in assuming a top level of LEED Gold being achieved. In order to reach a LEED Platinum certification, there should be involvement from the operations team for opportunities of extra points through designing for operations which happened in providing custodial and pest control related design contributions.

Efficient submetering at a higher resolution was not achieved in the project according to P7 and P16 which prevented useful comparisons against the baseline energy models to determine the energy and water performance efficiency. P17 also echoed the significance of submetering as an operational contribution in the design process because it is not a common practice for designers to efficiently design for submetering. In a precertification review, P17 modified the designs to have all the major systems for energy (air handling units, lighting, plug loads) and water (for irrigation and domestic usages) sub-metered at a higher resolution in floor wet areas to be clustered to pick up on any irregularities rather than having one submeter for the whole floor. There are examples in misinterpretations that CO_2 metering is only to be done in basements and not as per LEED requirements on floor levels holding certain occupant densities. Leak detection devices are also common to be overlooked in designs and would ultimately impact efficient control of deficiencies. Furthermore, the submeters connected to a building management automation system was specified by designers for monitoring only but not control.

From energy aspects, P17 established a common practice in design precertification to specify for cooling conservation efficiency to use variable air volume systems and variable frequency types of HVAC systems and for the designers to set an unoccupied set point temperature to be 27°C (also highlighted by P19 that designers had not incorporated this). This was based on previous auditing experience that air conditioning temperatures were set at 23°C throughout the 24-hour duration even when the building is unoccupied because of high humidity and pressurization conditions. P17 also stipulates modulating the air handling unit capacities through installing CO_2 sensors to optimize for the volume of occupants inside the building. In addition, lighting control management systems would have additional photocells and light dimming controls in glazed areas where daylighting becomes prevalent and to regulate the artificial lighting to operate at partial capacity.

P7 and P15 voiced the need to liaise with design teams in providing access points for equipment maintenance to prevent designs of large ceiling heights or congested Building Management Units that disable the cleaning capabilities for the facilities. For technical requirements, safety factors for cooling did not take into consideration changes in space arrangement and in reaching areas in the building to maintain the right temperatures. P13 as part of their commissioning review in design considers the access provisions and checks for missing specifications in the designs (such as flow rates in air handling units) to help in commissioning. P13 and P15 explains that usually the Facility Management team would join during the commissioning stage at the end of construction to recognize what they are dealing with but there is limited opportunity in providing feedback compared to what would be ideal in the design stage.

P9 as a commissioning entity recognizes the interaction of the building components and reviews the design drawings in terms of the equipment sizing, location and specifications in its implications on the construction and operational stages. P9 considers commissioning holds a central role between design and operations through linking the operational requirements into the design process. In particular, the design detailing is verified in terms of the market capability in supplying particular materials for the building envelope configuration with the required tests were done by the suppliers to comply with the designers' specifications.

Commissioning and Retro-commissioning

P3 describes a requisite for commissioning to effectively assure building performance upon completion requires an independent commissioning authority to be free from the supervision team and contractor and report directly to the owner. Ideally the commissioning authority to commence from the beginning of the project to finetune the owner's project requirements (OPR) because P3 finds such requirements usually contradicting and not cost feasible (for example owner requires fresh air increase and reduced energy efficiency). In addition, the commissioning authority that formulated the OPR would have a strong basis to reinforce such requirements throughout the project lifecycle by providing construction checklists, conducting verification checks on the MEP systems and checking the material submittals against the Basis of Design (BOD) and OPR. P18 voiced a dissatisfaction in the commissioning process happening in that an independent 3rd party was hired only in the end of construction which was compensated through in-house commissioning to cut down cost and only satisfy the paperwork necessary for commissioning credits.

P13 in preconstruction explains that a commissioning plan is finally articulated that contains all the systems with a high-level checklist to ensure compliance of installation and performance. Other suppliers' checklists are also

verified to ensure all the commissioning test points are captured. P16 as a certification consultant provides feedback to the contractor in how to prepare for the commissioning authority expectations in preconstruction and stipulates the commissioning plans and continues in gathering the reports throughout the construction lifecycle. In addition, P8 and P13 review the construction drawings to pick up discrepancies in construction drawings that were overlooked by the designer or contractor that the commissioning agent discovers from their commissionability and operability focus. A particular example is the integration of the metering devices and Extra Low Voltage (ELV) systems with a centralized Building Management System (BMS). P11 recommends commissioning agents to take extra caution from contractors providing multiple manufacturers for metering and ELV systems and to instead depend on one manufacturing supplier to ensure a seamless integration. Also, when commissioning large building facilities that are divided into zones or phases, P11 finds that the commissioning procedures done per zones would not match up to testing performance of a large building facility operated as a whole and major problems are discovered through the centralized BMS system. This includes operational pressures of hot and water systems and continuity of electronic systems.

P8 and P9 highlights the lack of early engagement of the commissioning authority can lead to severe consequences of abortive works in the execution because the sustainability performance requirements discovered may not match the specifications. Examples include the temperature levels of air conditioning that lead to reopening the ceilings and replace the ducts to appropriate sizes or in the fans positioning for fan coil units. P8 explains that there are instances where the faults are deliberate, and the contractor tried to hide such discrepancies. P8 also provides critique to the client before initiating a variation order for redesigning the space arrangement and ceiling space of the building in terms of its implications on machinery and mechanical units on the building performance. P8 and P16's role was limited only till the end of the Defects Liability Period in detecting any corrective maintenance that the contractor needs to comply to.

P9, 13 and 18 explained that the commissioning scope is only limited to the energy, water and indoor environmental quality aspects of the building in the electrical and mechanical scope (air conditioning, ventilation circulation, pressurization and air balancing), lighting performance, flow rate of water fixtures, water filtration accuracy for greywater and stormwater systems) but not as pronounced for the architectural scope that covers more effectively for passive design strategies (apart from U-values of building envelope components). For example, P13 had never done commissioning of the building envelope which a more critical component for the overall building energy and IEQ performances. P1 explains that there is no involvement of the commissioning

authority with the environmental team even for credits related to site requirements, although the environmental tam monitors and checks the machinery emissions during construction once every six months.

In operations, P10 signifies the value of commissioning because after construction there will always be misalignments or system challenges that do not comply with performances. As a result, the life expectancy of the building components gets reduced. P10 finds effective commissioning would surmount additional costs from happening in the future through an extended life period for the building components. P5, P15 and P17 explain that retro-commissioning to reap such extended life benefits were non-existent in the project. However, P15 compensates in following the manufacturers' recommendations in the operations manuals and the corrective works done. Retro-commissioning through an independent 3rd party was only done if there was a fundamental change in the building system through space management, duct size changing or refrigerant types. P5 and P6 blame the common lack of retro-commissioning present because of the certification system the client opted for (LEED D+C instead of LEED O+M) which led to lesser attention for long term quality assurance activities that are more effective for sustainability requirements. P6 in their LEED O+M certification had test reports from retro-commissioning that were compared to the reports of the start-up commissioning and were able to find faults that were easy to repair.

Labor Quality

In construction, there were mixed responses in affirming the importance of labor quality in executing works for sustainability requirements. P11 explains that there was a mechanism for choosing building components that did not require a unique labor skillset and the installation procedure is the same as a conventional building project. P2, P13 and 16 however acknowledges a huge challenge in labor competence for the workmanship expectations faced and that there is a language barrier with expatriate labor to convey the sustainability information and in particular for waste segregation requirements. P16 states "The labor come from impoverished places and only have their strengths therefore are unreliable for sustainability expectations." For installing green building technologies, P9 and 16 explain that there are specialist subcontractors who have teams competent to cover this in a supply-and-apply contract and are obliged to fulfil because of the warranty agreements. P4 and 14 encourage educational programs to be done as part of the labor induction for housekeeping and waste control as well as convey that sustainability requirements are part of their core work rather than an auxiliary. P18 states that even with awareness plans being declared but there needs to be monitoring in of such awareness plans in implementation because there are still workmanship issues.

From an operational perspective, P5 and P10 expressed the difficulty in finding a single facility management entity with a dedicated multitasked manpower to cover for all the operations features and also difficulty in attaining a budget for a specialist operator to do regular maintenance on a particular green technology. Certain green building technologies have greater sophistications and requesting for specialized labor will lead to a greater operations and maintenance costs for the labor. P19's expectations on a trained labor is one that understands the requirements for energy and water performance to help the engineers conduct their performance measures and avoid deficiencies. P5, 10, 17 and 19 believes the current Qatari labor market is not ready for green buildings in operations because of the scarcity of skilled labor and the high labor costs for operating such green building technologies and this needs to be addressed by the designers. P7 as a total facility management contractor states resistance in opening a new business arena of repairing green building technologies unless there is a larger market demand, which is unlikely to gain traction unless such technologies offer convincing superior performance. P7 states "you do not want to go and spend a lot of money on a cutting edge green building technology when you are isolated from the ability to maintain that effectively because it will become too tempting for the owner to say it will cost too much to maintain and operate so it is best to remove it". P7 and 17 find the labor's level of knowledge in facilities is also lacking and can compromise the operational sustainability objectives. Examples given were in the total light management system that already had photosensors and dimmers, but the facility labor switched off the automatic system and kept it on manual. In addition, a lack of proper training in operating the building management systems and unawareness of the operators on idle energy and water meters. P15 however does not find the need for skilled labor as long as their supervisors and managers to understand the interfacing with the technology. The labor only needs to follow their instructions for facilities requirements.

Project Delivery Systems Suitability in Achieving Quality for Green Building

Participant 2 preferred DBB because the contract given to the building contractor is more thorough in providing the material specification requirements, the recommendations of the contractor in the project specification as well as the performance level. For example, the contractor is given a "Preferred Vendor's List' which means that the designer has given more forethought when specifying the materials and from which vendor that the material is available from. Therefore, when the contractor has been successfully selected, the material submittal would be already expected to comply. DB however does not have the same case and the contractor as a designer specifies his own materials based on what is found suitable. P16 however finds that the DB arrangement has more flexibility in the avenue of a direct meeting with the designer to readjust the specifications to fit the market availability. P12 however states that quality in delivery is irrespective of the PDS system as long as the contract is written

effectively and not leave out any ambiguity. The perception of opportunism in a DB contractor can also happen in a DBB setting if the contract clauses are open to interpretations. It was recommended that an inexperienced owner to hire a supervision consultant involved in the construction stage to partake in formulating the contract clauses in the project brief stage and liaise in producing the tender package after the concept design stage. P12 however does commend DBB in having several design check validations that DB lacks. P3 explains a difficulty in DBB project that it does not accommodate for circumstances when design stage had taken a prolonged period and becomes outdated from the volatile market conditions, and this in particular for MEP equipment needed to comply with performance criteria for green buildings. The economic embargo that Qatar experienced made it not possible to import the MEP equipment from neighboring countries at affordable rates. Other circumstances can be from the owner ordering a design freeze from budgetary concerns and commences after 5 years. A DB contractual arrangement would reduce the periodic gap consequences between design and construction to enable a more current design complying with the market conditions.

P13 and P16 voiced caution on the value engineering process done by DB contractors during construction at the expense of sustainability requirements and justifies this as “the same was already done in other projects”. An energy recovery ventilation (ERV) system was removed for a school because the same was done for an open-door sports venue and was red-flagged by the sustainability consultant in doing the calculations and finding the ERV a necessity to achieve the sustainability credits. DB contractors after being contracted in a lumpsum manner are cost driven and are ready to prioritize descoping sustainability related traits for a project and convince the owner that is prioritizing on-time delivery to accept it when there are long term repercussions of such value engineering decisions. P13 prefers DBB to have the value engineering exercise incorporated in the design stage so that the judgements are not affected by the pressures from the construction stage. P13 explained that cost-cutting at the guise of value engineering was done on building envelopes and it was difficult to convince the building owner to reconsider the decision from the implications on the HVAC performance in the long run.

P16 expressed that only a case-by-case basis that the DB contractors may be overconfident in the construction execution and can bypass hold points for inspection in the construction sequence with the supervision teams because of the time pressure circumstances. P11 corroborated this and found DB more prone to abortive works especially as the contractor executes the civil works without fully designing the MEP works. P2 and P3 however states that respecting the hold points depends on the professionalism of the contractor and their ability to gain the trust of the supervision consultant irrespective of the PDS set up.

In operations, P17 noticed a quality difference and favored DBB for workmanship in the execution but DB in the quality of the solutions for sustainability in terms of creativity and innovations. The issue faced with DB is the cost cutting through value engineering especially if the DB contractor is engaged in schematic design. P12 however in championing DB contracts finds no gain if the contractor commences in the later design stages because the design solutions have already been formulated. P7 and 15 were unable to tell the difference between DB and DBB delivery as it is not part of the operational periphery to consider how the project was procured, which indicates the lack of facility management involvement in the project inception. For contracting post-construction expansions for buildings and facilities, P5, 6 and 10 explain that there are fewer unknown parameters in the design and it is safer to go for a DB contract as owner representatives unless the expansion would involve a large, complex building then it is preferred to choose DBB. P9 finds the greater the integration of the PDS systems (for example Design-Build-Operate (DBO)), the more guaranteed would be the quality of the project the single entity would also be solely responsible on the operational quality and would make considerations from the design stage on how to improve the overall lifecycle quality performance. Also, the DBO contractor retains the right of their own solutions for efficient operations rather than falling in a trap of more costly requirements from the owners to comply with.

3. Institutional Review Board Letter of Approval

QBRI
معهد قطر لبحوث الطب الحيوي
Qatar Biomedical Research Institute
جامعة حمد بن خليفة
HAMAD BIN KHALIFA UNIVERSITY

Qatar Biomedical Research Institute
Institutional Review Board

June 16, 2019

Sami Al-Ghamdi
Assistant Professor
College of Science and Engineering
HBKU
Doha, Qatar

Ref.: Approval for QBRI-IRB
Review Type: Exempt Review
IRB Approval Date: June 16, 2019
IRB Expiration Date: June 16, 2020
IRB Project Number: 2019-025
Project Title: Quality Performance Framework for Design, Construction and Operations of Green Buildings.

Dear Dr. Sami Al-Ghamdi,

The QBRI Institutional Review Board (IRB) has reviewed your research proposal that was submitted for the above referenced protocol (2019-025). **It has been determined that your research proposal is eligible for exempt status and requires no further review.** This falls under the category two in MOPH guidelines, regulations and policies for research involving de-identified human subjects that includes *research the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior, unless: (i) information obtained is recorded in such a manner that human subjects can be identified; and (ii) any disclosure of the human subjects' responses outside the research could reasonably place the subjects at risk of criminal or civil liability or be damaging to the subjects' financial standing, employability, or reputation.*

Although your research proposal falls under the exempt status, the research must be conducted according to the submitted research protocol outlined in the approved proposal. Any changes/modifications to the original submitted protocol should be reported to the IRB committee for guidance and review. **Please note that any modifications to the referenced research proposal may render this approval invalid and you may need to submit a new IRB application.**

Request for a renewal, if required, should be submitted to IRB at least one month prior to the expiry date to allow the IRB sufficient time to review and approve the request. It is the sole responsibility of the investigator to ensure the timely renewal of the IRB.

Wishing you all the success in conducting your research.

Sincerely,

Dr. Khalid Al-Ali
Chairperson

QATAR BIOMEDICAL RESEARCH INSTITUTE
IRB APPROVED
APPROVAL DATE: 16 JUN 2019
EXPIRATION DATE: 16 JUN 2020

PO Box [redacted]
Doha, Qatar
Tel: +974 4454 7152
Fax: +974 4454 1770

qbri.hbku.edu.qa

4. Interviewee Consent Form

SOLICITING FOR RESEARCH INTERVIEW

Dear Participant,

The Sustainability Division of the School of Science and Engineering in Hamad bin Khalifa University is currently engaging in a research project to tackle the quality performance in delivering green buildings.

The research as part of [redacted]'s PhD study, under the supervision of [redacted], which establishes a quality management framework for the construction industry to adopt in measuring the quality performance during the Design, Construction and Operation of a green building facility.

To achieve robust findings, the research requires an interview to be conducted with a construction industry expert to attain feedback to make the framework more practical and efficient and to affirm the facts obtained from a literature collection that the researchers have conducted to achieve validity and reliability of the research outcome.

This letter is to solicit your permission to be interviewed on this subject.

The framework is presumed to enable decision makers to make more judicious judgements on the contractual approaches and the investment needed for quality performance for green buildings.

The following interview will require approximately 30 minutes to complete. There is no compensation for participating nor is there any known risks. To ensure that all information will remain confidential, please do not write your name anywhere other than signing the consent form. If you choose to participate in this study, please answer all questions to the researcher as honestly as possible.

Participation is strictly voluntary, and you may withdraw at any time. The information collected will provide useful insight regarding the green building delivery process. Please note that there are 15 other mutually exclusive participants who will be interviewed with the same questions.

Strict confidentiality will be maintained, and the research is covered with all research ethics principles and practice. The interview will be transcribed but with anonymity maintained.

At completion of research, a copy of the works will be forwarded to you for record purpose.

We count on you for the achievement of this research success.

Thanks for the anticipated support.

Yours Sincerely,

[redacted], Assistant Professor
College of Science and Engineering
Hamad bin Khalifa University
[redacted]

[redacted], PhD Candidate in Sustainable Environment
College of Science and Engineering
Hamad bin Khalifa University
[redacted]

CONSENT TO ACT AS A PARTICIPANT IN AN INTERVIEW STUDY

TITLE: Quality Performance Framework for Design, Construction and Operations of Green Buildings
PRINCIPAL INVESTIGATORS: [redacted]

SOURCE OF SUPPORT: HAMAD BIN KHALIFA UNIVERSITY – QATAR FOUNDATION

CONSENT FORM

1. Description
This study involves developing a framework to tackle the quality performance in delivering a green building project. This will involve conducting interviews with industry professionals on the design, construction and operational activities of green buildings. The interview will take 30 minutes to complete.

2. Risks
There are no risks associated with participating.

3. Right to Withdraw
I understand that I am free to withdraw from this study at any time.

4. Confidentiality & Right to Privacy
I understand that any information about me obtained from this research, including answers to the interview will be kept confidential. It has been explained to me that my identity will not be revealed in any description or publication of this research. Therefore, I consent publication for scientific and scholarly purposes.

5. Cost and Payment
I understand that there is no cost associated with participation in this study nor is there payment of any kind.

6. Signatures
Both parties: the researchers of this study as well as the participants are signing on the following:
- Researchers: As the representative of this study, researchers have clarified the purpose of this research study. All quest ions asked by the participant were answered.
- The Participant: I acknowledge that I have been informed by the undersigned of the purpose of this study, and I am aware of my right to print and retain copies of this consent. I also know that I can ask any questions to researchers at any time, either before or after the participation. I willingly agree to participate in this study.

Do you agree to participate in this study?

☐Yes. I agree and would like to take part in the interview.

☐I do not agree to participate.

Do you agree to be audio-recorded?

☐Yes. I agree to be audio-recorded.
☐No. I do not agree to be audio-recorded.

5. Interview Questions

5.1 Construction Participants

Interview Questions	Discussion Areas or Probes	Purpose
Construction methodology assessment: Sustainability aspects in sequencing? Is there any engagement of the personnel with the design phase? Through constructability/operability feedback? Please provide examples. Are well trained labour unique for a green buildings readily available? What makes a well-trained labour for a green building? Please indicate sources of complications you experience with green building technologies. In preconstruction, are there metrics established to monitor performance against? Particularly sustainability metrics? Is BIM used by the construction team? Is LOD 400 and 500 implemented in construction?	General Process.	To determine if sustainability traits has an impact in the sequencing of construction works; influence of labor on the overall construction quality, green technology challenges
In a green building setting, do you find the project more prone to a larger frequency of items in the Deviation Report Do you take measures to prevent groundwater pollution, stormwater pollution, dust or noise pollution? Do such measures end up being monitored by an external party? What procedures are followed to protect that natural habitat during construction? Soil erosion and sediment control plan: how practical is it to execute? Any external party monitoring?	Site Assessment	To find out how site assessment measures are undertaken and how to assure the site measures indicated in site plans are implemented.
Is there any energy and water performance management during construction? Energy technologies: What is the commissioning authority role in preconstruction and post construction? For instance, does the commissioning authority provide a construction checklist. Any liaison with operations team about suitability of the system installed? Or is this not part of your responsibilities? Water technologies: readily available in the market? Any liaison with operations team about suitability of the system installed? Or is this not part of your responsibilities?	Energy and Water Performance	To attain information on how energy and water performance during construction and post construction are regulated and how the commissioning authority role engages in monitoring such issues. Also on liaison that happens with the operations teams for energy and water performance.
Any IEQ measures? For example, SMACNA guidelines for occupied buildings under construction Dust control measures: how practical is it to execute? Any auditing? In the event of a potential pollution source, are there any measures taken to track potential pollutants? Any isolation procedures done? Is this examined by an external party?	Indoor Environmental Quality Measures	To determine how IEQ is monitored and controlled and how issues are resolved

Interview Questions	Discussion Areas or Probes	Purpose
Construction activity sequencing to minimize IEQ issues. Is it still prioritized when under pressure to deliver?		
Waste management-where does it start? Do you find materials being approved easier/more difficult in a green building setting? Do you follow Chain of Custodies when looking for a material to approve? Do you consider EPDs as a priority in approving materials or is it left secondary? During the construction itself, do you find any biproducts that can be reused in the construction activity?	Material Resources and Waste management	To identify how materials are selected to be procured and how sustainability traits are considered. Also, the waste management procedures and issues faced.
As an owner/contractor: do you think the PDS type impacts the quality management process? And how so? Does it affect the inspection and testing expectations or material quality etc. PDS: In your opinion, how does the PDS type influence the activities in preconstruction/post-construction/during construction? How well adhered are the hold points followed? Depending on PDS type adopted do you think? Identify any defects you have experienced because of the design phase.	Project Delivery Systems; delivery process.	To attain information on the role of project delivery systems on the quality of delivery during construction.
Reworks: sustainability related issues that has caused for reworks to occur? Variations from owner requests? Sustainability traits getting denounced, thus compromising sustainability due to construction? Which green building traits do you find most difficult to deliver?	Reworks to Rectify Discrepancies	To uncover any lessons learnt from previous defects in the construction process especially in the context of sustainability related issues. Also how such issues can compromise sustainability traits.

5.2 Operations Participants

Interview Questions	Discussion Areas or Probes	Purpose
What operational metrics are established for sustainability? How often are these audited/periodically checked? Is there any engagement of the personnel with the design phase? Through constructability/operability feedback? Please provide examples. Is there any preventative maintenance that occurs in the project? What kind of retro-commissioning activities occur? Is there an occupancy behaviour outreach programme implemented? Such that teaches building end users about sustainability practices and the certification system that the building attained? Are well trained facilities labour unique for a green buildings readily available? What makes a well-trained labour for a green building?	Operational Procedures	To determine what operational procedures are done to ensure operational quality and sustainability traits being maintained during operations. Influence of labor on operational performance.

Interview Questions	Discussion Areas or Probes	Purpose
What measures are done to uphold the building site surroundings and natural environment?	Site Assessment	To explore what operational measures are done to uphold the site surroundings and protect the natural habitat.
Are the monitoring systems frequently calibrated? Are the technologies in the long run efficient to achieve the required energy consumption levels? Is there any system in place to engage participation in demand response plans? Any modifications done to the energy systems that were different from what was earlier produced? What are the procedures for refrigerant management, if any? I.e. Refrigerant impact assessment? Any water budget reporting done? How is it audited? Any cooling towers? Do you produce a potable water analysis report? Does it get audited?	Energy and Water Performance	To find out about operational measures done for energy and water performance and any issues faced
What are the air quality measures that you follow to ensure proper IEQ is present? Cleaning products Do you follow any standard for indoor env. Quality? E.g. I-BEAM?	Indoor Environmental Quality Measures	To depict how air quality measures are implemented during operations and any issues faced
What are the waste measures done during operations to reduce waste? Any facility maintenance waste system implemented? Do you find materials being approved easier/more difficult with green buildings? Is there any purchase policy implemented for building furniture, cleaning products etc? Environmentally Preferable purchases? Cleaning products?	Material Resources	To find out on waste management procedures during operations, how materials are procured and if measures are implemented to reinforce sustainability related needs
As an owner/contractor: do you think the PDS/procurement type impacts the quality management process? And how so? Does it affect the inspection and testing expectations or material quality etc. Identify any defects you have experienced because of the design phase. Which green building technologies do you find most troublesome in the operational stage? Please indicate sources of complications you experience with green building technologies. What kind of defects do you face in operational stage that was due to poor construction?	Project Delivery Systems; Delivery Process; Green Building Technologies, Lessons Learnt	To learn whether project delivery systems have an impact on the operational phase; any lessons learnt from defects/shortcomings found in operations; challenges of green building technologies. Also to discover how construction and/or operations

6. Elaborate Focus Group Results

Research Problem Definition

The research problem with green buildings have greater technical requirements. They have baseline standards such as ASHRAE 90.1 but you have to go beyond and exceed the expectations to meet the certification requirements. What tends to happen is quality performance does not have the same level of adherence as expected. But there was a lack of a robust system to measure quality performance. As a consequence, there is one overarching consequence in green buildings is a 10-30% cost overrun for green buildings, so when clients hear about this, they become less willing to go for green building solutions. So the drive towards sustainability is being hindered. The aim of this discussion is to bridge between professionals and academics.

So let me first define what I mean by quality performance. In construction stage, I am looking at conformance. For example, do the materials conform to sustainable requirements. For example, is the indoor environmental quality at the right level in construction stage? In operations, I am looking at operational performance. Has the building envelope been maintained in the right integrity to maintain its passive design strategy you are going for. Has the building been verified properly in terms of inspection and testing done in construction and operational stage. In terms of sustainability, has the building been made to last longer as it was meant to be? So as you can see, quality performance is embedded in the sustainability requirements.

Importance of Project Delivery Systems

Now a key instrumental tool to execute a green building is in project delivery systems. There are different stakeholders involved and what dictates the contractual relationship between contractor, client and consultant is the delivery system. such as DBB, DB or CMAR. It dictates

who owns the risk and the timing of engagement between activities. So we will see in discussion how they have a different effect on the overall execution.

What is Expected from Focus Group Study

Your involvement is part of the research process. Some of you have done a questionnaire survey. We got responses from the industry in that there is a shortage of proper quality performance done on green buildings. I then did a semi structured interview with some of you and I got some results. Today I would like to showcase the results and I would like to get a discussion going on on these results. And finally, we ll be looking at the framework that I developed. Some of the comments I got were that some activities for quality performance were not done properly. One of the reasons was that there's no proper awareness of activities done for quality performance. So I did a framework-one for construction and one for operations.

Confidentiality

One of my responsibilities as a research is to ensure your identity is kept confidential. So I have here a confidentiality agreement to ensure that your name is not published in research

Discussions

"Material submittals undergo more revisions because of greater performance requirements for green building certification systems"

For example, windows with argon gases, when contractors submit a material submittal for it.

Group Response: It's not a matter of easier of difficult. It requires another level of validation. Usually since you are working as an independent consultant, we enter a point where contractor to give submittal. It comes to us to validate green building performance. So it requires another layer for approval and sometimes I will reject it even if the main consultant has accepted it. Usually our concern is the U-value. Whatever gas is in glazing in itself. Our last check is the

U-value. Some materials we approve it without reading any data about it. As long as we see the pass it requires, it no longer is related to performance. For example, recycled content of materials. As long as we find evidence of recycled content such as a letter from manufacturer, we just take a note of it.

“Rating systems have more inclusions for operations stage so you have to maintain performance in operations for example if youre going for LEED O and M. So I get responses credits get denounced as you’re going through construction and into operations”

Group Response: I agree. Quite often I’ve seen drawings with a shopping list which points will pursue. If they are going to procure materials that have high costs, they will get deprioritized and sacrificed. So you’ll get long delays for the projects and so they will pursue other points easier to obtain.

I disagree, because with high performance requirements because submissions if they are not done in a proper way as per specs, it will come as a revision. So it is expected from the contractor and consultant. We’ve already told the contractor what material to procure. It only comes at a cost. We tell contractor

Problem happens when contractor wants to introduce something else or go for same material but different country of origin. So it’s not a problem of performance requirements but in costs to adhere to quality requirements.

“Construction Environmental Management plan is not well enforced and not well integrated in method of statement. It has a safety and risk. But not well for environmental”

Yes I agree. The management plan is used as a document. They are not integrating it well for the workers over there for plan execution. Because of this we are finding a limitation on environmental performance.

"Commissioning and Retro-commissioning involves a third party agent gets involved late in the construction stage and it's a big loss from commissioning feedback. Such as BMS system"

Commissioning should start from design. In practice however, either from ignorance or cost saving measure they don't appoint a commissioning agent early in the process. They put commissioning to the contractor's scope. So the contractor looks for a commissioning agent which they think that the agent should come at the end of the process to verify the system to sign off documentation without doing the proper job. The whole practice is actually wrong and so I recommend that the commissioning agent should be hired in design stage and should be hired by the owner of the project and not the contractor.

He's there to keep the contractor honest.

The commissioning agent should early on submit a commissioning plan to the owner as he is engaged in predesign stage. The contractor would need to execute the commissioning activities as per the Basis of Design and commissioning plan and report to owner all deficiencies and requirements.

"In operations, there are complaints that there is not enough sub-metering going on at a high enough resolution to capture energy and water monitoring and I was told it was the designers' fault. Theres not enough liaison going on"

Response: I agree with that because from my experience if you have a hotel building, a designer puts an energy sub-metering and in each distribution board there's a meter. But in a green building, there is a higher resolution requirement for how much is consumed in the laundry and kitchen. So we got involved in influencing the design but its not always the case that we can influence the design. So I agree the design is not done as the operational needs.

"Long lead items take a long time to arrive and as a consequence the actual performance of a green building technology such as a greywater system is no longer functioning anymore. So there isn't enough liaison happening between operations and construction and design."

The response is neutral. We are not much involved in maintenance. In terms of lead times yes, if the design has not incorporated a design for maintenance, then this happens. Long lead times will cause parts.

If you buy a step motor and keep it present in the shelf for a long time, it's a waste of money. A lot of problems can be solved with money. So you loose out on the economic aspect in green buildings in the operational phase. So you have to buy a lot of spare parts to ensure the performance.

I recommend the designer provides a spare parts list that the contractor or operator must have for procuring. There's for example a manufacturers' recommended list. It boils down to cost and how much the owner is willing to invest in spare parts and buy the bulk now. Plus there's an issue of technology changing and it would not be efficient to buy bulk technologies now. The repair issue also depends on operations quality activity such as preventative maintenance adherence. We as construction are rest assured that the operations team has proper measures to protect green building equipment.

Usually its also part of enhanced commissioning scope for the commissioning authority to prepare manuals and preventative maintenance plan. These documents are passed on to the operations team to train on how to operate the building.

"Liaison between design, construction and operations are feasibility studies done on green building technologies. Do you go for a stand-alone system or a grid system"

We only depend on supply studies for return on investment or feasibility study. We don't do a whole building project study. We only consider system by system. Usually in projects there are no studies. But when there are studies, the manufacturers provide it and it is a marketing tool. But it needs to be done on a project by project to find out how all the systems working together.

"Green building technologies that are novel and not used in industry before has risks especially from commissioning feedback"

Participant member: Usually when you have a technology or product, the supplier is responsible for commissioning that product. Then the commissioning agent will look at how it links to other systems. Supposing a supplier brings a solar panel to a market, they are the only people that know how it functions. They bear the responsibility and they guarantee this. Then the contractor or commissioning authority will verify based on the specialist recommendations.

Another participant: there is a chance for example instead of using a standard chiller that we are using a highly efficient chiller, so for that they install it and give a warranty period. Because no one knows the practices and experiences other than the conventional systems.

Other participant member: supplier given warrantee. Special contractors are able to conduct the green building technologies and is left to specialists.

"Project Delivery Systems: Late engagement of DB contractor. They don't come in from the very beginning in schematic design and loose out on innovations"

The way it happens is the designer produces the designs for client. And the client looks for the DB contractor. So you don't have early or late engagement. Once DB contractor gets on board, they develop the concept design and evolve it in different directions. So there's a chance for innovation and making a more green project when a DB contractor is on board.

Some clients have voice that if the contractor is involved in early stages, they will take advantage of value engineering to cut down costs and reduce the creativity. So it was recommended to have them at least in the preliminary design stage to prevent loosing out on important design elements while also giving them a room for flexibility in creativity.

in Qatar, many of the recent projects are going for DB for cost saving only. The client brings in an international architect to develop an initial design that makes the building seem more expensive. Then they give it to DB contractors to bid for doing the full design under a reduced budget. So DB is a cost cutting tool and not value engineering. This is happening in many major projects.

Value engineering is maximizing performance at a lower cost, as a consequence you might lower your certification system from platinum to gold. Or gold to silver. Sometimes it happens. We get invited to a value engineering practice. Although there's no complete assessment on LEED certification. So we do a gap analysis to see what kind of list, values or credits that can be missed to get the level you need and what must be kept. And what is the most feasible solution. It can be done. If there is a green building consultant is part of the value engineering team, they can reinforce and help agree on items to not be sacrificed as these are crucial items. Other items can be talked about and drop credits if needed.

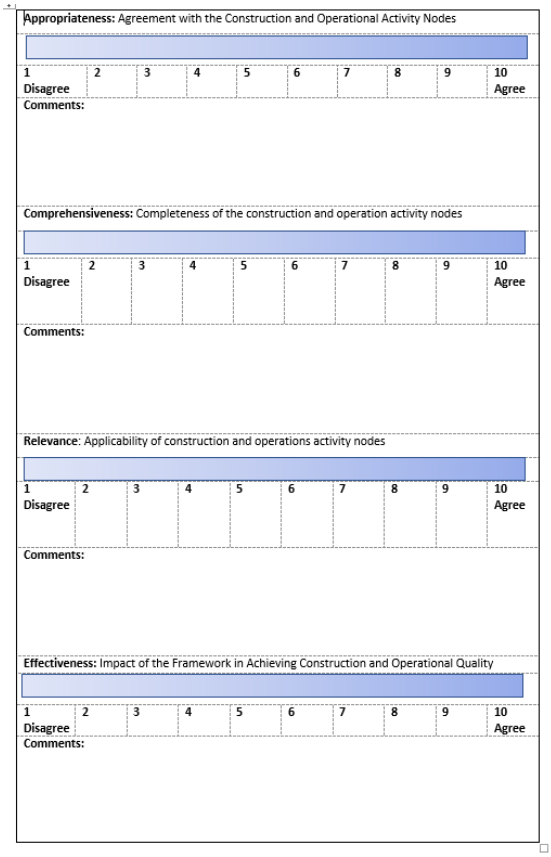
"DBB was seen to be a linear, traditional procedure that doesn't have much room for innovation but you do guarantee getting a LEED Gold level or GSAS 4 star level. But in DB you have a risk that although you do have such innovation but also have cost cutting and you may even have a reduced the certification level to be attained."

Because DBB usually the architect or consultant in the beginning is happy to showcase his innovations and ideas and give best ideas for the design regardless of the cost. He may even show cost studies that are not revealing sums in embedded items. And in construction the

contractor has to do it and it cannot be avoided. But in DB, the contractor has the consultant under their scope to eliminate certain items.

6.1 Framework Evaluation Forms

Form: Overall Framework Evaluation



6.2 Framework Evaluation Results

Overall Evaluation of Frameworks Score

	Applicability	Comprehensiveness	Relevance	Effectiveness
	8	9	7	9
	8	9	10	8
	7	8	8	3
	8	10	9	8
	9.5	8	9	9
	6	5	4	6
	7	7	7	8
	8	8	6	7
	8	8	8	9
	10	5	10	3
Upper Quartile	8	8.75	9	8.75
Lower Quartile	7.25	7.25	7	6.25
Median	8	8	8	8
Level of Agreement	**0.91**	**0.81**	**0.75**	**0.69**
Mean	**7.95**	**7.7**	**7.8**	**7**

References

Alborz, N., and Berardi, U. (2015). "A Post Occupancy Evaluation Framework For LEED Certified U.S. Higher Education Residence Halls." *Procedia Engineering*, 118, 19-27.

ASCE (2012). "Procedures for Selecting the Constructor." *Quality in the Constructed Project: A Guide for Owners, Designers and Constructions* American Society of Civil Engineers, ed.

ASCE (2012). "Quality Assurance and Quality Control." *Quality in the Constructed Project: A Guide for Owners, Designers and Constructors*, American Society of Civil Engineers.

ASHRAE (2013). "ASHRAE 202: The Commissioning Process for Buildings and Systems."

BS (2011). "BS ISO 15686-1:2011 Buildings and constructed assets — Service life planning Part 1: General principles and framework." British Standards Insitute.

Chan, A. D., Amos; Ameyaw, Ernest ; Owusu-Manu, De-Graft (2017). "Barriers Affecting the Adoption of Green Building Technologies." *Journal of Management in Engineering*, 25(3), 167-179.

Chan, A. P., Chuen; Darko, Amos; Olanipekun, Ayokunle ; Ameyaw, Ernest (2018). "Critical Barriers To Green Building Technologies Adoption In Developing Countries: The Case Of Ghana." *Journal of Cleaner Production*, 172, 1067-1079.

Ching, F. D. K., and Shapiro, I. M. (2014). *Green Building Illustrated*, Wiley, Hoboken.

Darko, A. C., Albert ; Ameyaw, Ernest Effah; He, Bao-Jie; ; Olanipekun, Ayokunle (2017). "Examining Issues Influencing Green Building Technologies Adoption: The United States Green Building Experts Perspectives." *Energy & Buildings*, 144, 320-332.

Deuble, M. P., and de Dear, R. J. (2012). "Green Occupants for Green Buildings: The Missing Link?" *Building and Environment*, 56, 21-27.

Elliot, A. (2019). "What Is Cooling Tower Bleed-Off / Blowdown?", <http://www.terlyn.com/what-is-cooling-tower-bleed-off-blowdown-2/>. (29/9/2019).

EPA (1991). *Building Air Quality: A Guide for Building Owners and Facility Managers*

EPA (2014). "Resource Manual for Building WaterSense® Labeled New Homes." US Environmental Protection Agency.

Flores-Colen, I., Brito, J. d., and Freitas, V. (2010). "Discussion of Criteria for Prioritization of Predictive Maintenance of Building Survey of 30 Experts." *Journal of Performance of Constructed Facilities*, 24(4), 337-344.

Geng, Y., Ji, W., Wang, Z., Lin, B., and Zhu, Y. (2019). "A Review of Operating Performance In Green Buildings: Energy Use, Indoor Environmental Quality and Occupant Satisfaction." *Energy and Buildings*, 183, 500-514.

GSA (2005). "The Building Commissioning Guide." US General Services Adminstration

Hassanain, M. A., Fatayer, F., and Al-Hammad, A.-M. (2015). "Design Phase Maintenance Checklist for Water Supply and Drainage Systems." *Journal of Performance of Constructed Facilities*, 29(3), 04014082.

Hwang, B.-g. S., Ming; Supaat, Nur (2017). "Green Commercial Building Projects In Singapore: Critical Risk Factors And Mitigation Measures." *Sustainable Cities and Society*, 30, 237-247.

ISO (2015). "ASQ/ANSI/ISO 9001 2015: Quality Management Systems."

Kang, Y., Kim, C., Son, H., Lee, S., and Limsawasd, C. (2013). "Comparison of Preproject Planning for Green and Conventional Buildings." *Journal of Construction Engineering and Management*, 139(11), 04013018.

Kubba, S. (2017). "Green Project Commissioning." *Handbook of Green Bulding Design and Construction LEED, BREEAM, and Green Globes*.

Li, P., Froese, T. M., and Brager, G. (2018). "Post-Occupancy Evaluation: State-Of-The-Art Analysis and State-Of-The-Practice Review." *Building and Environment*, 133, 187-202.

Love, P. E. D., Niedzweicki, M., Bullen, P. A., and Edwards, D. J. (2012). "Achieving the Green Building Council of World Leadership Rating in an Office Building in Perth." *Journal of Construction Engineering and Management*, 138(5), 652-660.

Madureira, S., Flores-Colen, I., de Brito, J., and Pereira, C. (2017). "Maintenance planning of facades in current buildings." *Construction and Building Materials*, 147, 790-802.

Mahoney, W. D. (2008). *Construction Inspection Manual*, BNI Building News, Los Angeles, CA.

Odom, D., and DuBose, G. (2000). *Commissioning Buildings in Hot, Humid Climates: Design and Construction Guidelines*, The Fairmont Press Inc., Lilburn, Georgia.

Pheng, L. (1998). *ISO 9000 and the Constructoin Industry* Chandos Publishing (Oxford) Ltd.

Reed, W., and Gordon, E. (2000). "Integrated Design and Building Process: What Research and Methodologies Are Needed?" *Building Research & Information*, 28(5-6), 325-337.

Richerzhagen, C., Von Frieling, T., Hansen, N., Minnaert, A., Netzer, N., and Russbild, J. (2008). *Energy Efficiency in Buildings in China: Policies, Barriers and Opportunities*, German Development Institute.

Sapp, D. (2017). "Facilities Operations and Maintenance-An Overview." National Institute of Building Sciences.
Schwieker, M., Carlucci, S., Anderson, R., Dong, B., and O'Brien, W. (2018). "Chapter 2 Occupancy and Occupants' Actions." *Exploring Occupant Behavior in Buildings: Methods and Challenges*

Springer Nature.
Scott, R., and MacPhaul, D. (2005). "Pioneering Building Envelope Commissioning to Prevent Moisture Intrusion."
Stukhart, G. (1989). "Construction Materials Quality Management." *Journal of Performance of Constructed Facilities*, 3(2), 100-112.
Tayyab, A., and Ajibade, A. (2017). "Project Delivery Attributes Influencing Green Building Project Outcomes: A Review And Future Research Directions." *Built Environment Project and Asset Management*, 7(5), 471-489.
USEPA (1992). "Stormwater Management for Construction Activities: Developing Pollution Prevention Plans and Best Management Practices ", EPA.
USEPA (2008). "Energy Star Building Upgrade Manual." United States Environmental Protection Agency.
USGBC (2016). *LEED reference guide for building design and construction*, United States Green Building Council, .
USGBC (2018). "LEED Building Operations and Maintenance." United States, Green Building Council
USGBC (2018). "LEED V4 for Building Operations and Maintenance." United States Green Building Council, United States
Williams, G., and Haston, J. (1984). "Construction Materials Engineer, a Perspective." *Journal of Construction Engineering and Management*, 110(3), 387-389.
Zimmerman, A., and Martin, M. (2001). "Post-occupancy evaluation: benefits and barriers." *Building Research & Information*, 29(2), 168-174.