

Article

Framework to Evaluate Quality Performance of Green Building Delivery: Project Brief and Design Stage

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Abstract: Design quality considers the extent to which the owner's requirements are accurately synthesized into conformance specifications and drawings for the construction team to execute. Expected superior performance and sustainability of a green building require diligence in design to ensure its specifications are accurately stipulated. Several studies reported mismatches between expected and actual performances in green buildings that were attributed to poor design. This study thus revisits the design process and proposes a framework to map the quality activities in the project brief and design stages using the integration definition for function modeling (IDEFO) process. Semi-structured interviews and a focus group validated the framework and revealed issues in the current design practice that cause insufficient design solutions. Additionally, project delivery systems were discussed, with conditions for improving their suitability. This research contribution elucidates recommended quality activities necessary for green buildings, which often are not implemented in the construction industry, to ultimately ensure that green buildings are properly designed to meet sustainability objectives.

Keywords: green buildings; quality performance; project delivery systems; sustainability; construction industry; design quality



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1. Introduction

Green buildings are notorious for cost and schedule overruns in meeting their superior performance objectives [1,2]. Greater foresight of potential problems that may arise in the construction and operational stages is therefore required [2–4]. Pursuing certification for a green building design requires attributes beyond the conventional purposes of a residential or commercial building. These include environmental aspects—reduction of greenhouse gas emissions through harnessing renewable energy [5], ecosystem and habitat protection, and reduction of construction and demolition waste through responsible material selection [6]; economic aspects—affordability in terms of direct and indirect costs relative to other vital needs [7]; and achievement of monetary gains from the project to benefit multiple stakeholders (clients, contractors, the public, and the government) [8]; and social aspects—enhanced health and well-being of building occupants and improved quality of living [9], and communal engagement in the decision-making process for the project [10]. Such transcendent objectives render green buildings more complex and deserving of greater rigor in the stages before construction commences. Kang, et al. [11] argued that pre-project planning, as a necessity in green buildings, has a positive relationship with cost conformance. A project commences as a project brief: a platform through which the design team can address and articulate the project requirements of the owners and thus convert the brief into a basis of design. The design stage transforms the requirements into a conceptualized model of procedures, technical specifications, and drawings, to which site construction must conform [12]. For a green building to be effectively designed and to avoid future problems in construction and operation, the designs must be code-compliant,

and the building must meet the functional expectations prescribed in the green rating systems. Measuring the extent of such conformance falls within the design quality domain.

Studies on green building design have highlighted the integrated nature of the process, and the need, relative to conventional buildings, for greater cross-disciplinary collaboration between mechanical, electrical, structural, and architectural designers. Good design allows the final result to surpass baseline standards for energy and water efficiency, use of environmentally conscious materials, handling of construction and operational waste, effective integration of the building with its natural surroundings, and cohesive public usage [13,14]. Ahmad, et al. [15] indicated that design elements should be optimized based on the evaluation of their impact and interrelationships. Without meticulously considering the design, decisions in sub-optimizing certain design elements (which may have short-term gain), can lead to negative consequences in construction execution and operational performance [16,17]. Therefore, it is essential that a green building is designed to a quality level that achieves the expectation of green certification.

1.1. Literature Review

1.1.1. Quality Performance Challenges in Green Building Design

Design quality refers to how well the requirements of the owner are processed and refined into clear conformance specifications and drawings for the construction team to implement [18,19]. This includes ensuring that the designed building is appropriate for its purpose, has a financial return value, adheres to design standards and codes, and, in the context of green buildings, meets the sustainability requirements to achieve a green certification rating [20]. Burgess [21] suggested the following important activities to assure design quality: (1) document, drawing, and specification control to ensure that specifications are up-to-date while supporting documents for design review reports, calculations, and notices are maintained in a procedural manner, (2) design verification through design analysis (calculations for specifying component dimensions and performance prediction) and review (professional reassessment of the design objectives to avoid mistakes and omissions), (3) versatile systems to handle design changes and respond to non-conformances. Bubshait et al. [18] expressed similar views and stressed the importance of communication between the design team members, stating that isolated and fragmented design processes can lead to project failures [22]. Green buildings are more sensitive to such issues than their conventional counterparts as their design entails exploring design synergies to achieve higher energy conservation and indoor environmental quality (IEQ) performance. In addition, their sophisticated technical nature requires greater diligence in design and greater exchange, in collaboration and coordination, between the design disciplines [23–25].

Osmani, et al. [26] established, through the literature, that poor design increases construction wastage. Construction waste can occur due to: design variations, as a result of owner requirements, during the construction phase; the designers' lack of construction experience, causing detailing errors; or, contractors' compensating for the lack of design details by ordering excess materials. A construction waste management plan should be implemented during the design process. This may require consultation with an independent sorting company to identify: opportunities within the locality for hauling and sorting; the intended percentage for waste to be sent to landfill; or, any material that can be salvaged [27]. Bubshait and Al-Abdulrazzak [28] highlighted other important quality control activities in the design process, including documentation and control of documents to enable reviews to be precise and accurate and to cross-link the revisions of documents to a design. Drawing and specifications control is another important aspect to ensure clarity and uniformity of design documentation.

A design philosophy known as integrated design (ID) considers a prospective building as an integrated system. During the initial project stages of the building, civil, mechanical, electrical, and lighting engineering designers are engaged with the interior and architectural teams. Further, teams from other project lifecycles are also included, such as construction and facility managers, who provide feedback on constructability and opera-

tional requirements. Issues of material selection, passive design, and massing are explored in relation to their energy impact, water consumption, indoor air quality, constructability, and durability [29,30]. Although the ID process may be theoretically established, its effectiveness and efficiency in practice, i.e., in producing powerful designs that meet green building sustainability requirements, has been contested by Leoto and Lizarralde [22]. They concluded that the collaboration needed to realize design innovations has increased tensions between stakeholders. They argued that this is a consequence of disorganized design charrettes and opposition to the involvement of owners, users, and researchers not traditionally involved in the design process, because of the time wasted explaining technical project details to non-experts with no perceived return value. Moreover, the authors argued that the transition from traditional to ID practice is not straightforward and faces resistance because designers, by nature, limit their interactions and insulate themselves from builders, users, and other project stakeholders as they view such interactions as a threat to their authority and habitual work patterns (ibid).

Green buildings are characterized by superior performance compliance that exceeds the baseline building codes that are in regular buildings. A few examples of such recognized baseline codes include American Standard for Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) 90.1 for energy performance, ASHRAE 62.1 for ventilation system design for acceptable indoor air quality, ASHRAE 55 for thermal comfort, and 1992 Energy Policy Act (EPAct) for water consumption. The exceedance requires extra design rigor and diligence to ensure that the specifications enable a performance expectation that meets the exceedance expectations.

1.1.2. Project Delivery Systems Impact on Design Quality

Mollaoglu-Korkmaz [31] investigated the impact of project delivery systems on green building project outcomes. They recognized that interdisciplinary collaboration is needed to derive solutions that meet the greater complexities faced when creating high-performance buildings. The study concluded that the Construction Management at Risk (CMAR) and Design-Build (DB) delivery methods facilitate early constructor involvement and provision of constructability feedback—essential factors for project success. The author of [32] described design constructability, a qualitative concept, that identifies “the ease with which the raw materials of the construction process (labor, production equipment and tools, and materials and installed equipment) can be brought together by a builder to complete the project in a timely and economic manner”. The complexity of green buildings, with their integrated technologies and construction methods, necessitates such constructability feedback. A constructability measure was also championed by the authors of [31], who extended it to include contractor involvement as an indicator of team integration.

In relation to performance quality, Zhang, et al. [20] saw design quality as intrinsic to final quality. They argued that additional value can be generated by innovative practices and engineering procedures introduced by a contractor with constructability experience. In a design-bid-build (DBB) delivery system, the contractor is not involved in design decisions and instead offers a lumpsum tender for the completed design work, at personal risk; as such, room for innovation may be obstructed. Gransberg and Molenaar [33] and Gransberg and Windel [34] compared the quality performance outcomes of DB and DBB based on the inherent traits of the two systems. DBB has cost as the central factor for the owner in evaluating constructors, whereas DB has the level of quality as the main competing variable within cost and scheduling constraints. DBB has an integral deliverable, based on complete design documents, for a potential builder to make a bid against and therefore has an established level of design quality well before construction commences [34]. In a DB contract, the builder is included in the final design documentation, and the competition is based on the offered level of quality. The DB contractor is challenged, within a fixed cost and schedule; this drives innovation and value engineering to maximize quality at a fixed price. A formal communication medium, between the owner and DB contractor, known as a Request for Proposal (RFP), contains information necessary to the DB contractor

in shaping a proposal: the expectations and evaluation criteria, as well as the scope of works, technical criteria, project specifications, and any preliminary design work, such as schematic designs, that the owner has performed [20,35]. The owner does not have the same influence on design quality level as in a DBB contract. The RFP stipulates the responsibilities of the DB contractor, including specific quality control responsibilities and which activities are retained by the owner. This, however, introduces greater susceptibility to opportunism and scheming in a DB contract. The contractor can, at the expense of quality and using prior knowledge, make constructability issues seem more severe to the inexperienced owner [36,37]. Zhang, et al. [20] discuss the ways that owner-provided design can impact design quality and argue that high levels of owner design input into the bidding process can undermine innovation, because this leads to prescriptive rather than performance requirements and can cause the contractor to emphasize fulfillment of the owner's design criteria rather than creating innovative performance-based solutions (a view also shared by Xia, et al. [38]). In addition, greater design changes can occur because the owner assumes a greater designer role and usually does not have the ability to forecast future conditions or appraise the design's efficiency and effectiveness in the construction phase. Akintoye [39] reported on the negative views of DB contractors who found it hard to determine client brief requirements accurately and to apportion the risks involved. An important communication tool used for clarification of design issues is called a Request for Information (RFI) [40]. The frequency of RFI use was adopted as a quality metric by [41] to compare Construction Management at Risk (CMAR) and Integrated Project Delivery (IPD) systems. Bilbo noted that IPD had lower RFI frequency because it can resolve issues through team meetings instead of requiring a formal RFI. A similar study by Choi, et al. [42] found owner satisfaction was higher under IPD than CMAR. Although CMAR had high team integration, this did not result in owner satisfaction. The study emphasized a more active role for Building Information Modeling (BIM) in IPD compared to CMAR.

1.1.3. Research Motivation and Objectives

The multiple entities engaged in a green building project (typically the owner, designer, and constructor) interact differently with one another and assume different responsibilities. Project delivery systems (PDSs) dictate these entity interactions. A systematic review of the effectiveness of such systems in green building delivery indicated that the quality of such delivery, in particular, is not addressed as thoroughly as it deserves, especially considering the higher performance expectations of green buildings [43]. This suggests that the full spectrum of quality control activities in the project brief and design are also not fully disseminated to the construction industry. In addition, it was reported that green buildings underperformed as predicted, attributing such underperformance to inaccurate or improper usage of design analysis tools; lack of integration of complex inter-connected systems; value engineering performed in late design stages and after design; deficiency in building commissioning; and incomplete understanding of operations and maintenance practices [44]. Such concurrent aspects feed into the quality performance domain in delivering green buildings.

Devising a framework process model to outline all the quality performance activities enables greater foresight of what is anticipated for quality performance and enables entities engaged in conceiving a green building to be better prepared and the risks of poor design to be reduced. Additionally, there will be greater predictability from the design stage on how the building will perform. The motivation of the work is to address quality performance research gaps and fulfill the following research objectives: (1) devise, for green buildings, an effective project brief and design quality process model that maps out the activities involved, (2) validate the framework model through a series of semi-structured interviews and a focus group with green building practitioners with different roles, (3) determine, from the responses, the shortcomings in the project brief and design process that had implications in the design development, as well as the impacts of project delivery systems on the whole process, and (4) validate the framework model through the focus group study.

2. Methodology

Figure 1 illustrates the research methodology, which is an extension from earlier research performed on the subject, as a three-stage process in Step 4: content analysis, semi-structured interviews, and focus group study.

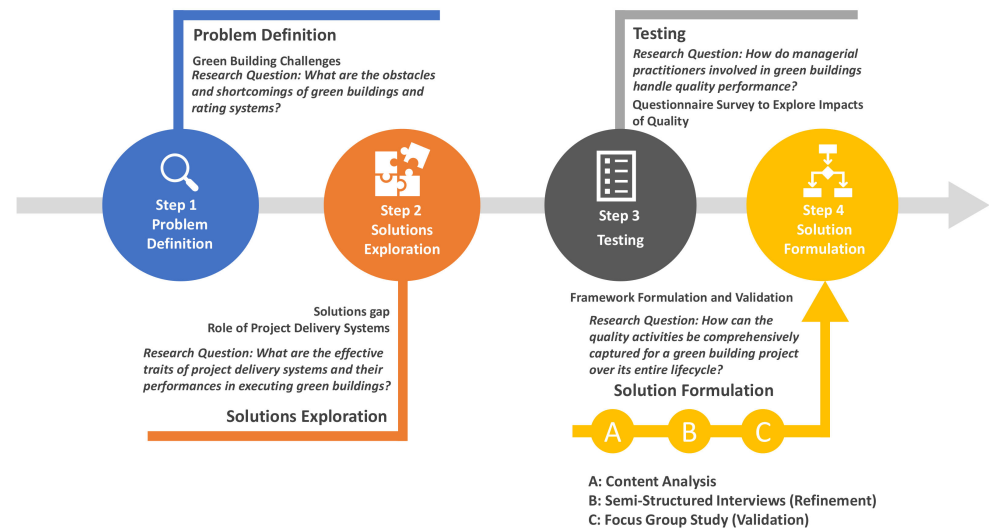


Figure 1. Research Methodology.

Step 1 involved a systematic review to collate the obstacles and challenges faced in green buildings from designs not adequately assessing the integration of multiple building component systems, deficiency in commissioning being pronounced in the design stage, and underperformance in sustainability requirements that a green building is supposed to meet. In addition, the impact of project delivery systems in successfully executing green buildings was also highlighted, and there was a research gap in studies evaluating quality performance for green building projects [43]. Furthermore, a consolidation of the research gap was realized in Step 3 from responses to a questionnaire survey given to managerial practitioners to determine whether sustainability traits of a green building can be affected by quality performance, and it was concluded that such traits are embedded in key performance indicators related to quality performance [45].

The affirmation of the need for evaluating green building quality performance led to a content analysis, in Step 4A, of peer-reviewed literature to deduce the important activities that occur in the project brief and design stages, together with the associated quality control procedures that ensure such activities are executed effectively. Several authors have used the preventative-appraisal-failure (PAF) model for conducting a cost of quality (CoQ) assessment for the construction process as a means of including all the quality control activities [46–48]. Preventative actions are those that proactively ensure that the quality sought is achieved. Such actions should be neither costly nor cumbersome and should prevent expensive non-conformities. Appraisal costs are related to any measures that gauge or audit products to determine their conformance to requirements, or that assess the effectiveness of preventative actions. In a case of non-conformance in quality, reworks involve bringing a product back up to the required quality level after a failed appraisal. This may be either internal failure (defects found before being handed over to the end-user) or external failure (defects occurring after being handed over to the end-user) [47]. The PAF model works on the premise that investments in prevention and appraisal activities reduce the burden of rework activities, and concurrently, investment in prevention activities reduces appraisal costs.

Using the PAF model as a basis, the framework was developed using the Industry Process Method (IDEFO) to map out the pertinent processes in the project brief and design stages (as shown in Figure 2). IDEFO was particularly suitable, allowing aggregation

of each of the activities while maintaining the intricacies of each process. Functions are represented by boxes that have both a name and a number. Material or information flows are represented as arcs. Flows to and from the functions represent either inputs (from the left), controls (from the top), outputs (to the right), or mechanisms (from the bottom). Previous studies in the construction industry have also used the IDEF0 model in their proposed frameworks [49–51].

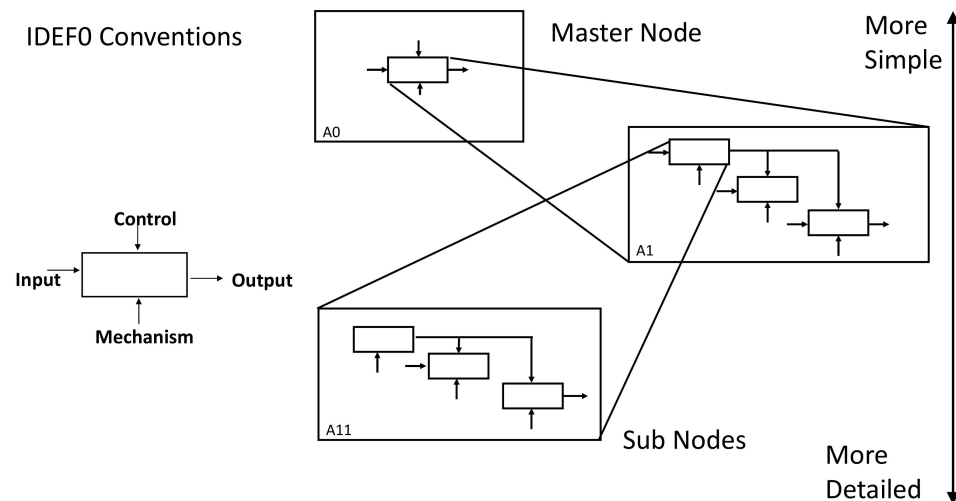


Figure 2. IDEF Model Conventions.

Stage 4B enabled refinement of the framework model to be more attuned to the current design practice and inclusion of ideal practices that the current practice is not fulfilling through a semi-structured interview method. The method was chosen to gain more thorough insights into the procedures and issues faced with quality control activities during a green building design. As part of adhering to research ethics in investigating human subjects, an application was submitted to the institutional review board (IRB) to ensure that the interview questions complied with the local codes of conduct and ethics, as well as ensuring that the interviewer profiles and companies remained confidential. A pre-designed set of open-ended questions, as approved by the IRB, was used to capture qualitative responses, based on participant experiences, about the project brief and design processes, about compliance with sustainability requirements, and about project delivery systems and their impact on quality. This technique, to gain in-depth understanding of a topic, is common in construction management studies [52–55]. The final step, 4C, was to convey statements from the semi-structured interviews to a focus group to verify the results. A mediator was assigned for the group discussion and would encourage participants to share ideas and express their views to statements made in a permissive, non-judgmental environment [56]. An invitation was sent to 12 participants involved in green building project briefs and design teams, from which five accepted to attend. The statements made to stimulate discussion were about project brief and design processes, how the sustainability traits to pursue are chosen, the integrative design process, planning for inspection, testing and commissioning, and project delivery systems.

The selected participants for the semi-structured interview satisfied the criteria of experience of more than 10 years working with green and conventional buildings, current or recent involvement in a green building project, a green accreditation, i.e., Leadership in Energy and Environmental Design (LEED) associate professional or Global Sustainability Assessment System (GSAS) certified green professional (CGP), and sound knowledge and understanding of PDSs (determined from the introductory questions during the interview). The suitable participants, representing diverse entities and green building project types, were selected using purposive sampling through the local green building council based in Qatar. The participants predominantly worked in projects seeking certifications under

international green building rating systems such as LEED and GSAS. In total, 18 persons were interviewed (five from the project brief and 13 from the design stages). The profiles of the participants are summarized in Table 1. Each interview lasted between 40 min and 90 min and was conducted face-to-face. Content analysis was then used to derive meaning from the interviews, identify commonalities and differences within the information that the participants provided, and determine potential reasons for such differences [57]. The number of participants involved was commensurate with other studies in the construction management field that used semi-structured interviews and focus group studies [52,53,58].

Table 1. Participant Profiles.

No.	Title	Green Accreditation	Experience Level	Entity Representing	Stage	Project Type	Certification Level	Participation
1	Project Manager	LEED AP	25+	CM Agency	Design	Educational	LEED Gold	Interview
2	MEP Engineer	LEED AP	25+	Owner Representative	Design	Educational	LEED Gold	Interview and Focus Group
3	Sustainability Manager	LEED AP and GSAS	15	CM Agency	Project Brief	Sports	LEED Gold	Interview
4	Design Manager	GSAS	25+	Owner Rep	Design	Sports	LEED Gold	Interview
5	Design Manager	GSAS	10	Owner Representative	Project Brief	Educational	GSAS 4 Star	Interview
6	Sr Architect	GSAS	25+	Owner Representative	Project Brief	Educational	GSAS 4 Star	Interview
7	Sr Architect	GSAS	25+	Owner Representative	Project Brief	Historical Restoration	GSAS 2 Star	Interview
8	Sustainability Manager	LEED AP, GSAS, WELL AP	15	Design Consultant	Design	Religious Facility	LEED Gold	Interview
9	Senior Architect	LEED AP and GSAS	10	Design Consultant	Design	Educational	LEED Gold	Interview
10	Sustainability Consultant	LEED AP	20	GSAS Consultant	Design	Sports	GSAS 4 Star	Interview
11	Sustainability Manager	GSAS	20	DB Contractor	Design	Sports	GSAS 4 Star	Interview
12	Sustainability Manager	GSAS	10	DB Contractor	Design	Sports	GSAS 4 Star	Interview
13	Sustainability Consultant	LEED AP, GSAS CGP, CEEQUAL	15	Sustainability Consultancy	Design	Sports	GSAS 4 Star	Interview
14	Sustainability Consultant	LEED AP and GSAS CGP	10	Sustainability Consultant	Design	Sports	GSAS 4 Star	Interview
15	Design Manager	LEED AP	25+	DB Contractor	Project Brief	Sports	GSAS 4 Star	Interview
16	Sr Architect	LEED AP	20+	Design Consultant	Design	Educational	LEED Gold	Interview
17	Commissioning Manager	LEED AP	15	Owner Representative	Design	Educational	LEED Gold	Interview and Focus Group
18	Commissioning Manager	LEED AP	20	CM Agency	Design	Sports	LEED Gold	Interview
19	Construction Manager	LEED AP	15	Design Consultancy	Design	Commercial	GSAS 4 Star	Focus Group
20	Sustainability Consultant	LEED AP	15	Sustainability Consultancy	Design	Sports	GSAS 4 Star	Focus Group
21	Sustainability Consultant	GSAS CGP	20	Sustainability Consultancy	Design	Sports	GSAS 4 Star	Focus Group

Finally, stage 4C involved using the same focus group to evaluate the appropriateness, comprehensiveness, relevance, and effectiveness of the framework in tackling quality performance for a green building using the method by [49]. Equation (1) below shows how the degree of agreement for each evaluation metric was calculated, where a value close to 1 reflects a greater agreement level. Q_3 , Q_1 , and M_{dn} are the upper and lower quartiles and the median values of the dataset.

$$Agreement = 1 - \frac{Q_3 - Q_1}{M_{dn}} \quad (1)$$

3. Results and Discussion

3.1. Framework Development

Overall client aspirations for a green building with sustainable features are first represented as a context diagram on an A0 page shown in Figure 3. This parent A0 node decomposes into four lower-level functional stages of the project life cycle. Each sub-node then further decomposes into more detailed nodes that represent the main functions. The

inputs, controls, outputs, and mechanisms are preserved in the decomposition of the master node (A0) [59]. The scope of this study was limited to Project Brief/ Architectural Programming (node A1) and Design (node A2), both respectively shown in Figures 4 and 5. The scopes for Construction and Operation (node A3 and A4) are found in a separate study [60]. The project phase definitions for A1 to A4 were collated from reference books, industry standards [61,62], and academic studies [27,63,64].

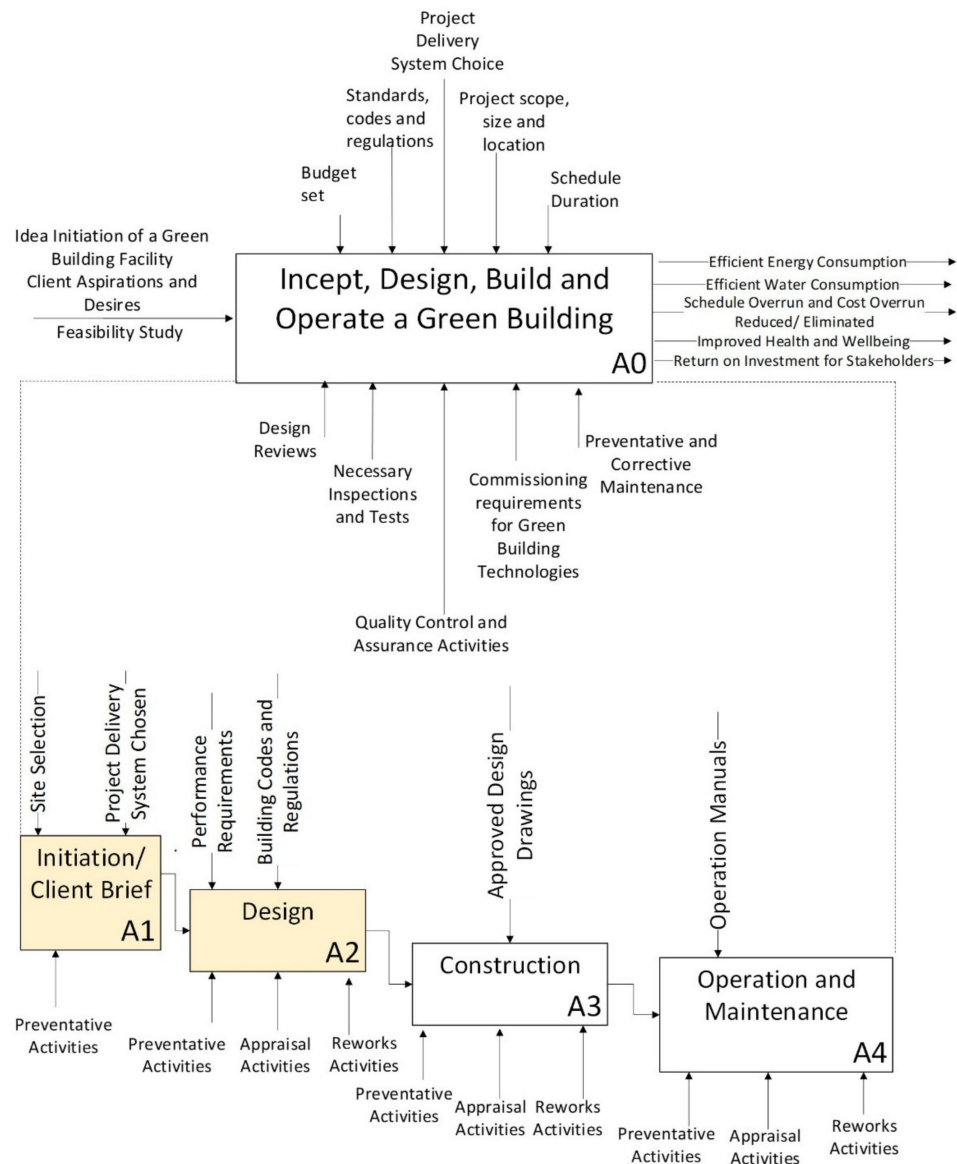


Figure 3. IDEF A0 Master Node expanding into Nodes A1 Project Brief and A2 Design.

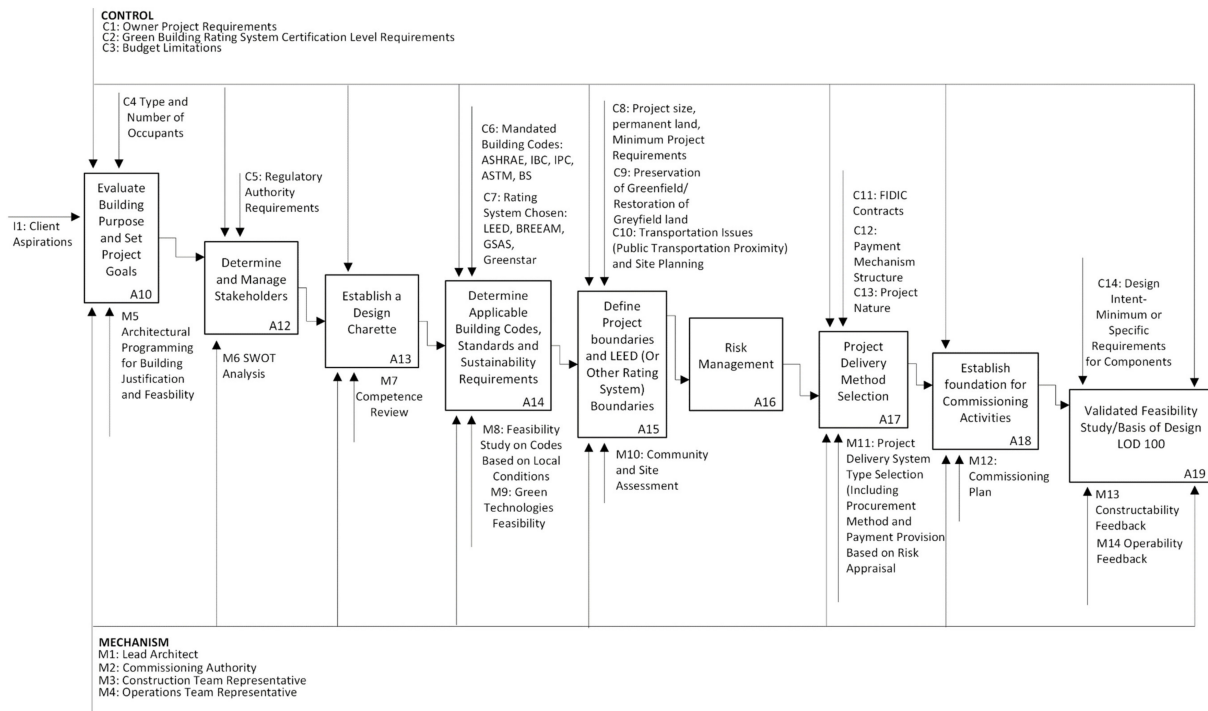


Figure 4. Node A1 Project Brief Stage.

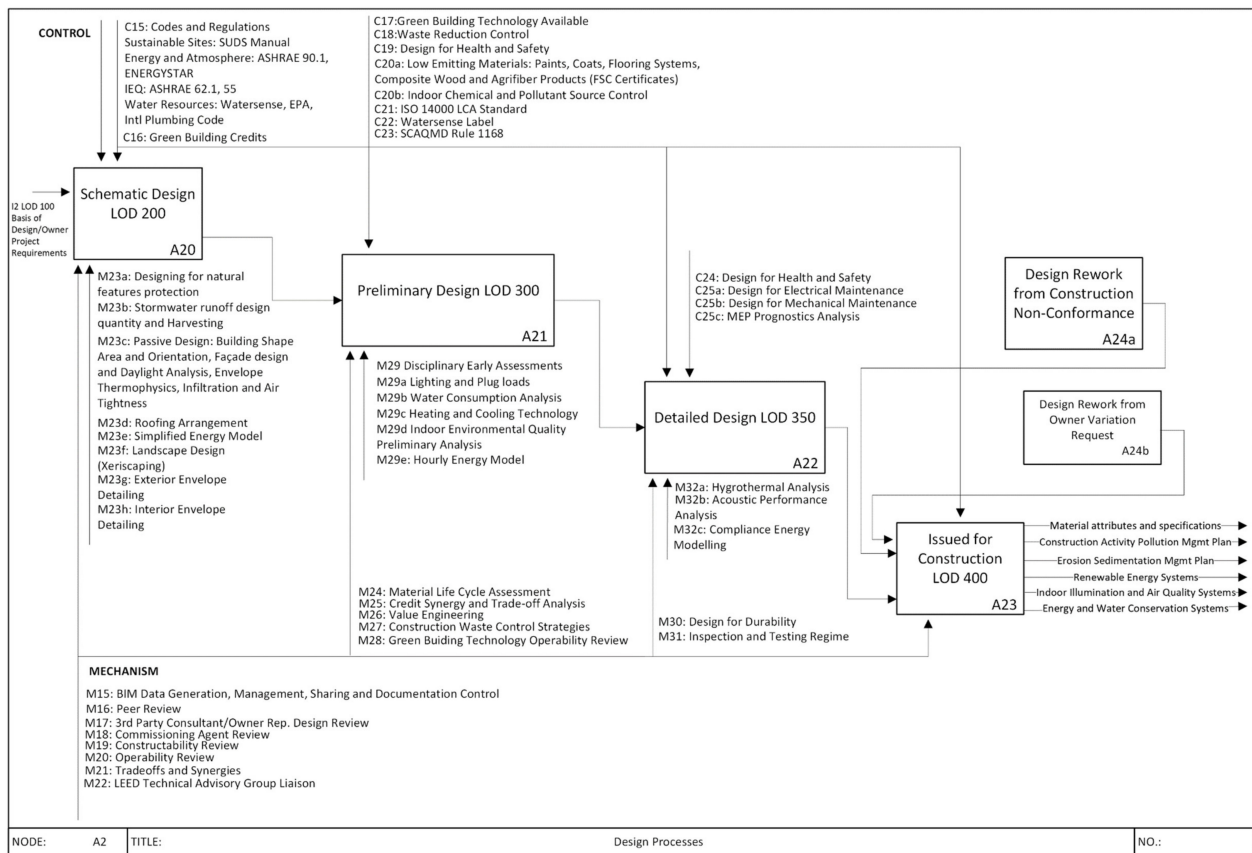


Figure 5. Node A2 Design Stage.

The subsequent Tables 2 and 3 provide explanations of the nodes: what they represent and their associated mechanisms. Further information, including references, is provided in the Supplementary Materials section.

Table 2. Explanation of Project Brief Nodes.

Project Brief A10-A18 Nodes and Mechanisms				
<p>A10. Evaluate Building Purpose and Set Project Goals Conduct feasibility study on the purpose of the building, the end-users it will serve, and the business case of the building.</p> <p><i>M5: Architectural programming of goal definition, economical, durational and sustainability aspects.</i></p>	<p>A11. Determine and Manage Stakeholders and End-Users Define primary and secondary stakeholders. Conflicting priorities determined. Legal obligations and regulations addressed.</p> <p><i>M6: Strengths, Weaknesses, Opportunities and Threats of Various Stakeholders.</i></p>	<p>A12. Establish Design Charrette Team Integrated meeting with multiple disciplines to brainstorm conceptual ideas for the owner requirements.</p> <p><i>M7: Evaluating team traits to ensure capabilities in facing green building design challenges and setting the expectations on teams in other lifecycle stages.</i></p>	<p>Node A13. Determine Applicable Codes, Standards and Sustainability Requirements Decide on applicable codes and standards to adhere to. Green certification type most suitable for the local conditions.</p> <p><i>M8: Feasibility Study on Various International Codes based on Local Conditions</i> <i>M9: Green technologies feasibility discussed</i></p>	<p>Node A14. Define Location, Boundaries and Green Certification Boundaries Articulate project size requirements depending on functionality and minimum requirements for green certification.</p> <p><i>M10: Site selection: community and assessment. Sensitive lands Proximity to transportation and amenities</i></p>
<p>Node A15. Risk Management Discuss potential design and construction risks and devise risk management plan</p>	<p>Node A16. Project Delivery System Selection and Procurement Methods Determine PDS type to adopt and payment mechanisms to assign, based on the given nature and risks of the project and the client experience in delivering green projects. Establish Request for Proposal Financial and Technical Evaluation Criteria</p> <p><i>M11: Appraise risks from Node A15 based on owner experience to assess most appropriate PDS</i></p>	<p>Node A17. Establish Foundation for Commissioning Activities Assess green credits/points to pursue. Testing and verification expectations discussed with team</p> <p><i>M12: Prepare a dynamic Commissioning Project Brief for Design Team Compliance</i></p>	<p>Node A18. Validated Feasibility Study/Basis of Design LOD 100 Review the Basis of Design.</p> <p><i>M13: Constructability Feedback</i> <i>M14: Operability Feedback</i></p>	
<p>Mechanisms active across all nodes:</p> <p><i>M1: Lead Architect: leads the design charette team in brainstorming the owner's project requirement expectations.</i></p> <p><i>M2: Commissioning Authority: Helps in determining the green certification to pursue and the credits to choose to effectively satisfy the certification level requirements. Provides feedback on the testing and verification expectations of the potential building systems discussed by the team.</i></p> <p><i>M3: Construction Team Representative: gives constructability feedback on the risks faced in the project, the budget expectations, the effectiveness of payment mechanisms for productivity in delivery and the expected durations.</i></p> <p><i>M4: Operations Team Representative: Helps in providing operability feedback on the building's purpose and its functionality expectations. Contributes to the design charette. Final review of Basis of Design and how it caters for operational issues.</i></p>				

3.2. Semi-Structured Interviews and Focus Group Insights

The interviews and focus group results cover the themes of Design Sensitive Issues and Iterations, sustainability traits selection, durability design, inspection and testing requirements, Value Engineering Green Building Technologies and finally, PDS Suitability. There is also cross-referencing for activities from the process model whenever they are mentioned within the results (for example, sustainability traits selection is tagged to respective node activity A13 from Figure 4). The full in-depth narrative is provided in the Supplementary Materials section. as well as the framework models for construction and operations stages.

Table 3. Explanation of Design Stage Nodes.

Design Stage A20 to A23 Nodes and Mechanisms				
A20: Schematic Design	A21: Preliminary Design	A22: Detailed Design	A23: Issued for Construction (IFC)	A24: Design Rework from Construction
1. Basis of Design assessed, and concept solutions initiated. Designing from the outside environment through to the overall building envelope and structure, basic mechanical and electrical composition.	1. Design development with further detailed analyses. Interdisciplinary approaches to design solutions.	1. Constructability details of the building components are articulated. Detailing for durability. Fully coordinated between the disciplines for MEP clash conflict resolution with structural system and architectural facades, simulation performance analyses.	Full design documents with specifications formulated to be ready for construction. More accurate baseline schedule and cost analysis.	A24a: Non-conformances in construction phase are redesigned within acceptable safety factors. A24b: Owner initiated variation orders; redesign during construction
2. Site and ground reconnaissance and designing for the external environment considering protection of environment. Low-impact development strategies for rainfall runoff conceived. Landscape design using xeriscaping and irrigation calculations.	2. Exterior and interior envelope detailing	2. Hygrothermal and acoustic analysis performance of exterior and interior building envelope		
3. Increased definition of building's functional requirements. Building envelope types with mechanical and electrical systems considered.	3. Metering and sub-metering branches for energy and water performance	3. Building management system. Verifying the integration of all the meters with the centralized building management system		
4. Passive design solutions: daylighting, orientation, wall: window ratio, natural ventilation, solar energy	4. Lighting and plug load analysis, water consumption analysis, indoor environmental quality preliminary analysis using Computational Fluid Dynamics	4. Compliance energy model for energy consumption in accordance with energy standards.		
5. Active design solutions: Green building technologies for energy, water and indoor environmental quality performances	5. Detailed analyses of building systems. Interrelationships between systems.	<i>M30: Design for Durability: detailing of the envelope to prevent dampness and leaks through flashings, corrosion coatings, prognostic assessment of mechanical and electrical components. Structural detailing to prevent cracks.</i>		
6. Simplified energy model for the building mass	6. Hourly Energy model for energy consumption	<i>M31: Inspection and Testing Regime for building components for construction phase. Check if testing facilities have the available tests needed for the building components</i>		
	<i>M24: Material Life Cycle Assessment: environmental impacts of the materials specified over the entire life cycle using ISO14000.</i>			
	<i>M25: Credit Synergy and Tradeoff Analysis</i>			
	<i>M26: Value Engineering: maximizing the building performance while reducing life cycle cost.</i>			
	<i>M27: Construction Waste Control Strategies: material choices with recycled content, specifying building component sizes to reduce waste, consider opportunities to salvage predicted construction waste into building components.</i>			
	<i>M28: Green Building Technology Operability Review</i>			

Mechanisms active across all nodes:

M15: BIM Data Generation, Management, Sharing and Documentation Control: BIM manager ensures that the level of design information complies with the Level of Development (LOD) 200, 300, 400 and 500 and that there is integration of the model across the various disciplines. Collisions are reported to the respective entities to resolve.

M16 Peer Review: Designing for natural features protection, storm-water runoff design quantity and harvesting, passive design (building shape area and orientation, façade design and daylight analysis, envelope thermo-physics, infiltration and air tightness), roofing arrangement, simplified energy model, landscape design (xeriscaping), exterior and interior envelope detailing

M17 3rd Party Consultant/Owner Representative Design Review

M18 Commissioning Agent Review: verifying the value engineering approaches of the designer do not lead to design sub-optimization. Lifecycle costs fully considered instead of the end of construction cost.

M19: Constructability Review: considering health and safety requirements pertinent to the construction process, feasibility of the design in terms of the construction sequencing (for example, building insulation can be fitted in areas difficult to reach to avoid thermal breaks.

M20: Operability Review: includes electrical and mechanical maintenance such as access to panels, switchboards, mechanical room facilities, ease of cleaning and repair, user comfort (air circulation, indoor air quality, and maintenance of building services (clean water supply, wastewater disposal), green technology repair.

M21: Credit Synergy and Tradeoff Analysis: team finds opportunities to achieve multiple credits and ways to resolve the difficulty of satisfying a certain credit by meeting alternative credits.

M22: Green Certification Technical Advisory Group Liaison

3.2.1. Project Brief and Design Process

There was general approval for the framework's green building design philosophy, from outside-in (M22). Air quality and light control interaction between outside and inside environment requires special consideration (M22c). Extra emphasis on sensitive design to balance daylighting and artificial lighting contributions with the cooling loads required for a building in a warm environment was required (M28a and M28d). If the building owner prioritizes the function of building, it will dictate its overall form, which will precede the form's contribution to passive climate control and the aesthetics of the building shape. A majority of participants found that the design process starts with passive design procedures determining building orientation, envelope, and space planning. It is not possible, however, to rely fully on passive climate strategies due to the hot and humid environment with dusty conditions (A20 an A21); hence, active design strategies are needed to supplement

the overall solution. Reliance on active design strategies poses a challenge to attaining a LEED Platinum level credit when compared to weather conditions faced in North America and Europe. Passive design strategies, however, form the basis of design and are rarely modified as the design develops further (M22c). It was found that active design strategies are the main cause of design changes.

Initiating Design Solutions

The design stage is more significant than the project brief stage in initiating solutions to earn green certification credits. Site surroundings and natural environment considerations are, however, initiated and assessed in the project brief (C8, C9, and M10): local habitat (transferring vegetation to nurseries and allowing escape routes for fauna to adjacent sites), stormwater runoff, and groundwater levels. Sediment and erosion control are provided for in the design, but with construction team advice (M18, M22a, M22b).

Site Selection

Participants unanimously stated no engagement with owners in selecting sites (A15). This is already defined before the project brief and has implications for the quality of the design solution and how it can meet the sustainability requirements (i.e., interconnectivity with site, protection of natural habitat, storm water runoff plans) (M22a, M10). Certification bodies assume that the designers have a say in choosing the site, but participants reported no site selection experiences. A common practice is to work within site perimeters.

Energy Modeling

Simplified, hourly and compliance energy modeling are performed in the conceptual, preliminary, and detailed design stages (M22e, M28e, M30c). Some interviewees left the energy modeling for the detailed design stage after space planning and building envelope configuration were finalized. IEQ is highly intertwined with the energy demand for lighting, cooling, and ventilation. It is therefore good practice to specify the wall and roof envelope, as well as the glazing, in the conceptual stage, especially as active design strategies are relied upon for cooling and ventilation.

Metering

Design of energy and water metering and leak detection systems was performed mostly in the design stage. It was considered important for indoor potable and non-potable water systems to have meters incorporated in branches and networks with 80% data capture. For outdoor irrigation, the responses varied with the design detail level and building typology. These were omitted in commercial buildings and left for operations teams to handle, while outdoor sports venues had a greater design focus (M22f).

Materials and Resources

Construction waste control was found to depend on the building typology type selected. Life cycle assessments of materials to compare the environmental impact of choices were not performed in the design stage by any of the participants (M23). An Environmental Product Declaration report was, however, requested from the construction team by a few designers. Specification of the Materials Recyclability and adherence to Chain of Custody requirements for the construction team were seen as essential in the design. The technical performance of materials prevailed over environmental aspects. A challenge for sustainability specialists is that materials specified with sustainability characteristics are not adhered to in construction because they are substituted by more economical materials.

3.2.2. Green Building Credits/Points Selection Process

The selection of the credits or points to pursue for green certification was left to the designer in the design stage and not discussed thoroughly in the project brief (A14).

The project brief only defines the overall certification level to attain, and it is up to the designer how to achieve this. There was no articulation of how much reduction in energy or water consumption is needed in the project brief. Designers complained about vague and unspecific project briefs and advocated for clients to be more involved in the selection of the credits. Sustainability managers ultimately face a challenge in providing a roadmap to sustainability goals that is vulnerable to client changes in the design stage. There were, however, counter arguments from some designers in preferring that the designer devise a strategy for fulfilling client aspirations to find what makes the project achievable. This gives the designer more freedom in deriving schematic design solutions rather than being constrained from the beginning by the owner's project requirements. There were also issues of design liability concerns, in that the client may have false perceptions of what the points and credits represent. The designer would have greater research capability and cognizance of what underlies the credit, and so is willing to accept the liability if given flexibility.

3.2.3. Design Iterations and Design Sensitive Issues

Energy Modeling and Architectural Space Configuration

Energy modeling is susceptible to design iterations as a result of space planning being modified by client requirements (M22e, M28e, M30c). Designers may omit sensitive issues in cladding complicated building envelopes, causing them to overlook thermal breaks. Energy models need to have a safety factor to allow for such discrepancies. The configuration of architectural spaces should not be further modified after the schematic design stage, as it is sensitive to natural ventilation and can affect interior pressurization calculations—in particular, in kitchens, cafeterias and corridors. However, in reality even as construction is about to commence, the spacing layout may not be finalized.

Building Envelope

The architect needs to fully develop the wall, window, and roof details, with full specifications of U-values, in the schematic stage before considering active design strategies with the aid of building information modeling tools (M22g and M22h). Poor design development can further exacerbate situations of non-compliance. Thermal breaks need to be addressed, especially when MEP conduit pipes need to run through the building envelope. The thermal insulation can involve several design iterations. Issues include having insulation in some parts of the envelope, and whether thickness could be varied by the contractor, who may question why insulation cannot be modified. There is a mentality of uncertainty about the tangible results of insulation on active design strategies. Furthermore, material selection, particularly recycled content, chemical content, and resource responsibility and material costs make it difficult for the DB contractor to have a design approved. This leads to iterations seeking balance between the variables.

Lack of Designer Diligence

There was heavy dependence on active strategies for ventilation and lighting, inhibiting proper forethought on passive design strategies (M22c and M27). Designers may specify certain types of chillers, but suppliers may provide a similar product with slightly lower efficiency. This creates a significant challenge for compliance with energy requirements. The calculations involved must be integrated with U-values; certain lighting performance intensities make it difficult to achieve the intended threshold energy level.

Impact of Client Engagement

Design iterations depend on whether the client chooses to provide inputs to the design. Design aspects that involve subjective contributions include space functionality, lighting, building envelope components, and overall structure. Space functionality, particularly, can change during the design, and it may even happen after the building is already built, leading to redesign of the interior envelopes to serve the purpose. Having multiple

clients involved in a single project makes the project brief a more dynamic document with implications for the design process.

Subsurface Drainage Design

Site reconnaissance discrepancies are a sensitive design issue affecting the project brief. Manholes, supposedly near a site, were not physically present and led to review of the whole storm water drainage system to prevent probable flooding (M22b).

3.2.4. Design for Durability

It was found that Design for Durability can make ample contributions if formally implemented (M29). For example, a project is sensitive to high-performance glazing; gases such as argon or krypton reduce in pressure after 5–10 years and cause the initial U-value to increase. Other aspects for durable design include verification of flashings and other water-repelling mechanisms to avoid moisture intrusion and mold or mildew growth, and finishes and detailing of cladding materials and windows to avoid cracking from heating and cooling through joints (M22g and M22h).

Some design issues were rescued by the designer's own experience but would have been avoided under a formal design-for-durability system. Firstly, regarding choice of pipe materials, stainless steel was chosen over carbon steel in laboratory facilities to avoid corrosion or pipe scaling. Secondly, the designer removed a greywater recycling system from a school because in idle periods its filters would have dried out and have to be replaced.

3.2.5. Product Attributes Specification

The high performance expected from green buildings requires certain materials and products that are not always available in the local market. Consequently, contractors can bring in materials of a lower quality and jeopardize attainment of a credit. In a project involving thicker insulation materials and extra meters for energy and water monitoring, the client was persuaded to remove the extra meters. There are instances where contractors try to save money by modifying the specifications. This is harder if they are contractually held to the specifications, obliging them to procure materials identical or equivalent to those specified. This also occurs as designers readily opt for higher materials specifications; but if these are not available in the market, inferior material puts certification at risk. It was recommended to provide a performance range in specifications rather than being restricted to a single performance standard and allow market availability to be part of the constructability review (M18).

3.2.6. Constructability and Operability Feedback

There were mixed responses, with some designers not experiencing any constructability or operability feedback in the design stage (M18, M19, and M27). Constructability feedback may include remarks that the sequencing does not allow for certain design aspects to be implemented, sensitive areas are not within reach for insulation, or paint material is unavailable.

Also, there was reliance on product vendors to provide their own design drawings, based on previously constructed installations, and the designers incorporated the vendors' drawings into their own.

There are multiple contributions for the commissioning agent in design, such as how to access concealed components; comparison of the credit requirements; performance of design reviews, contribution to the specifications, and provision of a dynamic commissioning plan during the design stages (M17 and M24). However, the commissioning requirements need to be driven by the client, but this is not usually the case in green building projects. It was found that commissioning agents seldom review energy and water performance and are mainly focused on accessibility for maintenance and whether electrical systems are isolated in separate circuits. Peak flow rates and volumes of chiller systems may be

measured, but the associated energy performance cannot be verified because it would require the commissioning agent to have a prolonged contract after project handover.

3.2.7. Inspection and Testing Requirements

Lack of Consideration for Inspection and Testing Requirements

One designer specifying materials did not consider the inspection and testing requirements involved, as initially it was assumed possible to bring in a specialist from overseas to handle the testing requirements, but the current political situation hindered this. Materials requiring overseas testing need to be discussed with the client from the beginning and should be reconsidered with the client. Low VOC paints need to be tested on site to compare against the laboratory certificate, yet may be not possible to test locally, requiring that a sample be shipped overseas. This a common issue with new materials that are not widely used in the industry. The U-values of insulation configurations are especially a challenge for compliance by contractors, because of a lack of third-party laboratories. A particular difficulty arises when seeking enhanced commissioning as a credit and facing the challenges of conducting blower pressure and infiltration testing through the envelope. A truly integrated design will have a contractor and commissioning agent providing appropriate design feedback.

There were views that designers need to ensure that materials fit within a certain performance range and be involved in the tendering and baseline scheduling that reflect inspection and testing requirements (M30). However, this is not always possible for strategic projects with a strict delivery date.

3.2.8. Value Engineering

Value engineering (maximizing performance at lower cost), when performed by the DB contractor, puts sustainability traits at risk when the client is ready to reduce the upfront cost of high-performance materials or technologies. Examples include alterations to the building envelope or stormwater drainage, adding solar energy systems without considering the need for mechanical rooms, removing greywater recycling, or rethinking metering, sub-metering, and landscaping modifications. When LEED certified buildings do not have a LEED consultant during schematic design, the main consultant may use the poor excuse that something is not cost-effective. Similarly, there is risk of design sub-optimization where the designer removes an aspect considering it as not cost-effective in the short-term. Value engineering, when left to be performed at the end of the design process, will have challenging implications for previously designed components. The new DB contractor would not bear design liability for such components. The construction industry needs to acknowledge that value engineering will be associated with slight cost overruns in the construction phase but will lead to efficiency gains in the operational phase (M25).

3.2.9. Designing Green Building Technologies

In most project brief stages, there was seldom a formal mechanism for choosing a particular green building technology or conducting market analyses on their availability and operability (M9 and M27). Unless the client wants a particular system implemented, an initial feasibility study is needed.

The difficulties in the maintenance of wind turbines were not adequately considered in the project brief. Similar maintenance restrictions discourage use of technologies that are not prevalent in the market. Regardless of the novelty of the technology, a system that is not tried and tested will pose a risk over the lifespan of the building. External stakeholders can also resist certain technologies, and hence, a stakeholder management system must discuss the feasibility of implementing diverse green building technologies in the project brief. In one project, government authorities were against bringing electricity produced from renewable energy technologies into the grid because it reduced their control of the local jurisdiction's input and output. This led to the technologies remaining idle

and deteriorating. There were also technical challenges for a mechanical engineer in space planning, in that plant rooms needed to be prioritized; unfortunately, the client and architects focused more on retail spaces and neglected the needs for mechanical services. This is especially true of energy related technologies such as variable air volume units that require larger ceiling spaces. Overlooking these puts energy-related green building credits at risk. Caution is appropriate when designing greywater recycling systems (GRS). If the system sits idle, and because there is no mandatory continuous circulation occurring, the filters will dry out and must be replaced. GRS are not suitable unless the building is operating throughout the year. Greywater volumes needed for GRS systems to function and be useful are not properly considered in the design stages. Certain technologies, such as audio-visual systems, become outdated as the design progresses. If the client requires the latest technology, delays in the design stage are especially problematic.

3.2.10. Suitability of PDS in Green Building Design Level of Project Brief Detail

There were mixed responses, with some finding no difference between PDS on the level of project brief detail (I2). Others argued that the DBB system would produce a more substantial brief, and the contractors would be ultimately bidding against a thorough contract with design elements already in place. Professional indemnity insurance and liability will be on the contractor in DB, and so the client will not be as stringent, from the beginning, about details in the project brief.

Cost-Driven DB Contractor

There are overarching principles or targets that can be established, and it is then up to the contractor to choose how to achieve the target. However, the DB contractor is cost-driven and agrees on a lump-sum, and if the lump-sum amount is not initially thought well through, then the DB contractor will cut corners to achieve the target requirements.

Owner's "Hands-Off" Approach in DBB

Under DBB, the owner has a "hand-off approach" with little involvement in providing details for the project brief. The brief may simply be to achieve a 3-star GSAS certification, which can lead to avoidance of fit-out related credits but compliance with energy and water requirements. Designers would take on rigorous energy and water performance simulations if the owner is not serious about sustainability needs.

Timing of Engagement

A certain design level is necessary before engaging a DB contractor to contain their perceived opportunistic nature. A DB contract needs the client to articulate thoroughly the credits and points sought; when there is no specific requirement from the client, there will be no need for details.

Fiscal Year Influence

A project commenced as DBB, but then modified into DB during the design process, had implications for the entity with design responsibility. The fiscal year coalesced with the gateway for delivery and led the team to phase out the project. Designs tendered as DB were relatively raw and put the client at the mercy of the DB contractor, risking the quality expectations.

Innovation

DBB provides greater opportunity for innovation as designers can take their time and look more into what can be done compared to DB. DB contracts are vulnerable to cost-cutting of sustainability traits masked as a value engineering exercise. The client, under financial pressure as construction progresses, readily accepts the immediate solution to be part of value engineering without considering the long-term impacts of the decision.

What constitutes value engineering needs to be stipulated, including the duration of its benefits and the implications for the sustainability requirements of a green building. DB contracts are very competitive, and innovation is essential for one tender to stand out from the others, so tenderers take risks. A DB contractor may introduce their own patented technology into the design, which leads to the owner making royalty payments.

Compromise on Sustainability Traits Due to PDS

Under a DB contract, construction can proceed ahead of the design, leading to the design work being rushed to ensure completion before the execution of works. The DB contractor will continue to take the risk and execute the works, leading to sustainability traits being compromised. The opposing view is that a procurement purchasing system, in place for a DB project, increases the level of influence over the contractor. In one case, a sustainability management plan and certification management plan were used as a foundation for the contractor's procurement team when choosing materials. In addition, the contractor still needed to seek approval of a consultant before procuring the materials. Once a design letter of conformance has been issued by GSAS, the designer's responsibilities are completed and there is little potential to influence the DB contractor.

3.3. Framework Validation

The same focus group study organized in step 4 was evaluated by experts involved in green building design. They had worked over the last 20 years in the building design industry and so were expected to provide credible evaluations and thorough opinions on possible improvements that could be done. The framework model was evaluated based on its appropriateness, comprehensiveness, relevance and effectiveness. Lee [65]'s level of agreement method was used similarly to the process model evaluation done by Shin, Lee, Park and Lee [49]. Values close to 1 indicate the answers are valid. Table 4 below shows the scores with an overall average of 8.1 out of 10.

Table 4. Framework Evaluation.

Category	Average	Level of Agreement
Appropriateness	8.4	0.89
Comprehensiveness	8.4	0.875
Relevance	8.4	0.67
Effectiveness	8.4	0.875

There were mixed responses on the relevance metric because of the value engineering mechanism (M11), and whether to have it accepted in the schematic design or preliminary design stage because of its potential to be a cost-cutting excuse rather than a true value engineering contribution. In addition, design reworks from variation orders (node A24b) were discouraged late in the project and were preferred to be ideally present under node A22. Overall, the professionals' evaluation concluded that the quality performance process model is suitable for compliance in the project brief and design stage of a green building project.

4. Conclusions

This research generated a quality performance model comprising 13 processes for the project brief and design stages of a green building project. Their definitions, inputs, controls, and mechanisms were depicted using an IDEF₀ model. The components of the process model were obtained through a content analysis literature review and semi-structured interviews of project brief and design practitioners involved in green buildings and validated through a focus group study.

Feedback from the interviews on PDSs in process A16 demonstrated their clear influence on the overall project brief and design procedures. The consensus was that, contrary to the common belief that DB contracts lead to greater innovation than DBB through value

engineering and speedy project delivery, the sustainability of a green building can be vulnerable to cost-cutting under the guise of value engineering. The timing of engagement of a DB contractor in the design process is critical to retention of control of the sustainability components and, thus, not jeopardizing the credits being pursued in a green building project.

Green building design is particularly sensitive to the following process pitfalls. First, a lack of designer involvement in site selection can limit the potential solutions to those possible within constraints imposed by the site. Second, formalized green building certification systems can compel the project brief team to select specific credits or points to pursue instead of specifying a desired certification level and allowing the designer to decide how it would be achieved (which may have implications in the long-run when the design stage is rushed). In addition, the formalization will promote integrated thinking in the early design stages. Third, if the building envelope and space configuration are not fully articulated and finalized before incorporating active design strategies, there may ultimately be energy efficiency implications. Finally, the key principles of design for durability (long-lasting against climatic conditions, avoidance of premature technology breakdown), constructability (market availability of materials, construction workmanship specification), and operability (maintenance access for electricity, HVAC, and plumbing services with equipment designed to be commissionable and streamlined within a building automation system with a focus on monitoring and verification) must be incorporated early in the design stage.

The contributions of this research are as follows: A design industry-validated quality process model for green buildings was proposed; it is based on preventative, appraisal, and rework activities that occur in the design lifecycle. Such a process has not previously been identified specifically for green buildings. The proposed process will allow different stakeholders embarking on a green building project to know what is expected from the design process to achieve an executable, high-performance building. There were limitations faced with the study methodology, in that there was a limited pool of participants in the State of Qatar with green building design experience, and so we were not able to have separate participants from the semi-structured interview and focus group study. Secondly, the participants were all based in the State of Qatar, and therefore their views on delivery systems may be skewed and tailored to the local industry environment preferences.

In conclusion, this research yielded insight into the pitfalls of the design process, especially those that have implications regarding how a green building serves its sustainability purpose. The framework was used as a basis to formulate questions deciphering the setbacks and the key sensitive issues that can jeopardize the conformance and performance quality in a green building. Such revelations would otherwise not have been revealed without a framework model to base upon. Through this framework model, a standard procedure can be followed to reduce the possibility of detrimental outcomes. It offers a unique and comprehensive approach through the interconnected activities that can aid decision makers to determine what can go wrong when certain quality activities are not given enough attention..

Supplementary Materials: The following are available online at <https://www.mdpi.com/article/10.3390/buildings11100473/s1>. The supplementary document contains further details of the framework nodes with the associated references under Section 1. Framework Details with References. A full narrative of the interview participant contributions under the various content themes is also provided under Section 2. Elaborate Interview Details. Section 6 contains detailed results of the focus group study.

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