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MUZIBUR RAHMAN
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CONSTRUCTORS' DECISION-SUPPORT FRAMEWORK FOR NZEB PROJECTS

A DISSERTATION APPROVED FOR THE
CHRISTOPHER C. GIBBS COLLEGE OF ARCHITECTURE

BY THE COMMITTEE CONSISTING OF

Dr. Tamera McCuen, Chair

Dr. Shaila Miranda

Dr. Suchismita Bhattacharjee

Dr. Khosrow Bozorgi

Dr. Charles Warnken

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This dissertation is dedicated to my dear parents.

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Abstract

Efficient construction project management is crucial to project success. As the construction industry changes, constructors find themselves confronted by new issues and must undertake roles that have not traditionally been part of their responsibility. This change in roles requires their traditional responsibilities to be supplemented with non-engineering knowledge and skills to meet today's professional demands. While many studies have examined competency for effective project management, few have done so in the context of NetZero Energy Building (NZEB) construction. Achieving NZEB is a complex process. The decisions made in the early stages of a project impacts its outcomes most in meeting NetZero energy (NZE) goals, which requires knowledge sharing of NZEB constructors in a collaborative work environment. So, the decision-making process and the delivery of the completed project should be integrated, and crucial for NZEBs in achieving the NZE goals. Another important aspect for NZEB projects is the successful integration of Building Information Modeling (BIM) and Building Performance Simulation (BPS) tools, which aid the constructors in selecting optimal solutions from a set of available alternatives. Therefore, this study primarily aimed to determine the critical knowledge areas and skills that are necessary to respond to NZEB construction challenges. Through a survey and follow up interviews with NZEB constructors, this study identified the knowledge and skills base for constructors to be competitive and to effectively execute NZEB projects.

Results from this study revealed that the most important challenges were workers' unawareness of the correct methods and procedures, reluctance to change from traditional practices, and lack of the technical skill regarding Green/NZEB technologies.

The most important knowledge areas were communication management, schedule management and planning, and cost management. The most important skills required to mitigate the challenges were teamwork, leadership, and problem-solving skills. In addition, this study summarized attitudes of the participants regarding the relative importance of the various mechanisms for professional development. The contribution of on the job site experience was rated higher than that of formal industry training provided by employers. The contribution of academic education to the competency of NZEB constructors was rated lower than that of industry training. For BIM implementation, industry's resistance to change from traditional working practices, inadequate in-depth expertise and know-how to operate sustainability related analysis software program, and high initial investment in staff training costs were the top challenges. Accuracy, intelligence, and usability were the important features for BPS tools.

This study is expected to be beneficial for the constructors' decision making in NZEB project context. Construction educators are also expected to benefit from this study in developing their academic curriculum with a goal to meet the industry need.

Chapter 1: Introduction

Problem Statement

With the increasing global concern for the negative impacts brought upon the environment by human activities in recent years, many industries are turning towards implementing sustainability and green measures. The construction sector consumes a significant amount of energy and emits greenhouse gases (GHG) which are among the key factors for global warming. According to the United States Environmental Protection Agency's (EPA) 2021 Annual Report, the buildings sector, which includes residential and commercial buildings, contributes nearly 40% of the energy consumed in the United States and over 30% of GHG emissions (EPA, 2021). The report also shows that emissions from buildings have been on the rise in recent years and reached a new high in 2019. To mitigate the negative impacts on the environment, facility owners are looking to build facilities that will operate with reduced levels of energy consumption and natural resources across the building life cycle (EPA, 2021). As a result of the increase in the demand for sustainable buildings, many construction companies have integrated green concepts into their construction plans. Initially green buildings were intended to reduce the negative impacts on the environment caused by the building industry. In recent years, the design and construction industry has expanded its green building efforts toward "net-zero" by consuming less resources than produced (Green Building and LEED Core Concepts Guide, 2014).

The term green building is often used interchangeably with the term sustainable building or high-performance building. When defining "green building", the U.S. Environmental Protection Agency (EPA, 2017) emphasized environmentally

responsible and resource-efficient processes throughout a building's life cycle from siting to design, construction, operation, maintenance, renovation and deconstruction, which complements economy, utility, durability, and comfort. Kibert (2016) defines resource efficiency in a design as it relates to the building's high level of energy and water efficiency; appropriate use of land and landscaping; the use of environmentally friendly materials; and minimizing the life-cycle effects of the building's operation. NetZero Energy Building (NZEB) is defined as an energy-efficient building where the actual annual consumed energy is less than or equal to the on-site produced renewable energy, and which is typically grid-connected to transfer any surplus of onsite renewable energy to other users (U.S. Department of Energy [DOE], 2015). With the goal of net-zero energy for all new Federal buildings by 2030, Net-Zero has become a part of the United States policies on energy efficiency in buildings.

As the green and net zero building construction continues to grow, there is a need to better understand the pivotal attributes that project constructors should possess to manage such projects. Despite numerous studies on competency needed for project management, few have specifically examined what critical knowledge and skills are required to successfully deliver a sustainable project (Hwang & Ng, 2013), much less a net-zero project. Previous studies mainly only focused on identifying the factors specific to the technical, cost, and organizational aspects of a green building project. A comprehensive study on the factors affecting the success and failure of managing green/NZEB building projects is lacking (Venkataraman & Cheng, 2018). Therefore, the main objective of this study is to identify the essential knowledge and skills required for construction professionals to successfully deliver NZEB projects.

The emergence of Building Information Modeling (BIM) as a design and visualization tool is considered as an important addition to the construction industry. BIM is a digital representation of physical and functional characteristics of a facility. A BIM is a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle; defined as existing from earliest conception to demolition (Costin, Adibfar, Hu, & Chen, 2018). BIM also provides data for energy performance and sustainability assessment, and the leading design and construction organizations are adopting BIM to enable integrated design, construction, and maintenance towards Net-Zero Energy buildings (Maltese, Tagliabue, Cecconi, Pasini, Manfren, & Ciribini, 2017). BIM identifies options to optimize building energy efficiency during the life cycle, hence can provide information to support the calculation of credit points related to rating systems (Maltese et al., 2017). The advantage of BIM is that it links variables, dimensions, and materials to the virtual geometry of the building in a way that when an input or simulation value changes, the model automatically updates all life-cycle scenarios and components simultaneously (Spiegelhalter, 2012). According to Haynes (2009), if the parameters, e.g., variables, dimensions, and materials, are fully integrated within the design process in a BIM platform, most data needed to support design decisions and relevant performance analysis can be obtained automatically as the design proceeds. As a result, a multitude of ‘what-if’ scenarios and their sustainable alternatives can be evaluated at the early stage, when they are most beneficial in terms of sustainability and cost effectiveness (Haynes, 2009).

At present. the major challenge for the construction professionals is to effectively use BIM parametric modeling in reaching the net-zero goals during the lifecycle, i.e., designing, constructing, operating, and monitoring of net-zero energy buildings. There are a number of challenges in applying BIM in sustainable/NZEB buildings (Zhang, Chu, He, and Zhai, 2019). Previous studies have not addressed these challenges totally, however, these challenges need to be carefully considered to develop and undertake effective measures for improving BIM technology use for NZEB. This study identified these challenges.

Research Background

Environmental Impact of Construction Industry and Net-Zero

Energy consumption by the construction industry is becoming a growing concern for the government. Challenges and problems affecting all aspects of construction are being addressed by the adoption of many emerging and fast-growing innovations, chief among which is a variety of sustainability initiatives. The energy consumption by the construction industry can be significantly reduced by incorporating energy-efficient approaches into the design, construction, and operation (Whole Building Design Guide [WBDG], 2016). An Executive Order (EO 13693) “Planning for Federal Sustainability in the Next Decade” was issued on 19 March 2015 which required all new construction, beginning in 2020, of federal buildings greater than 5,000 gross square feet to achieve energy net-zero and, where feasible, water or waste net-zero by fiscal year 2030 (Implementing Instructions for Executive Order 13693 [IIEO], 2015). The goal was to establish a cohesive approach towards sustainability and to prioritize GHG emissions reduction for federal agencies (WBDG, 2016).

The Role of Project Delivery Method in Decision Making

Generally, a construction project goes through three major phases within its lifecycle, e.g., design, construction, and maintenance and operation. Various decisions are associated with each of these project phases. According to Tiwari (2015), the pre-project planning phase involves major investment decisions; the schematic design phase is concerned with decisions related to building performance, cost and aesthetics through comparison of various design proposals; and the construction-planning phase is focused on decisions to improve the efficiency of the construction process. In the traditional design process, various role players like managers, architects, contractors, engineers, etc. work in isolation and make decisions without teaming up to share their knowledge, which makes the decision process more challenging (Tiwari, 2015). This lack of information sharing can potentially undermine the final outcome in terms of building performance, energy efficiency, life cycle cost as well as functionality and aesthetics (Tiwari, 2015).

Unlike the traditional segmented design process, an integrated project delivery method requires all the key players to participate and collaborate in the design and construction process. According to Implementing Instructions for Executive Order 13693 [IIEO] (2015), strategies for the design, construction, and operation of net zero buildings should take an integrative, whole building perspective to identify innovative approaches rather than a step-by-step traditional system, and these strategies should be initiated at the early stage of planning to maximize cost-efficiencies and chances for success. According to Pless, Torcellini, and Shelton (2011), achieving net zero goals efficiently will require new tools and strategies as well as modifications of existing

design, construction, operations, and maintenance practices. Pless et al. (2011) conducted a case study of the Research Support Facility (RSF), a Department of Energy (DOE) owned office building project in the National Renewable Energy Laboratory (NREL) at Colorado, that demonstrated a path to meeting the Federal high-performance building executive order (EO 13514). The goal of the study was to understand how to implement energy use performance requirements as part of a performance-based design-build process, where the owner focuses on the problem(s) to be solved and leaves the solutions to the design-builder to work out. It was found that significant gains in energy efficiency can be realized with existing technologies in a cost-competitive manner if careful attention is paid to project energy goals, building procurement, and integrative building design (Pless et al. 2011).

BIM and the Role of Building Performance Simulation (BPS) Tools for NZEB

NZEB requires precise building performance. Choosing environmentally most effective building products is a way to reinforce NZEBs' energy performance. Therefore, evaluating different design options is a necessity for NZEB projects. Presently, BIM combined BPS tools provide stakeholders options to choose among miscellaneous energy saving alternatives early within the design level, consequently escaping the time-consuming practice of re-getting access to complete constructing geometry and different vital supporting data to complete the energy analysis. Similarly, BIM incorporated energy assessments tools ought to have a sizeable contribution to choosing materials and additives with a lower effect on the overall aid's consumption of buildings. In most of the cases, these elements are selected thinking about most effective useful, financial and technical situations (Uddin, Wei, Chi, & Ni, 2019)

The building geometry, envelope and many building elements interact, thus requiring optimizing the combination of the building and systems rather than merely the systems on an individual level. One solution to address this issue is to use automated building performance optimization (BPO) paired with building performance simulation (BPS), so that many different design options can be evaluated to obtain the optimal solutions (e.g., lowest lifecycle cost, lowest capital cost, highest thermal comfort) while achieving fixed objectives (e.g., net zero energy) (Attia, Hamdy, O'Brien, & Carlucci, 2013). There are various types of BPS software in the market, that help architects to calculate natural and artificial lighting for indoor and outdoor spaces, such as: HEED, e-Quest, ENERGY-10, Open Studio, Radiance, Dialux, Relux, Sefaira, Velux, etc. Each of these BPS lighting simulation software offers their respective advantages. Even though there are many software options available, prospective users face the difficulty of selecting the appropriate program among this growing collection of BPS tools. It is necessary to identify different users need and identify what BPS tools can and can't do to overcome the barriers (Madina, Pratiwi, & Tundono, 2021)

Purpose Statement and Research Questions

The Project Management Institute (PMI) documented its nine knowledge areas in the Guide to the Project Management Body of Knowledge. Those were Integration, Time, Cost, Procurement, Quality, Communication, Human Resource, Scope and Risk (PMBOK, 2017). Each of the nine knowledge areas contains processes that need to be accomplished within its discipline to achieve an effective project management program. For example, project cost management encompasses processes that are required to ensure the project is completed within the approved budget and consists of resource

planning, cost estimating, cost budgeting and cost control. Likewise, project risk management is the process concerned with identifying, analyzing, and responding to project risk (Hwang & Ng, 2013). Dogbegah, Owusu-Manu, and Omoteso (2011) conducted a study on project management competencies for the construction industry and identified six new thematic project management competency areas that were explained in terms of human resource management and project control; construction innovation and communication; project financial resources management; project risk and quality management; business ethics and physical resources and procurement management.

Edum-Fotwe and McCaffer (2000) stated that acquiring the knowledge inputs for a particular type of project enables the project manager to develop two types of skills. The two types are specific skills and general skills. Specific skills relate directly and only to construction projects and the areas that reflect their specialty; general skills are transferable from one type of construction to another. According to Hwang and Ng (2013), direct skills are associated with one's technical competencies that have a direct influence on project performance. For example, the planning skill is a direct skill that is utilized for scheduling activities. Indirect skills, such as managerial effectiveness, have an indirect influence on project performance and are needed perhaps as much as direct skills to ensure that workers execute their work to meet the project's deadline.

Despite numerous studies on project management competencies, few have specifically examined what critical knowledge and skills are required for the constructors to successfully deliver an NZEB project. As a result, the intent of this study was to gain a deep understanding of 1) the challenges constructors face in delivering

NZEB projects; 2) the delivery processes used in practice and their impact on NZEB construction; 3) the challenges in using BIM and BPS tools within the NZEB project context. This study focused on the knowledge and general skills that construction professionals need to successfully deliver NZEB projects. On the job experience, education, training, and professional certification were examined as factors in the development of NZEB construction competencies. The perception of NZEB construction professional regarding the relative importance of these factors to their professional performance provides information for use in the design and development of training programs to prepare construction professionals for NZEB construction.

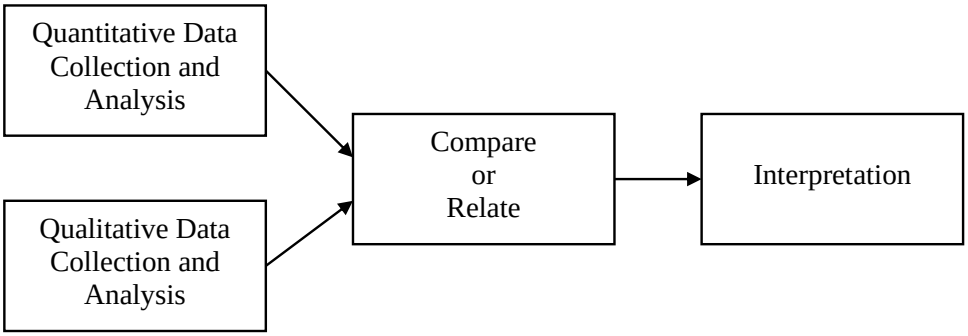


Figure 1. Convergent Parallel Mixed Methods Research Study

This convergent parallel mixed methods research study (Figure 1) used both qualitative and quantitative data to understand the current delivery process of NZEBs in individual project context and their limitations, the role and experience of key players and level of knowledge sharing among them, discipline specific issues and the way to address these issues. In sum, the goal of the study was to answer the following research questions:

Question 1: What are the challenges constructors face in delivering NZEB projects?

Question 2: What are the delivery processes that are used in practice and how do they impact the NZEB construction?

Question 3: What are the barriers and constraints in using BIM and/or BPS tools for NZEB project optimization?

Significance of Study

The outcome of this research will support the constructors' decision-making process in achieving goals for NZEB buildings. Educators will also benefit in developing academic curriculum. This goal can be achieved through the following objectives:

Objective 1: Identify the challenges of current NZEB delivery processes

Based on literature review, survey, and interviews, this research sought to understand the challenges the constructors face during the NZEB construction in a given project delivery environment. This research formulated best practices based on input and feedback from the NZEB professionals.

Objective 2: Mapping the current delivery processes

This research helped in understanding the decision-making process of the key stakeholders in the following categories - stakeholders and their roles, key processes they performed, phases of assessment of key decision-making, and technology used for analysis.

Objective 3: Documenting the BIM and BPS tools in practice

Studying and assessing the BIM and BPS tools in the completed NZEB projects and their uniqueness, interoperability, effectiveness, and limitations in achieving the

NZE goals helped documenting the appropriate optimization tool for the future NZEB projects.

Organization of the Study

This study and the results are organized in a five-chapter format. Chapter 1 provides an introduction to the study that includes the foundation of the problem under investigation, statement of the problem, purpose of the study, research questions, and significance of the study. Chapter 2 includes an extensive review of the relevant literature to provide the reader with examples of other studies that have been done with respect to the phenomenon under investigation. The literature review situates this study within the current conversation about the topic. Chapter 3 presents the details of the methodology of the study to facilitate replication of the study. More specifically, chapter 3 addresses the study participants, research design, data collection procedures, instruments used for data collection, and data analysis. Chapter 4 presents the findings of the data analysis. and Chapter 5 provides a discussion of the findings, conclusions, implications, limitations, and call for additional research.

Chapter 2: Literature Review

Background

The rapid increase in population and economic growth led to the massive construction of buildings and infrastructures all over the world. The construction work has a significant negative impact on energy use, greenhouse gas (GHG) emissions, and global warming. The buildings consume enormous amounts of energy, clean water, and materials, and emit carbon at every stage of their life cycle, from the site development phase to the demolition phase. The environmental impact has been accentuated due to the long transportation distances to be covered to transport the building products around the world. In the United States (U.S.). At present, the building industry consumes 40% of total energy. Improving the ways buildings are designed, built, operated, renovated, and recycled can significantly reduce the use of resources. To address this issue, a number of sustainability initiatives have been adopted. The term “green building” came into use in the 1990s, but the practice of sustainability in the building construction industry can be traced back much further in time. The European Union (EU) introduced the mandatory construction of nearly Zero Energy Buildings (nZEBs) to be fully implemented from 2020 onwards, which has already begun to help minimize carbon emissions. This legislation covers the design and future construction of all new public and privately-owned buildings. Net-Zero has become a part of the U.S. policies on energy efficiency in buildings, with the goal of net-zero energy for all new Federal buildings by 2030. Net-Zero Energy Building (NZEB) is an energy-efficient building where the actual annual consumed energy is less than or equal to the on-site produced renewable energy. As a result, the concept of NZEB has drawn increased attention in

recent years as a measure to counter the negative impacts the building construction industry is creating in terms of energy consumption and greenhouse gas emissions.

Net-Zero Policy

At present, the building industry consumes 40% of total energy in U.S. (U.S. Energy Information Administration [EIA], 2017). This energy consumption can be significantly reduced by incorporating energy-efficient approaches into the design, construction, and operation (Whole Building Design Guide [WBDG], 2016). Dependence on fossil fuel can also be reduced by introducing on-site and off-site renewable energy sources. An executive order (EO 13514) "Federal Leadership in Environmental, Energy, and Economic Performance" was issued in October 2009 which required all new federal buildings from 2020 and thereafter be designed to achieve zero-net-energy by 2030. The goal was to establish a cohesive approach towards sustainability and to prioritize greenhouse gas (GHG) emissions reduction for federal agencies (WBDG 2016). Zero Energy Building (ZEB) is defined as an energy-efficient building where the actual annual consumed energy is less than or equal to the on-site produced renewable energy, and which is typically grid-connected to transfer any surplus of on-site renewable energy to other users (U.S. Department of Energy [DOE] 2015). However, a new Executive Order (EO 13693) "Planning for Federal Sustainability in the Next Decade" was issued on 19 March 2015 which expands upon requirements established by EO 13514 (U.S. Environmental Protection Agency [EPA], 2017). It proposes to cut GHG emissions 40 percent over the next decade from 2008 levels and increase the share of electricity the federal government consumes from renewable sources to 30 percent (EPA 2017). The Executive Order requires all new

constructions, beginning in 2020, of federal buildings greater than 5,000 gross square feet to achieve energy net-zero and, where feasible, water or waste net-zero by fiscal year 2030 (Implementing Instructions for Executive Order 13693 [IIEO] 2015). This requirement is similar that of E.O. 13514, except the 5,000 gross square feet limitation, and the water or waste net-zero aspirational goal. (IIEO 2015).

Approaches for Net-Zero Energy Building

According to IIEO (2015), strategies for the design, construction, and operation of net zero buildings should take an integrative, whole building perspective to identify innovative approaches rather than a step-by-step traditional system, and these strategies should be initiated at the early stage of planning to maximize cost-efficiencies and chances for success. The net zero building will ensure that the actual annual source energy consumption is balanced by on-site renewable energy (IIEO 2015). Following approaches for net-zero energy buildings have been outlined by IIEO (2015).

1. A combination of minimizing energy use and implementing renewable energy strategies.
2. Energy modeling and energy use targets during design process to stretch thinking.
3. Not to oversize primary mechanical systems.
4. Energy recovery and cogeneration (combined heat and power [CHP]) possibilities).
5. Alternative strategies for building design such as solar (photovoltaic), wind, solar hot water, solar ventilation preheating, ground sources heat pump, biomass/waste to energy, and geothermal. The alternative energy only can be

used when its fuel stock is renewable, or it is a CHP facility that displaces conventional fuel.

6. Pre-occupancy commissioning and monitoring the first 12 months of building operations.

Approaches for Net-Zero Water Building

The goal is to reduce total water consumption and return the equivalent amount of consumed water, including municipal supply, to the same watershed without compromising groundwater and surface water quantity or quality (IIEO 2015). IIEO (2015) outlined the following approaches for net-zero water buildings.

1. Limit the consumption of freshwater resources.
2. Return water to the same watershed by not depleting groundwater and surface water.
3. Perform water balance assessments of building systems during design to identify unnecessary water uses.
4. Implement water conserving approaches.
5. Consider rainwater harvesting and alternative water sources (including, recycling and reuse of water).
6. Meet lower quality water needs with lower quality water supply (use lightly treated rainwater and tertiary treated wastewater for flushing toilets).

Approaches for Net-Zero Waste Building

The target is to "reduce, reuse, recycle, compost, or recover solid waste streams (except for hazardous and medical waste) thereby resulting in zero waste disposal"

(IIEO 2015). According to IIEO (2015), some of the approaches for net-zero waste buildings are:

1. Reduce the amount of solid waste generated, and reuse or re-purpose when possible.
2. Maximize recycling opportunities.
3. Use composting for organic materials.
4. Design to provide water supply/drainage as necessary to maintain cleanliness in compostable holding container areas.
5. Consider waste to energy to eliminate waste.

The Role of the Project Delivery Method

Project Delivery Systems

A successful project is the one that can achieve the quality objective specified during the design phase and can be delivered on time and within budget. According to Col Debella and Ries (2006), choosing the appropriate delivery system is important to place a project on the right track. When private owners have the flexibility to select the delivery system according to the project objective; public owners, in most cases, are required to use the traditional design-bid-build delivery system (Col Debella & Ries, 2006). The number of project delivery systems has been increasing and going through constant changes during the past decades. However, many of these delivery systems are quite similar with only certain features differing from one another. Kantola and Saari (2016) categorized these delivery systems in four categories. Before evaluating the roles of project delivery method and multidisciplinary collaboration skills in NZEB BIM implementation, we will review the following categories of delivery systems.

The Traditional Delivery Systems

The widely used traditional delivery system is the design-bid-build (DBB) system, in which the owner has contractual relationship with only one single prime contractor (Col Debella & Ries, 2006). In this system, the designing and building phases are separate which helps the bidders to have a clear understanding of the scope of the project. According to Dorsey, this feature enables the bidders to produce well-defined bids that have similar content with the lowest possible price for the desired design (as cited in Kantola & Saari, 2016). However, there is no room for innovation for the bidders in this delivery system as the design is pre-defined. Multiple prime is a type of the DBB system, in which the owner has multiple contractual relationships with more than one prime contractor (Col Debella and Ries, 2006). The procurement method most commonly used with the design-bid-build system is the low-bid method (Kenig, in Kantola & Saari, 2016).

Fast-Tracking Delivery Systems

Delivery systems based on fast-tracking allow the overlapping of design and construction phases of the project, so that the construction phase can begin before the whole design has been completed (Kantola & Saari, 2016). Design-build (DB) and construction management (CM) at-risk are the two fast-tracking delivery systems where collaboration between the owner and the other parties is not based on a multi-party contract (Dorsey, in Kantola & Saari, 2016). Besides its suitability to fast-tracking, the DB system also saves time as only one bidding competition is required instead of requiring the designer and the constructor to bid separately. The chief advantage of the CM at-risk system is the early involvement of the constructor in the project. Aspects of

the integrated project delivery (IPD) approach (discussed in the following section) can be utilized in this system, such as, pull scheduling, building information modelling (BIM) protocols and “Big room” - a co-location of key project members from different parties for enhancing collaboration (Kenig, in Kantola & Saari, 2016).

Integrated Delivery Approach

The IPD approach involves a multi-party contract, at the minimum, the owner, designer and constructor are involved in this contract, but other key members of the project may also be invited to be involved in it (Kantola & Saari, 2016). The co-operation allows the project to include a larger number of experts at every stage, who contributes by giving their ideas (Matthews & Howell, in Kantola & Saari, 2016). The contract divides the responsibilities, risks and profits between each member to an extent defined in the contract, which creates a high motivation to work for a mutual goal.

Life Cycle-orientated Delivery System

Public-private partnering (PPP) procurement is relatively a new project delivery system that uses a single service provider for design, building, maintenance and financing (Kantola & Saari, 2016). The owner compensates the service provider by paying a monthly service fee. The main benefit of the PPP is that the whole life cycle of the building is taken into consideration during the design and construction phases (Kantola & Saari, 2016).

The Delivery Systems for NZEB Construction

DBB works well for standard construction projects. But for high performance building construction where technology is an added dimension, the same approach might end up as an ineffective approach in terms of functionality and money. For

example, the ventilation technology plays an important role in nZEB and it is improving so rapidly that owners should be open to all new propositions concerning ventilation provided by the bidders. Generally, a construction project goes through three major phases within its lifecycle, e.g., design, construction, and maintenance and operation. Various decisions are associated with each of these project phases. According to Tiwari (2015), the pre-project planning phase involves major investment decisions; the schematic design phase is concerned with decisions related to building performance, cost and aesthetics through comparison of various design proposals; the construction-planning phase is focused on decisions to improve the efficiency of the construction process. In the traditional design process, various role players like managers, architects, contractors, engineers, etc. work in isolation and make decisions without teaming up to share their knowledge, which makes the decision process more challenging (Tiwari 2015). This lack of information sharing can potentially undermine the final outcome in terms of building performance, energy efficiency, life cycle cost as well as functionality and aesthetics (Tiwari 2015).

Unlike the traditional segmented design process, an integrated project delivery method requires all the key players to participate and collaborate in the design and construction process. According to Implementing Instructions for Executive Order 13693 [IIEO] (2015), strategies for the design, construction, and operation of net zero buildings should take an integrative, whole building perspective to identify innovative approaches rather than a step-by-step traditional system, and these strategies should be initiated at the early stage of planning to maximize cost-efficiencies and chances for success. According to Pless et al. (2011), achieving net zero goals efficiently will

require new tools and strategies as well as modifications of existing design, construction, operations, and maintenance practices. Pless et al. (2011) conducted a case study of the Research Support Facility (RSF), a Department of Energy (DOE) owned office building project in the National Renewable Energy Laboratory (NREL) at Colorado, that demonstrates a path to meeting the Federal high-performance building executive order. The goal of the study was to understand how to implement energy use performance requirements as part of a performance-based design-build process, where the owner focuses on the problem(s) to be solved and leaves the solutions to the design-builder to work out. It was found that significant gains in energy efficiency can be realized with existing technologies in a cost-competitive manner if careful attention is paid to project energy goals, building procurement, and integrative building design (Pless et al. 2011).

In choosing delivery systems for NZEB projects, state-of-the-art HVAC and insulation technology and onsite renewable energy are the features to be taken into consideration. These features require the involvement of HVAC contractor early in the project. Hence, the early contractor involvement in CM at-risk system works well in this context. But according to Kenig, by involving the HVAC contractor in the project at the early stage, the project delivery system actually becomes a hybrid one, known as a IPD lite, hybrid IPD or non-multi-party IPD system. In this delivery system, the tools of an IPD system are used without a multi-party contract (as cited in Kantola & Saari, 2016). This IPD system includes the fundamental aspects of the lean project delivery system and the philosophy of the multi-party contracting system. According to Kantola and Saari (2014), “the modern project management tools such as building information

modeling and lean principles are essential when managing a construction project involving state-of-the-art technology; however, even more important is collaboration and information flow between the parties". To ensure the group communication and collaboration among team members, the size of the group is also important. Group should be composed in a way, so that the group members can clearly and explicitly exchange information for communication to effectively support collaboration. According to Lowry, Roberts, Romano Jr, Cheney, and Hightower (2006), the impact of communication may vary depending on task, group size, or level of social presence. Modern technologies, such as computer-mediated communication (CMC) and BIM, have created a great range of social presence situations in which team communication can occur. However, it was found from a study that the 3-person groups experienced better communication regarding appropriateness, openness, and accuracy than did the 6-person groups (Lowry et al. 2006). Lowry et al. (2006) also noted that although group size increases do decrease quality of communication, CMC minimizes the negative impact. This finding is vital in practice, given the increased use of virtual work groups (Lowry et al. 2006).

An Energy-Performance-Based Design-Build Process: Case Study

The National Renewable Energy Laboratory (NREL) Commercial Building researchers developed and demonstrated an acquisition method that successfully integrates energy-efficiency requirements into the project requests for proposals (RFP) and the design-build contracts for new buildings and piloted this process with their large new office building, the Research Support Facility (RSF), in Golden, Colorado. They replicated and refined the process in several additional new construction projects. Each

project incorporated unique and measurable energy performance requirements in the design-build contracts, resulting in the use of aggressive efficiency strategies with typical construction budgets (Scheib, Pless, & Torcellini, 2014). NREL team documented recommended practices (RPs) so that other owners can achieve energy performance in their projects without increasing first costs.

RP #1: Include a Measurable Energy Goal in the RFP and Contract

1. Energy requirements should be included in the RFP, and later in the contract. This goal should be presented in context with other project requirements.
2. The following options for energy goals are presented in order of most to least effective for reducing total annual energy use.
    a. Whole-building EUI target: A building's energy use per unit area.
    b. Net zero energy building: The renewable energy technologies.
    c. Percent savings relative to a baseline: Energy cost savings compared to a well-documented baseline representing the code minimum form of the building design.
    d. Sustainability rating system requirement: Encourages wise use of land, materials, water, and energy, while promoting occupant comfort.
3. Owners should consider using a combination of goal types. Whenever possible, an EUI target should be used. This encourages reducing energy demand before supplying renewable energy, sets a hard boundary for net zero energy design (Scheib et al., 2014).

RP #2: Develop the Energy Goal Using Multiple Resources

1. A broad range of resources to be used to ensure that it is aggressive yet achievable. The ideal approach is to use of all available data, taking advantage of the strengths of each data type.
2. Examples of data types are:
    a. High-level sector data: Commercial Buildings Energy Consumption Survey and ENERGY STAR® Target Finder.
    b. High performance case studies: High Performance Buildings Database (DOE 2013), ASHRAE High Performance Buildings magazine, Advanced Energy Design Guides case studies (Leach, Rockström, Raskin, Scoones, Stirling, Smith, ... & Folke, 2012), and New Buildings Institute reports (NBI 2014).
    c. Portfolio energy use data: An example is a retailer with a number of stores that share the same prototypical design.
    d. Whole-building energy simulation: Examples of energy simulation programs include EnergyPlus, eQUEST, and DOE-2 (Scheib et al., 2014).

RP #3: Develop the EUI Goal Using Normalization Factors

Normalizing energy use goals to floor area is helpful for building comparisons but unintended consequences could happen when put into a competitive environment. For example, the EUI of a building will decrease if fewer people are in the building and space efficiency can be compromised. In this example, incentive factors can be defined that encourage space efficiency while maintaining the integrity of the energy goal as defined for a given building size and occupancy (Scheib et al., 2014).

RP #4: Include Technology-Specific Efficiency Requirements in the RFP

Additional end use or technology-specific goals can add value. Some examples of technology-specific requirement to include in the RFP are:

1. Passive system requirements such as daylighting or natural ventilation. Add specific performance language such as a daylight quantity-hour metrics to ensure attention to detail in the execution of the passive systems.
2. System efficiencies: General language such as “best in class” can be used if specific efficiencies are unknown or cannot be determined. Language should be performance based and not solutions based. Design teams, along with their contractor, are to generate creative solutions, when owners need to provide the boundaries.

RP #5: Define Owner Specified Energy Loads

Examples of owner loads are:

1. Miscellaneous loads: Primarily plug loads such as computers, printers, phones, and video displays.
2. Process equipment: List the equipment required to complete a specialized function such as cooking or surveillance.

RP #6: Provide Calculation Methods for Substantiation

1. There are many energy calculation/modeling approaches for any given design solution. To prevent ambiguity, the RFP should include an appendix that lists all calculation methods to be used.
2. Examples of specific calculation methods to include are:

a. Net zero energy site-to-source factors so that renewable energy systems can be sized accordingly.
b. Central plant and conversion efficiencies: Energy loss factors to be used when calculating the effectiveness of plant or off-site energy resources.
c. ALL building loads in energy use requirements: Identify possible efficiency strategies, including distribution transformers, elevator lights and fans, etc.
d. Definition of minimal thermal comfort, lighting levels, and ventilation rates: Sets the minimal level of services required for each space type.

RP #7: Require Goal Substantiation Throughout Design

1. The energy goal and supplemental calculation information/methods are only helpful if substantiation results are available prior to key decision points.
2. A substantiation schedule in the RFP includes:
    a. Energy modeling schedule: This schedule should coincide with design package completion for owner review. For energy goals, the energy model should match the as-built condition of the building at time of turnover.
    b. Model results for commissioning: If possible, a final, updated design model should be provided prior to commissioning so that end use system profiles and sequence of operations can be used as an extension of typical functional testing checklists.

RP #8: Develop a Process for Performance Assurance in Operations

1. The owner must be able to get feedback on the energy performance, compare the results to model predictions, and leverage the design team to correct installation or control mistakes.
2. Specific considerations to include in the RFP are:
    a. Sub metering requirements: Separate metering for at least end use and whole-building energy consumption, water, and gas.
    b. End use budgets: Determined through the energy goal substantiation process in order to supply a point of reference for comparing end use metering data.
    c. Real performance incentives: An award fee can be structured so that a large portion of the money can be withheld until predicted energy performance is realized within a defined error range. This delayed incentive can help smooth the transition process of the building from the intimate knowledge of the design team to new owner operation.
3. It is important to include the design substantiation schedule and performance assurance plan in the RFP so that design teams understand the time commitment necessary to produce a high-performance building.

While RFP requirements cannot guarantee a world-class energy design, these RPs are a comprehensive list of actions that has proven to be effective for the NREL facilities (Scheib et al., 2014).

The Role of BIM

NZEB requires precise building performance. Therefore, evaluating different design options is a necessity for NZEB projects. The building geometry, envelope and

many building elements interact, thus requiring optimizing the combination of the building and systems rather than merely the systems on an individual level (Hamdy, Hasan, & Siren, 2011). One solution to address this issue is to use automated building performance optimization (BPO) paired with building performance simulation (BPS), so that many different design options can be evaluated to obtain the optimal solutions (e.g., lowest lifecycle cost, lowest capital cost, highest thermal comfort) while achieving fixed objectives (e.g., net zero energy) (Attia, Hamdy, O'Brien, & Carlucci, 2013). There are several simulation tools that are often used in different stage of the design process of a building, e.g., HEED, e-Quest, ENERGY-10, Open Studio, etc. Besides these tools, Building Information Modeling (BIM) is also gaining importance as an effective tool to be used in NZEBs. According to Kwasnowski, Fedorczak-Cisak, and Knap, (2017, October), "A solution guaranteeing realization of integrated design process is BIM technology which offers not only the effectiveness of the design process itself, but also guarantees integration of this process at every stage, what is an indispensable condition for designing a building of NZEB class". As multi-disciplinary information can be integrated in one model through BIM, it creates an opportunity for sustainability measures to be incorporated (Azhar, Carlton, Olsen, & Ahmad, 2011). Moreover, BIM digitally represents physical and functional characteristics of a facility, acts as a shared knowledge resource, or process for sharing information, hence form a reliable basis for decisions during the life cycle of a facility (Suermann & Issa 2009). To achieve the goals of NZEBs, BIM promotes communication and collaboration among the stakeholders by working as both a technology and a process. The technology component helps the team members to identify any potential design, construction or

operational issues of the NZEB project by visualizing it in a virtual environment, when the process component enables close collaboration and integration of the roles of all stakeholders on a project (Azhar, Khalfan, & Maqsood, 2015).

Generally, a construction project goes through three major phases within its lifecycle, e.g., design, construction, and maintenance and operation. At the initial stage of this lifecycle, authoring tools offer the opportunity to simulate the performance of a building before it is constructed by evaluating different types of materials that could be used in the project, and then choose the best one that meets the criteria (Msawealfi, 2010). The advantage of BIM is that it links variables, dimensions, and materials to the virtual geometry of the building in a way that when an input or simulation value changes, the model automatically updates all life-cycle scenarios and components simultaneously (Spiegelhalter, 2012). According to Haynes (2009), if the parameters, e.g., variables, dimensions, and materials, are fully integrated within the design process in a BIM platform, most data needed to support design decisions and relevant performance analysis can be obtained automatically as the design proceeds. As a result, a multitude of 'what-if' scenarios and their sustainable alternatives can be evaluated at the early stage, when they are most beneficial in terms of sustainability and cost effectiveness (Haynes 2009).

National 3D-4D-BIM Program

The General Services Administration (GSA) established the National 3D-4D-BIM Program in 2003 through its Public Buildings Service (PBS) (The General Services Administration [GSA], 2017). The program supports BIM uses across all PBS business lines. The application of BIM in visualization, coordination, simulation, and

optimization allows GSA to more effectively meet customer, design, construction, asset management, facility management, and program requirements. GSA (2017) considers BIM as a shared knowledge resource that can serve as a "reliable basis for decision making and reduce the need for re-gathering or re-formatting information". To achieve its BIM goal, GSA requires model-based design, including native and the Industry Foundation Classes (IFC) data deliverables at all project milestones (GSA, 2017). The IFC data model contains a rich set of classes, supports representing building geometry, and at the same time allows variations in the implementation of IFC geometry export from different BIM-authoring tools (Hitchcock & Wong, 2011, November). GSA also requires open-standard facility management data as a project deliverable. At the same time, all GSA projects are encouraged to deploy BIM to the maximum extent, "to continue to lead industry in the development and adoption of BIM as a building lifecycle tool" (GSA, 2017). According to GSA (2017), the following are the highlights of National 3D-4D-BIM Program:

1. Establishing policy to require BIM adoption for all major projects and across GSA business lines.
2. Providing expert support and resources for ongoing capital projects to incorporate 3D, 4D, and BIM technologies.
3. Providing guidance for continued use of BIM data in asset and facility management.
4. Assessing industry readiness and technology maturity.
5. Developing solicitation and contractual language for 3D-4D-BIM services (for GSA internal use only).

6. Partnering with BIM vendors, other federal agencies, professional associations, open standard organizations, and academic/research institutions.
7. Building a community of BIM Champions within GSA.

BIM for NZEB Projects

To design and construct a low energy building, is its essential to develop a precise energy model. According to Kwasnowski et al, (2017, October), this model contains both energy demand for heating, cooling, ventilation and lighting of the buildings as well as exploitation parameters in order to optimize the architectonic or installation solutions of the designed object. Hence, it is possible to avoid oversizing heat source power of a building. The experience of implementing BIM in Great Britain shows a positive integration of the designing processes of passive and BIM buildings, which may be used to verify the model visually and to generate numerical data in real time (Kwasnowski et al., 2017).

In order to make organizations enable to adopt and implement BIM effectively, an understanding of factors that lead and hinder the process has to be achieved. The factors leading to BIM adoption are strategies and approaches that correspond to the overall company objectives. According to Doumbouya, Gao, and Guan (2016), BIM processes and model management tools are integrated with enterprise systems to produce information in a collaborative setting across the organization and project teams. Prior studies revealed that top management support, compatibility, and computer self-efficacy act as key factors that impact individual's attitude to embrace BIM (Doumbouya et al. 2016). On the other hand, technical complexity, scheduling, and financing act as barriers to BIM implementation in the construction industry. The

successful implementation of BIM at each level demands a structured and meticulous approach method, taking into consideration numerous combined segments of an organization's business (Doumbouya et al. 2016). So, to adopt and implement BIM efficiently, significant changes need to be brought at various levels within the building process as well as in the organization’s workflow. This requires reorganizing the overall workflow, train staff and distribute responsibilities. From a set of guidelines outlining an effective strategy and methodology of implementing BIM, the industry could benefit at organizational level (Doumbouya et al. 2016).

To effectively implement BIM for NZEB construction, a structured approach for individual organizational development for BIM implementation is needed prior to developing the BIM project execution plan (BIM plan) for an individual project, so that each stakeholder will have a starting point for planning and be able to modify existing organizational standards rather than creating entirely new processes. On the other hand, a BIM plan will outline the overall vision along with implementation details for the team to follow throughout the NZEB project (BIM Project Execution Planning Guide, 2011).

BIM Implementation at the Organization Level

The BIM Project Execution Planning Guide (2011) provided some suggestions on how to implement BIM at organizational level. According to this guideline, organizations should develop internal standards defining how they intend to use BIM as an organization. These standards will be shared within the organization to help communicate typical means and methods. Organizations can create BIM Project Execution Planning standards to be used on future projects by using a five-step

procedure, consists of BIM mission statements and goals for the organization, BIM uses, BIM process maps, BIM information exchange procedures, and identifying the supporting infrastructure to successfully implement the plan.

The five-step of the BIM Implementation Plan is as follows:

1. BIM Mission Statement and Goals - This will give an idea about the importance of BIM to the organization for NZEB projects in increasing productivity, design quality, and reacting to industry demand, in terms of energy modeling and other aspects of NZEB.
2. BIM Uses - Defining typical BIM uses for future projects that align with the NZEB goals. Some Uses should be required for every project, like energy, while others are optional based on project characteristics, such as zero-water and zero waste.
3. BIM Process Maps - To demonstrate the organization's BIM process to project team members internally and externally.
4. BIM Information Exchanges - The organizational planning team should establish standard information exchanges for each BIM use they perform.
5. BIM Infrastructure - To consider all the resources and infrastructure required to perform the selected processes.

BIM Implementation at the Project Level

Based on a multi-step research process, the BIM Project Execution Planning Guide (2011) developed a four-step procedure to develop a detailed BIM plan. The four steps consist of identifying the appropriate BIM goals and uses on a project,

designing the BIM execution process, defining the BIM deliverables, and identifying the supporting infrastructure to successfully implement the plan.

1. Identify BIM Goals and Uses

Unlike traditional design, NZEB design not only rely on project budget, project schedule, and project quality, but are driven by energy performance as a more dominating factor for the success of the project (Tiwari & Jones, 2015). For NZEB, project performance is a measure of energy performance and other indicators, and these indicators need to be clearly defined for project team members through defining the overall goals for BIM implementation. Delivery method and contraction methods should be determined before the project begins. Ideally a more integrated approach such as design-build or Integrated Project Delivery (IPD) would be used. Along with energy performance, these goals also include items such as reducing the schedule duration, achieving higher field productivity, or obtaining important operational data for the facility. Once the team has defined measurable goals, specific BIM uses on the project can be identified (BIM Project Execution Planning Guide, 2011).

2. Design the BIM Execution Process

Once the team has identified the BIM Uses, a process mapping procedure for planning the BIM implementation needs to be performed. Four components were identified to be critical to understand and map the NZEB BIM execution process (Tiwari & Jones, 2015).

    a. Stakeholders - It is imperative to identify the stakeholder's role in decision-making, decision facilitation, technical expertise, or regulatory role for decision mapping.

b. Phases of assessment - Within each design phase, the design approach is centered on various iterative cycles of phases of assessments.
c. Processes - Identifying the key design processes, sub-processes and design activities that led to the effective project performance and achieving of the project objectives.
d. Technology - Identifying knowledge type and flow for the assessments used by the stakeholders, tools selection, team communication, and collaboration.

After the high-level map is developed, showing how the BIM authoring, energy modeling, cost estimating, and 4D modeling are sequenced and interrelated, a detailed map will show the "detailed process that will be performed by an organization or, in some cases, several organizations, such may be the case for energy modeling" (BIM Project Execution Planning Guide, 2011).

3. Develop Information Exchanges

The information exchange procedure to be developed complementing the standard exchange requirements, based on the National Building Information Modeling Standard (NBIMS-US), so that a project team can impeccably integrate the information exchanges. As the information exchanges become standardized throughout the industry, the process could be simplified by following the standard exchanges, instead of providing a custom information exchange requirement for each task. This format is also applicable for NZEB projects. Eventually, team members and the owner will understand and evaluate execution plans effectively since they will be organized in a standard format with consistent information (BIM Project Execution Planning Guide, 2011).

4. Define Supporting Infrastructure for BIM Implementation

Based on the BIM Project Execution Planning Guide (2011), some of the key aspects of supporting infrastructure for NZEB BIM implementation are as follows:

a. Collaboration Procedures - The electronic and activity collaboration procedures that include model management (e.g., model check-out, revision procedures, etc.), and standard meeting actions and agendas.
b. Interactive Workspace - The physical environment throughout the project lifecycle to accommodate the necessary collaboration, communication, and reviews that will improve the BIM Plan decision making process.
c. Electronic Communication Procedures - Establish communication protocol with all project team members and stakeholders can be created, uploaded, sent out and archived through a collaborative project management system.
d. Technology Infrastructure - The requirements for hardware, software platforms, software licenses, networks, and modeling content for the project.

Adoption, Implementation, and the Recommended Practices

'Adoption' means choosing to take up or follow an idea, method, or course of action, when 'implementation' means the process of putting a decision or plan into effect, or execution (Oxford dictionary, 2017). Bouwman, Van Den Hooff, and Van De Wijngaert (2005) defined the adoption phase, and the implementation phase elaborately as follows:

1. Adoption phase is the phase of investigation, research. consideration, and decision making in order to introduce a new innovation in the organization. So, this phase is the start of the decision-making process, resulting in a decision whether or not to introduce an innovation to the members of the organization, based on researching what strategic benefits and efficiency gains it can bring. In other words, adoption primarily takes place at the organization level (Bouwman et al., 2005).
2. The implementation phase is the phase of internal strategy formation, project definition, and activities in which an adopted application is introduced within the organization and stimulate the optimum use of the application. Along with the technical aspects (realizing the physical infrastructure, installing the software, etc.), the implementation strategy aims at countering any resistance against the application, and provides training to the users to enable them using the application effectively (Bouwman et al., 2005).

According to Arayici, Coates, Koskela, Kagioglou, Usher, and O'reilly (2011), BIM adoption and implementation require significant changes in the way construction business works at almost every level, not limited to learning new software applications, but also learning to reinvent the workflow, modelling of the construction, and to train staff and assign responsibilities. In the context of the United Kingdom, Aravici et al. (2011) identified several challenges in BIM adoption and implementation in the construction practice, such as:

1. Overcoming the resistance to change and getting people to understand the potential of BIM.

2. Adapting existing workflows to collaborative BIM processes.
3. Training people in BIM and recruiting people with BIM skills.
4. The understanding of the required high-end hardware resources and networking facilities to run BIM applications and tools efficiently.
5. The required collaboration, integration and interoperability between the structural and the MEP designers/engineers.
6. Clear understanding of the responsibilities of different stakeholders in the new process by construction lawyers and insurers (Aravici et al., 2011).

According to Khosrowshahi and Arayici (2012), business culture is an important factor for organizational readiness to adopt BIM successfully. To achieve that, it is necessary to install necessary training program. Changes in technology and business processes enable improved capabilities. However, such standards cannot be implemented by training providers, which leads to a growing need for such educational programs to be hosted by academic organizations (Khosrowshahi & Arayici, 2012).

According to Kumar (2015), an organization should have a BIM strategy that is comprised of three elements:

1. A BIM Champion.
2. Perceived challenges, both internal and external.
3. Training program.

A BIM champion, who is sufficiently knowledgeable in key aspects and issues of BIM, will identify the main challenges that the organization might be facing regarding BIM adoption and implementation, ranging from the usual resistance to change to lack of infrastructure and even to a lack of sufficient expertise within the

organization (Kumar 2015). Along with that, the external challenges also need to be identified, such as, shortage of skills available locally. Only after a proper understanding of these issues, a training strategy and policy can be designed properly for the organization (Kumar 2015).

Recommended Practice for Adoption

BIM Essential Guides (2013) devised a template to develop the organizational BIM adoption plan based on the seven categories. The seven categories are as follows:

1. Leadership: Involve senior management
    a. Set up BIM committee with clear roles and responsibilities
2. Planning: Develop BIM adoption plan
    a. Define BIM vision, goal, themes, change management, software and hardware requirements in the plan
3. Information: Define BIM standard
    a. Define BIM quality assurance checks
    b. Define BIM information management
4. Processes: Define project BIM process
5. People: BIM competency map
    a. BIM training roadmap
    b. BIM roles (project BIM manager/coordinators)
6. Customer: BIM execution plan
    a. BIM conditions
7. Results: Define KPIs (at project, organization, and employee levels)

An organization needs to incorporate all these criteria when developing its BIM adoption plan, and then be endorsed by the senior management. This plan also needs to be reviewed regularly and refined if necessary. This close monitoring will guide the organization moving towards successful BIM adoption (BIM Essential Guide 2013).

The project team should first examine the business needs of the project and explore relevant BIM technologies. This should be the basis for defining the scope. After the scope has been defined, an implementation plan will be developed to carry-out the project. During the project, the project needs to be evaluated regularly with the metrics established in the implementation plan.

Recommended Practice for Implementation

To implement BIM at the organization level, senior management will set up BIM committee with clear roles and responsibilities and will also develop the BIM vision and goals for the organization. They will communicate and reinforce the vision to employees and stakeholders. They will also provide necessary resources and monitor progress of the program. The BIM committee will support the senior management to execute the organization's BIM adoption plan. This committee will be comprised of representatives from the various levels of organization's structure. In respect of roles and responsibilities, the BIM champion will lead the committee, manage the progress, and provide the necessary resources. The committee will identify BIM opportunities in key business processes. The committee will also experiment and evaluate new practices, processes, and technology. BIM manager will select BIM technology/software and will provide training. (BIM Essential Guide 2013).

According to the BIM Essential Guide (2013), a BIM implementation plan for a project typically contains the following information:

1. Project information
2. Project members
3. Project goals
4. BIM use cases for each stage of a project
5. BIM deliverables for each BIM use case
6. Model author and users for each BIM deliverables
7. Model elements, level of details and attributes for each BIM deliverable
8. Process for BIM creation, maintenance, release and collaboration
9. Technical Environment

The execution plan is usually defined at the start of the project and can be updated to accommodate new project members or new uses of BIM (BIM Essential Guide 2013). All updates should be made with the permission of the BIM Manager.

The Impact of BIM and NZEB at the Organization and Project Levels

BIM technology is rapidly gaining speed within the Architecture, Engineering, and Construction (AEC) industry. Lee, Whang, and Kim (2014) define BIM as the technology of generating and managing a parametric model of a building. According to them, the successful implementation of BIM brings many benefits throughout the project life cycle. Those benefits include less document errors, less rework, and less cycle time of design process. It also improves the productivity (Lee et al. 2014). On the other hand, to mitigate the greenhouse gas (GHG) emission by building industry, all new federal buildings greater than 5,000 gross square feet, from 2020 and thereafter

required to be designed to achieve net-zero-energy by 2030 according to a new executive order (WBDG 2016). For net-zero-energy buildings (NZEBs) to become reality, manufacturers and designers need to integrate systems into buildings that are significantly different from most buildings constructed today (ASHRAE 2008).

1. Impact at the Organization Level

Despite various advantages, the use of BIM during feasibility, planning, and development stage remains significantly limited with very few owner organizations adopting BIM. According to the SmartMarket Report (2014), only 3% of survey respondents stated that they experience its full benefits. Several previous studies identify several factors that work as the barriers for successful implementation of BIM. Among them, the main issues include management and technical support, compatibility of BIM technology, software skills and organizational culture (Gu and London, 2010). Gu and London (2010) mentioned about some other supporting factors such as lack of awareness and training; hesitation to learn new technologies; industry's reluctance to change existing work practice and the lack of clarity on roles, responsibilities and distribution of benefits as major barriers to BIM adoption. implementing BIM in an organization brings a major change in work practices. It also reconfigures the internal structures of the organization to make BIM fully functional. So, owners are often hesitant about if they should go through the challenges related to implementation. They are also confused about the transition process. In this regard, Cavka, Staub-French, and Pottinger (2015) mentioned that “although previous studies have documented the potential benefits of BIM adoption for owners, such as improvements in work order processing, very little research has specifically looked at the transition to BIM and the

scale of the effort required for large and diverse owner organizations". According to Cavka et al. (2015), implementing BIM in large owner organizations is a complex task, as it has many departments, processes, cultures, networks of systems and databases that provide different functions, and are operated by people from different backgrounds and with different interest. Despite the significant adoption of BIM by design firms, understanding the factors that influencing this adoption by owner organizations has yet to be meticulously explored. There has not been sufficient research on BIM adoption that studies all involved AEC disciplines collectively. Consequently, it is important to examine the question of what factors affect an organization's decision to adopt BIM (Cavka et al. 2015).

2. Impact at the Project Level

Collaboration between project stakeholders is crucial from the early stage of the project to achieve the goals of NZEBs. According to Song, Sun, Li, and Xie (2014), the designer needs to set up a collaboration-based design framework and methodology for NZEBs at the beginning of project to maximize cost-efficiencies and chances for success. In this context, the application of BIM technology in an integrated project delivery (IPD) system is considered as an effective approach to design and construct NZEBs (Spiegelhalter, 2012). The changes in workflow and processes at the organizational level to create a favorable environment to achieve NZEB goals have a direct positive impact on BIM execution and inter-project coordination at the project level.

The Metrics and Key Performance Indicators (KPIs)

The full benefits of BIM need to be measured over the lifecycle of the project to ensure that continual improvement can be achieved. It is generally assumed that building life cycle starts with the building design whereas it starts long before. The information that is created in the feasibility, planning, and the early development phase is building information. Smith and Tardif (2009) discussed about the importance of the data generated in this early phase of a building life cycle. The data may be a table of functional space requirements, a budget, or a construction cost estimate. According to Smith and Tardif (2009), professionals should identify these data as building information and take easy step to compile and conserve it for possible later use. The authors specifically suggested to compile building information in spreadsheets as "the structured data contained in spreadsheets can be imported directly into BIM programming and planning tool such as the Onuma Planning System (OPS) or Trelligence Affinity" (Smith & Tardif 2009).

There are several types of data generated from BIM-NZEB projects as follows:

1. Construction/material data, such as thermal conductivity, heat, emissivity, reflectivity.
2. Mechanical data from HVAC equipment and operations.
3. Lighting, occupant, and equipment Load data.
4. Spatial data associated with modeled space.

The ability to import data into energy models directly from a BIM can significantly reduce time in energy modeling process and uncertainty. The assumptions about thermal properties of the project can be compared with the actual data gathered

from the model to analyze the project's success in attaining its goal (GSA 2017). It is necessary for the project team to discuss the specific elements where the output information (authored) does not match the input information (requested).

The use of key performance indicators (KPIs) allows schemes to be benchmarked against similar schemes to identify standards in the national performance of the construction industry and identify areas for improvement. To develop the KPIs, it is necessary to understand the organizational inputs, outputs, and desired outcomes and these KPIs should be linked to the goals of the business. Specifically, with BIM and NZEB, there has been a lack of consistent fiscal benchmarking to evaluate the business improvements and gains from BIM adoption (Gerber & Rice, 2009). One way of developing the metrics or KPIs for BIM in attaining NZEB, certification process, such as Leadership in Energy and Environmental Design (LEED) can be introduced. The certification process of a net-zero energy building (NZEB) can be done by using the structure of the Living Building Challenge, managed by International Living Future Institute (ILFI), which is a performance based standard and can be applied to any building type, includes landscape and infrastructure projects, partial renovations and complete building renewals, new building construction, neighborhood, campus and community design (WBDG, 2016). This certification requires 12 consecutive months of zero energy performance for a project, without the use of onsite combustion (International Living Future Institute [ILFI], 2018). The performance areas include site, water, energy, materials, health, equity, and beauty, and all these are requirements. The additional requirement for NZEB is that the project's energy needs must be fulfilled completely by on-site renewable energy on a net annual basis (WBDG, 2016).

According to ILFI (2017), it formed a partnership with the New Buildings Institute (NBI) to streamline the certification process and database for NZEB. Within this partnership, ILFI will continue to administer the certification, while NBI will act as lead certification auditor as well as administer the database (ILFI, 2018).

The Knowledge and Skills Essential for the BIM Manager

The BIM Manager is responsible for carrying out, directing, and coordinating all work associated with BIM, including project planning, design, engineering management, construction, operation and overall coordination, and for providing authoritative advice, assistance and information on all matters related to BIM. To successfully lead the adoption and implementation of BIM strategy for NZEB construction at both the organization and project level, the BIM manager needs to take time to learn the procedure to compile the final BIM Plan. He needs to be proactive and explains the value and necessity of the process to the other project team members. For implementing BIM in a project, the BIM manager encourages the team to take the time to plan the work, even if there is strong schedule pressure to begin developing model content prior to the completion of the planning process. The BIM manager could be from any primary organization, but usually they are from the owner or construction manager organization (BIM Project Execution Planning Guide, 2011).

Without top management's active involvement, BIM cannot be efficiently adopted at the organizational level. The BIM implementation plan needs to be reviewed regularly, and to be refined if necessary. This close monitoring will guide the organization moving towards successful BIM adoption. Senior management will set up a BIM committee under the leadership of a BIM manager with clear roles and

responsibilities. The BIM manager, along with the committee members, will develop the BIM vision and goals for the organization. They will communicate and reinforce the vision to employees and stakeholders. They will also provide necessary resources and monitor progress of the program. This committee will be comprised of representatives from the various levels of organization's structure. In respect of roles and responsibilities, the BIM manager will lead the committee, manage the progress, and provide the necessary resources. The principal architect will identify BIM opportunities in key business processes. BIM manager will select BIM technology/software and will provide training. BIM specialist will experiment and evaluate new practices, processes, and technology (BIM Essential Guide 2013).

Decision Making in Sustainable Construction

Like any other field, decision making plays a crucial role in construction industry to make a project successful. According to Jato-Espino, Castillo-Lopez, Rodriguez-Hernandez, and Canteras-Jordana (2014), construction projects involve many different tasks and requirements, involving a great variety of aspects to consider. As a result, making decisions in such environments can often be difficult. Hence, the need for a decision-making method capable of assisting in such complex scenarios arises. According to Senaratne and Sexton (2008), with the emergence of information technology (IT), IT enabled collaboration systems to support problem-solving in construction projects has drawn increased attention. However, with the complexity and messiness arising from construction project environments, IT-enabled collaborative environments alone are not sufficient for problem-solving. In construction projects, where pragmatic problem-solving on site is a common occurrence, these knowledge-

based perspectives have not yet been fully realized. For such problem-solving to become true innovation, the solutions reached for particular problems should be learned, codified and applied in future projects (Senaratne and Sexton, 2008). This need led to the emergence of multi-criteria decision-making methods (MCDM). MCDM refers to making decisions in the presence of multiple, usually conflicting, criteria. According to Erdogan, Šaparauskas, and Turskis (2017), each different criterion may have different units of measurement, quality characteristic, and relative weight. It is possible that some criteria can be measured numerically, and other criteria can only be described subjectively.

Model Creation for Multi-Criteria Decision Making (MCDM)

Erdogan et al. (2017) described the steps in making decision based on multi criteria method in the context of selecting the proper contractor.

1. Alternatives of the solution should be defined. When choosing contractor in construction process, all possible contractors for the project should be identified.
2. Criteria of those alternatives should be set. The factors that are important and have influence on choice of contractor should be identified.
3. System of criteria evaluation should be established. Each criterion is evaluated differently, so the system should be defined. For example, experience of contractor could be evaluated as outstanding, very good, average, below average or unsatisfactory whereas profitability could be defined as high, average or low and etc.
4. Criteria weights should be defined. In this step, important and less important criteria should be identified. The more important the criterion is, the bigger

weight it should have. Then each criterion of each alternative should be evaluated.

5. Finally, counting with the help of computer software should be made and the best alternative chosen.

In applying the principles of sustainability in a construction project, environmental and social aspects also need to be considered along with technological and economic aspects. To choose the most effective project decisions, the stakeholders are faced with the need to evaluate the performance of a number of criteria. According to Zavadskas., Antucheviciene, Vilutiene, and Adeli (2017), mixed information and a wide variety of information types can be managed by applying multi-criteria decision analysis methods. The use of MCDM methods reached various subareas of construction/building technology, proving the importance of considering multiple aspects of reality when it comes to sustainable decision-making in construction/building technology (Zavadskas et al. 2017).

MCDM Methods

Sustainability assessments require the management of a wide variety of information types, parameters and uncertainties. According to Cinelli, Coles, and Kirwan, 2014), multi criteria decision analysis (MCDA) is a suitable set of methods to perform sustainability evaluations because of its flexibility and the possibility of facilitating the dialogue between stakeholders, analysts and scientists. Cinelli (2014) described several MCDA methods as follows.

1. Analytical Hierarchy Process (AHP):

The standard process requires firstly the identification of a set of alternatives and a hierarchy of evaluation criteria (value tree), followed by pairwise comparisons to evaluate alternatives' performance on criteria (scoring) and criteria among themselves (weighting). All the weights/alternatives are compared in respect to the criteria by asking the decision maker (DM) his preference on a scale from 1 to 9, with 1 indicating equal preference and 9 absolute preferences. The resulting output of this procedure is a matrix of comparisons expressed as ratios. Once the criteria weights and alternatives scores have been derived with the described process, overall performance of the alternative can be calculated by means of a linear additive model. The final result is a value between 0 and 1, where the weights indicate the trade-offs between the criteria.

2. Elimination and choice expressing the reality (ELECTRE):

ELECTRE are preference aggregation-based methods, working on pair-wise comparisons of the alternatives. They are also defined as outranking approaches because they aim to assess whether option A is at least as good as (in other words it outranks) B. ELECTRE methods were developed in order to account for heterogeneous criteria whose aggregation in a common scale is difficult.

3. Preference ranking organization method for enrichment of evaluations (PROMETHEE):

PROMETHEE methods are also part of the outranking MCDA family, and are based on a set of prerequisites: (i) the extent of difference between the performance of two alternatives must be accounted for; (ii) the scales of the criteria are irrelevant as comparisons are performed on a pairwise base; (iii) three cases are possible: alternative A is preferred to alternative B; alternative A and alternative B are indifferent;

alternative A and alternative B are incomparable; (iv) the methods should be easily understandable by the decision makers; and (v) weights must be assigned in a flexible manner. Once the preference functions for all the criteria and the weights of the criteria are identified, a comprehensive preference index indicating the degree of preference of A over B can then be calculated as the weighted average. Lastly, the leaving and entering flows can be combined, resulting in the net outranking flow that provides the performance of each alternative.

4. Dominance-based rough set approach (DRSA):

The dominance-based rough set approach is a relatively new technique which can handle classification, choice and ranking problems. DRSA is based on an information table whose rows are defined as alternatives, while the columns are divided into condition attributes; namely the criteria that are needed to assess the alternatives and the decision attribute, which represents an overall evaluation of the alternative. When a DM is involved in the process, he/she is asked to select a class where each alternative belongs or to compare one alternative with the other and decide which one performs better, without the need to specify any weights.

The Method for Decision Making

The alternatives may be varied in decision making (DM) processes, and the decision consists in choosing the most desirable alternative after considering a set of criteria. The decision process can be complicated for several reasons. One of these reasons arises from the fact that criteria are not often comparable using the same unit of measurement. Also, there is a tendency in current governance processes to involve all the stakeholders in the DM process. For these reasons the process of decision making

can be very complex and so adequate tools are necessary to support the process (Benítez, Delgado-Galván, Izquierdo, and Pérez-García, 2015).

Previous research underlines that multi-criteria decision-making (MCDM) methods can deal effectively with the intrinsic multidimensionality, complexity and subjectivity of sustainability issues. In particular, AHP is ever more prevalent among MCDM methods, mainly because of its understandability in theory and the simplicity in application (Calabrese, Costa, Levialdi, and Menichini, 2019).

The AHP developed by Saaty formalizes the intuitive understanding of complex problems by building a hierarchical model. The purpose of the method is to allow the actor involved to visually structure a multicriteria problem in a hierarchical manner. This hierarchy consists of three levels: the highest level contains the goal, the middle level contains the criteria, and the lowest level presents alternatives. Once the hierarchical model is constructed, comparisons are made between pairs of criteria and also between pairs of alternatives for each criterion. The process typically concludes by providing a summary of results through a process of aggregation. The entire process is based on the fact that it enables the assignation of numerical values to the judgments given by the actor, making it possible to measure how each element contributes to the level of the hierarchy that is immediately above. Use is made of a specific scale for these comparisons in terms of preference or importance (Benítez et al, 2015).

According to Calabrese et al. (2019), even if the main drawback of AHP is the high number of pair-wise evaluations required for completing large matrices, they become useful when the decision maker has difficulties to rank criteria and alternatives holistically and directly with respect to an upper-level criterion. In this circumstance,

pair-wise comparisons, on which AHP is based, are the most user transparent and technically sound method for determining weights representing the relative importance of alternatives and criteria. The user usually give input like whether a variable is more or less or equal important than another. Then the process assigns a quantitative value based on the qualitative factors. For pair-wise comparison, i.e., relative importance of one option over another is done using a 'scale of relative importance' (Hossain, Adnan, and Hasin, 2014).

Two different 'scale of relative importance' (1-9 and 1-5 point) is shown in table 1. Now if a user wants to give equal importance to option A & C and wants to give moderate importance on option B, then the pairwise comparison matrix may look like table 2 and table 3. From the table 2 and table 3, it is seen that, for same typical user input, various result occurs due to scale difference. It is also noticed that assigning only moderate importance to one of the variables, generates a weighting percentage of three times (in case of 1-9 scale) or two times (in case of 1-5 scale) than other alternatives. Though the weighting percentage differs, the ranking is same in both the cases (Hossain, Adnan, and Hasin, 2014).

Table 1. Two different types of 'scale of relative importance'

Scale of relative importance (1-9 point)		Scale of relative importance (1-5 point)	
Qualitative variables	Quantitative variables	Qualitative variables	Quantitative variables
Equal importance	1	Equal importance	1
Moderate importance	3	Moderate importance	2
Strong importance	5	Strong importance	3
Very strong importance	7	Very strong importance	4

Extreme importance	9	Extreme importance	5

Table 2. Pairwise comparison matrix formed by using traditional 1-9 point scale

	A	B	C	Geometric Mean b_k	Normalized weight x_k	%	Rank
A	1	1/3	1	0.69	0.2	20	2nd
B	3	1	3	2.08	0.6	60	1st
C	1	1/3	1	0.69	0.2	20	2nd

Table 3. Pairwise comparison matrix formed by using traditional 1-5 point scale

	A	B	C	Geometric Mean b_k	Normalized weight x_k	%	Rank
A	1	1/2	1	0.794	0.25	25	2nd
B	2	1	2	1.587	0.5	50	1st
C	1	1/2	1	0.794	0.25	25	2nd

Table 1, 2, and 3 are reproduced from Hossain, M. F., Adnan, Z. H., & Hasin, M. A. A. (2014). Improvement in weighting assignment process in Analytic Hierarchy Process by introducing suggestion matrix and Likert scale. *International Journal of Supply Chain Management*, *3*(4), 92.

There are several problems associated with this methodology. The main problem is the possible lack of consistency in comparison matrices, as comparative judgments are subjective since they are issued by experts and/or other actors in the decision process. A major problem is caused by the growing necessity for all the actors to be involved in decision processes. This leads to a couple of challenges. Firstly, the design of appropriate mechanisms for achieving consensus on a final decision that integrates the different points of view, possibly conflicting, of the various actors. However, as a precondition, some actors may not be completely familiar with one or more of the elements about which they have to issue their judgment or opinion. It seems reasonable to allow such an actor to express their preferences several times at his or her own

convenience. Meanwhile, partial results based on partial preference data may be generated from data collected at various times—and this data may eventually be consolidated when the information is complete (Benítez et al, 2015).

An MCDA process scores performance of all decision alternatives relative to multiple objectives, highlights the trade-offs presented by the decision problem, and aggregates each criterion score into a preferential rank ordering identifying the alternatives likely to be most satisfying to decision-makers and stakeholders. It can also evaluate how changes in stakeholder values affect the rank-ordering (Seager, Gisladottir, Mancillas, Roege, and Linkov, 2017). As an analytical approach, it is well suited to accommodate the vast quantity and diversity of information that needs to support the inspired initiative. MCDA provides a systematic framework for integrating data, both quantitative and qualitative, from several different domains and facilitating a deliberative process from which informed decisions are made (Linkov and Moberg, 2012). It elicits information from stakeholders and experts continuously, beginning with the formulation of problem scope, alternatives, merit criteria, technological or design performance, and values. The insights it provides in turn enable open-ended, iterative development and assessment of prospective solution sets that can help build decision consensus, which in turn can enhance decision commitment (Seager et al., 2017).

Chapter 3: Methodology

The objectives of this research were to understand the current delivery process of NZEBs in individual project context and their limitations, the role and experience of key players and level of knowledge sharing among them, discipline specific issues and the way to address these issues. A case study was conducted using a convergent mixed methods design to enable an in-depth understanding of the research objectives (Figure 3.1). The two parts of the study were as follows: a) a structured survey was performed to generate the quantitative data, and b) interview was conducted using a semi-structured questionnaire to generate the qualitative data. Chapter three describes the participants and sampling strategy used in the study, the survey instruments used for quantitative and qualitative data collection procedures, and the methods for analysis of the data collected. In sum, the goal of the study was to answer the following research questions:

1. What are the challenges constructors face in delivering NZEB projects?
2. What are the delivery processes that are used in practice and how do they impact the NZEB construction?
3. What are the barriers and constraints in using BIM and/or BPS tools for NZEB project optimization?

Research Design

The research design is intended to provide an appropriate framework for a study. A very significant decision in research design process is the choice to be made regarding research approach since it determines how relevant information for a study will be obtained (Sileyew, 2019). The steps taken to answer the research questions and

identify the primary process-based key performance indicators (Figure 2) are described in this section.

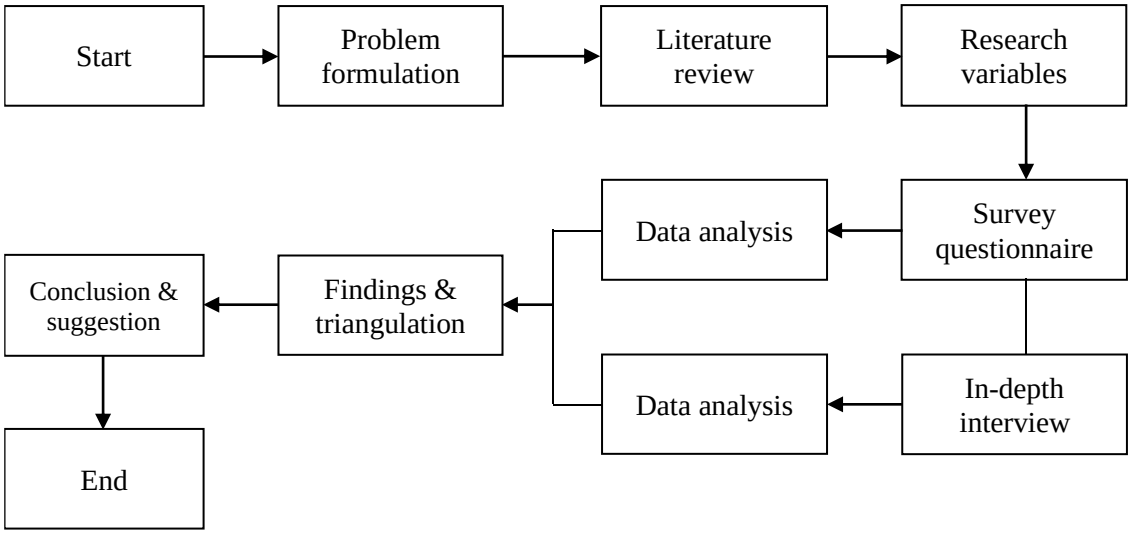
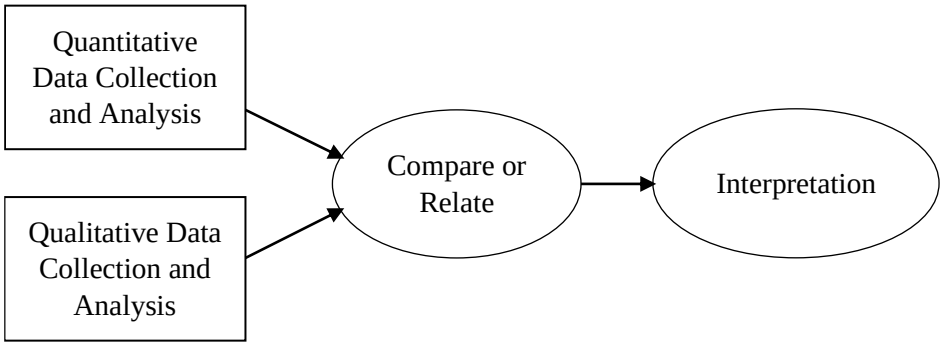


Figure 2. Research Steps

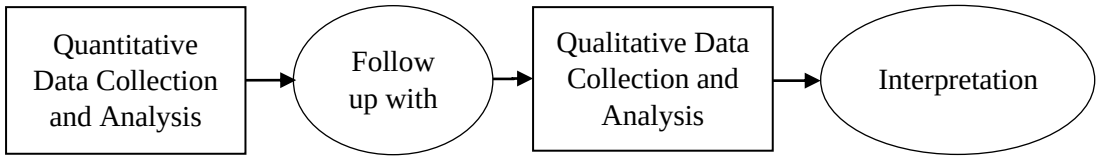
According to Creswell and Clark (2011), the four basic mixed methods designs are the convergent design, the explanatory design, the exploratory design, and the embedded design as shown in Figure 3. The convergent design was initially conceptualized as a "triangulation" design. In this design, the researcher collects and analyzes both quantitative and qualitative data during the same phase of the research process and with equal weight, and then merges the two sets of results into an overall interpretation. The explanatory design starts with the collection and analysis of quantitative data. The qualitative phase follows from the results of the quantitative phase. The researcher interprets how the qualitative results help to explain the quantitative results. In contrast to the explanatory design, the exploratory design begins with and prioritizes the collection and analysis of qualitative data in the first phase. Building from the exploratory results, the researcher conducts a second, quantitative

phase to test or generalize the initial findings. The researcher then interprets how the quantitative results build on the initial qualitative results. In an embedded design, the researcher may add a qualitative strand within a quantitative design, such as an experiment, or add a quantitative strand within a qualitative design, such as a case study. In the embedded design, the supplemental strand is added to enhance the overall design in some way.

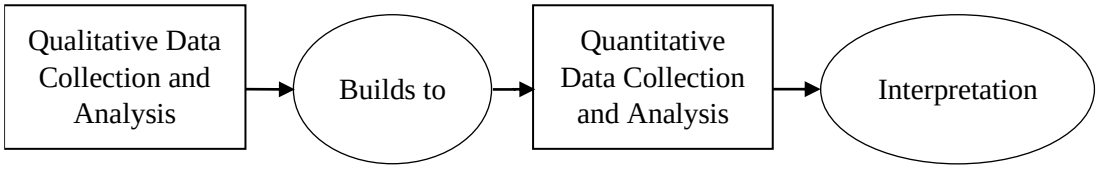
(a) The Convergent Design



(b) The Explanatory Design



(c) The Exploratory Design



(d) The Embedded Design

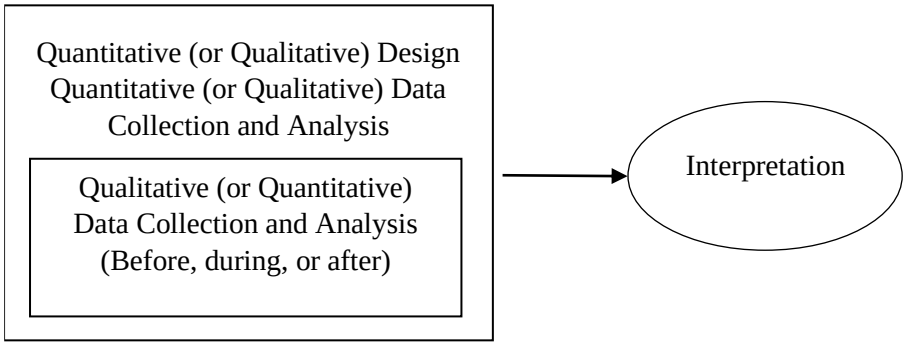


Figure 3. The Four Basic Mixed Methods Designs

The convergent mixed methods approach was selected for this study to gain a deep understanding of (1) the challenges faced by constructors during the design and construction process; (2) the delivery processes used and their impact; (3) the barriers and challenges in using BIM and BPS tools within the NZEB project context. The two parts of the study were as follows: (a) a survey was administered to generate the quantitative data, and (b) semi-structured interviews were conducted using a questionnaire to generate the qualitative data. Comparison of the qualitative data to the quantitative data through analysis would illuminate any inconsistencies or correlations and provide a complete picture of the data. Individual perceptions can be measured using a quantitative Likert-style instrument; however, experiences are best understood through individual narrative. Thus, this study incorporated both quantitative and qualitative data and used both quantitative and qualitative data analysis. After analysis of all qualitative and quantitative data was complete, the results of the analyses were compared for interpretation and explanation. Figure 4 shows a diagram depicting the convergent design of this study.

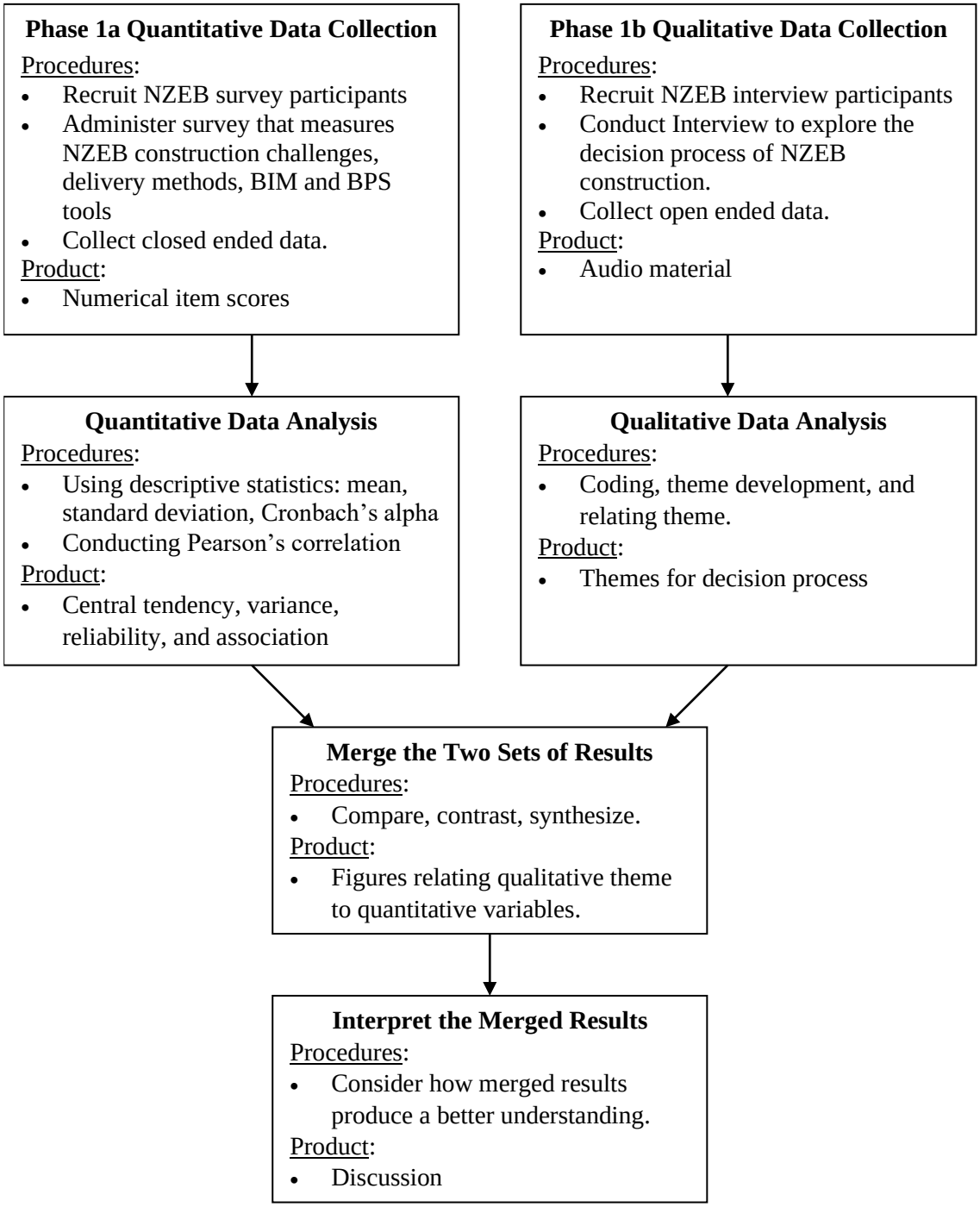


Figure 4. Convergent Study Phases

As indicated in the figure, there were four major steps in this study. First, both quantitative and qualitative data were collected about the topic of interest. The quantitative data was collected using a questionnaire and the qualitative data was collected through semi-structured interviews. These two types of data collection were concurrent but separate in Phase 1. The two types of data also had equal importance for addressing the study's research questions. Second, the two data sets were analyzed independently from each other using quantitative analytic procedures, such as descriptive statistics, and qualitative analytic procedures, such as coding and theme development. The results of the two data sets were then merged in Phase 3. This side-by-side comparison for merged data analysis involved presenting the quantitative results and the qualitative findings together in a discussion or in a summery table so that they could be easily compared. The presentation then became the means for conveying the merged results (Creswell and Clark, 2011). The final phase interpreted and discussed to what extent and in what ways the two sets of results converged, diverged, and related to each other.

Participants

The population of the study, the construction professionals who worked in NZEB projects, were recruited to participate in the study through purposive sampling. The purposive sampling technique is the deliberate choice of a participant with particular characteristics who will better be able to assist with the relevant research (Etikan, Musa, & Alkassim, 2016). In this research, the particular characteristics was the experience of working a NZEB projects, and respondents were general contractors, subcontractors, project managers, project engineers, architects, energy consultants,

owners, etc. There was no directory or list of NZEB constructors. So, the researcher first searched for literature on the NZEB construction projects of the United States from the online sources, such as living-future.org, energy.gov, usgbc.org, etc. From the projects' profile, the name of the stakeholders, (general contractors, architects, engineers) were identified. The researcher then went to the stakeholders' company website to find the contact information of the company's construction professionals. The researcher also collected the email addresses of the LEED certified constructors from usgbc.org directory. This way, a total 236 industry professionals were identified to recruit for the survey. The assumption was made that some of them had experience working on a NZEB project. An email was sent to the identified industry professionals explaining the study with a link to the Qualtrics survey questionnaire. Forty-nine professionals attempted the survey. A total of 29 completed responses were received in a timeframe of 9 months. 74% of the valid responders had industry experience of more than 20 years.

Context

The scope of the study was limited to the NZEB construction projects of the United States. Both vertical and horizontal construction were included for the study. The project delivery methods were not specified as the purpose of study was to gain a deep understanding of the barriers and challenges in actual delivery process, knowledge and skills to address these issues, and challenges in implementing BIM and BPS tools within the NZEB project context. The study was limited to the NZEB projects of the United States to gain uniformity and to avoid cultural difference between foreigners and domestic participants.

Procedures

The study procedures included the following three steps: (1) Create instruments (2) recruit participants, and (3) administer the study. The implementation procedures are diagrammed in Figure 5.

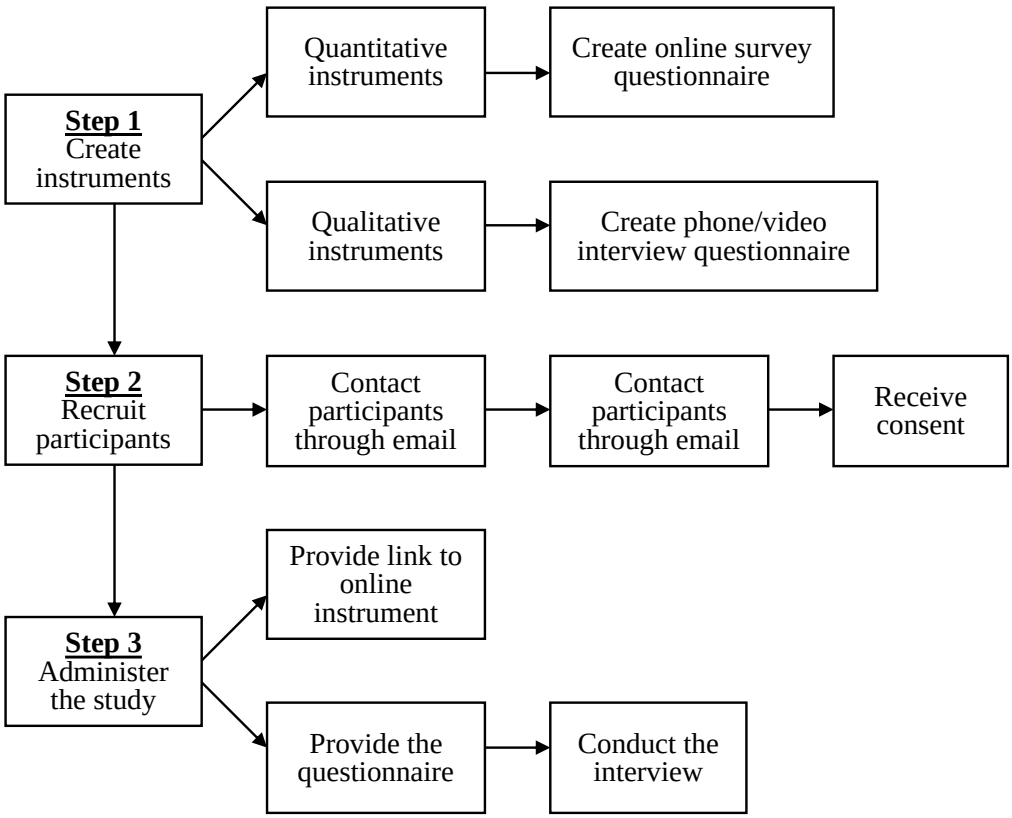


Figure 5. Study Procedures

Step 1: Create instruments

Instruments to gain a deep understanding of the experiences and perceptions of the NZEB construction professionals were created based on the convergent parallel mixed methods approach. An online survey questionnaire was created to collect the quantitative data. A semi-structured interview questionnaire was also created in this step to collect the qualitative data.

Step 2: Recruit participants

A brief overview of the study's purpose and link to the online instrument was provided in an email sent to the recruit participants. Participants were informed of the approximate time required to complete the study and were assured those responses would be kept confidential, participants needed to be at least 18 years of age, and participation in the research was voluntary.

Step 3: Administer the study

Participants were given the electronic address to access the online instrument in the Qualtrics™ survey tool. The first page of the instrument provided participants with information once again about the study purpose and procedures. A consent form followed, and participants were required to indicate their consent. After consent the participants started through the instrument, free to advance through sections at their own pace. When a participant reached the end of a section would automatically advance to the next section with the instructions. The participants who agreed to take part in a follow-up interview were provided a semi-structured questionnaire by the principal investigator in advance of the date the interview being administered. The interview was done through Skype™.

Data Collection Techniques

Quantitative Data Collection

Prior to collecting the quantitative data, the potential participants were given the informed consent form to let them know about the aim of the study, confidentiality of the data, and ethical issues; they were also assured that their information would be kept confidential. Only the construction professionals who filled out the informed consent

form were allowed to participate in the study. The study was carried out by receiving essential permissions from Institutional Review Board of the University of Oklahoma. The constructors who had practical experience in constructing NZEB projects were recruited to participate in the study. A survey questionnaire was designed to examine the Constructors' decision-support framework for Net Zero Energy Building (NZEB) projects based on an extensive literature review. The questionnaire consists of six sections: (1) general information soliciting demographic data of the respondents (Q1-Q4, Q23-Q24); (2) a list of potential barriers/challenges to the implementation of NZEB construction (Q5-Q10); (3) a list of management knowledge and skills to effectively deal with the challenges of NZEB construction (Q11-Q14); (4) a list of project delivery methods and their role in NZEB construction (Q15-Q16); (5) a list of potential barriers/challenges in implementing BIM on NZEB projects (Q17-Q18); (6) a list of BPS tools and their features for NZEB projects (Q19-Q21). A 5-point Likert scale was used to measure the perceived barriers and challenges in actual construction process, necessary knowledge and skills to address these challenges, and challenges in the implementation of BIM and BPS tools within the NZEB project context. A text box was provided at the end of the questionnaire to allow respondents to add any additional comment, if any.

Qualitative Data Collection

In the qualitative stage, the semi-structured interview form was used. The researcher used the semi-structured interview form to be able to ask additional probe questions to analyze the issue in depth and to understand the reasons behind participants' answers. The interview form was composed of three demographic

questions (Q1-Q3) and thirteen main questions (Q4-Q16) and additional probe questions, as necessary. Additional probing questions were asked to gain a deeper understanding of participants' views (Demir & Pismek, 2018). For example, the main questions of "What methods did you use to overcome project challenges?" and "Describe the approach taken for decision making when there were differences of opinions among the stakeholders?" were followed by probes like "Did you find it effective?", and "Can you explain it with concrete examples?" Among the thirteen main questions, Q4 was about the selected delivery methods and its impact on NZEB construction process which complemented the survey questions 16 and 17. Q5 asked about the project challenges and complemented the survey questions 5 to 11. Q6 to Q8 were about the decision-making process in NZEB construction. Q9 to Q11 were about the necessary management skills and knowledge to deal with the challenges faced on NZEB projects and complemented the survey questions 12 to 14. Q12 to Q15 of the interview questions explored the role and challenges of BIM and BPS tools in NZEB construction and complemented the survey questions 19, 21, and 22.

Data Analysis Strategy

Quantitative Data Analysis

Clason and Dormody (1994) described the difference between Likert-type items and Likert scales. They identified Likert-type items as single questions that use some aspect of the original Likert response alternatives. While multiple questions may be used in a research instrument, there is no attempt by the researcher to combine the responses from the items into a composite scale. Likert-type or frequency scales use fixed choice response formats and are designed to measure perceptions (Bowling, 1997;

Burns, & Grove, 1997). These ordinal scales measure levels of agreement/disagreement. A Likert-type scale assumes that the strength/intensity of experience is linear, i.e., on a continuum from strongly agree to strongly disagree and makes the assumption that attitudes can be measured. Respondents of this study were offered a choice of five pre-coded responses with the neutral point being neither agree nor disagree. Numbers assigned to Likert-type items express a "greater than" relationship; however, how much greater is not implied. Because of these conditions, Likert-type items fall into the ordinal measurement scale. Descriptive statistics recommended for ordinal measurement scale items include mean, mode or median for central tendency and frequencies for variability (Boone & Boone, 2012). As the study had a series of individual questions that have Likert response options for the participants to answer, the analysis used 1) mean *(M)* to measure central tendency, 2) standard deviation *(SD)* to measure dispersion, 3) Cronbach's alpha *(α)* to measures reliability or internal consistency, and 4) Pearson's Correlation Coefficient *(r)* to measure the association between two variables.

Qualitative Data Analysis

The researcher analyzed individual responses by participants to the open-ended questions to capture each individual's perception. A set of common questions asked to all the participants helped the researcher to characterize the perceptions of all the experts about particular areas of interest. Since the research objectives were to understand the decision processes of NZEBs, the unit of analysis in this case was the process described as a whole, specific key decision questions within each decision phase, and the specific key decision rationale.

According to Miles and Huberman (1994), to review a set of field notes, transcribed or synthesized, and to dissect them meaningfully, while keeping the relations between the parts intact, is the stuff of analysis. This step is where coding and other forms of ongoing, iterative reflection come in. “Codes are tags or labels for assigning units of meaning to the descriptive or inferential information compiled during a study.” One method of creating codes is creating a provisional “start list of codes,” that comes from the conceptual framework, list of research questions, hypothesis, problem areas, and/or key variables (Miles & Huberman, 1994).

Table 4. Start List of Codes

Theme/Category	Descriptive Label	Code	RQ
CHALLENGES		CH	1
	PLANNING RELATED	CH-PL	
	PROJECT RELARED	CH-PR	1
	CLIENT RELATED	CH-CL	1
	PROJECT TEAM RELATED	CH-PT	1
	LABOR RELATED	CH-LA	1
	MATERIAL AND EQUIPMENT RELATED	CH-ME	1
IMPACT OF CHALLENGES		IC	1
	ON SCHEDULE	IC-SC	1
	ON BUDGET	IC-BU	1
	ON QUALITY	IC-QU	1
MANAGEMENT KNOWLEDGE		MK	1
	COST	MK-COS	1
	SCHEDULE	MK-SC	1
	MATERIAL RESOURCE	MK-MR	1
	RISK	MK-RI	1
	COMMUNICATION	MK-COM	1
	STAKEHOLDER	MK-ST	1
	CONFLICT AND DISPUTE	MK-CD	1
	CLAIMS	MK-CL	1
	HUMAN RESOURCES	MK-HR	1
	HEALTH AND SAFETY	MK-HS	1
MANAGEMENT SKILLS		MS	1
	DECISION MAKING	MS-DM	1
	DELEGATION	MS-DE	1
	ANALYTICAL	MS-AN	1

	TEAMWORK	MS-TW	1
	PROBLEM SOLVING	MS-PS	1
	LEADERSHIP	MS-LS	1
	NEGOTIATION	MS-NE	1
	HUMAN BEHAVIOR	MS-HB	1
	CHAIRING MEETING	MS-CM	1
	PRESENTATION	MS-PR	1
PROFESSIONAL DEVELOPMENT		PD	1
	ON THE JOB EXPERIENCE	PD-JE	1
	EDUCATION	PD-ED	1
	TRAINING	PD-TR	1
	PROFESSIONAL CERTIFICATION	PD-PC	1
DECISION MAKING APPROACHES		DMA	1
	DECISION MATRIX	DMA-DM	1
	SCORING PROCESS	DMA-SP	1
	CONSENSUS	DMA-C	1
DELIVERY METHODS		DM	2
	DESIGN-BUILD	DM-DB	2
	INTERGRATED PROJECT DELIVERY	DM-IPD	2
	DESIGN-BID-BUILD	DM-DBB	2
	CM AT RISK	DM-CM	2
	ENGINEERS JOINT CONTRACT DOCUMENTS COMMITTEE (EJCDC)	DM-EJCDC	2
IMPACT OF PROJECT DELIVERY METHODS		ID	2
	ON COST MANAGEMENT	ID-CM	2
	ON COMMUNICATION MANAGEMENT	ID-COM	2
	ON SCHEDULE MANAGEMENT	ID-SC	2
	ON RISK MANAGEMENT	ID-RI	2
	ON CONFLICT AND RISK MANAGEMENT	ID-CR	2
	ON STAKEHOLDER MANAGEMENT	ID-ST	2
	ON MATERIALS RESOURCES MANAGEMENT	ID-MR	2
	ON CLAIMS MANAGEMENT	ID-CL	2
	ON HUMAN RESOURCE MANAGEMENT	ID-HR	2
	ON HEALTH AND SAFETY MANAGEMENT	ID-HS	2
		BIM	3
	LACK OF CLIENT DEMAND	BIM-CD	3

BIM IMPLEMENTATION CHALLENGES	ORGANIZATIONAL CHALLENGES	BIM-OC	3
	INDUSTRY'S RESISTANCE	BIM-IR	3
	LONGER TIME TO ADAPT	BIM-LT	3
	LACK OF UNDERSTANDING OF BIM AND SUSTAINABILITY WORKFLOW	BIM-LU	3
	INADEQUACY OF KSA FROM THE WORKPLACE	BIM-IN	3
	HIGH COST	BIM-HC	3
	HIGH INITIAL INVESTMENT IN STAFF TRAINING	BIM-II	3
	INCOMPATIBILITY WITH DIFFERENT SOFTWARE	BIM-DS	3
	LACK OF SUPPORTING SUSTAINABILITY ANALYSIS TOOLS	BIM-ST	3
BPS TOOLS		BPS	3
	EQUEST	BPS-EQ	3
	TRANE TRACE	BPS-TT	3
	ENERGYPLUS	BPS-EP	3
BPS FEATURES		BF	3
	USABILITY	BF-US	3
	INTELLIGENCE	BF-INTEL	3
	INTEROPERABILITY	BF-INTER	3
	ACCURACY	BF-ACC	3
	PROCESS ADAPTABILITY	BF-PA	3

In the Start List of Codes (Table 4), the first column shows the general categories, and the second column has the short descriptive labels. The third column shows the codes, and the fourth keys the code to the research question (RQ) or sub question from which it derives. All the qualitative data collected in the form of interview transcripts were brought into MAXQDA, an analytical software, and analyzed as a whole for the entire research.

Chapter 4: Results

The objectives of this research were to identify challenges faced by constructors who execute NZEB construction projects and to determine the knowledge areas and skills that are necessary to respond to such challenges. As mentioned in Chapter 3, a convergent mixed methods design was adopted to enable an in-depth understanding of the research objectives. The two parts of the study were as follows: (a) a survey was administered to generate the quantitative data, and (b) semi-structured interviews were conducted using a questionnaire to generate the qualitative data. The convergent mixed methods approach was selected for this study to gain a deep understanding of (1) the challenges faced by constructors during the design and construction process; (2) the delivery processes used and their impact; (3) the barriers and challenges in using BIM and BPS tools within the NZEB project context.

A directory of NZEB constructors and projects does not exist, therefore, the researcher first searched for literature on the NZEB construction projects in the United States from online sources, such as newbuildings.org, living-future.org, energy.gov, and usgbc.org. From the search, 21 NZEB projects were identified. Purposive sampling was then used to recruit industry professionals with NZEB project experience as the study's participants. The purposive sampling technique is the deliberate choice of a participant with particular characteristics who will better be able to assist with the relevant research (Etikan, Musa, & Alkassim, 2016). For this study, the characteristic used was NZEB project experience as a: general contractor; subcontractor; project manager; estimator; architect; MEP engineer, energy consultant; sustainability consultant; project engineer; and owner.

Using the online information about NZEB projects, a search of projects with names of stakeholders were identified. Next, the researcher searched the stakeholders' company website to find the contact information of the company's construction professionals. The researcher also collected the email addresses of the LEED certified constructors from United States Green Building Council directory. In the search for participants with the appropriate experience, the assumption was made that if an individual did not have NZEB experience they would forward the request to a colleague who had NZEB experience within the organization.

An email request to participate in the study was sent to 236 industry professionals explaining the study with a link to the Qualtrics™ survey questionnaire, but 47 emails were not delivered because some email addresses had permanent fatal errors and some email addresses were not found. 189 professionals received the email. Forty-nine of them entered the survey, but eleven had not worked on a NZEB project, therefore they could not continue the survey. Nine participants indicated that they had NZEB experience but did not complete the survey. A total of 29 completed surveys were received in a timeframe of 9 months. Two participants completed the survey twice. Their second completed surveys were not considered for the analysis. So, the total accepted completed surveys were 27. Twenty of the participants had industry experience of more than 20 years. Most of the participants mentioned more than one role on NZEB projects. The demographic data for the participants is presented in Table 5.

Table 5. Participant Demographic Characteristics

Role on NZEB Projects	n
Energy Consultant	10
Project Manager	9

MEP Engineer	5
Architect	4
General Contractor	3
Owner	3
Owner's Representative	1
Estimator	1
Specialty Contractor/Subcontractor	1
Other (Sustainability Planner, NZE Coach, LEED Consultant, LBC Consultant, Design-Build Project Executive, Green Rater)	10

Experience in years	n
20+	20
16-20	2
11-15	3
6-10	2
0-5	0

Position and Organization Name
AECOM
CEO, The Green Engineer, Inc.
Principal, Integral Group
Developer
Director of Sustainability - 11 years with Jacobs
Director of Sustainable Design, BR+A
Senior Project Manager, Design and Design Engineering, LendLease
Managing Principal
NE Preconstruction Manager, DPR Construction
NZE Integrator, Stok
Senior Project Manager, Bright Green Strategies, Inc.
President, Emery Mechanical Engineering
Principal
Principal, Consilience LLC
Principal, Stok
Project Executive, C. W. Driver
Senior Director, Linnean Solutions
Senior ME Engineer
Senior VP, LHB, Corp.
Sustainability Manager, California Department of General Services
Vice President
Vice President, National Collaboration Director, JE Dunn Construction
Founder/Principal, Design AVEnues LLC
National Director of Sustainable Design

The following map (Figure 6) shows the location of the NZEB projects the study participants worked on. There were two more projects not shown in the map, one in Ontario, Canada and the other in South Korea.

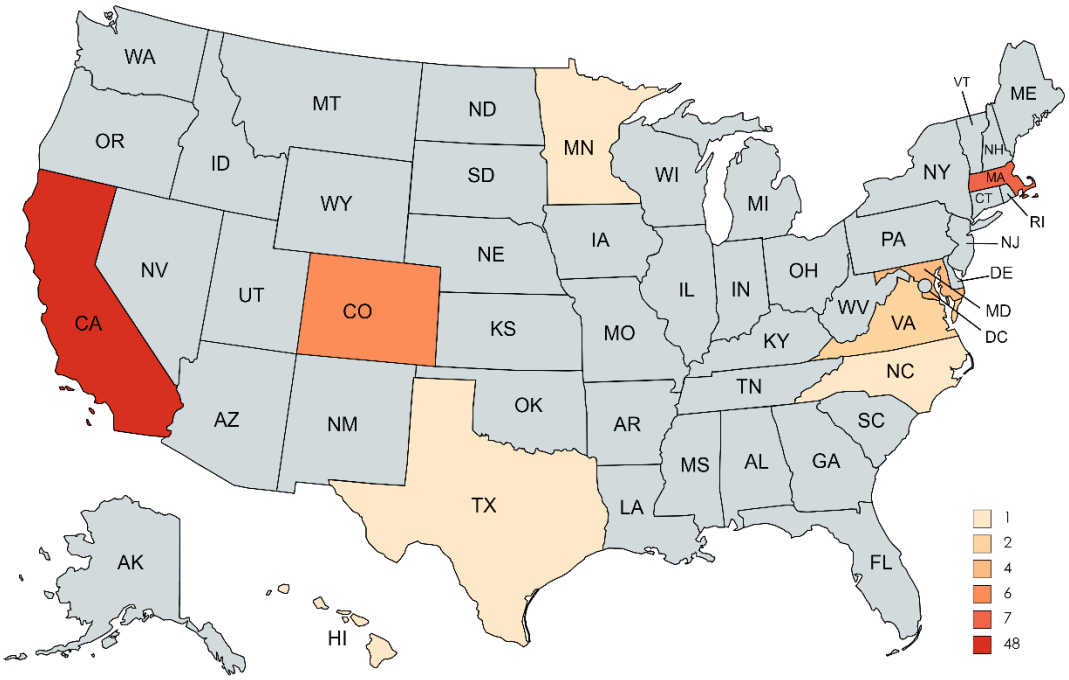


Figure 6. Location of the projects

Participants were given the electronic address to access the online instrument in the Qualtrics™ survey tool. The first page of the instrument provided participants with information about the study purpose and procedures. A consent form followed, and participants were required to indicate their consent. After consent the participants started through the instrument, free to advance through sections at their own pace. When a participant reached the end of a section they would automatically advance to the next section with the instructions. At the end of the survey questionnaire, the participants were asked if they wanted to take part in a follow-up interview. The five participants who agreed to take part in a follow-up interview were provided a

questionnaire by the principal investigator in advance of the semi-structured interview. The internet platform Skype™ was used for all interviews.

Quantitative Analysis

The survey consisted of 24 questions in six sections:

Section 1: This section consisted of six questions soliciting general information and demographic data from the participants. (Q1-Q4, Q23-Q24)

Section 2: The second section comprised a list of potential challenges to the implementation of NZEB construction (Q5-Q10). The challenges were listed under several categories as follows: (1) planning related, (2) project related, (3) client related, (4) project team related, (5) labor related, and (6) material and equipment related. This section adapted the questionnaire developed by Hwang and Ng for their 2013 study, *Project management knowledge and skills for green construction: Overcoming challenges*. Based on a comprehensive literature review and interviews with industry experts, Hwang and Ng (2013) summarized the major challenges that project managers face in managing green construction projects and developed the questionnaire. A list of NZEB project objectives was also included in this section (Q11).

Section 3: This section consisted of a list of management knowledge areas and management skills to effectively deal with the challenges of NZEB construction (Q12-Q13). Hwang and Ng for their 2013 study, *Project management knowledge and skills for green construction: Overcoming challenges*, developed a pre-survey questionnaire to validate 39 management knowledge areas and management skills that had been identified through the literature review. Using the mean value ranking method, they selected the top 20 knowledge areas and skills. These 20 knowledge areas and skills

were adopted in this section. Q14 asked about professional development and Q15 asked to write in how contractors address barriers on NZEB projects.

Section 4: This section consisted of a list of project delivery methods (Q16) and a list of project management tasks (Q17). The participants were asked to rate the project delivery methods for NZEB construction and how the delivery methods influence the project management tasks on NZEB projects.

Section 5: In this section, Q18 asked if the participants used Building Information Modeling (BIM) in any NZEB projects. A list of potential challenges in implementing BIM on NZEB projects (Q19) was included to be rated by the participants. This section adapted the questionnaire developed by Olawumi, Chan, Wong and Chan for their 2018 study, *Barriers to the integration of BIM and sustainability practices in construction projects: A Delphi survey of international experts*. Based on a comprehensive literature review, Olawumi et al. (2018) summarized the major challenges in implementing BIM in construction projects and developed the questionnaire.

Section 6: In section six, participants were asked if they used any building performance simulation (BPS) tool in NZEB projects (Q20). A list of BPS tools (Q21) and their features for NZEB projects (Q22) were included in this section (Attia & De Herde, 2011).

A 5-point Likert scale was used for the questionnaire to measure participants' responses with a number between '1' to '5', where '1' indicated the lowest and '5' indicated the highest level of attitudes or opinions. In this survey, Q5 to Q10 asked participants to rate NZEB construction project challenges from "not at all" labeled as 1

to “extreme” labeled as 5. Q11 asked participants to rate the extent to which the challenges influence the NZEB project objectives from “no impact” labeled as 1 to “extreme impact” labeled as 5. Q12 and Q13 asked participants to rate the management knowledge areas and management skills to effectively deal with the challenges of NZEB construction. Q14 asked participants to rate the level of importance of different means relating to NZEB professional development. All these three questions measured the level of importance from “not important” labeled as 1 to “extremely important” labeled as 5. Q16 asked participants to rate the NZEB project delivery methods from “not suitable” labeled as 1 to “extremely suitable” labeled as 5. Q17 asked participants to rate the extent to which the project delivery methods influence the NZEB project management tasks. Q19 asked participants to rate the challenges in implementing BIM on NZEB projects. Both these questions measured the level of agreement from “not at all” labeled as 1 to “extreme” labeled as 5. Q21 asked participants to rate BPS tools for NZEB projects from “not suitable” labeled as 1 to “extremely suitable” labeled as 5. Q22 asked participants to indicate the level of importance of the BPS tool features on NZEB projects from “not important” labeled as 1 to “extremely important” labeled as 5. The summary of the types of rating scales is provided in Table 6.

Table 6. Types of Rating Scales

	1	2	3	4	5
Q5-Q10, Q17, Q19	Not at all	Minimal	Moderate	Significant	Extreme
Q11	No impact	Minimal impact	Moderate impact	Significant impact	Extreme impact
Q12-Q14, Q22	Not important	Minimally important	Moderately important	Important	Extremely important
Q16, Q21	Not suitable	Minimally suitable	Moderately suitable	Suitable	Extremely suitable

Data Analysis

The data analyses used for this study were 1) means *(M)* to measure central tendency, 2) standard deviation *(SD)* to measure dispersion, 3) Cronbach's alpha *(α)* to measures reliability or internal consistency, and 4) Pearson's Correlation Coefficient *(r)* to measure the association between two variables.

1. Mean *(M)*:

The responses were then numerically ranked based on their mean value. Rank ordering provides a relative placement of units to each other without regard to the relative distance between the evaluations (Allen, 2017).

2. Standard Deviation *(SD)*:

According to Othman et al. (2011), item standard deviation is applied to test whether the items in each hypothesized grouping contain approximately the same proportion of information about the construct being measured. It is also used to examine whether the items have roughly equal standard deviations, such that they contribute equally to the total scale score. In other words, items should have roughly equivalent standard deviations within a Likert scale. A rule of thumb is that the ratio of the maximum standard deviation to the minimum standard deviation should be about 2:1 (Othman et al., 2011).

3. Cronbach's alpha *(α)*:

Ursachi et al. (2015) suggest that an instrument's internal consistency is based on the correlation between different items of the same test. This correlation indicates if a number of items that are supposed to measure the same construct produce similar scores. For Cronbach's alpha, computed with correlations between all pairs of items,

internal consistency can vary between zero and one. A general accepted rule is that α of 0.6-0.7 indicates an acceptable level of reliability, and 0.8 or greater a very good level. (Ursachi et al., 2015).

4. Pearson's Correlation Coefficient *(r)*:

According to Obilor and Amadi (2018), correlation involves the measurement of association, or relationship, or correlation between two variables to ascertain whether they are positively or negatively related, or not related in any way whatsoever. To measure association or relationship between variables we use correlation coefficients to express the degree of association or relationship. Correlation coefficients can be high or low (magnitude), and positive or negative (direction). Correlation coefficients vary from -1 to +1: whereas -1 and +1 indicate perfect negative and perfect positive correlation coefficients respectively, a correlation coefficient of 0 implies no correlation. Further, correlation coefficients lower that 0.40 (whether negative or positive 0.40) are said to be low, between 0.40 and 0.60 are moderate, and above 0.60 are high (Obilor & Amadi, 2018).

Results from the quantitative data analyses are reported in the following two sections. A detailed discussion about the descriptive statistics is provided in the first section. Correlations between variables are discussed in the next section.

Descriptive Statistics

1. Challenges

This section presents the results of the challenges that constructors face during NZEB construction project management. Table 7 displays the results. Challenges are organized into six categories. Their mean scores *(M)*, standard deviation *(SD)*, count

(N), and ranks within *(RW)* and ranks across the categories *(RA)* are included in the table.

Table 7. Analysis Summary: Challenges

Category	*Challenge*	*M*	*SD*	*N*	*RW*	*RA*
Planning-related	Difficulty in comprehending the NZEB specifications in the contract details	3.00	1.02	27	1	9
	Planning of NZEB construction technique	2.96	0.79	27	2	10
	Planning of NZEB construction sequence	2.56	0.79	27	3	19
	Lengthy approval process for new green/NZEB technologies within the organization	2.52	1.00	27	4	21
	Adoption of different contract forms of project delivery	2.22	0.96	27	5	23
Project-related	Difficulty in the selection of subcontractors in providing NZEB construction service	3.04	0.92	27	1	8
	More alteration and variation with the design during the construction process	2.78	1.03	27	2	11
	More time is required to implement green/NZEB construction practices onsite	2.74	1.07	27	3	13
	Difficulty in assessing the progress of completion in NZEB Construction	2.19	0.94	27	4	24
Client-related	Level of risk the client is willing to take in Green/NZEB technologies	3.19	0.86	27	1	4
	Client uses a lot of time in making decision	3.07	0.86	27	2	6
	Special request from client pertaining to specified Green/NZEB technologies to be used	2.73	0.86	26	3	14
	Required date of completion	2.63	0.99	27	4	16
	Objective of the building project	2.52	0.92	27	5	21
Project team-related	Lack of communication among project team members	2.78	1.1	27	1	11
	Frequent meeting with green specialists	2.59	0.95	27	2	18
	Conflict with the architect over the type of material to be used	2.56	0.83	27	3	19
	Conflict of interest between consultant and project manager	2.19	1.06	27	4	24
	Green consultant's delay in providing information	1.85	0.76	27	5	26
Labor-related	Workers' unawareness of the correct methods and procedures	3.37	1.19	27	1	1
	Reluctance to change from traditional practices	3.33	1.15	27	2	2
	Lack of the technical skill regarding Green/NZEB technologies and techniques	3.30	1.18	27	3	3
Material and Equipment-related	High cost of green/NZEB material and equipment	3.11	0.74	27	1	5
	Uncertainty with green/NZEB material and equipment	3.07	0.94	27	2	6

Decision on different green/NZEB material and equipment	2.73	0.90	26	3	14
Availability of green/NZEB material and equipment	2.63	0.82	27	4	16

The results in Table 7 reveal that the maximum *SD* is 1.19 for workers' unawareness of the correct methods and procedures, and the minimum *SD* is 0.74 for high cost of green/NZEB material and equipment. The ratio of the maximum *SD* to the minimum *SD* is less than 2:1. Hence, the items contribute equally to the total scale score. The Cronbach's alpha *(α)* was 0.94. *α* measures reliability, or internal consistency. So, α of 0.94 indicates a very good level internal consistency.

The ten most rated challenges based on their mean *(M)* values across categories (Figure 7) are discussed in the following section.

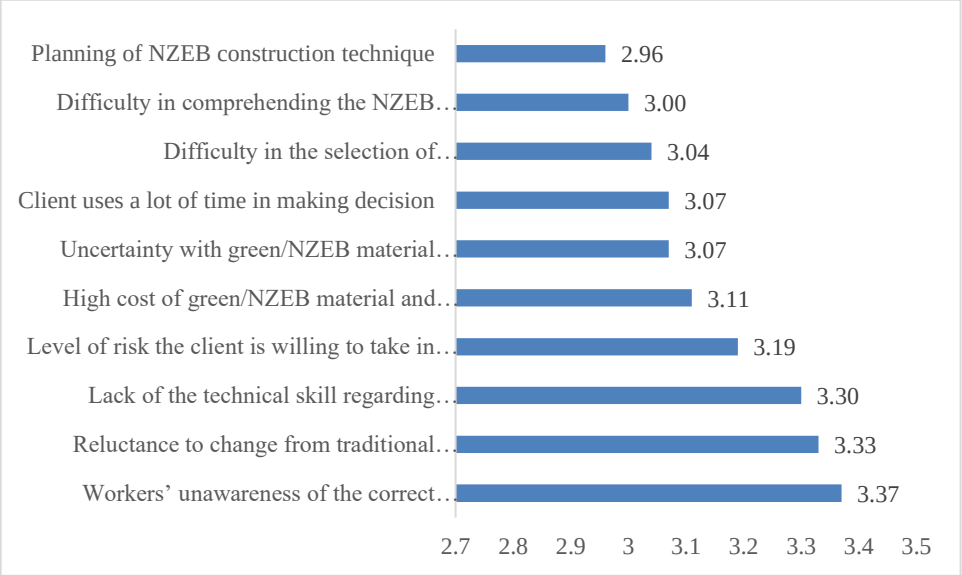


Figure 7. The top challenges

a) Workers' unawareness of the correct methods and procedures *(M=3.37)*

According to Shi et al. (2013), awareness of green/NZEB construction is closely related to the public awareness of environmental issues. At present, the knowledge and cognition on sustainability of all parties, including policy makers, owners, designers,

construction personnel and the public need to be further enhanced. The project managers have an important role in this regard. Zhao et al. (2016) mentioned that in the construction industry, a project manager can be deemed a leader because he/she has the authority to delegate work tasks to his/her project team and to make important decisions on site. Although the project managers may not directly deal with the workers on site, their work plays a significant role in the success of the project. Project managers have to provide appropriate and timely training for their workers and in addition to other topics, some workers may need training on green/NZEB construction (Hwang & Ng, 2013).

b) Reluctance to change from traditional practices *(M=3.33)*

According to Shi et al. (2013), the unwillingness of industry practitioners to change the conventional way of specifying existing methods and processes became a challenge. The limitation of the scope and applicability of new products and new technologies and associated cost may force industry practitioners to move back to traditional construction methods. Shi et al (2013) emphasized the role of the project managers in enhancing the awareness of the industry practitioners to both the costs and the benefits associated with green/NZEB construction.

c) Lack of the technical skill regarding Green/NZEB technologies and techniques *(M=3.30)*

The lack of knowledge on green/NZEB technology and the durability of green/NZEB materials is a significant barrier preventing the construction industry from implementing the strategies and specifying green/NZEB construction (Shi et al., 2013). To address this challenge, contractors and suppliers should be engaged during early

stage of construction projects due to their knowledge on the environmental issues associated with construction activities, building materials and plants (Shi et al., 2013).

d) Level of risk the client is willing to take in Green/NZEB technologies *(M=3.19)*

According to Hwang and Ng (2013), project managers are responsible for ensuring that the NZEB technologies applied in the project are safe, especially if the client has a low threshold for risk. In some cases, green/NZEB consultants may try to convince the client to adopt a particular system (Hwang & Ng, 2013).

e) High cost of green/NZEB material and equipment *(M=3.11)*

As compared to conventional projects, green projects tend to cost more to construct (Hwang & Ng, 2013). To respond to this challenge, selection of the green/NZEB materials has to be cost-conscious.

f) Uncertainty with green/NZEB material and equipment *(M=3.07)*

Unlike conventional construction materials, many green/NZEB materials may not be available locally. Green/NZEB materials and equipment are crucial for achieving green/NZEB construction goal. Uncertainty in the performance of green materials and equipment often leads to a reduction in the efficiency of green construction (Hwang & Ng, 2013).

g) Client uses a lot of time in making decision *(M=3.07)*

The client may need more than the usual amount of time to make decisions on whether or not to implement such a system. According to Shi er al. (2013), many developers are still reluctant and uncertain about the adopting sustainability in their projects due to limited understanding and the pursuit of cost reductions.

h) Difficulty in the selection of subcontractors in providing NZEB construction service *(M=3.04)*

According to Hwang and Ng (2013), it is likely that there is insufficient performance information for subcontractors who are involved in NZEB construction projects. As a result, the selection process becomes tougher and takes more time.

i) Difficulty in comprehending the NZEB specifications in the contract details *(M=3.00)*

According to Kubba (2017), a fundamental change in specification writing has been witnessed in recent years due to technology and green-related practices, and efficient information retrieval is only possible when a standard filing system is used by everyone. The Construction Specifications Institute's (CSI) MasterFormat provides such a standard filing and retrieval scheme which is available in electronic format, and green building specifications can be easily incorporated into it.

j) Planning of NZRB Construction Technique *(M=2.96)*

A project manager implements a project plan by authorizing the execution of activities to produce project deliverables (Hwang & Ng, 2013). Often, green/NZEB technologies require complicated techniques and construction processes. If complexities are not addressed well, it may affect the NZEB project goal.

2. Impact of challenges on NZEB project objectives

The top three challenges that constructors face during the NZEB construction project management are all labor related. Those are (1) Workers' unawareness of the correct methods and procedures; (2) Reluctance to change from traditional practices; and (3) Lack of the technical skill regarding Green/NZEB technologies and techniques.

The participants were asked to rate the extent to which these challenges influence the NZEB project objectives. Table 8 summarizes the results.

Table 8. Analysis Summary: Impact of Challenges on Objectives

Objective	*M*	*SD*	*N*	*Rank*
Budget	3.52	0.96	27	1
Schedule	2.96	0.96	27	2
Quality	2.93	1.12	27	3

The results in Table 8 show that the maximum *SD* is *1.12* for Quality, and the minimum *SD* is *0.96* for both budget and schedule. According to Othman et al. (2011), a rule of thumb is that the ratio of the maximum *SD* to the minimum *SD* should be about 2:1. Here, the ratio of the maximum *SD* to the minimum *SD* is less than 2:1. Hence, the items contribute equally to the total scale score. The Cronbach's alpha *(α)* was computed and found as 0.67. Ursachi et al. (2015) suggest that α of 0.6-0.7 indicates an acceptable level of reliability.

The top two NZEB project objectives that are impacted by challenges are budget *(M=3.52)* and schedule *(M=2.96)*. According to Whang and Ng (2013), green/NZEB projects tend to cost more (up to 25%) to construct compared to conventional projects. The higher costs are due to design complexity, and the modeling costs needed to integrate green/NZEB practices into projects. Higher costs are also associated with green materials and using green construction technologies. The higher costs of green/NZEB construction directly affect the allocated budget (Whang & Ng, 2013)

Shi et al. (2013) stated that the schedule serves as a crucial benchmark for the performance and cost of green/NZEB construction projects. Green/NZEB construction demands integration of sustainable technologies and interaction with other building

components. Hwang and Ng (2013) argued that delays will be caused if this issue is not taken into consideration thoroughly.

3. Knowledge areas and skills to meet the challenges

This section presents the analysis of the knowledge areas and skills that constructors need to effectively deal with the challenges of NZEB construction. Table 9 and 10 summarize the survey results.

Table 9. Analysis Summary: Knowledge

Knowledge	*M*	*SD*	*N*	*Rank*
Cost Management	3.63	0.78	27	1
Schedule Management and Planning	3.63	0.82	27	1
Communication Management	3.63	0.87	27	1
Stakeholder Management	3.52	0.92	27	4
Materials Resource Management	3.30	0.81	27	5
Risk Management	3.15	0.89	27	6
Conflict and Dispute Management	2.85	0.93	27	7
Health and Safety Management	2.48	1.07	27	8
Claims Management	2.41	0.87	27	9
Human Resources Management	2.30	0.97	27	10

The results show that the maximum *SD* is *1.07* for health and safety management, and the minimum *SD* is *0.78* for cost management. The ratio of the maximum *SD* to the minimum *SD* is less than *2:1*. Hence, the items contribute equally to the total scale score. The Cronbach's alpha *(α)* was computed and found as *0.91* which indicates a very good level of reliability.

As shown in Table 9, the survey responses revealed that the three areas of knowledge are equally required for industry professionals to deal with the NZEB projects challenges. The knowledge areas were (1) cost management; (2) schedule management/planning; and (3) communication management *(M=3.63)*.

Cost management activities include planning, estimating, budgeting, and controlling the costs of the project. All these activities ensure the lowest overall project

cost possible consistent with the owner's investment objectives. As compared to conventional projects, green/NZEB projects tend to cost more to construct. The higher costs are due to design complexity, and the modeling costs needed to integrate green/NZEB practices into projects (Hasan, 2017). This increased cost affects the performance of project managers, as they must manage and deliver the project within the budget constraint.

Schedule management and planning is a crucial activity for the success of any construction project. However, NZEB building projects progressively incorporate more advanced and intricate systems. At the pre-construction stage, the impact of the elements on each system must be considered. A failure to consider the integration of NZEB technologies and its impact on other building elements results in construction conflicts, leading to delays (Hwang and Ng, 2013). That being the case, sequencing for NZEB construction requires to be more detailed when planning the project.

Communicating involves the exchange of information which drives innovation, brings project stakeholders to both business and project interfaces, and works towards achieving project goals. According to Yap, Abdul-Rahman, and Chen (2017), poor communication between team members is a major cause for project overruns, rework, and disputes. Communications management facilitates the creation of information, distribution, receipt, acknowledgement and understanding (Senaratne and Ruwanpura, 2016). Effective communication management plan encourages collaboration in project team which also promotes active participation in decision making (Livesey, 2016).

Table 10. Analysis Summary: Skills

Skill	*M*	*SD*	*N*	*Rank*
Teamwork	3.93	0.77	27	1
Leadership	3.81	0.72	27	2

Problem Solving	3.74	0.84	27	3
Decision Making	3.63	0.87	27	4
Analytical	3.33	0.77	27	5
Human Behavior	3.19	0.82	27	6
Delegation	3.11	0.79	27	7
Negotiation	3.04	0.88	27	8
Chairing Meetings	2.81	0.90	27	9
Presentation	2.78	0.87	27	10

The results show that the maximum *SD* is *0.90* for chairing meetings, and the minimum *SD* is *0.72* for leadership. The ratio of the maximum *SD* to the minimum *SD* is less than 2:1. Hence, the items contribute equally to the total scale score. The Cronbach's alpha (α) was computed and found as 0.88 which indicates a very good level of reliability.

Teamwork was found to be the most important skill required to address the NZEB project challenges *(M=3.93),* followed by leadership skill *(M=3.81)* and problem-solving skill *(M=3.74).* Since challenges are related to the project team, it is reasonable that project managers who are equipped with leadership and good team building skills could enhance team cohesiveness, improving the overall team performance (Hwang & Ng, 2013).

Construction project teams are unique entities, created with inter-disciplinary players, varying roles, responsibilities, goals, and objectives. Collaboration and teamwork are therefore crucial to minimize errors, time delays and rework. To enhance teamwork and performance outcomes, Salas et al. (2015) suggested some interventions, such as conducting team cross-training and team building prior beginning the project, self-correction during the performance episode, and debriefs and huddles after completing the work in recognizing where teams were efficient as well as where improvement can be made.

The organizational leadership of the construction industry requires one have the knowledge and skills to take bold steps to move beyond efficiency, compliance or just being green, to a higher level of performance due to the significant negative impacts construction activities can cause (Hwang & Ng, 2013). Leaders have a significant role to play as the industry undertakes its critical role in the efforts to attain sustainable development. According to Opoku, Cruickshank, and Ahmed (2015), leadership has a key role in driving the sustainability agenda within their organizations by spearheading the formulation of policies, devising procedures, and disseminating best practice throughout the organization.

Problem solving is an activity in which a learner perceives a discrepancy between a current state and a desired goal state, recognizes that this discrepancy does not have an obvious or routine solution, and subsequently tries to act upon the given situation to achieve that goal state (Hesse et al., 2015). The problems may be technical, managerial, or interpersonal. Hesse et al. (2015) stated that the difference between individual and collaborative problem solving is that in collaboration each of these steps is directly observable. Participants need to exchange and share their identification of parts of the problem, their interpretation of the connections between the parts, relationships between action and effect (rules) and the generalizations they propose in search of a solution.

4. Professional development

The development of the requisite knowledge and skills have traditionally relied on academic degree programs that reflect a technological content. To ensure their continued relevance in the sustainable construction industry, constructors often rely on

various learning activities, such as training, and professional certification. Table 11 lists the different learning mechanisms for professional development.

Table 11. Analysis Summary: Professional Development

Professional Development	*M*	*SD*	*N*	*Rank*
On the job experience	4.00	0.61	27	1
Training	3.67	0.77	27	2
Education	3.48	0.63	27	3
Professional Certification	2.67	0.82	27	4

The results show that the maximum *SD* is *0.82* for professional certification, and the minimum *SD* is *0.61* for on-the-job experience. The ratio of the maximum *SD* to the minimum *SD* is less than 2:1. Hence, the items contribute equally to the total scale score. The Cronbach's alpha *(α)* was computed and found as 0.56 which is below the accepted level of reliability. However, as there were only four items in this analysis, a low value of alpha could be due to that reason (Tavakol & Dennick, 2011).

The participants cited on the job experience as the most effective mean of professional development *(M= 4.00)* to work in NZEB construction. Training was ranked second *(M=3.67)*, followed by education *(M=3.48)*. The contribution of academic education to the competency of NZEB constructors was rated lower than that of formal industry training attended provided by employers. Similarly, the perceived contribution of industry training was outranked by that of experiences on the job site. This is indicative of the important role of experience for achieving skills and competency in construction project management, and to address the changing conditions and requirements that the NZEB industry environment presents from day to day.

5. Delivery methods and their impacts on management tasks

This section presents the results of the survey analysis of delivery methods and their influence on management tasks. Tables 12 and 13 list the delivery methods and management tasks, respectively.

Table 12. Analysis Summary: Delivery Method

Delivery Method	*M*	*SD*	*N*	*Rank*
Integrated Project Delivery (IPD)	4.23	0.70	26	1
Design-Build	3.54	1.22	26	2
CM at Risk (CMAR)	3.21	0.96	24	3
Design-Bid-Build	3.04	1.32	26	4
Engineers Joint Contract Documents Committee	2.78	1.03	18	5

The results show that the maximum *SD* is *1.32* for design-bid-build, and the minimum *SD* is *0.70* for IPD. The ratio of the maximum *SD* to the minimum *SD* is less than 2:1. Hence, the items contribute equally to the total scale score. The Cronbach's alpha *(α)* was *0.60* which indicates an accepted level of reliability.

Integrated Project Delivery (IPD) method was cited as the most preferred delivery method *(M=4.23)*. The second ranked delivery method was Design-Build *(M=3.54)*, followed by CM at Risk *(M=3.21)*. These delivery methods allow constructors to work more collaboratively, which is essential for the success of NZEB projects.

Table 13. Analysis Summary: Impact of Delivery Methods on Management Tasks

Project Management Tasks	*M*	*SD*	*N*	*Rank*
Cost Management	4.00	0.75	25	1
Communication Management	3.88	0.65	25	2
Schedule Management and Planning	3.88	0.67	24	3
Risk Management	3.60	0.69	25	4
Conflict and Dispute Management	3.56	0.85	25	5
Stakeholder Management	3.52	0.90	25	6
Materials Resource Management	3.20	0.98	25	7
Claims Management	3.00	1.10	25	8
Health and Safety Management	2.48	0.85	25	9
Human Resources Management	2.44	0.85	25	10

The results show that the maximum *SD* is *1.10* for claims management, and the minimum *SD* is *0.65* for communication management. The ratio of the maximum *SD* to the minimum *SD* is less than 2:1. Hence, the items contribute equally to the total scale score. The Cronbach's alpha (α) was computed and found as *0.60* which indicates an accepted level of reliability.

The top 3 management tasks that are impacted by the chosen delivery method are cost management *(M=4.00),* communication management *(M=3.88),* and schedule management and planning *(M=3.88).* In a collaborative work environment, communication among the professionals is enhanced. Teamwork and collaboration among the constructors are prerequisites for the successful completion of NZEB projects in terms of cost management and sequencing and planning the construction work.

6. Challenges in implementing BIM

This section presents the barriers and challenges in BIM implementation on NZEB construction projects. Table 14 shows the survey results. It was found that industry's resistance to change from traditional working practices was the most cited challenge *(M=3.20)*. The second ranked challenges were inadequate in-depth expertise and know-how to operate sustainability related analysis software program, and high initial investment in staff training costs *(M=3.15).*

Table 14. Analysis Summary: BIM Implementation

Challenges	*M*	*SD*	*N*	*Rank*
Industry's resistance to change from traditional working practices	3.20	1.12	20	1
Inadequate in-depth expertise and know-how to operate sustainability related analysis software program	3.15	1.01	20	2
High initial investment in staff training costs	3.15	1.15	20	2

Longer time in adapting to new technologies (steep learning curve)	3.10	1.09	20	4
Lack of understanding of the processes and workflows required for BIM and sustainability	3.10	1.09	20	4
Inadequacy of requisite experience, knowledge, and skills from the workforce	3.10	1.18	20	4
Shortage of cross-field specialists in BIM and sustainability	2.95	0.92	20	7
Difficulty in assessing environmental parameters of building properties	2.95	0.97	20	7
High cost of BIM software, license, and associated applications	2.65	1.11	20	9
User unfriendliness of BIM analysis software programs	2.60	0.97	20	10
Lack of client demand and top management commitment	2.60	1.28	20	10
Low level of involvement of BIM users in green/NZEB projects	2.50	0.74	20	12
Incompatibility issues with different software packages	2.50	0.81	20	12
Lack of supporting sustainability analysis tools	2.50	0.87	20	12
Lack of suitable procurement policy and contractual agreements	2.50	1.02	20	12
Organizational challenges, policy, and project strategy	2.50	1.07	20	12

The results show that the maximum *SD* is *1.28* for lack of client demand and top management commitment, and the minimum *SD* is *0.74* for low level of involvement of BIM users in green/NZEB projects. The ratio of the maximum *SD* to the minimum *SD* is less than 2:1. Hence, the items contribute equally to the total scale score. The Cronbach's alpha *(α)* was computed and found as *0.99* which indicates a very high degree of internal consistency.

7. BPS tools and their features

This section presents the preferred BPS tools to be used on NZEB construction projects and their important features. As shown in Table 15, the most cited BPS tool

was IES-VE *(M=4.36)*. The second ranked tool was Open Studio *(M=3.91)*, followed by EnergyPlus *(M=3.88)*.

Table 15. Analysis Summary: BPS Tools

BPS Tools	*M*	*SD*	*N*	*Rank*
IES-VE	4.36	0.48	14	1
Open Studio	3.91	1.00	11	2
EnergyPlus	3.88	1.22	16	3
DesignBuilder	3.80	1.08	10	4
eQUEST	3.59	0.84	17	5
PHPP	3.33	0.82	9	6
TRNSYS	3.00	0.67	9	7
Trane TRACE	3.00	1.10	15	7
Modelica	2.75	0.43	8	8

The results show that the maximum *SD* is *1.22* for EnergyPlus, and the minimum *SD* is *0.43* for Modelica. The ratio of the maximum *SD* to the minimum *SD* is less than 2:1. Hence, the items contribute equally to the total scale score. The Cronbach's alpha (α) was computed and found as *0.93* which indicates a very good level of internal consistency.

Table 16 shows the important features of BPS tools from the survey results. The participants cited accuracy as the most important feature for a BPS tool *(M=4.11)* to be used in NZEB projects. Intelligence *(M=3.95)* and usability *(M=3.89)* were the two other important features according to the participants.

Table 16. Analysis Summary: BPS Features

BPS Features	*M*	*SD*	*N*	*Rank*
Accuracy	4.11	0.64	19	1
Intelligence	3.95	0.76	19	2
Usability	3.89	0.72	19	3
Process Adaptability	3.71	0.75	17	4
Interoperability	3.42	1.04	19	5

The results show that the maximum *SD* is *1.04*, and the minimum *SD* is *0.64*. The ratio of the maximum *SD* to the minimum *SD* is less than 2:1. Hence, the items

contribute equally to the total scale score. The Cronbach's alpha *(α)* was computed and found as *0.98* which indicates a very high level of internal consistency.

Correlations

According to Obilor and Amadi (2018), Pearson's correlation measures the association, relationship, or correlation between two variables to verity if they are positively or negatively related, or not related at all. Correlation coefficients lower that 0.40 are said to be low, between 0.40 and 0.60 are moderate, and above 0.60 are high.

In research, any relationship should be assessed for its significance in addition to its strength (Obilor & Amadi, 2018). The strength of a relationship is indicated by the correlation coefficient *r*, and the significance of the relationship is expressed in probability levels *p* (where $p = .05; .01$; etc). The value of *p* tells how unlikely a given correlation coefficient *r* will occur given that no relationship exists in the population. It must be noted that the larger the correlation *r*, the stronger the relationship, whereas a smaller *p*-level indicates more significant relationship (Obilor & Amadi, 2018).

The goal of the study was to answer the following research questions:

1. What are the challenges constructors face in delivering NZEB projects?
2. What are the delivery processes that are used in practice and how do they impact the NZEB construction?
3. What are the barriers and constraints in using BIM and/or BPS tools for NZEB project optimization?

In the following sections, correlation analysis for each research questions are discussed.

RQ1: What are the challenges constructors face in delivering NZEB projects?

To answer the first research question, the survey questionnaire consisted of a list of potential challenges to the implementation of NZEB construction (Q5-Q10), a list of NZEB project objectives (Q11), a list of management knowledge areas (Q12) and management skills (Q13) to effectively deal with the challenges of NZEB construction, and a list of means of professional development (Q14).

So, there were five sets of variables related to challenge, objective, knowledge area, skill, and professional development to answer the first research question. Based on their mean ranking, the top three variables in each set were: challenge set (Variable 1 = Workers' unawareness of the correct methods and procedures; Variable 2 = Reluctance to change from traditional practices; Variable 3 = Lack of the technical skill regarding green/NZEB technologies and techniques;); objective set (Variable 4 = Budget; Variable 5 = Schedule; Variable 6 = Quality); Knowledge area set (Variable 7 = Cost management; Variable 8 = Schedule management and planning; Variable 9 = Communication management); Skill set (Variable 10 = Teamwork; Variable 11 = Leadership; Variable 12 = Problem solving); professional development set (Variable 13 = On the job experience; Variable 14 = Training; Variable 15 = Education).

The correlation coefficient among these fifteen variables were measured (Table 17) to determine the degree of association *(r)* and significance of the relationship *(p)* between two variables.

Table 17. Correlation of Challenge Variables

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	--														
2	.88**	--													
3	.84**	.82**	--												
4	.19	.08	.03	--											
5	.53**	.45*	.43*	.34	--										
6	.77**	.59**	.66**	.31	.55**	--									
7	-.13	-.15	.00	-.09	-.17	-.24	--								
8	.29	.21	.23	-.18	.22	.09	.42*	--							
9	.35	.31	.43*	-.22	-.02	.24	.13	.48*	--						
10	.36	.28	.52**	-.15	-.10	.21	.20	.25	.52**	--					
11	.21	.25	.37	-.18	-.06	.12	-.12	.20	.60**	.71**	--				
12	.32	.28	.41*	-.06	-.06	.06	.25	.24	.48*	.89**	.71**	--			
13	.41*	.37	.36	.13	.25	.33	.24	.22	.14	.32	.34	.43*	--		
14	.26	.25	.23	-.02	-.32	-.03	.04	.33	.37	.52**	.42*	.50**	.16	--	
15	-.04	.19	.11	-.11	-.22	-.16	.06	.13	.33	.30	.52**	.37	.10	.41*	--

Note, challenge set (Variable 1 = Workers' unawareness of the correct methods and procedures; Variable 2 = Reluctance to change from traditional practices; Variable 3 = Lack of the technical skill regarding green/NZEB technologies and techniques;); objective set (Variable 4 = Budget; Variable 5 = Schedule; Variable 6 = Quality); Knowledge area set (Variable 7 = Cost management; Variable 8 = Schedule management and planning; Variable 9 = Communication management); Skill set (Variable 10 = Teamwork; Variable 11 = Leadership; Variable 12 = Problem solving); professional development set (Variable 13 = On the job experience; Variable 14 = Training; Variable 15 = Education); *p<.05, **p<.01

In the first part of the analysis, the correlation within each set were analyzed to measure if there was any association between variables.

1. In the challenge set, workers' unawareness of the correct methods and procedures had a strong positive correlation with both reluctance to change from traditional practices *(r = .88, p < .01)*, and lack of the technical skill regarding green/NZEB technologies and techniques *(r = .84, p < .01)*. Reluctance to change from traditional practices had a strong positive correlation with lack of the technical skill regarding green/NZEB technologies and techniques *(r = .82, p < .01)*.
2. In the objective set, schedule had a moderate positive correlation with quality *(r = .55, p < .01)*.
3. In the knowledge area set, schedule management and planning had a moderate positive correlation with both cost management *(r = .42, p < .05)* and communication management *(r = .48, p < .05)*.
4. In the skill set, teamwork had a strong positive correlation with both leadership *(r = .71, p < .01)*, and problem solving *(r = .89, p < .01)*. Leadership had a strong positive correlation with problem solving *(r = .71, p < .01)*.
5. In the professional development set, training had a moderate positive correlation with education *(r = .41, p < .05)*.

In this second part of the analysis, correlation between variables across sets were analyzed. This analysis was intended to measure if a variable in one set was related to a variable of another set.

1. Workers' unawareness of the correct methods and procedures had a moderate positive correlation with schedule *(r = .53, p < .01)*, a strong positive correlation

with quality *(r = .77, p < .01)*, and a moderate positive correlation with on-the-job experience *(r = .41, p < .05)*.

2. Reluctance to change from traditional practices had a moderate positive correlation with both schedule *(r = .45, p < .05)*, and quality *(r = .59, p < .01)*.
3. Lack of the technical skill regarding green/NZEB technologies and techniques had a moderate positive correlation with schedule *(r = .43, p < .05)*, and a strong positive correlation with quality *(r = .66, p < .01)*.
4. Communication management had a moderate positive correlation with teamwork *(r = .52, p < .01)*, leadership *(r = .60, p < .01)*, and problem solving *(r = 0.48, p < .05)*.
5. Teamwork had a moderate positive correlation with training *(r = .52, p < .01)*.
6. Leadership had a moderate positive correlation with both training *(r = 0.42, p < .05)* and education *(r = .52, p < .01)*.
7. Problem solving had a moderate positive correlation with both on the job experience *(r = .43, p < .05)*, and training *(r = 0.50, p < .01)*.

RQ2: What are the delivery processes that are used in practice and how do they impact the NZEB construction?

To answer the second research question, the survey questionnaire consisted of a list of project delivery methods for NZEB projects (Q16), and a list of NZEB project management tasks (Q17).

So, there were two sets of variables related to delivery methods and project management tasks to answer the second research question. Based on the mean ranking, the top three variables in each set were: delivery methods set (Variable 1 = Integrated

Project Delivery (IPD), Variable 2 = Design-Build; Variable 3 = CM at Risk (CMAR); project management task set (Variable 4 = Cost management; Variable 5 = Communication management; Variable 6 = Schedule management and planning).

The correlation coefficient among these six variables were measured (Table 18) to determine the degree of association *(r)* and significance of the relationship *(p)* between two variables.

Table 18. Correlation of Delivery Process Variables

	1	2	3	4	5	6
1	--					
2	.39*	--				
3	.29	-.03	--			
4	.68**	.18	.06	--		
5	.67**	.19	.12	.95**	--	
6	.54**	.02	.38	.76**	.79**	--

Note, delivery methods set (Variable 1 = Integrated Project Delivery (IPD), Variable 2 = Design-Build; Variable 3 = CM at Risk (CMAR); project management task set (Variable 4 = Cost management; Variable 5 = Communication management; Variable 6 = Schedule management and planning).
*p<.05, **p<.01

First, the correlation within each set were analyzed to measure if there was any association between variables.

1. In the delivery methods set, IPD had a weak positive correlation with Design-Build *($r = .39, p < .05$)*.
2. In the project management task set, cost management had a strong positive correlation with both communication management *($r = .95, p < .01$)*, and schedule management and planning *($r = .76, p < .01$)*. Communication management had a strong positive correlation with schedule management and planning *($r = .79, p < .01$)*.

In this second part of the analysis, correlation between variables across sets were analyzed. This analysis was intended to measure if a variable in one set was related to a variable of another set.

1. IPD had a strong positive correlation with both cost management *(r = .68, p < .01),* and communication management *(r = .67, p < .01);* and a moderate positive correlation with schedule management and planning *(r = .54, p < .01).*

RQ3: What are the barriers and constraints in using BIM and/or BPS tools for NZEB project optimization?

To answer the third research question, the survey questionnaire consisted of a list of challenges in implementing BIM on NZEB projects (Q19), a list of BPS tools (Q21), and a list of features of BPS tools (Q22).

There was one set of variables related to BIM challenges. Based on the mean ranking, the top three variables were: Variable 1 = Industry's resistance to change from traditional working practices, Variable 2 = Inadequate in-depth expertise and know-how to operate sustainability related analysis software program; Variable 3 = High initial investment in staff training costs.

The correlation coefficient among these three variables were measured (Table 19) to determine the degree of association *(r)* and significance of the relationship *(p)* between two variables.

Table 19. Correlation of BIM variables

	1	2	3
1	--		
2	.78**	--	
3	.79**	.88**	--

Note, Variable 1 = Industry's resistance to change from traditional working practices, Variable 2 = Inadequate in-depth expertise and know-how to operate sustainability

related analysis software program; Variable 3 = High initial investment in staff training costs.
*p<.05, **p<.01

In the BIM challenge set, industry's resistance to change from traditional working practices had a strong positive correlation with both inadequate in-depth expertise and know-how to operate sustainability related analysis software program *(r = .78, p < .01)*, and high initial investment in staff training costs *(r = .79, p < .01)*. Inadequate in-depth expertise and know-how to operate sustainability related analysis software program had a strong positive correlation with high initial investment in staff training costs *(r = .88, p < .01)*.

There were two more sets of variables to answer the third research question. Based on the mean ranking, the top three variables in each set were: BPS tools set (Variable 1 = IES-VE, Variable 2 = Open Studio; Variable 3 = EnergyPlus); BPS feature set (Variable 4 = Accuracy; Variable 5 = Intelligence; Variable 6 = Usability).

The correlation coefficient among these six variables were measured (Table 20) to determine the degree of association *(r)* and significance of the relationship *(p)* between two variables.

Table 20. Correlation of BPS Variables

	1	2	3	4	5	6
1	--					
2	.45*	--				
3	.68**	.69**	--			
4	.48*	.53**	.58**	--		
5	.59**	.57**	.63**	.98**	--	
6	.51**	.57**	.57**	.95**	.96**	--

Note, BPS tools set (Variable 1 = IES-VE, Variable 2 = Open Studio; Variable 3 = EnergyPlus); BPS feature set (Variable 4 = Accuracy; Variable 5 = Intelligence; Variable 6 = Usability).
*p<.05, **p<.01

First, the correlation within each set were analyzed to measure if there was any association between variables.

1. In the BPS tools set, IES-VE had a moderate positive correlation with Open Studio *(r = .45, p < .05)*, and a strong positive correlation with EnergyPlus *(r = .68, p < .01)*. Open Studio had a strong positive correlation with EnergyPlus *(r = .69, p < .01)*.
2. In the BPS feature set, accuracy had a strong positive correlation with both intelligence *(r = .98, p < .01)*, and usability *(r = .95, p < .01)*. Intelligence had a strong positive correlation with usability *(r = .96, p < .01)*.

In this second part of the analysis, correlation between variables across sets were analyzed. This analysis was intended to measure if a variable in one set was related to a variable of another set.

1. IES-VE had a moderate positive correlation with accuracy *(r = .48, p < .05)*, intelligence *(r = .59, p < .01);* and usability *(r = .51, p < .01)*.
2. Open Studio had a moderate positive correlation with accuracy *(r = .53, p < .01)*, intelligence *(r = .57, p < .01);* and usability *(r = .57, p < .01)*.
3. EnergyPlus had a moderate positive correlation with both accuracy *(r = .58, p < .01)*, and usability *(r = .57, p < .01)*; and a strong positive correlation with intelligence *(r = .63, p < .01)*.

Qualitative Analysis

The qualitative data was gathered through semi-structured and open-ended interviews. The interview form was composed of three demographic questions (Q1-Q3) and thirteen main questions (Q4-Q16) and additional probe questions, as necessary.

Additional probing questions were asked to gain a deeper understanding of participants' views (Demir & Pismek, 2018). The contents of the questions are described in Table 21.

Table 21. Questions and Contents

Interview Question	*Contents*	*Survey Question*
1, 2, 3	General information and demographic data	1, 2, 3, 4, 23, 24
4	Selected delivery methods and its impact on NZEB construction process	16, 17
5	Project challenges	5, 6, 7, 8, 9, 10, 11
6, 7, 8	Decision making process in NZEB construction	
9, 10, 11	Management skills and knowledge	12, 13, 14
12, 13, 14, 15	Role and challenges of BIM and BPS tools	19, 21, 22
16	Experiences with the construction of NZEB projects	

The five interviews were recorded and later transcribed. The transcribed qualitative data were organized in Microsoft® Word and then imported into MAXQDA for coding and analysis. The next step involved rereading the individual answers to each of the thirteen main questions. The primary coding cycle consisted of marking responses to each question with codes using MAXQDA. The process of coding involves aggregating the text into small categories of information, seeking evidence for the code from different databases being used in a study, and then assigning a label to the code (Creswell, 2013). As detailed in Chapter 3, the start list of codes was developed with eleven themes or categories with sixty-eight shorthand labels or codes. According to Creswell (2013), themes and categories in qualitative research are synonymous, and are broad units of information that consist of several codes aggregated to form a common idea. The themes of this qualitative study were 1) Challenges, 2) Impact of Challenges, 3) Management Knowledge, 4) Management Skills, 5) Professional Development, 6) Delivery Methods, 7) Impact of Delivery Methods, 8) Decision Making Approaches, 9) BIM Implementation Challenges, 10) BPS Tools, and 11) BPS Features. This start list

was developed based on the research questions, the initial analysis of the literature, the quantitative survey undertaken as part of the project and a preliminary scan of the raw interview data.

The coding feature highlights the relevant words based on the frequency of answers to a single question on the questionnaire. Themes and codes were highlighted, identifying significant words or statements of the participants' responses conveying personal experiences or perspectives relevant to the research questions. Once the coding process was complete, reports containing codes and summaries were developed for each question.

RQ1 Results

Related to the first research question (i.e., "What are the challenges constructors face in delivering NZEB projects?"), the five themes were 1) Challenges, 2) Management Knowledge, 3) Management Skills, 4) Professional Development, and 5) Decision Making Approach. Each theme is described below.

1. Challenges: Five sub-themes were discovered related to challenges. Those were a) Planning-related, b) Project-related, c) Client-related, d) Project Team-related, and e) Labor-related.
    a) Planning-related challenges: One participant emphasized the need to establish a clear goal of the NZEB project as there are different ways of defining Net Zero Energy, and the builders want a clear objective. This goal should be clearly put into words in the NZEB specifications. The participant mentioned, "*So, if the goal is clear, then, there's a commitment, that the attitude of the team is well, okay, well, how do we meet this goal rather than how do we avoid meeting the*

goal, then, that's the number one challenge, is being, clear on, why the requirement is there". Another interviewee mentioned about the technology and public policy related challenges, "*we frequently run into the electric utility policies on accessing the grid, or the way that they want to price the electricity, or what's purchased versus what is put back on the grid. So, the net metering agreements and the access to the grid takes a great deal of time and effort to negotiate those*".

b) Project-related challenges: Participants indicated that selection of subcontractors in providing NZEB construction service was a challenge. One interviewee mentioned, "*If you don't have a contractor or a supervisor who understands the need for our tightness, the impact of penetrations, correct ceiling, then, it's going to be really difficult if you haven't done that before*". Another participant indicated about the challenge related to alteration and variation with the design during the construction process as it impacts the schedule and cost. The interviewee mentioned, "*the longer you live in the process of the project design changes, the cost starts going up*".

c) Client-related challenges: Level of risk the client is willing to take and time in making decision were mentioned as two significant challenges. One interviewee mentioned, "*people could be nervous or hesitant to use some of these technologies that might make their life easier in the end, but they're just hesitant because they're new and that's fairly typical of human nature*".

d) Project Team-related challenges: One interviewee mentioned the lack of familiarity with high-performance enclosure detailing & specification needs as a

challenge for the project team. Another participant emphasized the need for early collaboration among the team members to overcome the project team related challenges. The participant said, "*everyone has to be on the same page, there's a lot of back and forth, but you can easily get there if you're willing to be open-minded about it, you're not stuck to a certain design*".

e) Labor-related challenges: Workers' unawareness of the correct methods and procedures, reluctance to change from traditional practices, and lack of the technical skill regarding NZEB technologies and techniques were regarded as challenges by the interviewees. One participant said that the contractors lack familiarity with high-performance enclosure construction details and practices. Another participant said, "*There's a lot of tendency to revert back to the old ways of doing things that people know and understand and have always done but doing net zero energy buildings requires people to do things differently*". Another participant said, "*It's the willingness to change that I find to be so critical. People can learn better if they're not resistant to doing something different, and I find a lot more resistance to change than we should have*".

2. Management Knowledge: Among all management knowledge, communication management knowledge was cited as the most important knowledge by the interviewees. One interviewee said, "*Communication really is key, especially in this kind of process*". Another interviewee said, "*We use various methods of coordinating team members so that everybody has frequent communications*". About cost management knowledge, one participant said, *"... understanding the*

relationship between the design decisions and their first cost implications, compared to the cost over time is probably the biggest thing".

3. Management Skills: The most cited management skill was teamwork. One participant said, "… *then we'll divide our team into what we call component teams. Rather than having them work in traditional silos, where mechanical, electrical, et cetera, are just working by themselves, we will make a series of inter-disciplinary component teams to work together throughout the entire project so that we're always working together*". Another participant said, "… *the teamwork … is actually the core skill, because no one is going to ever get everything they want in a net zero building*". One participant mentioned leadership as the most important skill, "*especially leadership of or within a team*". Another participant said, "*you need to understand and have some skills at managing stakeholders, managing groups of people and figuring out what they really want from a building*".
4. Professional Development: For professional development, the importance of training and on-the-job experience were mentioned by the interviewees. One interviewee said, "*we have a system of mentoring, so we'll assign less experienced people with more experienced, so they'll get direct one-on-one mentoring. … And with that, we have a round table of seasoned professionals that get together on a regular basis, figure out what is happening on the boards, on projects today, right now, what do project managers need, what do project architects need, and then they'll go and provide the needed information or the one-on-one coaching, again, needed for a specific individual.*". About the role of education, one participant said,

"*You have to come out of school knowing how to design buildings that are extremely energy efficient, if not net zero*".

5. Decision Making Approach: Most of the interviewees mentioned that the decision-making process is basically consensus base. One participant said, "*... we found that a consensus-based approach helped us bring the best solutions to the client*". Another participant said, "*We use a document form called an A3, which helps us to quickly, on a single sheet of paper, summarize an issue, document the relevant facts, and then everyone on the team participates in making the decisions on what needs to be done*". The third participant said, "*I think it was consensus on the private project, we were usually able to come up with solutions that the contractor, the design team and the owner could agree with. The owner trusted us and we had good evidence for our decisions*".

RQ2 Results

Related to the second research question (i.e., "What are the delivery processes that are used in practice and how do they impact the NZEB construction?"), the two themes were 1) Delivery Methods, and 2) Impact of Delivery Methods. Each theme is described below.

1. Delivery Methods: For Net Zero construction, most of the participants preferred an integrated approach for the success of the projects. One participant mentioned, "*We really need the construction people on the project as early as possible so that they're integrated into the document development process while we're still working on the design. ... If they're involved from the beginning then they can give input as we're developing the details of the project for constructability. They will also be on*

to give pricing information so that we have that kind of direct input, and they also begin to understand the project better, and they're with us so it isn't just a handoff and then the contractor has to figure that out what we were trying to accomplish in a bidding environment. And that's a much more beneficial way to do things so that the construction part of the team is integrated with the design portion of the team". Another participant said, "*The office building high rise in downtown Sacramento was a design build delivery method, and that was more beneficial for the net zero achievement because they have more of an integrated team approach"*.

2. Impact of Delivery Methods: One participant said that "*a more integrated approach, i.e., with the general contractor and major trades involved early, facilitates achieving the energy and other high-performance outcomes because it enables those parties to have input on design and also fosters commitment to the goals, a more collaborative process, reduced friction/blaming, and deeper understanding of the project goals, requirements, and details of construction"*.

RQ3 Results

Related to the third research question (i.e., What are the barriers and constraints in using BIM and/or BPS tools for NZEB project optimization?), the three themes were 1) BIM Implementation Challenges, 2) BPS Tools, and 3) BPS Features. Each theme is described below.

1. BIM Implementation Challenges: Two participants mentioned that incompatibility with different software is the biggest challenge for BIM implementation. One participant said, "*So we have first to find out what platform is everybody working on and then standardize on some electronic version of Revit. If somebody is not on*

Revit, that might hamper our ability to do everything we need to, so there will be some conversation about that". Another participant mentioned, "*So I think the frustration is not having one tool that's integrated into BIM that everybody knows that can be used from beginning to end. I don't know if that'll ever happen, it's just that highlights the limitations today*".

2. BPS Tools: For energy modeling, two participants mentioned that eQuest was effective. One of them also found RedScreen to be useful. Another participant said that Safaira is good for its speed in creating model, but not robust enough to give a very high resolution.
3. BPS Features: According to one participant, speed in creating model quickly, producing high resolution model, and creating a model that helps to get deeper understanding of the components of the building are the features a BPS tool should have. Another participant suggested that BPS tools needs to be used early rather than later in the process.

Summary of Results

RQ1: What are the challenges constructors face in delivering NZEB projects?

1. Challenges:

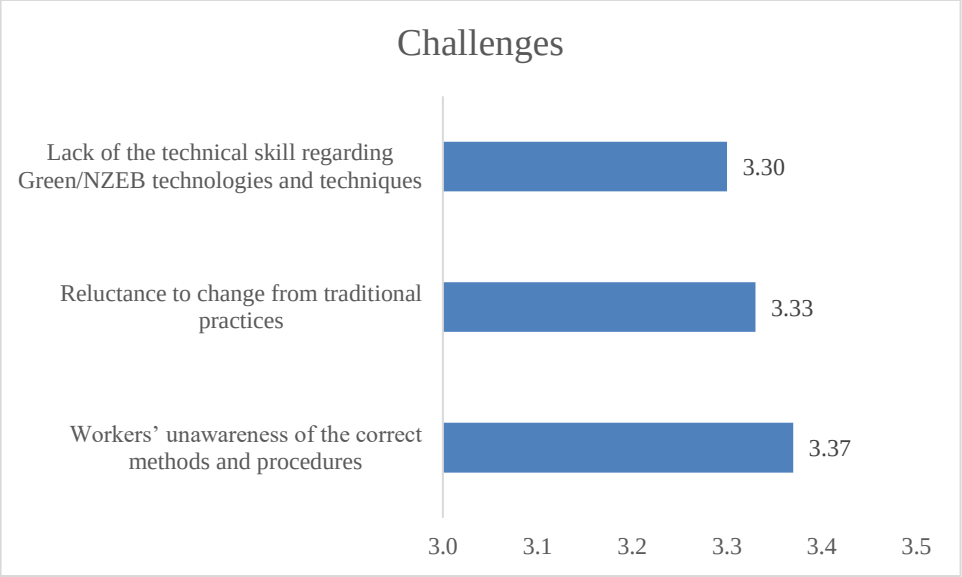


Figure 8. Top three challenges from the Mean rank

As shown in Figure 8, survey responses revealed that the top three challenges were (1) workers' unawareness of the correct methods and procedures (M=3.37), (2) reluctance to change from traditional practices (M=3.33), and (3) lack of the technical skill regarding Green/NZEB technologies (M=3.30).

The correlation analysis (Table 17) indicates that workers' unawareness of the correct methods and procedures had a moderate positive correlation with schedule *($r = .53$, $p < .01$)*, a strong positive correlation with quality *($r = .77$, $p < .01$)*, and a moderate positive correlation with on-the-job experience *($r = .41$, $p < .05$)*. On the other hand, reluctance to change from traditional practices had a moderate positive correlation with both schedule *($r = .45$, $p < .05$)*, and quality *($r = .59$, $p < .01$)*. Lack of the technical skill regarding green/NZEB technologies and techniques had a moderate positive correlation with schedule *($r = .43$, $p < .05$)*, and a strong positive correlation with quality *($r = .66$, $p < .01$)*. It is evident from the correlation analysis that the top three identified challenges influence the NZEB project objectives, specifically, schedule

and quality of the NZEB construction projects. Hwang and Ng (2013) suggested that the project managers must provide appropriate and timely training for their workers, and in addition to other topics, some workers may need training on green/NZEB construction.

These findings were also verified by the participants. One participant said that the contractors lack familiarity with high-performance enclosure construction details and practices. Another participant said, "*There's a lot of tendency to revert back to the old ways of doing things that people know and understand and have always done but doing net zero energy buildings requires people to do things differently*." Awareness of green/NZEB construction is closely related to the public awareness of environmental issues. The knowledge and cognition on sustainability of all parties need to be further enhanced (Shi et al., 2013). Lack of knowledge on green/NZEB technology and the durability of green/NZEB materials is a significant challenge in implementing the strategies and specifying green/NZEB construction. To address this challenge, Shi et al. (2013) suggested that contractors and suppliers should be engaged during early stage of construction projects due to their knowledge on the environmental issues associated with construction activities, building materials and plants.

Another participant said, "*It's the willingness to change that I find to be so critical. People can learn better if they're not resistant to doing something different, and I find a lot more resistance to change than we should have*". Shi et al. (2013) also mentioned that the unwillingness of industry practitioners to change the conventional way of specifying existing methods and processes became a challenge. The limitation of the scope and applicability of new products and new technologies and associated cost may force industry practitioners to move back to traditional construction methods. Shi

et al (2013) emphasized the role of the project managers in enhancing the awareness of the industry practitioners to both the costs and the benefits associated with green/NZEB construction.

2. NZEB Project Objectives:

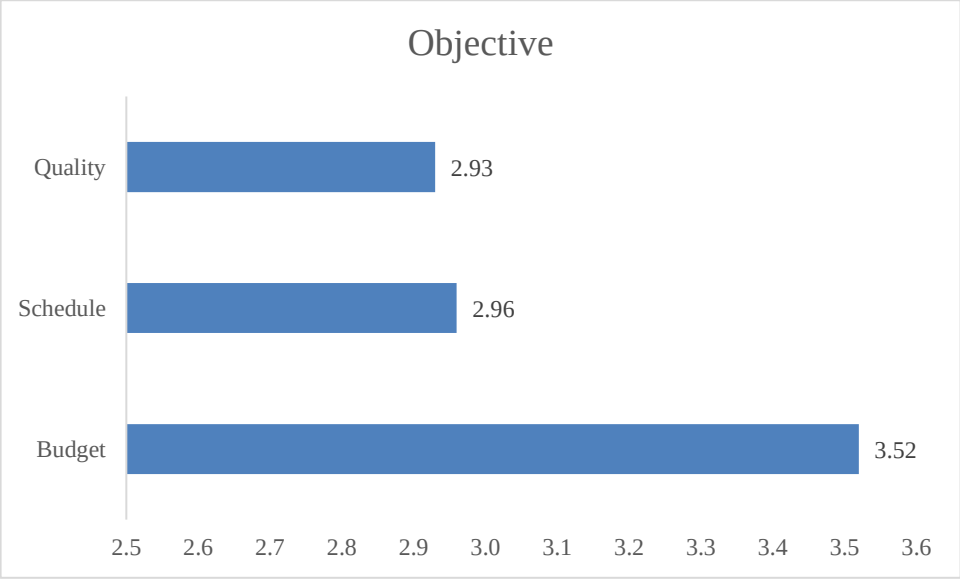


Figure 9. Top three objectives from the Mean rank

As shown in Figure 9, survey responses revealed that the top three NZEB project objectives were (1) budget *(M = 3.52)*, (2) schedule *(M = 2.96)*, and (3) quality *(M = 2.93)*. The correlation analysis (Table 17) shows that schedule had a moderate positive correlation with quality of the NZEB construction projects ($r = .55$, $p < .01$).

The participants verified these findings. One participant mentioned that keeping an eye on budgets, timelines, and quality procedure in place are important for NZEB construction. Another participant mentioned, "*cost and schedule, really understanding the relationship between the design decisions and their first cost implications, compared to the cost over time is probably the biggest thing*."

Green/NZEB projects tend to cost more to construct compared to conventional projects due to design complexity, materials, and using green/NZEB construction technologies, which directly affect the allocated budget (Whang & Ng, 2013). Schedule serves as a crucial benchmark for the performance and cost of green/NZEB construction projects (Shi et al., 2013). Hwang and Ng (2013) argued that delays will be caused if this issue is not taken into consideration thoroughly.

3. Knowledge:

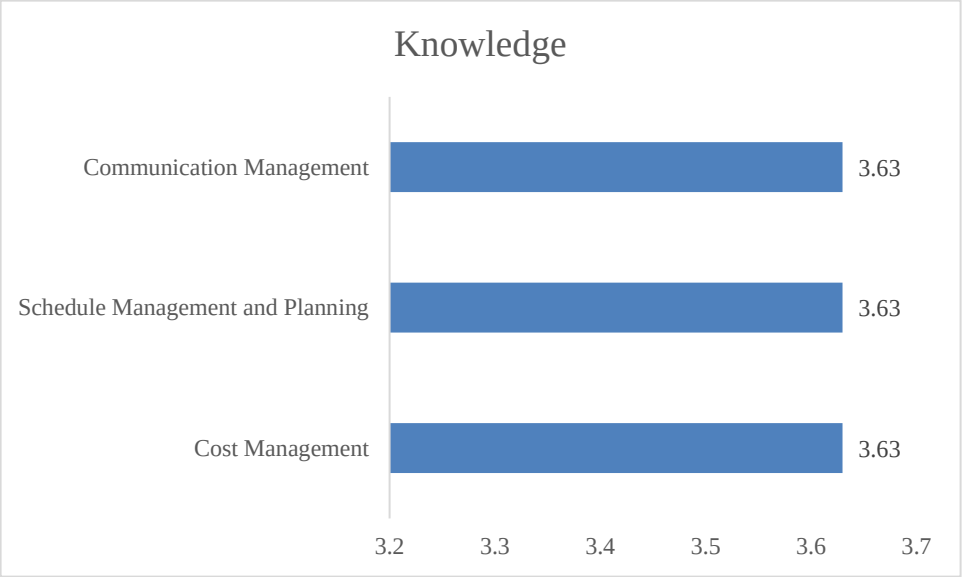


Figure 10. Top three knowledge areas from the Mean rank

As shown in Figure 10, the top three knowledge areas were (1) cost management, (2) schedule management and planning, and (3) communication management (M=3.63). The correlation analysis (Table 17) revealed that schedule management and planning had a moderate positive correlation with both cost management ($r = .42$, $p < .05$) and communication management ($r = .48$, $p < .05$). Communication management had a moderate positive correlation with teamwork ($r = .52$, $p < .01$), leadership ($r = .60$, $p < .01$), and problem solving ($r = 0.48$, $p < .05$).

Most of the participants mentioned communication management knowledge as the most important knowledge. One participant said, "*Communication really is key, especially in this kind of process*." Another participant said, "*We use various methods of coordinating team members so that everybody has frequent communications*." About cost management knowledge, one participant said, *"understanding not a simple payback, but more of a complex payback analysis to be able to justify probably spending more up front, in time design fees and construction costs, but to have a longer-term savings over time, and to be able to get to that net zero goal."*

As discussed previously in 4.1.3. section, communication management is important since green/NZEB projects require a more holistic and integrated approach. Poor communication between team members is a major cause for project overruns, rework, and disputes (Yap et al., 2017). Effective communication management plan needs to be in place for NZEB projects to facilitate collaboration in project team, which also promotes active participation in decision making (Livesey, 2016).

Cost management ensures the lowest overall project cost possible consistent with the owner's investment objectives. As compared to conventional projects, green/NZEB projects tend to cost more to construct (Hasan, 2017). This increased cost affects the performance of project managers, as they must manage and deliver the project within the budget constraint.

Schedule management and planning is a crucial activity for the success of NZEB construction project. A failure to consider the integration of NZEB technologies and its impact on other building elements results in construction conflicts, leading to delays

(Hwang and Ng, 2013). That being the case, sequencing for NZEB construction requires to be more detailed when planning the project.

4. Skills:

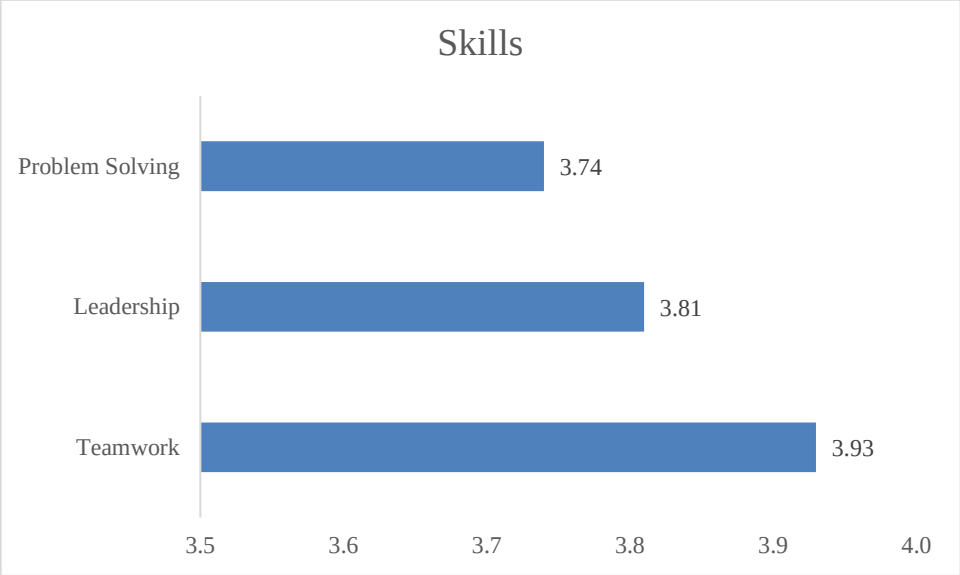


Figure 11. Top three skills from the Mean rank

The Figure 11 shows that the top three skills from the Mean rank were (1) teamwork *(M = 3.93)*, (2) leadership *(M = 3.81)*, and (3) problem solving *(M = 3.74)*. The correlation analysis (Table 17) shows that teamwork had a moderate positive correlation with training ($r = .52$, $p < .01$). Leadership had a moderate positive correlation with both training ($r = 0.42$, $p < .05$) and education ($r = .52$, $p < .01$). Problem solving had a moderate positive correlation with both on the job experience ($r = .43$, $p < .05$), and training ($r = 0.50$, $p < .01$).

The most cited management skill was teamwork. One participant said, *"... then we'll divide our team into what we call component teams. Rather than having them work in traditional silos, where mechanical, electrical, et cetera, are just working by themselves, we will make a series of inter-disciplinary component teams to work*

together throughout the entire project so that we're always working together". Another participant said, *"... the teamwork is actually the core skill, because no one is going to ever get everything they want in a net zero building."*

One participant mentioned leadership as the most important skill, *"especially leadership of or within a team."* Another participant said, *"you need to understand and have some skills at managing stakeholders, managing groups of people and figuring out what they really want from a building."*

As discussed in 4.1.3. section, construction project teams are unique entities comprised of inter-disciplinary professionals. Collaboration and teamwork are therefore crucial to minimize errors, time delays and rework. To enhance teamwork and performance outcomes, Salas et al. (2015) suggested some interventions, such as conducting team cross-training and team building prior beginning the project.

Leadership has a key role in driving the sustainability agenda within their organizations by spearheading the formulation of policies, devising procedures, and disseminating best practice throughout the organization (Opoku et al., 2015).

Problem solving is an activity in which a learner perceives a discrepancy between a current state and a desired goal state (Hesse et al., 2015). The problems may be technical, managerial, or interpersonal. In collaboration, each of these steps is directly observable, and the team members need to exchange and share their identification of parts of the problem in search of a solution.

5. Professional Development:

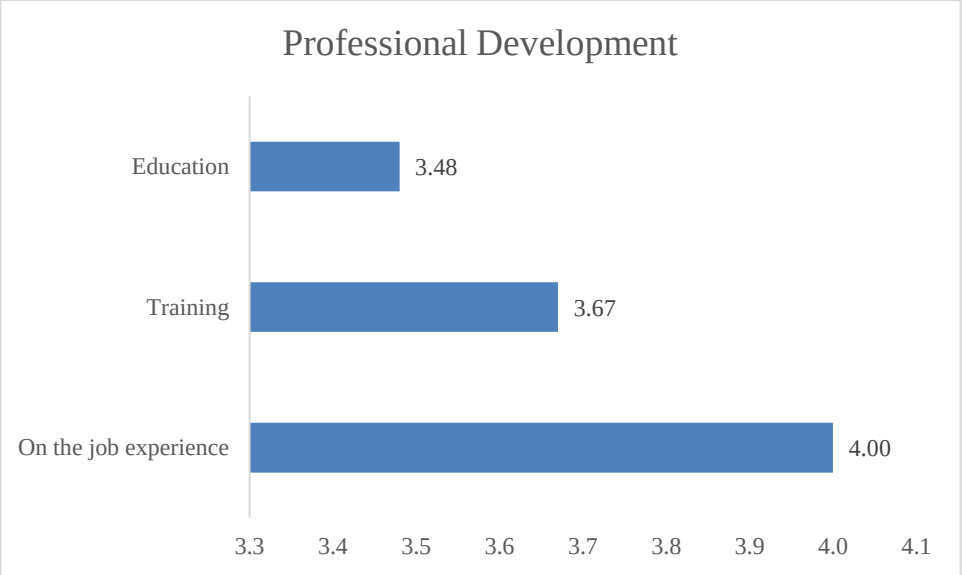


Figure 12. Top three Professional Development means from the Mean rank

Figure 12 shows that the top three professional development means were (1) one the job experience *(M = 4.00)*, (2) training *(M = 3.67)*, and (3) education *(M = 3.48)*. The correlation analysis (Table 17) shows that training had a moderate positive correlation with teamwork *(r = .52, p < .01)*, leadership *(r = 0.42, p < .05)*, and problem solving *(r = 0.50, p < .01)*. On the job experience had a moderate positive correlation with problem solving *(r = .43, p < .05)*. Education had a moderate positive correlation with leadership (r = .52, p < .01).

For professional development, the importance of training and on-the-job experience were mentioned by the participants. One participant said, "*we have a system of mentoring, so we'll assign less experienced people with more experienced, so they'll get direct one-on-one mentoring. … And with that, we have a round table of seasoned professionals that get together on a regular basis, figure out what is happening on the boards, on projects today, right now, what do project managers need, what do project*

architects need, and then they'll go and provide the needed information or the one-on-one coaching, again, needed for a specific individual.".

About the role of education, one participant said, "*You have to come out of school knowing how to design buildings that are extremely energy efficient, if not net zero*".

The contribution of academic education to the competency of NZEB constructors is rated lower than that of formal industry training attended provided by employers. Similarly, the perceived contribution of industry training was outranked by that of experiences on the job site. This is indicative of the important role of experience for achieving skills and competency in construction project management, and to address the changing conditions and requirements that the NZEB industry environment presents from day to day. Barrows et al. (2020) noted that many skills required for today's construction professionals may lie outside the current construction management education systems and beyond the in-house training programs offered by the employers. Higher education institutes have yet to respond effectively to the current and future challenges and addressing the gap between the industry expectations and the competencies of graduates in construction-oriented programs (Perera et al., 2017).

RQ2: What are the delivery processes that are used in practice and how do they impact the NZEB construction?

1. Delivery Method:

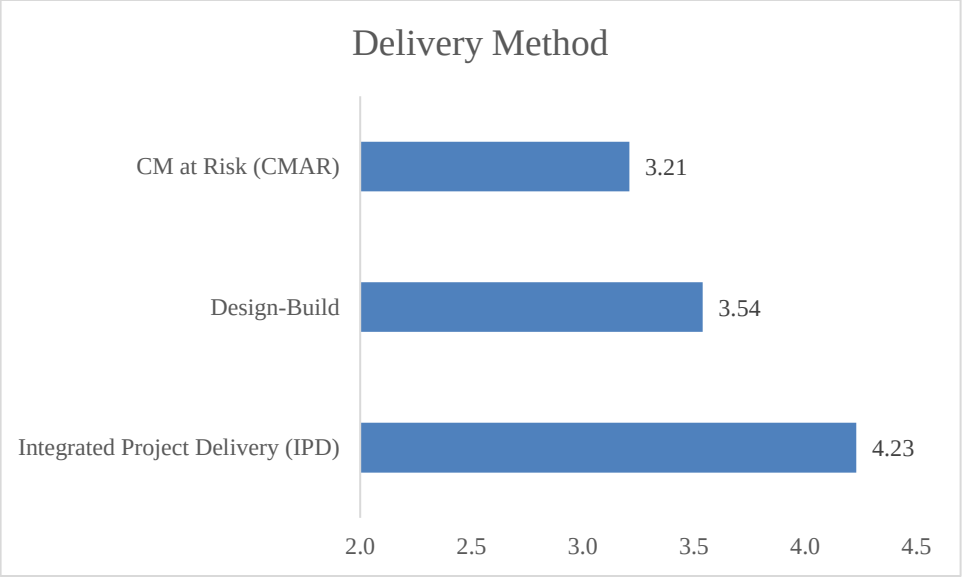


Figure 13. Top three Delivery Methods from the Mean rank

From the Mean rank, the top three delivery methods were IPD *(M = 4.23)*, Design-Build *(M = 3.54)* and CMAR *(M = 3.21)*.

Most of the participants preferred an integrated approach for the success of the projects. One participant mentioned, "*We really need the construction people on the project as early as possible so that they're integrated into the document development process while we're still working on the design. … If they're involved from the beginning then they can give input as we're developing the details of the project for constructability"*.

Another participant said, "*The office building high rise in downtown Sacramento was a design build delivery method, and that was more beneficial for the net zero achievement because they have more of an integrated team approach"*.

2. Impact of Delivery Methods

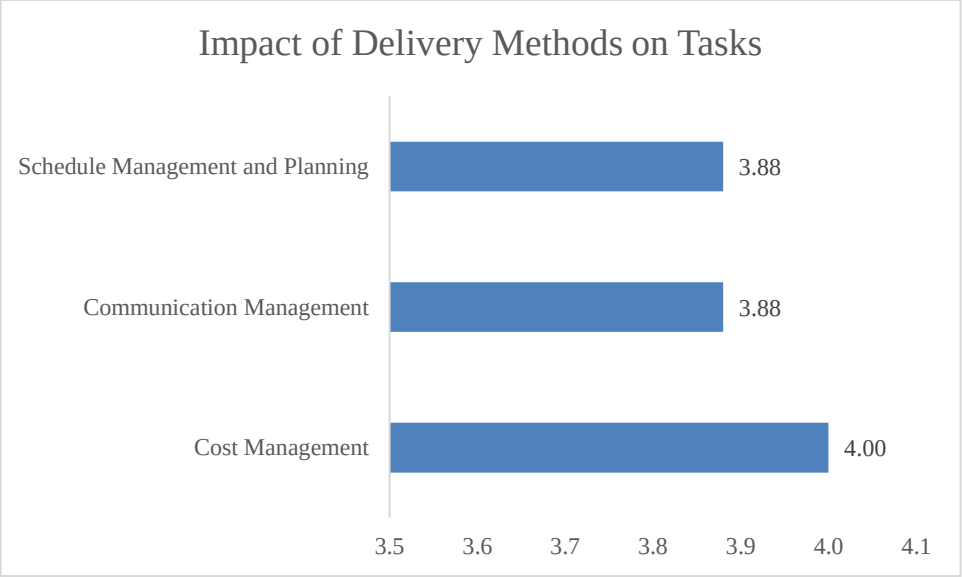


Figure 14. Top three management tasks impacted by delivery methods from the Mean rank

Figure 14 shows that the top three NZEB project management tasks that are impacted by the delivery methods were (1) cost management *(M = 4.00)*, (2) communication management *(M = 3.88)*, schedule management and planning *(M = 3.88)*.

The correlation analysis (Table 18) shows that IPD had a strong positive correlation with both cost management ($r = .68$, $p < .01$), and communication management ($r = .67$, $p < .01$); and a moderate positive correlation with schedule management and planning ($r = .54$, $p < .01$).

One participant said that "*a more integrated approach, i.e., with the general contractor and major trades involved early, facilitates achieving the energy and other high-performance outcomes because it enables those parties to have input on design and also fosters commitment to the goals, a more collaborative process, reduced friction/blaming, and deeper understanding of the project goals, requirements, and details of construction"*. Another participant said, "*They (contractor) will also be on to*

give pricing information so that we have that kind of direct input, and they also begin to understand the project better, and they're with us so it isn't just a handoff and then the contractor has to figure that out what we were trying to accomplish in a bidding environment. And that's a much more beneficial way to do things so that the construction part of the team is integrated with the design portion of the team".

In a collaborative work environment, communication among the professionals is enhanced. Teamwork and collaboration among the constructors are prerequisites for the successful completion of NZEB projects in terms of cost management and sequencing and planning the construction work.

RQ3: What are the challenges in using BIM and/or BPS tools for NZEB project optimization?

1. BIM Implementation Challenges

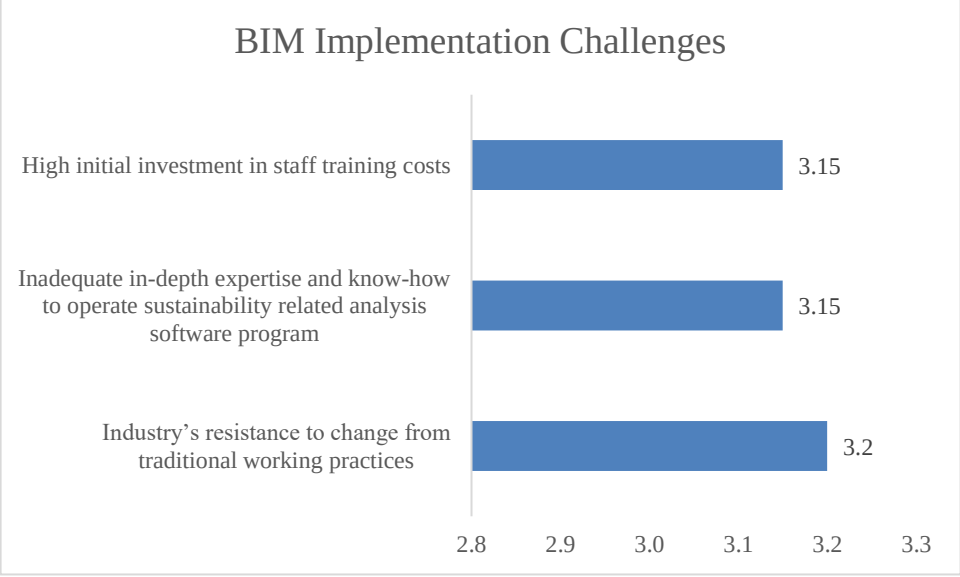


Figure 15. Top three BIM Implementations Challenges from the Mean rank

Figure 15 shows that the top three BIM implementation challenges were (1) industry's resistance to change from traditional working practices *(M = 3.20)*,

inadequate in-depth expertise and know-how to operate sustainability related analysis software program *(M = 3.15)*, and (3) high initial investment in staff training costs *(M = 3.15)*.

Two participants mentioned that incompatibility with different software is the biggest challenge for BIM implementation. One participant said, *"So we have first to find out what platform is everybody working on and then standardize on some electronic version of Revit. If somebody is not on Revit, that might hamper our ability to do everything we need to, so there will be some conversation about that"*. Another participant mentioned, *"I think the frustration is not having one tool that's integrated into BIM that everybody knows that can be used from beginning to end. I don't know if that'll ever happen, it's just that highlights the limitations today"*.

The construction industry is facing a shortage of skilled workforce due to a rapidly changing technology landscape and the transformed business practices driven by emerging industry trends including sustainability, BIM, and lean construction (Wu et al., 2018). To keep up with these trends and stay competitive in business, companies are urged to recruit graduates with new knowledge and skillsets, which are not readily addressed in existing construction management or construction engineering management curricula. To address these challenges, greater levels of university and industry collaboration in developing and delivering construction programs is needed.

2. BPS Tools

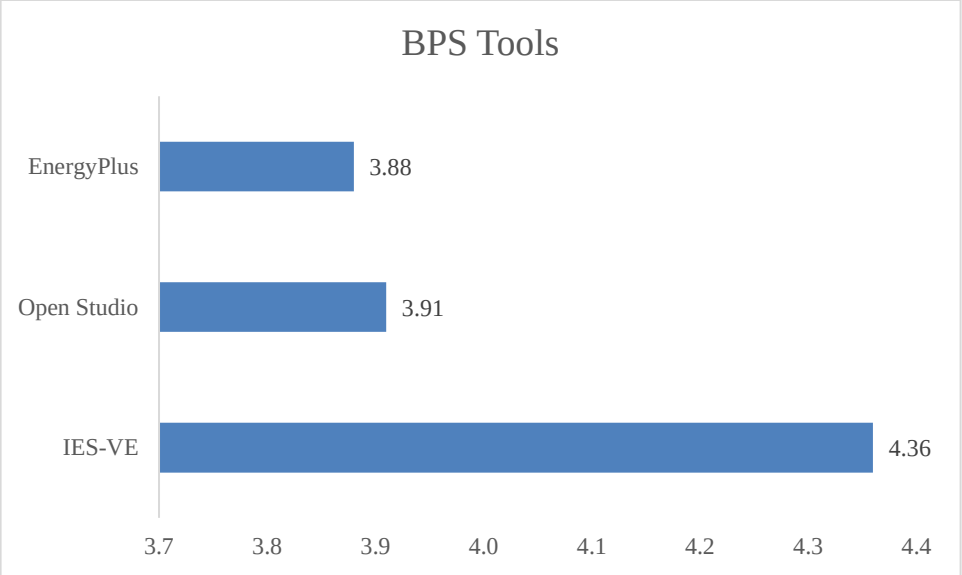


Figure 16. Top three BPS Tools from Mean rank

The Mean rank shows that the most preferred BPS tool was IES-VE (M = 4.36), followed by Open Studio (M = 3.91), and EnergyPlus (M = 3.88).

Two participants mentioned that eQuest was effective. One of them also found RedScreen to be useful. Another participant said that Safaira is good for its speed in creating model, but not robust enough to give a very high resolution.

3. BPS Features:

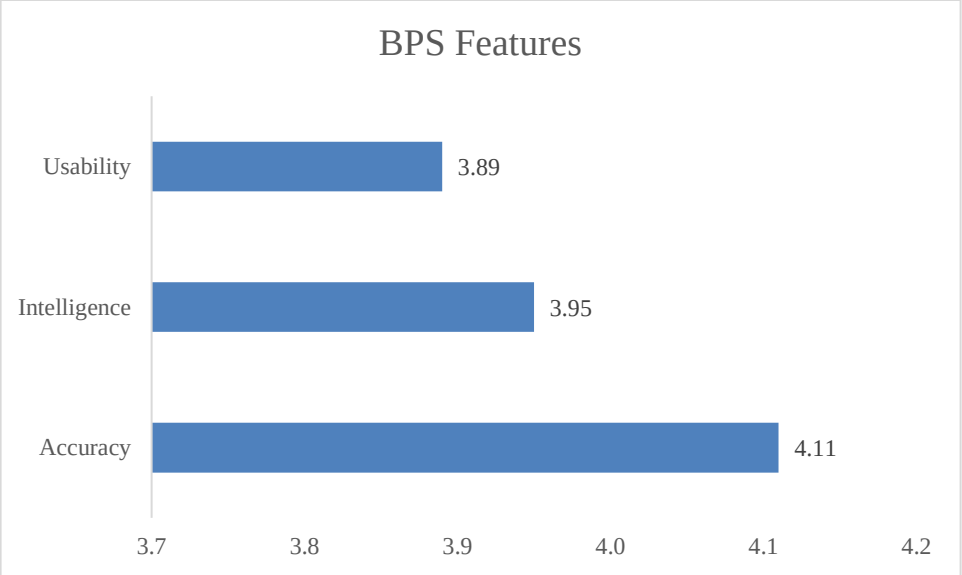


Figure 17. Top three BPS Features from Quantitative Study

The Mean rank shows that the most desired BPS features were accuracy *(M = 4.11)*, followed by intelligence *(M = 3.95)*, and usability *(M = 3.89)*.

The correlation analysis (Table 20) shows that IES-VE had a moderate positive correlation with accuracy *(r = .48, p < .05)*, intelligence *(r = .59, p < .01);* and usability *(r = .51, p < .01)*. Open Studio had a moderate positive correlation with accuracy *(r = .53, p < .01)*, intelligence *(r = .57, p < .01);* and usability *(r = .57, p < .01)*. EnergyPlus had a moderate positive correlation with both accuracy *(r = .58, p < .01)*, and usability *(r = .57, p < .01)*; and a strong positive correlation with intelligence *(r = .63, p < .01)*.

According to one participant, speed in creating model quickly, producing high resolution model, and creating a model that helps to get deeper understanding of the components of the building are the features a BPS tool should have. Another participant suggested that BPS tools needs to be used early rather than later in the process.

Chapter 5 Discussion and Conclusions

the construction industry has been riding a wave of green building over the past 20 years. Despite the growth, available rating systems only cover stringent energy regulation in the design and construction phase and therefore new leader in energy efficient buildings is required to emerge. Net-Zero Energy (NZE) standard which has captured the attention and engagement of practitioners in design, construction, real estate, and policy has the possibility to assess building performance not just in design and construction but also once in the operation phase (Tabrizi, 2021). This study primarily aimed to determine the critical knowledge areas and skills that are necessary to respond to NZEB construction challenges. Through a survey and follow up interviews with NZEB constructors, this study identified the knowledge and skills base for constructors to be competitive and to effectively execute NZEB projects.

This convergent parallel mixed methods research study used both qualitative and quantitative data to understand the current delivery process of NZEBs in individual project context and their limitations; the role and experience of key players and level of knowledge sharing among them; along with discipline specific issues and the way to address these issues. The objective of the study was to gain a deep understanding of 1) the challenges constructors face in delivering NZEB projects; 2) the delivery processes used in practice and their impact on NZEB construction; 3) the challenges in using BIM and BPS tools within the NZEB project context.

There were four major steps in this study. First, quantitative, and qualitative data were collected. These two types of data collection were concurrent but separate in Phase 1. The quantitative data was collected using a questionnaire and the qualitative data was

collected through semi-structured interviews. Second, the researcher analyzed the two data sets independently from each other. The quantitative analytic procedures used for this study were 1) means (*M*) to measure central tendency, 2) standard deviation (*SD*) to measure dispersion, 3) Cronbach's alpha (α) to measures reliability or internal consistency, and 4) Pearson's Correlation Coefficient (*r*) to measure the association between two variables. The qualitative analytic procedures included coding and theme development. The researcher then merged the results of the two data sets in Phase 3. This merging step included the direct comparison of the separate results to facilitate relating the two types of data during additional analysis. In the final phase, the researcher interpreted to what extent and in what ways the two sets of results converged, diverged, and related to each other. Qualtrics^{XM}, Microsoft Excel, IBM SPSS 26, and MAXQDA were used for data analysis.

Overview of the Results

The study consisted of a survey to generate the quantitative data, and semi-structured interviews to generate the qualitative data. Twenty-seven completed surveys were received in a timeframe of nine months. The participants were the NZEB construction professionals who had worked as project manager, energy consultant, MEP engineer, architect, general contractor, owner, estimator, or specialty contractor. Twenty of the participants had industry experience of more than 20 years. Five of the participants were interviewed for the qualitative data collection.

The Challenges Constructors Face in Delivering NZEB Projects

a) Challenges:

Based on the Mean rank, the top three challenges faced by the constructors executing NZEB construction projects were labor related. Workers' unawareness of the correct methods and procedures yielded the highest mean scores *(M=3.37),* indicating that it is the most frequently encountered challenge. Reluctance to change from traditional practices was ranked second highest *(M=3.33),* while lack of the technical skill regarding Green/NZEB technologies and techniques was third ranked challenge *(M=3.30).*

Pearson correlation analysis indicated that these three challenge variables were strongly correlated. Correlation between variables across sets indicated that lack of the technical skill regarding green/NZEB technologies and techniques had a moderate positive correlation with communication management ($r = .43$, $p < .05$), teamwork ($r = 0.52$, $p < .01$), problem solving ($r = .41$, $p < .05$), schedule ($r = .43$, $p < .05$), and a strong positive correlation with quality ($r = .66$, $p < .01$). Workers' unawareness of the correct methods and procedures had a moderate positive correlation with on-the-job experience ($r = .41$, $p < .05$), schedule ($r = .53$, $p < .01$), and a strong positive correlation with quality ($r = .77$, $p < .01$). Reluctance to change from traditional practices had a moderate positive correlation with both schedule ($r = .45$, $p < .05$), and quality ($r = .59$, $p < .01$).

The participants from this study verified that there is a tendency to revert to the old ways of doing things that people know and understand and have always done, as doing net zero energy buildings requires people to do things differently. One participant emphasized that the willingness to change was found to be very critical, and people can learn better if they are not resistant to doing something different.

The conclusions inferred from the analysis are as follows:

1. Workers' unawareness of the correct methods and procedures, and the lack of technical skills regarding green/NZEB technologies can be addressed by engaging contractors with knowledge on the environmental issues associated with construction activities and building materials during early stages of design. Forming inter-disciplinary teams to work together throughout the project, increasing communication among team members, and implementing continuing professional develop training would be a good strategy in this regard.
2. To address workers' reluctance to change from traditional practices, there must be a commitment to change the current mentality of employees. According to Shan, Liu, Hwang, and Lye (2020), senior management can have a huge amount of influence over their subordinates and the projects they are managing. So, the project managers should play an active role in enhancing the awareness of environmental issues, knowledge, and cognition on sustainability of all employees.

b) NZEB Project Objectives:

The top three NZEB project objectives from the Mean rank were budget *(M = 3.52)*, schedule *(M = 2.96)*, and quality *(M = 2.93)*.

The correlation analysis revealed that schedule had a moderate positive correlation with quality ($r = .55$, $p < .01$), lack of the technical skill regarding green/NZEB technologies and techniques ($r = .43$, $p < .05$), workers' unawareness of the correct methods and procedures ($r = .53$, $p < .01$), and reluctance to change from traditional practices ($r = .45$, $p < .05$). Quality had a strong positive correlation with lack of the technical skills regarding green/NZEB technologies and techniques ($r = .66$, $p <$

.01), workers' unawareness of the correct methods and procedures ($r = .77$, $p < .01$), and a moderate positive correlation with reluctance to change from traditional practices ($r = .59$, $p < .01$).

One participant mentioned that keeping an eye on budgets, timelines, and quality procedure in place are important for NZEB construction. Another participant mentioned that understanding the relationship between the design decisions and their first cost implications, compared to the cost over time is important.

The conclusions inferred from the analysis are as follows:

1. Workers' lack of technical skills and unawareness of the correct methods and procedures of NZEB construction, and reluctance to change from traditional practice influence the budget, schedule, and cost of the NZEB projects.
2. Design decision has an impact on the budget of the NZEB construction project. According to Hwang, Shan, and Lye (2018), the adoption of sustainable construction requires extra investment for the procurement of new equipment required by sustainable construction, and for the education of current workforce to enhance their skills and knowledge on sustainable construction. Input from the contractors at the design stage can have a positive impact on budget by selecting economic alternatives in design and material selection.

c) Knowledge area:

The Mean rank indicates that the three knowledge areas are equally required for industry professionals to deal with the NZEB projects challenges. Those were cost management, schedule management and planning, and communication management *(M=3.63).*

The correlation analysis indicated that communication management had a moderate positive correlation with teamwork ($r = .52$, $p < .01$), problem solving ($r = 0.48$, $p < .05$), leadership ($r = .60$, $p < .01$), and lack of the technical skill regarding green/NZEB technologies and techniques ($r = .43$, $p < .05$).

Communication management was cited as the most important knowledge by the participants. One participant emphasized communication as the key factor in NZEB construction process. Another participant discussed various methods of coordinating team members so that everybody had frequent communications. With regards to cost management knowledge, one participant emphasized understanding the relationship between the design decisions and their first cost implications, compared to the cost over time as an important factor.

The conclusions inferred from the analyses in this study are as follows:

1. Communication management is important for NZEB construction since it impacts teamwork, problem solving, and leadership. NZEB projects require a more holistic and integrated approach where communication plays a critical role to achieve the project goal. Livesey (2016) verified that effective communication management plan needs to be in place for NZEB projects to facilitate collaboration in project team, which also promotes active participation in decision making.
2. When compared to conventional projects, green/NZEB projects tend to cost more to construct. As a very competitive industry dominated by price, cost control is vital for contractors in the construction industry. The capability of the project manager has considerable impact on the success of projects. They must manage and deliver the project within the budget constraint. Shan et al. (2020) stated the necessity to

appoint a capable project manager that can lead the implementation of the green building construction project.

d) Skills

From the Mean rank, teamwork was found to be the most important skill required to address the NZEB project challenges *(M=3.93)*, followed by leadership skill *(M=3.81)* and problem-solving skill *(M=3.74)*.

The correlation analysis revealed that teamwork had a moderate positive relation with training ($r = .52$, $p < .01$). Problem solving had a moderate positive relation with on-the-job experience ($r = .43$, $p < .05$), and training ($r = 0.50$, $p < .01$). Leadership had a moderate positive correlation with education ($r = .52$, $p < .01$), and training ($r = 0.42$, $p < .05$).

Participants cited teamwork as an important management skill to work on NZEB projects. One participant mentioned teamwork as the core skill. Another participant said that rather than working in traditional silos where mechanical, electrical, et cetera, are just working by themselves, a series of inter-disciplinary component teams work together throughout the entire NZEB project. One participant mentioned leadership as the most important skill stating “especially leadership of or within a team”. Another participant emphasized the role of a leader in understanding and having some skills at managing stakeholders, managing groups of people and figuring out what they really want from an NZEB building.

The conclusions inferred from the analysis are as follows:

1. Teamwork can be facilitated by training, when both training and on-the-job experience play a positive role in enhancing problem solving skill. Leadership skill can be developed by both education and training.
2. To enhance teamwork and performance outcomes, some interventions are suggested, such as, conducting team cross-training and team building prior beginning the project (Salas et al., 2015).

e) Professional development

Based on the Mean rank, on-the-job experience as the most effective mean of professional development *(M= 4.00)* to work in NZEB construction. Training was ranked second *(M=3.67),* followed by education *(M=3.48)*.

The correlation analysis revealed that training had a moderate positive correlation with teamwork *($r = .52$, $p < .01$)*, leadership *($r = 0.42$, $p < .05$)*, and problem solving *($r = 0.50$, $p < .01$)*. On-the-job experience had a moderate positive correlation with problem solving *($r = .43$, $p < .05$)*. Education had a moderate positive correlation with leadership ($r = .52$, $p < .01$).

The importance of training and on-the-job experience were discussed by the participants. One participant mentioned about the system of mentoring where less experienced people were assigned with more experienced to facilitate one-on-one mentoring. The role of seasoned professionals in providing the needed information or the one-on-one coaching needed for a specific individual was also mentioned. About the role of education, one participant mentioned that a graduate should have the knowledge of designing energy efficient building if not net zero.

The conclusions inferred from the analysis are as follows:

1. On-the-job experience is the most effective mean for professional development where seasoned professionals can mentor the less experienced professionals in NZEB construction projects.
2. It is expected that the graduates who work in the NZEB construction projects should have the knowledge of designing energy efficient building at a minimum.

Delivery Processes in Practice and Their Impact on NZEB Construction

The Mean rank indicated that integrated project delivery (IPD) method was the most preferred delivery method *(M=4.23)* for NZEB construction. The second ranked delivery method was design-build *(M=3.54)*, followed by CM at Risk *(M=3.21)*.

The Mean rank also revealed that the top 3 management tasks that were impacted by the chosen delivery method were cost management *(M=4.00)*, communication management *(M=3.88)*, and schedule management and planning *(M=3.88)*.

The correlation analysis revealed that IPD had a strong positive correlation with both cost management ($r = .68$, $p < .01$), and communication management ($r = .67$, $p < .01$); and a moderate positive correlation with schedule management and planning ($r = .54$, $p < .01$).

Participants emphasized on an integrated approach for the success of the NZEB projects. One participant said that the involvement of the construction people from the beginning allowed them to give input regarding constructability and pricing information. One participant mentioned that a more integrated approach, i.e., with the general contractor and major trades involved early, facilitates achieving the energy and other high-performance outcomes because it enables those parties to have input on

design and fosters commitment to the goals. It was also mentioned that a more collaborative process reduces friction/blaming, and enhance deeper understanding of the project goals, requirements, and details of construction. Another participant said that the design-build delivery method for a specific high rise office building was more beneficial for the net zero achievement because they had more of an integrated team approach.

The conclusions inferred from the analysis are as follows:

1. Delivery methods that foster an integrated work environment are suitable for the success of delivering NZEB construction projects.
2. The integrated project delivery method that allows general contractor and major trades involved early, promotes communication, cost, and schedule management and planning.

BIM and BPS tools for NZEB projects

a) Challenges in implementing BIM

The Mean rank revealed that industry's resistance to change from traditional working practices was the most cited challenge *(M=3.20)*. The second ranked challenges were inadequate in-depth expertise and know-how to operate sustainability related analysis software program, and high initial investment in staff training costs *(M=3.15)*.

The correlation analysis revealed that Industry's resistance to change from traditional working practices had a strong positive correlation with inadequate in-depth expertise and know-how to operate sustainability related analysis software program *($r = .78, p < .01$)*, and high initial investment in staff training costs *($r = .79, p < .01$)*.

Inadequate in-depth expertise and know-how to operate sustainability related analysis software program had a strong positive correlation with high initial investment in staff training costs *(r = .88, p < .01)*.

According to the participants, incompatibility with different software was the biggest challenge for BIM implementation. One participant mentioned that if someone is not using Revit®, that hampers their ability to do everything they need to meet the project requirements, which eventually leads to delay in setting a BIM standard for all, hence, decrease the efficiency. Another participant mentioned that not having one tool integrated into BIM that everybody knows that can be used from beginning to end is frustrating.

The conclusions inferred from the analysis are as follows:

1. The BIM implementation challenges, i.e., industry's resistance to change from traditional working practices, inadequate in-depth expertise and know-how to operate sustainability related analysis software program, and high initial investment in staff training costs are correlated. Hwang et al. (2018) also verified that adoption of sustainable construction requires extra investment from contractors for the education of current workforce to enhance their skills and knowledge on sustainable construction, which leads to resistance from the contractors to change from traditional working practices as these investments may result in the loss of their profit margin.

b) BPS tools and their features

Based on the Mean rank, the most cited BPS tool was IES-VE *(M=4.36)*. The second ranked tool was Open Studio *(M=3.91)*, followed by EnergyPlus *(M=3.88)*.

The participants cited accuracy as the most important feature for a BPS tool *(M=4.11)*. Intelligence *(M=3.95)* and usability *(M=3.89)* were the two other important features according to the participants.

The correlation analysis revealed that IES-VE had a moderate positive correlation with accuracy *(r = .48, p < .05)*, intelligence *(r = .59, p < .01);* and usability *(r = .51, p < .01)*. Open Studio had a moderate positive correlation with accuracy *(r = .53, p < .01)*, intelligence *(r = .57, p < .01);* and usability *(r = .57, p < .01)*. EnergyPlus had a moderate positive correlation with both accuracy *(r = .58, p < .01)*, and usability *(r = .57, p < .01)*; and a strong positive correlation with intelligence *(r = .63, p < .01)*.

One participant mentioned that eQuest and RedScreen are effective. Another participant said that Safaira is good for its speed in creating model, but not robust enough to give a very high resolution.

According to one participant, speed in creating a model quickly, producing high resolution model, and creating a model that helps to get deeper understanding of the components of the building are the features a BPS tool should have. Another participant suggested that BPS tools need to be used early rather than later in the process.

The conclusions inferred from the analysis are as follows:

1. Using BPS tools early rather than later is more effective.
2. Accuracy, intelligence, and usability are the desired features for BPS tools to be used on NZEB projects.
3. Speed in creating a model, producing high resolution model, and creating a model that helps to get deeper understanding of the components of the building are the important features a BPS tool should have.

Reliability and Correlation

As discussed in the data analysis section of chapter 4, item standard deviation *(SD)* is applied to test whether the items in each hypothesized grouping contain approximately the same proportion of information about the construct being measured. It is also used to examine whether the items have roughly equal standard deviations, such that they contribute equally to the total scale score. A rule of thumb is that the ratio of the maximum standard deviation to the minimum standard deviation should be about 2:1 (Othman et al., 2011).

On the other hand, an instrument's internal consistency is based on the correlation between different items of the same test. This correlation indicates if a number of items that are supposed to measure the same construct produce similar scores (Ursachi et al., 2015). For Cronbach's alpha *(α)*, computed with correlations between all pairs of items, internal consistency can vary between zero and one. A general accepted rule is that α of 0.6-0.7 indicates an acceptable level of reliability, and 0.8 or greater a very good level. (Ursachi et al., 2015).

a) Challenge set of variables

The maximum *SD* was *1.19* for workers' unawareness of the correct methods and procedures, and the minimum *SD* was *0.74* for high cost of green/NZEB material and equipment. The ratio of the maximum standard deviation to the minimum standard deviation was less than 2:1. So, the items contribute equally to the total scale score.

The Cronbach's alpha *(α)* was *0.94* which indicates a very good level internal consistency.

b) Objectives set of variables

The maximum *SD* was *1.12* for Quality, and the minimum *SD* was *0.96* for both budget and schedule. The ratio of the maximum *SD* to the minimum *SD* was less than 2:1. Hence, the items contribute equally to the total scale score.

The Cronbach's alpha *(α)* was 0.67, indicates an acceptable level of reliability.

c) Knowledge sets of variables

The maximum *SD* was *1.07* for health and safety management, and the minimum *SD* was *0.78* for cost management. The ratio of the maximum *SD* to the minimum *SD* was less than 2:1 which indicates the items contribute equally to the total scale score.

The Cronbach's alpha *(α)* was 0.91 which indicates a very good level of reliability.

d) Skill set of variables

The maximum *SD* was *0.90* for chairing meetings, and the minimum *SD* was *0.72* for leadership. The ratio of the maximum *SD* to the minimum *SD* was less than 2:1. Hence, the items contribute equally to the total scale score.

The Cronbach's alpha *(α)* was 0.88 which indicates a very good level of reliability.

e) Professional development set of variables

The maximum *SD* was *0.82* for professional certification, and the minimum *SD* was *0.61* for on-the-job experience. The ratio of the maximum *SD* to the minimum *SD* was less than 2:1. Hence, the items contribute equally to the total scale score.

The Cronbach's alpha (α) was 0.56 which is below the accepted level of reliability. However, as there were only four variables in this set, a low value of alpha could be due to that reason (Tavakol & Dennick, 2011).

f) Management tasks set of variables

The maximum *SD* was *1.10* for claims management, and the minimum *SD* was *0.65* for communication management. The ratio of the maximum *SD* to the minimum *SD* was less than 2:1. Hence, the items contribute equally to the total scale score.

The Cronbach's alpha *(α)* was *0.60* which indicates an accepted level of reliability.

g) BIM challenges set of variables

The maximum *SD* is *1.28* for lack of client demand and top management commitment, and the minimum *SD* is *0.74* for low level of involvement of BIM users in green/NZEB projects. The ratio of the maximum *SD* to the minimum *SD* is less than 2:1. Hence, the items contribute equally to the total scale score.

The Cronbach's alpha *(α)* was *0.99* which indicates a very good level of reliability.

h) BPS tools set of variables

The maximum *SD* was *1.22* for EnergyPlus, and the minimum *SD* was *0.43* for Modelica. The ratio of the maximum *SD* to the minimum *SD* was less than 2:1. Hence, the items contribute equally to the total scale score.

The Cronbach's alpha *(α)* was *0.93* which indicates a very good level of internal consistency.

i) BPS features set of variables

The maximum *SD* was *1.04*, and the minimum *SD* was *0.64*. The ratio of the maximum *SD* to the minimum *SD* is less than 2:1. Hence, the items contribute equally to the total scale score.

The Cronbach's alpha *(α)* was *0.98* which indicates a very good level of reliability.

Limitations of this Study

Every research study has a set of limitations or potential weaknesses that are beyond the control of the researcher after a plan of study is formed. Initial choices regarding the study are made with respect to the research topic, world view and physical limitations, such as, available time, funding, location, etc. (Simon, 2011). This section outlines the limitations of this study.

1. A purposive sampling was used to recruit industry professionals with NZEB project experience as the study's participants. As mentioned in chapters 3 and 4, there was no directory of NZEB constructors, therefore, the researcher searched for literature on the NZEB construction projects in the United States from online sources. Using the online information about NZEB projects, the researcher searched the stakeholders' company website to find the contact information of the company's construction professionals. The researcher also collected the email addresses of the LEED certified constructors from USGBC directory. A total of 29 completed surveys were received in a timeframe of 9 months. Two participants completed the survey twice. Their second completed surveys were not considered for the analysis. So, the total accepted completed surveys were 27.

According to Hackshaw (2008), researchers are often confounded by issues related to the required sample size. The definition of “large” or ‘‘small’’ sample size depends on the main study objective. When simply describing the characteristics of a single group of subjects, the larger the study the more reliable the results. According to Kar and Ramalingam (2013), various factors like level of significance, power of the study, effect size, precision and variability affect sample size. There is no such thing as a magic number, such as 30, when it comes to sample size.

The sample size for running Pearson's *r* varies according to authors. For a study, Sari et al. (2017) found the sample size needed to estimate the Pearson coefficient of correlation varied between 10 and 200. According to Bonett and Wright (2000), a sample size equal or superior to 25 suffices. However, as the analyses of this study were performed with a small sample, caution is warranted when the results are generalized.

2. According to Ursachi et al. (2015), for Cronbach’s alpha *(α)*, a general accepted rule is that *α* of 0.6-0.7 indicates an acceptable level of reliability, and 0.8 or greater a very good level. On the other hand, Bujang et al. (2018) suggested that for a single coefficient alpha test, the approach by assuming the Cronbach’s alpha coefficient equals to zero in the null hypothesis will yield a smaller sample size of less than 30 to achieve a minimum desired effect size of 0.7.

   In this study, the Cronbach’s alpha *(α)* was 0.67 for the objective set of variables; 0.56 for the professional development set of variables; and 0.60 for the management tasks set of variables. The remaining six sets of variables, i.e.,

challenge, knowledge, skill, BIM challenge, BPS tool, and BPS features had a value of alpha greater than 0.8.

According to Tavakol and Dennick (2011), a low value of alpha could be due to a low number of questions, poor inter-relatedness between items or heterogeneous constructs. If a low alpha is due to poor correlation between items, then some should be revised or discarded.

Implications for Future Research

The sample size of this study was 27. Several authors (Sari et al., 2017; Bonett & Wright, 2000) verified this sample size as sufficient to estimate the Pearson coefficient of correlation. However, the larger the study the more reliable the results (Hackshaw, 2008). The future study with a larger sample size will give a higher response rate for individual items of the study, hence can be more useful for extensive coverage of challenges encountered, and knowledge and skills to respond to them.

As mentioned in the previous section, the Cronbach's alpha *(α)* analysis shows that the alpha of the three sets of variables is low. These sets of variables must be revisited to see if it was due to poor correlations between items so that they can be revised or discarded. One method to find them is to compute the correlation of each test item with the total score test; items with low correlations (approaching zero) are deleted (Tavakol & Dennick, 2011).

Most of the survey participants of this study mentioned more than one role on NZEB construction projects. Constructors in different roles may have a different set of challenges to overcome. The future research can limit the scope of selecting more than

one role by the survey participants so that the researcher can compare project managers, designers, engineers, energy consultants, owners, and contractors' perceptions.

Finally, participants who have both NZEB and conventional construction project management experience could be requested to rate their perceptions of knowledge and skills to respond to the project challenges in both NZEB and conventional buildings for a comparative analysis. Compared with conventional building project management framework, the framework for managing NZEB building projects should be more detailed and allow greater communication between all personnel involved (Hwang & Tan, 2012).

Conclusion

Managing construction projects is a challenging job due to the significant impacts of construction activities on the environment, economy, and surrounding community. Concerns over these impacts have spurred the need for NZEB buildings in the construction industry. Since constructors play an important role in the success of construction projects, it is essential to identify the critical knowledge and skills that contractors require to deal with the challenges of NZEB construction project. The objectives of this study were to identify (1) the challenges constructors face in delivering NZEB projects; (2) the delivery processes and their impacts on the NZEB construction; and (3) the challenges in using BIM and BPS tools for NZEB project optimization.

As shown in Table 22, the analysis of survey responses revealed the challenges, knowledge areas, and skills that are essential to respond to the challenges. The most important challenges were workers’ unawareness of the correct methods and

procedures, reluctance to change from traditional practices, and lack of the technical skill regarding Green/NZEB technologies. The most important knowledge areas were communication management, schedule management and planning, and cost management. The most important skills required to mitigate the challenges are teamwork, leadership, and problem-solving skills. For BIM implementation, industry's resistance to change from traditional working practices, inadequate in-depth expertise and know-how to operate sustainability related analysis software program, and high initial investment in staff training costs were the top challenges. The top three BPS tools were IES-VE, Open Studio, and EnergyPlus. Important features for BPS tool were accuracy, intelligence, and usability.

Table 22. Summary of Survey Results

Category	*Top Variables*
NZEB Project Challenges	Workers' unawareness of the correct methods and procedures Reluctance to change from traditional practices Lack of the technical skill regarding Green/NZEB technologies
NZEB Project Objectives	Budget Schedule Quality
Knowledge	Communication management Schedule management and planning Cost management
Skills	Teamwork Leadership Problem-solving
Professional Development	On-the-job experience Training Education
Delivery Process	Integrated Project Delivery (IPD) method Design-build CM at Risk (CMAR)
Management Tasks	Cost management Communication management Schedule management and planning

BIM Implementation Challenges	Industry's resistance to change from traditional working practices Inadequate in-depth expertise and know-how to operate sustainability related analysis software program High initial investment in staff training costs
BPS Tools	IES-VE Open Studio EnergyPlus
BPS Feature	Accuracy Intelligence Usability

The contribution of academic education to the competency of NZEB constructors is rated lower than that of formal industry training provided by employers. Similarly, the perceived contribution of industry training was outranked by that of experiences on the job site. This is indicative of the important role of experience for achieving skills and competency in construction project management, and to address the changing conditions and requirements that the NZEB industry environment presents from day to day.

According to Wu, Clevenger, and Abdallah (2018), the construction industry is facing a shortage of skilled workforce due to a rapidly changing technology landscape and the transformed business practices driven by emerging industry trends including sustainability, Building Information Modeling (BIM) and lean construction. To keep up with these trends and stay competitive in business, companies are urged to recruit graduates with new knowledge and skillsets, which are not readily addressed in existing construction management or construction engineering management curricula.

According to Valdés, Correa, and Mellado (2018), the professionals working in sustainable construction must be able to work in a team in a collaborative way. It is proposed that the training should be based on the topics: Design, Feasibility

Assessment, Technical Inspection, Execution Construction Process, Planning Construction, Reuse and Renovation and Demolition. Each of these topics should also address issues of energy, environmental comfort, water, wastes and construction materials. In addition, training in interdisciplinary integration, ethics, creativity and innovation, communication and negotiation and empathy with stakeholders should be taken into consideration. Finally, technology innovation and transfer must be present in all sustainable construction training.

Higher education institutes have yet to respond effectively to the current and future challenges and addressing the gap between the industry expectations and the competencies of graduates in construction-oriented programs (Perera et al., 2017). This research, therefore, advocates greater levels of university and industry collaboration in developing and delivering construction curriculum relevant to NZEB construction projects. The high scores associated with the contribution of on-the-job experience implies that designing academic programs in construction project management should consider the real-world experience factor.

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Appendix A: Survey Questionnaire

The UNIVERSITY of OKLAHOMA

English

Informed Consent

Welcome to the research study!

I am Muzibur Rahman from the Department of Construction Science of the University of Oklahoma and I am interested in knowing the "Constructors' Decision-Support Framework for Net Zero Energy Building (NZEB) Projects" as part of my doctoral research. You were selected as a possible participant because of your experience in Net Zero Energy Building (NZEB) construction. You will be presented with information relevant to the NZEB project and asked to answer some questions about it. Please be assured that your responses will be kept completely confidential. The study should take you around 10 minutes to complete. Your participation in this research is voluntary. You have the right to withdraw at any point during the study, for any reason, and without any prejudice. If you would like to contact the principal investigator in the study to discuss this research, please e-mail me at muzibur.rahman@ou.edu or call at (469) 714-7425. You can also e-mail my advisor Dr. Tamera McCuen at tammymccuen@ou.edu or call at (405) 325-4131.

By clicking the button below, you acknowledge that your participation in the study is voluntary, you are 18 years of age, and that you are aware that you may choose to terminate your participation in the study at any time and for any reason.

Please note that this survey will be best displayed on a laptop or desktop computer. Some features may be less compatible for use on a mobile device.

- ○ I consent, begin the study
- ○ I do not consent, I do not wish to participate

NZEB Project Experience

Have you worked in any **Net-Zero Energy Building (NZEB)** project?

- ○ Yes
- ○ No

Please write in the following box the **name, city,** and **state** of the NZEB projects you worked in.

Your role in the NZEB project (please check all that apply)

- ☐ Project Manager
- ☐ Project Control Engineer / Scheduler
- ☐ Project Engineer
- ☐ Energy Consultant
- ☐ MEP Engineer
- ☐ Owner
- ☐ Owner's Representative
- ☐ Other (Please specify in the following box)
- ☐ General Contractor
- ☐ Specialty Contractor / Subcontractor
- ☐ Estimator
- ☐ Architect
- ☐ BIM Manager
- ☐ Interior Designer
- ☐ Landscape Architect

Block 5

Based on your experience, please rate the following **planning-related challenges** that contractors face in delivering NZEB construction projects.

	Not At All	Minimal	Moderate	Significant	Extreme
Adoption of different contract forms of project delivery	○	○	○	○	○
Difficulty in comprehending the NZEB specifications in the contract details	○	○	○	○	○
Planning of NZEB construction sequence	○	○	○	○	○
Planning of NZEB construction technique	○	○	○	○	○
Lengthy approval process for new green/NZEB technologies within the organization	○	○	○	○	○
Other (please specify)	○	○	○	○	○

Based on your experience, please rate the following **project-related challenges** that contractors face in delivering NZEB construction projects.

	Not At All	Minimal	Moderate	Significant	Extreme

	Not At All	Minimal	Moderate	Significant	Extreme
More alteration and variation with the design during the construction process	○	○	○	○	○
Difficulty in the selection of subcontractors in providing NZEB construction service	○	○	○	○	○
More time is required to implement green/NZEB construction practices onsite	○	○	○	○	○
Difficulty in assessing the progress of completion in NZEB construction	○	○	○	○	○
Other (please specify)	○	○	○	○	○

Based on your experience, please rate the following **client-related challenges** that contractors face in delivering NZEB construction projects.

	Not At All	Minimal	Moderate	Significant	Extreme
Objective of the building project	○	○	○	○	○
Required date of completion	○	○	○	○	○
Level of risk the client is willing to take in green/NZEB technologies	○	○	○	○	○
Client uses a lot of time in making decision	○	○	○	○	○

	Not At All	Minimal	Moderate	Significant	Extreme
Special request from client pertaining to specified green/NZEB technologies to be used	○	○	○	○	○
Other (please specify)	○	○	○	○	○

Based on your experience, please rate the following **project team-related challenges** that contractors face in delivering NZEB construction projects.

	Not At All	Minimal	Moderate	Significant	Extreme
Conflict with the architect over the type of material to be used	○	○	○	○	○
Lack of communication among project team members	○	○	○	○	○
Frequent meetings with green specialists	○	○	○	○	○
Green consultant's delay in providing information	○	○	○	○	○
Conflict of interest between consultant and project manager	○	○	○	○	○
Other (please specify)	○	○	○	○	○

Based on your experience, please rate the following **labor-related challenges** that contractors face in delivering NZEB construction projects.

	Not At All	Minimal	Moderate	Significant	Extreme
Reluctance to change from traditional practices	○	○	○	○	○
Lack of the technical skill regarding green/NZEB technologies and techniques	○	○	○	○	○
Workers' unawareness of the correct methods and procedures	○	○	○	○	○
Other (please specify)	○	○	○	○	○

Based on your experience, please rate the following **material and equipment-related challenges** that contractors face in delivering NZEB construction projects.

	Not At All	Minimal	Moderate	Significant	Extreme
High cost of green/NZEB material and equipment	○	○	○	○	○
Uncertainty with green/NZEB material and equipment	○	○	○	○	○
Availability of green/NZEB material and equipment	○	○	○	○	○
Decision on different green/NZEB material and equipment	○	○	○	○	○
Other (please specify)	○	○	○	○	○

Please rate the extent to which **the challenges** described above influence the following NZEB project **objectives**.

	No Impact	Minimal Impact	Moderate Impact	Significant Impact	Extreme Impact
Schedule	○	○	○	○	○
Budget	○	○	○	○	○
Quality	○	○	○	○	○
Other (please specify)	○	○	○	○	○

Please rate the **management knowledge areas** that contractors need in order to effectively deal with the challenges of NZEB construction

	Not Important	Minimally Important	Moderately Important	Important	Extremely Important
Cost management	○	○	○	○	○
Schedule management and planning	○	○	○	○	○
Materials resources management	○	○	○	○	○
Risk management	○	○	○	○	○
Communication management	○	○	○	○	○
Stakeholder management	○	○	○	○	○
Conflict and dispute	○	○	○	○	○

	Not Important	Minimally Important	Moderately Important	Important	Extremely Important
management					
Claims management	○	○	○	○	○
Human resources management	○	○	○	○	○
Health and safety management	○	○	○	○	○
Other (please specify)	○	○	○	○	○

Please rate the **management skills** that contractors need in order to effectively deal with the challenges of NZEB construction

	Not Important	Minimally Important	Moderately Important	Important	Extremely Important
Decision making	○	○	○	○	○
Delegation	○	○	○	○	○
Analytical	○	○	○	○	○
Team working	○	○	○	○	○
Problem solving	○	○	○	○	○
Leadership	○	○	○	○	○
Negotiation	○	○	○	○	○
Human behavior	○	○	○	○	○
Chairing meetings	○	○	○	○	○
Presentation	○	○	○	○	○
Other (please specify)	○	○	○	○	○

	Not Important	Minimally Important	Moderately Important	Important	Extremely Important
	○	○	○	○	○

Please indicate the level of importance for each of the following as it relates to **NZEB professional development**.

	Not Important	Minimally Important	Moderately Important	Important	Extremely Important
On the job experience	○	○	○	○	○
Education	○	○	○	○	○
Training	○	○	○	○	○
Professional certification	○	○	○	○	○
Other (Please specify)	○	○	○	○	○

Please write in the following box how contractors currently **address the barriers** on NZEB projects.

Based on your experience, please rate the following **project delivery methods** for NZEB project.

	Not Suitable	Minimally Suitable	Moderately Suitable	Suitable	Extremely Suitable
Design-Build	○	○	○	○	○
Integrated Project Delivery (IPD)	○	○	○	○	○

	Not Suitable	Minimally Suitable	Moderately Suitable	Suitable	Extremely Suitable
Design-Bid-Build	○	○	○	○	○
CM at Risk (CMAR)	○	○	○	○	○
Engineers Joint Contract Documents Committee (EJCDC)	○	○	○	○	○
Other (Please Specify)	○	○	○	○	○

Please rate the extent to which the **project delivery methods** described above influence the following **project management tasks** on NZEB projects.

	Not At All	Minimal	Moderate	Significant	Extreme
Cost management	○	○	○	○	○
Communication management	○	○	○	○	○
Schedule management and planning	○	○	○	○	○
Risk management	○	○	○	○	○
Conflict and dispute management	○	○	○	○	○
Stakeholder management	○	○	○	○	○
Materials resources management	○	○	○	○	○
Claims management	○	○	○	○	○
Human resources management	○	○	○	○	○
Health and safety management	○	○	○	○	○

	Not At All	Minimal	Moderate	Significant	Extreme
Other (please specify)					

Have you used **Building Information Modeling (BIM)** in any Net-Zero Energy Building (NZEB) project?

- Yes
- No

Based on your experience, please rate the following **barriers/challenges** that contractors face in **implementing BIM** on NZEB projects.

	Not At All	Minimal	Moderate	Significant	Extreme
Lack of client demand and top management commitment					
Organizational challenges, policy, and project strategy					
Industry's resistance to change from traditional working practices					
Longer time in adapting to new technologies (steep learning curve)					
Lack of understanding of the processes and workflows required for BIM and sustainability					
Inadequacy of requisite experience, knowledge, and skills from the workforce					

	Not At All	Minimal	Moderate	Significant	Extreme
	Not At All	Minimal	Moderate	Significant	Extreme
Inadequate in-depth expertise and know-how to operate sustainability-related analysis software programs	○	○	○	○	○
Difficulty in assessing environmental parameters of building properties	○	○	○	○	○
Shortage of cross-field specialists in BIM and sustainability	○	○	○	○	○
High cost of BIM software, license, and associated applications	○	○	○	○	○
High initial investment in staff training costs	○	○	○	○	○
Incompatibility issues with different software packages	○	○	○	○	○
	Not At All	Minimal	Moderate	Significant	Extreme
Lack of suitable procurement policy and contractual agreements	○	○	○	○	○
Lack of supporting sustainability analysis tools	○	○	○	○	○
Low level of involvement of BIM users in green/NZEB projects	○	○	○	○	○
User-unfriendliness of BIM analysis software programs	○	○	○	○	○

	Not At All	Minimal	Moderate	Significant	Extreme
Other (please specify)	○	○	○	○	○

Have you used any **building performance simulation (BPS) tool** in the NZEB project?

○ Yes
○ No

Please rate the following **BPS tools** (the one or all you have used) for NZEB projects.

	Not Suitable	Minimally Suitable	Moderately Suitable	Suitable	Extremely Suitable
eQUEST	○	○	○	○	○
Trane TRACE	○	○	○	○	○
IES-VE	○	○	○	○	○
EnergyPlus	○	○	○	○	○
Open Studio	○	○	○	○	○
DesignBuilder	○	○	○	○	○
TRNSYS	○	○	○	○	○
Modelica	○	○	○	○	○
PHPP	○	○	○	○	○
Other (please specify)	○	○	○	○	○

Please indicate the level of importance of the following **features of BPS tools** on NZEB projects.

	Not Important	Minimally Important	Moderately Important	Important	Extremely Important
Usability	○	○	○	○	○
Intelligence	○	○	○	○	○
Interoperability	○	○	○	○	○
Accuracy	○	○	○	○	○
Process adaptability	○	○	○	○	○
Other (please specify)	○	○	○	○	○

Respondent's Profile

Your position and organization name

Years of experience

- ○ 0 - 5
- ○ 6 - 10
- ○ 11 - 15
- ○ 16 - 20
- ○ 20 or more

Would you like to participate in a brief follow-up interview?

○ Yes (please write your name, email address, and phone number)

○ No

Would you like to receive the results of this survey?

○ Yes (please write your name, email address, and phone number)

○ No

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Appendix B: Interview Questionnaire

Interview Questions

1) Please tell me your name, the name of the company you work for, and your designation.
2) Please name the Net Zero Energy Building (NZEB) project(s) you have worked on.
3) What was your role in the project(s)?
4) Explain ways in which the project delivery method selected may impact a NZEB construction process.
5) Describe the challenges you experienced with NZEB project(s) for the following, if relevant
    a) Related to planning (ref. survey q#5)
    b) Related to the overall project (ref. survey q#6)
    c) Related to the client (ref. survey q#7)
    d) Related to the project team (ref. survey q#8)
    e) Related to labor workforce (ref. survey q#9)
    f) Related to material and equipment (ref. survey q#10)
    g) Other challenges not listed
6) What methods did you/the team use to overcome project challenges?
7) Describe the approach taken for decision making when there were several alternatives for a solution? (i.e. decision matrix, scoring process, consensus, etc.)
8) Describe the approach taken for decision making when there were differences of opinions among the stakeholders?
9) Elaborate on the necessary management skills and knowledge most important to deal with the challenges faced on NZEB projects?
10) What strategies have you found effective for improving the management skills to overcome the challenges experienced with NZEB construction in the areas of
    a) Decision making
    b) Delegation
    c) Analytical capabilities
    d) Teamwork
    e) Leadership
    f) Negotiation

g) Human behavior
h) Meetings
i) Presentation

11) What strategies have you found effective for improving management knowledge needed of team members to overcome the challenges experienced with NZEB construction in the areas of
    a) Cost management
    b) Schedule management and planning
    c) Materials resources management
    d) Risk management
    e) Communication management
    f) Stakeholder management
    g) Conflict and dispute management
    h) Claims management
    i) Human resources management
    j) Health and safety management
12) Describe how Building Information Modeling (BIM) can effectively contribute to NZEB construction management?
13) Describe your experience with the implementation of BIM on NZEB projects.
14) How did you address the challenges of BIM implementation discussed in your answer to the previous question (#12)?
15) Which Building Performance Simulation (BPS) tool is most effective for NZEB construction?
16) Is there anything else you would like to share regarding your experiences with the construction of NZEB projects?