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Behavior-Based Quality System (BBQS)

By

Sulyn Cossett Gomez Villanueva

A dissertation submitted in partial satisfaction of the

requirements for the degree of

Doctor of Philosophy

in

Engineering – Civil and Environmental Engineering

in the

Graduate Division

of the

University of California, Berkeley

Committee in charge:

Professor Iris D. Tommelein, Co-Chair
Dr. Glenn Ballard, Co-Chair
Professor William Ibbs
Professor Juliana Schroeder

Spring 2023

Behavior-Based Quality System (BBQS)

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Sulyn Cossett Gomez Villanueva

Abstract

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Sulyn Cossett Gomez Villanueva

Doctor of Philosophy in Engineering - Civil and Environmental Engineering

University of California, Berkeley

Professor Iris D. Tommelein, Co-Chair

Dr. Glenn Ballard, Co-Chair

Meeting quality expectations is vital to the successful delivery of construction projects. Still, the levels of quality achieved in practice are often unsatisfactory, resulting in rework or acceptance of poor work. Quality management research has relied on statistical process control, tolerance management, and standards development. In recent years, though, attention has been shifting toward theoretical and philosophical foundations of quality, and the role people play in defining quality expectations and achieving them. Behavior-Based Quality (BBQ) embraces the human factor (e.g., beliefs, principles) in the management of quality. BBQ proposes improving the delivery of quality by focusing on people's behaviors to foster alignment and minimize quality issues. Anecdotal evidence in this research shows people understand BBQ's intent but struggle to figure out what it all encompasses and how to implement it. A more systemic view of BBQ, providing a description of what BBQ entails, could facilitate its understanding and adoption. Yet, what such a system might look like hasn't been defined yet. This motivated this research.

In this dissertation, I present a Behavior-Based Quality System (BBQS) and describe its theoretical and philosophical foundations to deliver quality outcomes. I designed the BBQS on the foundations of Lean and psychological safety. Inspired by the Last Planner® System (LPS) benchmark, I identified the following features of the BBQS: (1) functions needed to deliver quality, (2) presuppositions about the world where these functions are performed, (3) the behaviors needed to perform the functions and the principles on which they are based, (4) the processes used to perform the system functions, and (5) methods and tools that facilitate executing the processes. Inspired by studies that explore the construct of psychological safety and its impact on teams and their outcomes in industries such as healthcare and technology, I incorporated this construct across the BBQS features, from fostering psychological safety as a principle in the system to reporting mistakes for learning as a step in the quality delivery process.

Using design science research, I developed the BBQS in four iterations. First, I conducted exploratory studies where I analyzed the construct of psychological safety in two construction project teams and the use of BBQ to manage quality in one of them. Second, I analyzed responses collected from practitioners who had applied BBQ to some extent and shared their perspectives of what worked well for them and the behaviors they observed within their teams. Third, I conducted a retrospective case study to learn what a team did to deliver quality on a project known by the

general contractor participating in the research as one of their best-in-class projects. Fourth and last, I conducted longitudinal studies on two projects in parallel; I used one as a control case and implemented BBQS on the other and then compared their outcomes.

I argue that implementing the BBQS could improve (1) the behaviors desired for quality, and in doing so, can indirectly improve (2) psychological safety and (3) team performance. These three are my research variables. To test this argument, I collected information to assess these variables and examined their relationship. I found that psychological safety is positively associated with behaviors desired for quality, and these, in turn, are positively associated with team performance. I also found that the behaviors desired for quality mediate between psychological safety and team performance. BBQS led to a statistically significant increase in the behaviors for quality in the project where it was implemented. While I also observed an increase in psychological safety and team performance in that project, the difference was not statistically significant. A question remains open: would a larger sample allow to observe a statistically significant increase in psychological safety and team performance when implementing the BBQS? Furthermore, I analyzed my research variables by staff and craft members and found a gap that needs to be closed. On the projects studied, staff members reported higher levels of psychological safety and higher scores for the desired behaviors than craft members. Through the implementation of BBQS, I was able to reduce that gap by increasing psychological safety and fostering behaviors for quality among craft members.

This research is a first step toward understanding the impact of the BBQS on a construction project team's psychological safety, behaviors for quality, and performance. This research contributes to knowledge by augmenting the literature on quality management and psychological safety, proposing a psychometric tool to assess construction teams' psychological safety and the behaviors desired for quality, closing the gap between staff and craft psychological safety and their behaviors for quality, and presenting a system that highlights the human factor in the delivery of quality and guides teams implementing a behavioral approach to quality.

Future research can further refine the BBQS features, design simulations to train participants in the BBQS, and deepen understanding of the relationship between psychological safety, behaviors for quality, and performance, in addition to better understanding the factors influencing psychological safety in construction teams, and the managerial actions that these teams can take to foster psychological safety.

DEDICATION

To my daughter, Emilia Juliette,
for bringing immeasurable joy to my life

To Glenn,
who personifies the world Lean in all his self,
for inspiring me to start this journey and staying by my side all the way

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ACKNOWLEDGMENTS

I am most grateful to my family for their endless love. To my mother, Julia, words cannot express my gratitude for all you have done and taught me. Because of you, I know family always comes first, and our family has given me the strength I needed to complete this dissertation. To my sister and best friend, Michelle, thank you for caring for me in many ways and bringing that little craziness I need into my life. I know you will always be there for me, as I will always be there for you. To my brother, Cesar, thank you for your patience and support, especially since I became a mom; somehow, you knew I needed you more than ever. To my husband, Kevin, thank you for the countless hours we spent talking about my research and the construction industry as a whole. I love hearing your perspective because I admire you. I am confident that our journey of growth and learning will continue to flourish. And, of course, to our daughter, Emilia Juliette, you are MY WORLD. I owe you many hours of playing together and look forward to continuing our music lessons and seeing you smile! As you embark on your journey of life, I hope you remember that I am always here for you. Thank you for lighting up my days!

I am deeply indebted to my research advisors, Professor Iris Tommelein and Dr. Glenn Ballard, for guiding me in this academic endeavor. I would like to express my deepest appreciation to Iris for helping me build the discipline and consistency needed to complete this research. I could not have undertaken this journey without Glenn, who walked with me every step of the way, teaching me with humility what Lean really is. I also extend my gratitude to my Ph.D. committee members. I want to thank Professors Juliana Schroeder and William Ibbs for helping me view my engineering research through other lenses, considering the perspectives of both psychology and business.

At DPR Construction, I have immense gratitude for my dear friends Dr. Paz Arroyo and Ralph Romayor. Paz, your words of encouragement and support gave me strength when I needed it most. Ralph, all our field walks and extensive conversations enriched my work tremendously. I also want to thank Rodney Spencley and Stephen Terni, who believed in me and in this research, opened the company's doors to experiment together, and welcomed me to the Quality Strategic Team.

At Webcor, I want to thank Todd Mercer, Bryan Bishop, and Mario Saenz for their encouragement and support in exploring psychological safety in construction.

I want to convey my gratitude to the architects and designers from Smith Group, Mark Cavagnero Associates (MCA), and Jacobs, whose unique perspectives enriched this work.

I want to thank all the research participants for their time and the stories illustrated here. These will serve many in their Lean journey and their pursuit to improve the delivery of quality.

At the University of California San Francisco (UCSF), I want to thank Michael Bade and Dr. Patricia Tillmann for contributing to this research with the exploratory studies.

This work was funded in part by industry contributions made in support of the Project Production Systems Laboratory at U.C. Berkeley. All support is gratefully appreciated. Any opinions, findings, conclusions, or recommendations expressed here are those of the author and do not necessarily reflect those of contributors to P2SL.

GLOSSARY

Alignment	The process of incorporating [considering] all the distinct priorities and requirements [expectations] of project participants to create a uniform set of project objectives that meet the business needs of the facility (Griffith and Gibson 1997 p. 38). Not all expectations are likely to be met either because they are not reasonable or achievable (e.g., due to insufficient funds or time), inconsistent, or conflicting across scopes (Sims and Anderson 2001, McManus 2002, Cunningham 2018).
Cause Mapping	Cause Mapping is a root cause analysis method that improves how people analyze, document, communicate, and solve problems by visualizing the cause-and-effect relationships that contribute to a problem. The cause-and-effect map shows how all of the causes work together to create the problem (ThinkReliability 2021).
Conditions of Satisfaction (CoS)	CoS are not objective realities, independent of interpretations. They exist in the listening, and there is always the potential for difference among the parties (Winograd 1986). These are conditions the requestor likes to be fulfilled by the performer (Flores 2012).
Customer Dissatisfaction	A state of affairs in which deficiencies (in goods or services) result in customer annoyance, complaints, claims, and so on (Juran and Godfrey 1999).
Customer Satisfaction	A state of affairs in which customers feel that their expectations have been met by the product features (Juran and Godfrey 1999).
Defect	An output that does not conform to a condition of satisfaction or specification; not to standard; not of quality (P2SL n.d.). Defects arise because errors [mistakes] are made (Shingo 1986 p. 82)
Deficiency	Any fault (defect or error [mistake]) that impairs a product's fitness for use. Deficiencies take such forms as office errors [mistakes], factory scrap, power outages, failures to meet desired aesthetics and delivery dates, and inoperable goods (Juran and Godfrey 1999).
Deming Cycle	Also known as the Plan Do Check Act (PDCA) cycle. The cycle of scientific experimentation, used for example, in pursuit of continuous improvement (P2SL n.d.).
Distinguishing Features of Work (DFOW)	The term DFOW was coined by DPR, a general contractor that collaborated in this research (Spencley et al. 2018). DFOW is commonly referred to as a subset of requirements that needs particular attention because (1) these requirements are key to meeting the owner's and designer's intent, (2) they are a common source of rework during construction or owner's complaints post-construction, (3) they have a high impact on the project cost or schedule, or (4) the information regarding these is vague or conflicting.

Error	(noun) 1. An act or condition of ignorant or imprudent deviation from a code of behavior; 2. An act involving an unintentional deviation from truth or accuracy; 3. Something produced by mistake (Merriam Webster 2020).
Expectations	Expectations are mental models (Luoma-aho and Olkkonen 2016) created as individuals anticipate or look forward to the coming or occurrence of (Merriam Webster 2022).
Fitness for Use	The degree to which products conform to a set of requirements and meet the users' needs for which they are intended (Juran 1995).
(to) Hand off	The act of releasing an output from a step or operation to the customer or production unit performing the next step or operation (P2SL n.d.).
Hand-off Criteria	The criteria spelled out as conditions of satisfaction discussed and explicitly agreed upon between the provider and the customer (i.e., the parties to a hand-off) (P2SL n.d.).
Hazard	An inherent property or ability of something to cause harm – the potential to interrupt or interfere with a process or person (Holt 2001 p. 3).
Inspection	Assessing some features of a process or completed work against a standard. That standard, rooted in someone's purpose or need, is expressed in technical terms that can be observed and measured. Due to the risk that there is a break in value flow-down, even when you are in complete conformity with requirements, you may not contribute to value because your specifications are wrong (P2SL n.d.).
Interpersonal Risk	Interpersonal risk, at the lightest level, is the risk that people will not think well of you, at the more extreme degree, interpersonal risk is the risk of rejection or humiliation (Edmondson 2018).
Jidoka	The Japanese term referring to the quality control process with four steps: (1) Detect the abnormality, (2) Stop, (3) Fix or correct the immediate condition, and (4) Investigate the root cause and install a countermeasure (P2SL n.d.).
Last Planner®	The person making commitments on behalf of and assignments to direct workers (P2SL n.d.).
Lean	Creating more value for customers with fewer resources (Lean Enterprise Institute 2019).
Lean Construction	Application of Lean thinking to the designing and making (or delivery at large) of capital projects (or projects in general) (P2SL n.d.).
Measurable Acceptance Criteria (MAC)	An objective way to evaluate a deliverable. By agreeing on MAC, the team increases the likelihood that the job will be done right the first time. Defining the MAC allows the team to evaluate the work before releasing it to the next phase (Gomez et al. 2019a).
Mistake	(noun) 1. A wrong judgment; 2. A wrong action or statement proceeding from faulty judgment, inadequate knowledge, or inattention (Merriam Webster 2020). In this research, mistake and error are used interchangeably.

Mistakeproofing	The practice of designing products and processes to eliminate (or at least to reduce) the likelihood of occurrence of mistakes, and thereby avoid creating defects (or reduce their severity) (P2SL n.d.).
Plan-Do-Check-Act (PDCA)	The cycle of scientific experimentation, used for example, in pursuit of continuous improvement (P2SL n.d.).
Pointing and Calling	Pointing and calling is a safety standard that combines looking at something, pointing at it, calling out the observation, and listening to your voice (Roser 2014).
Predictability	The degree to which something can be forecast within a certain time frame and with a degree of accuracy and precision (P2SL n.d.).
Psychological Safety	Feeling able to show and employ one's self without fear of negative consequences to self-image, status, or career (Kahn 1990 p. 708). It is a shared belief that the team is safe for interpersonal risk-taking (Edmondson 1999 p. 350).
Quality	Determining customer needs and expectations requires ongoing, disciplined activity. Conformance [conformity] to a customer's valid and agreed-upon conditions of satisfaction (LCI n.d.).
Quality Expectations	It describes the needs and wants of the customer and translates them into the projects' objectives. Meeting these expectations impacts whether customer satisfaction is achieved (Juran 1986).
Requirements (or Project Requirements)	Conditions or capabilities that must be met by the project or present in the product, service, or result to satisfy an agreement or other formally imposed specification (PMI 2017). These are vast and diverse, ranging from the project's general requirements, resource requirements, technical requirements, space requirements, and functional requirements (Hendrickson and Au 1989). Expectations are the basis for building requirements. The former exists in the minds of stakeholders. The latter is the product of aligning and recording what they agree. The requirements that are the center of this study are those that are used for the inspection of craftwork.
Safety	The condition of being safe from undergoing or causing hurt, injury, or loss (Merriam Webster 2020). In construction, safety is a philosophy that identifies and eliminates job site hazards throughout the lifecycle of a work project while discouraging work practices that place individuals at risk of injury (Hislop 1999).
Speak up	Speaking up describes back-and-forth exchanges people have at work – from volunteering a concern in a meeting to giving feedback to a colleague (Edmondson 2018 p. 7).
Specifications (or Project Specifications)	Written instructions used in conjunction with drawings to fully describe and define the work that is to be accomplished, along with the methods and quality that will be required (Jellinger 1981).
Stakeholder	Participants or individuals involved in and affected by the activities of construction projects throughout the whole-life cycle of the project (Oke and Aigbavboa 2017).

Team	A group of people that are interdependent in achieving some shared outcome (Edmondson 2012).
Value	Something is "of value" to someone when it is appreciated by them. This may be expressed by saying "Thank You," willingness to pay for it, offering something non-monetary in return, etc. (P2SL n.d.).
Zero Defects	Zero defects are achieved because errors [mistakes] do not turn into defects (Shingo 1986 p. 84).

ACRONYMS

AEC: Architecture Engineering and Construction
AIA: American Institute of Architects
BBQ: Behavior-Based Quality
BBQS: Behavior-Based Quality System
BIM: Building Information Modelling
BQ: Behavior for Quality
CII: Construction Industry Institute
CQEC: Construction Quality Executive Council
DFOW: Distinguishing Feature of Work
LCI: Lean Construction Institute
MAC: Measurable Acceptance Criteria
P2SL: Project Production Systems Laboratory
PDCA: Plan-Do-Check-Act
PPE: Personal Protective Equipment
PS: Psychological Safety
TP: Team Performance

1. INTRODUCTION

This chapter presents an overview of my research interest organized as follows. Section 1.1 describes the research background and presents the problem statement. Section 1.2 highlights the motivation underlying this research. Section 1.3 summarizes the research framework. Section 1.4 describes the research objectives. Section 1.5 formulates the research questions and hypotheses. Section 1.6 presents the research scope. Last, Section 1.7 outlines the dissertation structure.

1.1 Research Background and Problem Statement

The literature describes two primary ways to cause conformity to quality expectations (Crosby 1979, Shingo 1986, Juran 1995). The first one, inspecting-in-quality (IiQ), consists in relying on inspections by focusing on doing the work and then checking to determine what happens next (e.g., accept it as is, rework to conform, or redo entirely). The second one, building-in-quality (BiQ), consists in reducing the probability of rejection and repair by focusing on designing and executing mistakeproof processes. Rather than being exclusively one or the other, this distinction is one of emphasis. When approaching the task of delivering quality, no one entirely disregards shaping production processes to deliver desired outputs, and no one can entirely dispense with inspection; even processes that are designed to be automated can produce defects, e.g., as a result of defective materials. IiQ emphasizes identifying non-conformities during inspections (representing a reactive approach to quality where defects trigger actions), whereas BiQ emphasizes avoiding non-conformities throughout the delivery process (representing a proactive approach to quality following mistakeproofing practices where mistakes are prevented, or their impact mitigated to the extent possible).

Through this research, I developed a quality management system, Behavior-Based Quality System (BBQS), intended to improve upon current forms of BiQ by incorporating critical behaviors. Quality management research has relied on statistical control, tolerances, and standards development (e.g., Milberg 2006, ASTM 2020). In the last years, though, attention has been shifting toward the theoretical and philosophical foundations of quality and the role of people in planning to define and achieve quality expectations. Spigener (2001) and Flynn (2001) proposed shifting the emphasis of quality management from a process-oriented to a more behavior-oriented approach due to people's role in planning and executing the processes to deliver quality. They suggested this shift allows (1) improving the "likelihood that the right behavior occurs," (2) engaging those who are needed in the quality process, (3) assuring upstream identification of mistakes and deficiencies, and (4) moving away from disciplinary actions as a tool for improvement towards learning through feedback.

I measured the results of implementing the BBQS using a combination of qualitative (e.g., assessing participants' perception of performance and behaviors pre- and post-BBQS) and quantitative metrics (e.g., quality issues identification timing, percentage of issues assigned per trade). The BBQS expands on existing forms of BiQ approaches by adding *people* to *product, process,* and *philosophy* and providing a structured system for delivering quality, including the following features: (1) functions to perform, (2) presuppositions to be aware of, (3) principles and behaviors that are the foundations for the system (e.g., behaviors driven by psychological safety

and the Lean thinking), (4) processes involved, and (5) methods and tools that facilitate the processes to deliver quality. Some of these had been developed in the quality management literature, to some extent, while others are added here in the development of the BBQS.

The BBQS is centered on the notion of deliverables (which can be something as small as concrete pile caps or as big as the entire project) and its connection with behaviors. Deliverables in construction projects are either physical (e.g., millwork, terrazzo flooring) or informational (e.g., contracts, submittals). This research is focused on the delivery of physical products. Among the physical products, a project as a whole can be understood as a unique product to be delivered to the paying customer to meet their expectations (Ballard et al. 2001). That product consists of various scopes of work (e.g., concrete foundations, acoustical ceilings). In this research, I focused on two scopes, architectural concrete walls, and drywall walls.

The BBQS guides those involved in delivering any scope of work throughout the process of understanding, aligning and communicating stakeholders' expectations, designing capable operations, and carrying out those operations. Stakeholders in construction projects include owners, users of the facilities, governing agencies, designers, general contractors (GCs), fabricators, installers, operators, maintainers, surrounding communities and associations, and the society as a whole (Smith and Love 2004, Winch 2010, Nash et al. 2010, Oke and Aigbavboa 2017). In most cases, GCs rarely, if ever, play the lead role in managing external stakeholders (e.g., city planning departments, neighborhood associations, regulatory agencies) or in the initial determination of requirements. However, to fulfill their responsibility of delivering a project that meets quality requirements, GCs must understand how those requirements were determined and if they were properly determined, e.g., by assuring compatibility of requirements and capability of construction operations to meet such requirements, assessing methods to use for determining conformity to requirements, etc. To differentiate stakeholders who are to be involved in the quality process (e.g., architects, craftworkers) from those who do not directly participate in the process (e.g., external stakeholders), I call the former "project participants."

Project participants involved in the delivery of a project have their own expectations about what the end product should be like. Such expectations are mental models, which need to be transformed into a set of requirements (agreed expectations) that GCs can use to build. I developed the BBQS from the perspective of the GCs because they are the ones in the position of leading the process to make sure that the requirements that are used for construction clearly convey project participants' expectations, and then transform such requirements into reality (physical deliverables). GCs are responsible for verifying that what they are building meets the agreed expectations of project participants, within project constraints.

In designing, testing, and refining the BBQS, I used design science research (March and Smith 1995, Simon 1996, Vaishnavi 2007, Holmström et al. 2009) as the main methodology. I refined the BBQS and demonstrated its utility through action research by testing it on a project and improving it based on the feedback from the research participants (March and Smith 1995). The utility of the BBQS is that:

1. GCs have a structured system to guide project participants in the process of delivering quality by making sure that before building, they (1) have a clear set of requirements that convey project participants' expectations, (2) design operations capable of achieving such requirements, and (3) execute and measure delivered work against such requirements.

2. The behaviors desired to support the delivery of quality can be assessed and monitored to determine actions for improvement as needed.
3. Project participants implement actions to foster psychological safety and promote the behaviors desired for quality.

1.2 Motivation

The motivation for this research is twofold: (1) to improve the delivery of quality in construction projects through a system that focuses on project participants' behaviors for managing quality, and (2) to understand the correlation between psychological safety, the behaviors desired for quality, and team performance. Regarding the first motivation, evidence of lack of quality delivery can be found in many ways, such as requests for information (which reflects issues or flaws in the design), rework (which reflects issues during construction), and callbacks and owner's dissatisfaction (which reflects defects that were not perceived or ignored at the moment the project was delivered). Regarding the second motivation, the importance of people's behavior has been highlighted for achieving and sustaining any change, such as a different way to deliver quality (Spigener 2001, Flynn 2001, Spencley et al. 2018). I identified some of those behaviors and assessed their potential impact on quality performance. For example, delivering quality products requires people to report any mistake they or someone else has caused. Reporting mistakes as close to their occurrence allows a prompt solution, which includes fixing the consequences of the mistake and taking action to avoid its reoccurrence. Delivering quality also requires people to commit to something and assess the work against what was agreed upon. For the first, it allows looking at mistakes as opportunities for improvement rather than punishment. For the second, it fosters respect for people and the pursuit of continuous improvement.

1.3 Research Framework

1.3.1 Challenges in Managing Quality in Construction Projects

Delivering quality in construction projects is a challenging endeavor due to many reasons, such as:

1. Project stakeholders have different contractual relationships (Sutterfield et al. 2006, Winch 2010, Leung and Olomolaiye 2010), different attitudes towards the project (i.e., proponents, opponents, or neutral) (Olander 2007, Chinyio and Akintoye 2008), or different attributes (e.g., power, urgency) (Mitchell et al. 1997, Walker et al. 2008).
2. The subjectivity of what is understood as quality (e.g., aesthetics, performance, financials). This makes it necessary to come to a common understanding about what quality is for project participants before building.
3. Project documents (e.g., specifications, drawings) often have ambiguous, inconsistent, or conflicting information (Porteous 1992, Stasiowski and Burstein 1993, Assaf et al. 1995, Juran and Godfrey 1999, Lowe 2001).
4. Project participants have their own expectations (Carty 1995, Newcombe 1996, Egan 1998, Jefferies et al. 1999, Cornick and Mather 1999). Such expectations might conflict (e.g., due to different interests), and some might not be achievable (e.g., due to project constraints such as budget, schedule, and project priorities).

5. Project participants join the project at different times; some early during project definition, such as the owners and designers, some later during design, supply, or assembly (Ballard 2000a), and participate in different ways in delivering quality.
6. Often owners either do not know how to express what they want (Juran and Godfrey 1999) or do not know how to design and construct it (Pheng and Yeap 2001), making their understanding of the implications (e.g., time, feasibility) of their expectations limited.
7. Project participants who execute the operations by which scopes are built are not often involved in the discussions where quality expectations are defined but are mostly limited to being receivers of information (Juran and Godfrey 1999).

The BBQS addresses some of these challenges by highlighting and proposing methods and tools to perform the BiQ steps and the behaviors that are needed to sustain the system. In the BBQS, GCs are responsible for marshaling suppliers and builders in the delivery of each scope. They start to do that by making sure expectations are clear and provisionally doable, which involves collaborating with upstream project participants (e.g., customers, designers). As the GC-led process moves forward, these upstream project participants are involved in agreeing on how the delivered scope will be assessed. The expectations to be met are captured, with the participation of owners, architects, suppliers, builders, and inspectors to the extent possible, in the form of Distinguishing Features of Work (DFOWs) and Measurable Acceptance Criteria (MAC) (Spencley et al. 2018, Gomez et al. 2019a). DFOWs refer to a subset of requirements that need particular attention. These result from conversations about (1) key requirements to meet the owner's and designer's intent, (2) where rework would often be required either during construction or post-occupancy, (3) requirements that have a high impact on the project cost or schedule, or (4) requirements that have vague or conflicting information. MAC are the criteria used to objectively evaluate a deliverable. MAC describe the way (e.g., by durability, finish, appearance) in which the project participants involved in the process agreed to determine whether or not a scope has a property that is desired.

1.3.2 Behaviors for Delivering Quality in Construction Projects

Through this research, I proposed some of the behaviors desired for quality, and trained the research project participants to foster such behaviors. For instance, Edmondson (1999, 2012a, 2018) highlighted some behaviors driven by psychological safety and described possible consequences in the absence of such behaviors. For example, people's decision to speak up can affect everything from detecting mistakes before they become defects, to keeping people away from hazardous situations, to more generally expressing their thoughts and opinions about expectations and their feasibility to be achieved. In defining quality for any scope of work, having an environment where psychological safety and respect for people govern would help project participants rely on each other to speak up in case they miss a detail, are distracted, or the priorities are not in place. Behaviors desired for the BBQS are also described in the Lean literature, Howell et al. (2017) drew connections between the Lean principle of respect for people and psychological safety. They suggested that behaving in accordance with this principle can promote psychological safety. Another behavior is highlighted by Flores (2012) and Macomber and Howell (2003), who described the importance of making reliable promises, which is fundamental in the quality delivery process. Reliable promising aims to ensure a common understanding of the requests being made (what needs to be done under what constraints) and the commitments.

This research builds on the work of Edmondson (1999, 2003) and Howell et al. (2017), who connected psychological safety with learning and team performance, and psychological safety with Lean, respectively. I found evidence that supports the argument that psychological safety is positively associated with behaviors desired for quality, and these, in turn, are positively associated with team performance. In addition, I found that the behaviors for quality mediate between team psychological safety and team performance (Figure 1.1). While a psychologically safe environment is essential for teams to thrive, psychological safety on its own may not be sufficient to enhance their performance. To improve their performance managing quality, these teams must embrace the behaviors desired for quality.

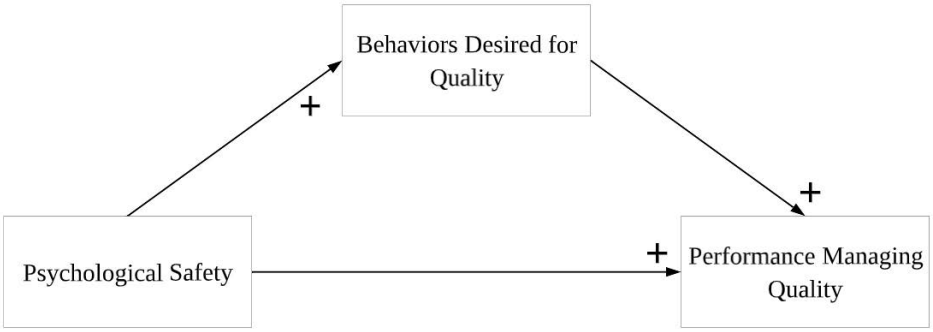


Figure 1.1: Psychological Safety Influence on Learning Behaviors and Team Performance

1.4 Research Objectives

The objective of this research on quality management is to:

> *Develop the Behavior-Based Quality System (BBQS) for building-in quality and making BBQS actionable. BBQS expands current work on Built-in-Quality (BiQ) by describing functions needed to deliver quality products, the presuppositions the system is built on, the principles and behaviors desired to sustain the system, and the processes, methods, and tools to perform such functions.*

Sub-objectives to develop and validate the BBQS are:

1. Design the BBQS structure and define the functions I expect it to accomplish.
2. Explore and define the presuppositions (i.e., things considered to be true) that ground the BBQS.
3. Define the principles and behaviors that support the implementation of the BBQS and identify actions to foster such behaviors.
4. Describe the processes needed to execute the BBQS functions.
5. Identify and explore methods and tools for executing the BBQS functions.
6. Test the BBQS for drywall and framing scopes and assess the system in terms of process metrics (how well the process is executed) and outcome metrics (how good the results are).
7. Assess the relationship between psychological safety, behaviors desired for quality, and team performance.

1.5 Research Questions and Hypotheses

Achieving the objectives requires answering the following questions:

1. What are the features of the BBQS?
   1.1 What functions does the BBQS aim to accomplish for delivering quality?
   1.2 What presuppositions is the BBQS built on?
   1.3 What principles and behaviors are needed, including those fostered by Lean and psychological safety, for implementing the BBQS? Why are these needed for delivering quality?
   1.4 What processes define the BBQS? Who participates in executing these processes?
   1.5 What BiQ methods and tools can be used for implementing the BBQS? What new methods and tools are needed to support the BBQS implementation?
2. What managerial actions can be taken to foster the behaviors desired for the successful realization of the BBQS?
3. How to assess the BBQS effectiveness?
4. What relationships exist, if any, between psychological safety, behaviors for quality, and team performance?

In addition to answering the question above, I tested the following hypotheses:

1. Team psychological safety is positively associated with behaviors desired for quality.
2. Behaviors desired for quality are positively associated with team performance.
3. Behaviors for quality are a mediator between team psychological safety and team performance.
4. Implementing the BBQS develops behaviors desired for quality management.
5. Implementing the BBQS improves team psychological safety.
6. Implementing the BBQS improves team performance in quality.

1.6 Research Scope

1.6.1 Industry Partner Priorities

Table 1.1 captures the scopes suggested by one of the GCs participating in this research for testing the BBQS. Table 1.2 summarizes some challenges this GC faces when building these scopes.

Table 1.1: Scopes to Include in the Study per GC Suggestion

Scope	Motivation
Interior partition walls	1. Scope is built in tight spaces, and trade stacking needs to be well managed. When the drywall subcontractor gets to taping, they often put finished coats and mud on walls. Simultaneously, other trades start scrambling to try and get their workers in the same area. 2. Issues related to this scope are a consistent cause for callbacks due to water intrusion.
Exterior metal stud framing and panel	1. Scope can be prefabricated in some capacity, and design coordination (part of the process to determine quality requirements) is critical for the successful delivery of the scope.

Table 1.2: Challenges GC Encounters when Building Scope Studied for BBQS Refinement

Struggle	How It Impacts Drywall and Framing Construction
Coordinating work	When coordination fails, quality is diminished, and extra money is spent when a subcontractor has to go back and cut in an opening, take off a piece of wall because of a forgotten outlet, or deal with patching walls as opposed to doing it right the first time.
Having the information needed	When the information used to do the work is incomplete or vague, even the most competent craftworkers may fail to build the scope to meet expectations. In this case, psychological safety can strengthen the relationship craft-staff and foster speaking up to get what they need to deliver work as expected.
Communicating quality expectations	Somewhere in the process of delivering a scope, information breakdowns may occur (i.e., things get missed), which impacts the communication of quality expectations from design to construction. Visual tools such as BIM can be used in many ways, from organizing work sequences to detailing work to identify quality concerns. However, challenges to using visual tools may also impact how well coordination gets done, e.g., by not having all the trades needed when creating a model.

1.6.2 Scope Studied

The BBQS can be applied to many types of scopes. The scope I studied to develop my initial prototype was concrete walls. The scope I used to test and refine that prototype was drywall and framing. This scope can be divided into (1) horizontal work (e.g., ceilings, soffit ceilings), (2) vertical work (e.g., partition walls, chase walls), and (3) a combination of both (e.g., furred walls and beams). I focused on vertical scopes, including interior walls (Figure 1.2) and exterior metal stud framing (Figure 1.3).

Figure 1.2: Interior Partition Walls (Photo: © Sulyn Gomez, 2022-08-25)

Figure 1.3: Exterior Metal Stud Framing (Photo: © Sulyn Gomez, 2021-09-29)

1.6.3 Typical Quality Issues

Quality issues associated with drywall can be observed during its installation and after the scope is completed (Negri 1997, United States Gypsum Company (USG) 2005, Drywall Finishing Council (DWFC) 2010, Ferguson 2002, 2009, 2020, Perfection Drywall 2016, Home Painters 2020, Kaplan 2020, All American Painting Plus 2021, Parker 2021). I grouped these issues into:

1. Misalignment of expectations about the delivered product.
2. Inadequate installation operations, including nail holes, screws popping, and joint defects caused by incorrect framing or joint treatment.
3. Caused by other scopes of work, e.g., defects caused by electrical trades when cutting holes in walls to put their boxes.

Appendix 1 expands on examples of each of these groups.

1.7 Dissertation Structure

The chapters are organized as follows:

- Chapter 1: Introduction
- Chapter 2: Literature Review
- Chapter 3: Research Methodology
- Chapter 4: Exploratory Study on Psychological Safety
- Chapter 5: Exploratory Study on Quality Management
- Chapter 6: Building Quality Builders (BQB) Training
- Chapter 7: BBQS Refinement Case 1
- Chapter 8: BBQS Refinement Case 2
- Chapter 9: Control Case, Cross-Case Analysis, and Mediation Analysis
- Chapter 10: Behavior-Based Quality System (BBQS)
- Chapter 11: Conclusions

2. LITERATURE REVIEW

This chapter provides an overview of different aspects of quality management to answer the question of how quality is being managed now and how it should be managed from the perspective of the general contractor (GC) to deliver quality right the first time.

The chapter is organized as follows. Section 2.1 summarizes the definitions of quality in the literature and the role of laws, regulations, codes, and standards in defining quality requirements. Section 2.2 describes some particularities of construction teams and how quality requirements are defined and communicated among them. Section 2.3 presents contributing concepts that support achieving quality requirements. Section 2.4 illustrates ways to assess whether quality requirements are met. Section 2.5 describes the role of those involved in the quality delivery process and what actions leaders can take to foster psychological safety. Section 2.6 illustrates some quality approaches. Section 2.7 highlights the importance of behaviors in managing quality. Section 2.8 describes some metrics used to assess the effectiveness of a quality management system. Last, Section 2.9 concludes this chapter.

2.1 Quality Defined in the Construction Industry

2.1.1 Definitions of Quality

Quality is a term for which many definitions have been offered (e.g., Crosby 1979, Deming 1982, Juran and Gryna 1988, Juran and Godfrey 1999). Crosby's (1979) definition focuses on conformity to requirements, Deming's (1982) focuses on a predictable degree of uniformity, Juran and Gryna's (1988) focuses on fitness for use, and Juran and Godfrey's (1999) focuses on freedom from deficiencies. These definitions are not really conflicting with each other; products can (1) be made to conform to requirements, (2) be made to be within a target level of uniformity or standard products, (3) be made for specific purposes, and (4) be made to be free from defects. Industries might focus on one aspect of quality over others according to their needs (e.g., manufacturing focuses on uniformity (Gitlow and Hertz 1983), while construction focuses on conformity to requirements (ASCE 2012)).

In construction, projects get contracted to conform to a set of drawings and specifications that are handed over to the GC. CII's (1990), Arditi and Gunaydin's (1997), and ASCE's (2012) definitions for quality in construction focus on conforming to requirements (e.g., legal, aesthetic, functional) established by the owners (i.e., paying customers), designers, contractors, and regulatory agencies. This focus on requirements, however, is limited because these are not all defined or defined at the level of detail needed for fabrication and installation, prior to design, but they are progressively developed over time, even after contracts are signed (Mehta et al. 2012).

Requirements are "conditions or capabilities that must be met by the project or present in the product, service, or result to satisfy an agreement or other formally imposed specification" (PMI 2017). Project requirements are vast and diverse (Hendrickson and Au 1989), ranging from general requirements (e.g., payment and submittal procedures), resource requirements (which determine the technology, equipment, and manpower needed, e.g., vibrators for concrete walls), technical requirements (e.g., minimum reinforcement in walls to hold vertical loads), space requirements

(for specific operations), and functional requirements (e.g., work breakdown, budgeting). Any scope of work in construction projects may be subject to one or more of these requirements to be sufficiently defined in a way that can be used for construction.

A related concept to understanding quality in construction is project specifications, which are part of the bidding process and contractual documents (Kamara and Anumba 2000, Kamara et al. 2002, Kubba 2010). These specifications "detail the scope of work and *means and methods to achieve them*" (Harris 2005). In a broader understanding of specifications, Jellinger (1981) defined specification, in construction, as "written instructions used in conjunction with drawings to *fully* describe and define the work that is to be accomplished, *along with the methods* and quality that will be required." His definition goes beyond seeing specifications as a contractual document but rather as a set of instructions that define the product requirements and the methods used to meet them. Both definitions suggest that specifications can be "fully" defined and include the means and methods to do the work (i.e., build the project). However, in practice, specifications indicate requirements but rarely include means and methods to achieve these. Determining means and methods, to some extent, is a job intended to be fulfilled in the submittal process led by GCs (Atkins and Simpson 2008).

Submittals are used to "prevent misunderstanding or problems during construction" (Kingsley 2019). GCs and subcontractors, in collaboration with suppliers, design operations and prepare the project submittals, including shop drawings, samples, installation methods, manuals, and product information that they plan to use for construction (Atkins and Simpson 2008). Nevertheless, even though GCs use submittals in an intent to clarify requirements, quality-related problems are present in many ways, and even the submittal process itself needs improvement (Pestana and Alves 2011, Alsinaidi 2013, Spragins et al. 2017).

Another definition for quality that expands the focus on requirements is the Lean Construction Institute's (LCI) (n.d.) definition. LCI suggests that quality is "conformance to a customer's valid and agreed upon conditions of satisfaction (CoS)." To define and meet the intended quality, CoS need to be (1) valid, meaning meet standards, applicable codes, and be appropriate for the intent aimed to achieve, and (2) agreed upon, meaning that because quality may be subject to interpretation, then defining CoS requires conversations where these are aligned.

Winograd (1986) said, "CoS are not objective realities, independent of interpretations. They exist in the listening, and there is always the potential for difference among the parties." Flores (2012) said, "CoS are conditions we like to be fulfilled by the performer" and emphasized that these are created in the context where there is a speaker [the requester or customer], a hearer [the performer], and concerns (things that are important or matter) for the outcomes of the request. Flores' definition conveys the following characteristics of CoS:

1. These are conditions identified in response to a request (e.g., an owner who orders a new project) and incorporated into a promise.
2. They require conversations (i.e., request, negotiation, commitment, declaration of satisfaction) to achieve mutual interpretation of the request made and assessment of the delivered product.
3. They help to determine the deliverable requirements (i.e., quality).

Requirements that convey the owner's and designers' expectations are provisionally fixed until project participants who deliver each scope are engaged in the process of clarification and

negotiation of the CoS, and a common understanding is achieved about the conditions to meet, potentially refining the initial set of requirements.

For this dissertation, I adopted the P2SL's (n.d.) definition for quality, "meeting requirement." The next section describes my understanding of requirements.

2.1.2 From Expectations to Requirements: Distinguishing Features of Work (DFOW) and Measurable Acceptance Criteria (MAC)

Expectations are the basis for building requirements. The former exists in the minds of stakeholders. The latter is the product of aligning and recording what they agree. Expectations may change either because they could not be provided or because of suggestions for improvement in the reliable promising process.

To define quality as a set of requirements, one must be able to "translate future needs of the user [owner] into measurable characteristics, so that a product can be designed and turned out to give satisfaction at a price that the user will pay" (Deming 1986 p. 169). Spencley et al. (2018) and Gomez et al. (2019a) proposed two concepts to help drive the conversations about requirements: Distinguishing Features of Work (DFOWs) and Measurable Acceptance Criteria (MAC). DFOWs refer to a subset of requirements that need particular attention. These result from conversations about features that project participants value the most or are important to them (by looking at unique features of the work, where problems often arise, or where there is no shared understanding of what needs to be built and how to do it). MAC are an objective way to assess whether the delivered scope met the agreed expectations. DFOWs and MAC are used to provide clarity on what the delivered scope should be and how to build it (i.e., design operations) to meet project participants' expectations. These are determined through the reliable promising process of clarification and negotiation.

Moving from expectations to requirements recognizes the following:

1. Multiple project participants are needed for delivering these projects, and expectations can be subject to interpretation (Winograd 1986, Abuhav 2017, Dougherty et al. 2012). Project participants might think they understand the same thing in a statement, assertion, or request, but they may not, so meeting quality requires conversations and commitments to define the requirements to meet.
2. Requirements are progressively developed (e.g., it starts early during design for broad details such as the number of operating rooms in a hospital and continues during construction for detailed operations) and benefit from a participatory approach (Blomberg and Henderson 1990, Sfandyarifard and Tzortzopoulos 2011).
3. Expectations written as requirements considering only the designers' perspective (e.g., a specification for concrete walls requiring "mirror-like" finishes) may not be buildable. Adding the contractors' perspective enriches the clarity of the requirements for construction.

2.1.3 Role of Laws, Regulations, Codes and Standards in Delivering Quality

Laws (developed by legislative bodies), regulations (by government agencies), and codes and standards (by development agencies, often in the private sector) are promulgated to serve specific purposes (Arditi and Gunaydin 1997, AGC et al. 2008, ASCE 2012):

1. Laws: Rules made by the government as guides that everyone is expected to follow. For example, the Environmental Protection Agency (EPA) established the Asbestos Information Act (AIA) that requires all manufacturers of asbestos-containing products to report production to the EPA (US EPA 2021).
2. Regulations: Serve to instruct or provide guidance about how laws are to be carried out. For example, the construction regulations for managing health and safety in construction (HSE 2015) focus on guiding projects to be in compliance with the laws pertaining to health, safety, and welfare in the project.
3. Codes: Are a set of rules that describe what needs to be done. For example, in the US, all projects, independently of their size, must comply with the National Fire Protection Association code for advancing public safety in the built environment.
4. Standards: Serve to guide the building of specifications to protect the public's health and safety (ASCE 2012), feed information for design criteria (Arditi and Gunaydin 1997, Ballard 1999, Ballard and Tommelein 2016), and assess the delivered project during inspections (AGC et al. 2008). Standards can be extended to the level of tools that organizations use (Ballard and Tommelein 2016) and can be published in codes. For example, Title 29 of the Code of Federal Regulations (CFR-1926) specifies the Safety and Health Regulations for Construction, which are called The Occupational Safety and Health Administration (OSHA) standards (US Department of Labor 2021).

Laws, regulations, codes, and standards (1) are used throughout the construction process to elaborate plans and specifications and then evaluate the constructed facility, and (2) are to be considered when aligning expectations about quality and developing the MAC for all requirements. Standards are developed by a group of people with certain interests (e.g., American Concrete Institute (ACI) is a leading authority that develops standards for work with concrete). These standards can conflict with others as project scopes are not in isolation but depend on various trades' work. Standards keep evolving, and stakeholders choose what standards to use; therefore, applicable standards need to be clarified in the conversations to define quality. Following codes and standards to define quality, though, is not as simple as *reading and doing* due to problems found in practice. Milberg (2006), for example, described problems related to tolerances, such as (1) inconsistency within and between codes, standards, and specifications, (2) ignorance of practitioners about what exists in the codes, standards, and specifications (e.g., project engineers entering the job market may be limited in their knowledge about all the possible scopes of work in a project) and lack of training or the understanding of it, (3) gaps between what is recommended and the real capabilities of contractors, making requirements and expectations infeasible, (4) standards being ambiguous and subject to interpretation. This research is limited to the process of managing and aligning information, including codes, standards, and specifications, led by GCs to build quality into the scopes of work. In instances when a lack of clarity, gaps, or conflicts in information exists, conversations to define DFOWs, MAC, and operations to meet expectations, all within relevant laws, regulations, codes, and standards, are to be conducted to fully determine quality requirements and a way to meet them.

2.2 Understanding, Aligning, and Communicating Project Participants' Expectations

Stakeholders in construction are "participants or individuals involved in and affected by the activities of construction projects throughout the whole-life cycle of the project" (Oke and

Aigbavboa 2017). These stakeholders (i.e., owners, users, governing agencies, designers, fabricators, installers, operators, maintainers, the surrounding community and associations, and the whole society) are classified according to how they can influence or be influenced by the project (Table 2.1). Project participants are a subset of the project stakeholders who directly participate in the execution of the project and therefore participate in the quality delivery process.

Table 2.1: Stakeholders Classification

Stakeholder Type	Description
Criterion: Legal or contractual relationship with a project (Sutterfield et al. 2006, Winch 2010, Leung and Olomolaiye 2010).	
Internal	Those who have a contractual relationship with the project (e.g., owners, designers, suppliers, users, contractors).
External	Those who do not have a contractual relationship with the project but could affect or be affected by it (e.g., community where the project is built, government agencies, and media).
Criterion: Attitudes towards the project (Olander 2007, Chinyio and Akintoye 2008).	
Proponents / supportive	Those who are in support of the project (e.g., neighbor associations that support the construction of a school in the neighborhood).
Opponents / against	Those who are against the project (e.g., rural communities who are against mining projects).
Neutral	Those who are indifferent towards the project (e.g., the population of the capital city in a country with regards to a small project to be built in a small village far away).
Criterion: According to the stakeholder's attributes (Figure 2.1), i.e., power, legitimacy, urgency (Mitchell et al. 1997, Walker et al. 2008). Power refers to the relationship among social factors, legitimacy refers to generalized perceptions that the actions are desirable, proper, or appropriate, and urgency refers to the degree to which stakeholders' claims call for immediate attention.	
Dormant	Those who have power but lack legitimacy and urgency to exert their will.
Discretionary	Those who have legitimacy but lack power and urgency.
Demanding	Those who have the urgency but lack power and legitimacy.
Dominant	Those who have both power and legitimacy but lack urgency.
Dangerous	Those who have power and urgency but lack legitimacy.
Dependent	Those who have urgency and legitimacy but lack power.
Definitive	Those who have all three attributes of power, legitimacy, and urgency to exert their will.

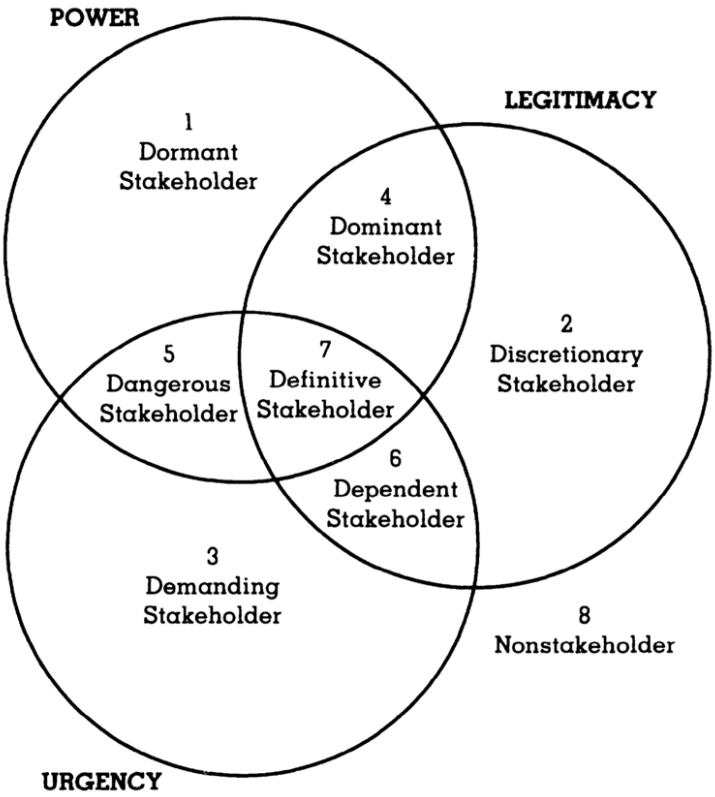


Figure 2.1: Stakeholders by Attribute (Figure 2 in Mitchell et al. 1997)

Not all stakeholders' expectations are relevant to building a specific scope because their influence on decision-making varies (Molwus 2014). For example, a neighborhood association may be concerned about the increased traffic load in their area, but how architectural shear walls are produced and evaluated have nothing to do with traffic load. Similarly, not all stakeholders' expectations are achievable. Expectations to be met are primarily determined by the owner's intent and project constraints (e.g., location, cost, time, anything that can prevent things from starting, advancing, or completing as planned) (Ballard 2008). In order to deliver quality work, expectations around it (from what the scopes should look and do to what these encompass, e.g., cost, schedule, and construction process associated) need to be understood, aligned, and communicated.

2.2.1 Distinguishing Features of Construction Teams

Construction teams are unique and bring together people from diverse backgrounds to form a temporary organization with one objective, delivering a project within certain constraints (Cornick and Mather 1999). Table 2.2 describes the characteristics of these teams that project participants need to consider when planning for quality.

Table 2.2: Characteristics of Construction Project Teams

Characteristics of Construction Teams	References
Different levels of operation: Teams operate at the levels of (1) human (people type to people type), (2) operational (discipline work process to discipline work process), (3) information (knowledge data to knowledge data), and (4) organizational (business firm to business firm).	Cornick and Mather (1999)
Temporary nature: Teams are formed temporarily by individuals from multiple organizations working together towards delivering a project.	Jefferies et al. (1999), Alshawi and Faraj (2002)
Task-oriented: Teams get assembled for specific tasks, and a person can be part of multiple teams at a time (e.g., a project engineer managing execution of operations for building interiors while coordinating plans through submittals with architects and designers) throughout the project life cycle.	Arditi and Gunaydin (1997), Cornick and Mather (1999), Uher and Loosemore (2004)
Loosely defined processes: Teams have some level of flexibility granted for how work is organized and executed (e.g., by having different manpower and levels of expertise), even for standardized processes.	Mitropoulos and Cupido (2009)
Accelerated learning curve: Teams need to learn quickly how to work together as a team and build the project to achieve the expectations safely and use the resources they have.	Cornick and Mather (1999)
High dependency between teams with "competing" interests: Teams from different companies might have vested interests in their own companies unless "shared goals" are aligned, established, and accepted by all.	Cornick and Mather (1999), Mitropoulos and Memarian (2012)

2.2.2 Understanding and Aligning Project Participants' Expectations

Expectations to define quality for project scopes of work are progressively developed. Figure 2.2 represents a scheme of the different project phases based on the Lean Project Delivery System (LPDS). The level of detail in which expectations are defined and DFOWs and MAC developed changes in the phases of project definition, design, supply, assembly, and use (Ballard 2000a).

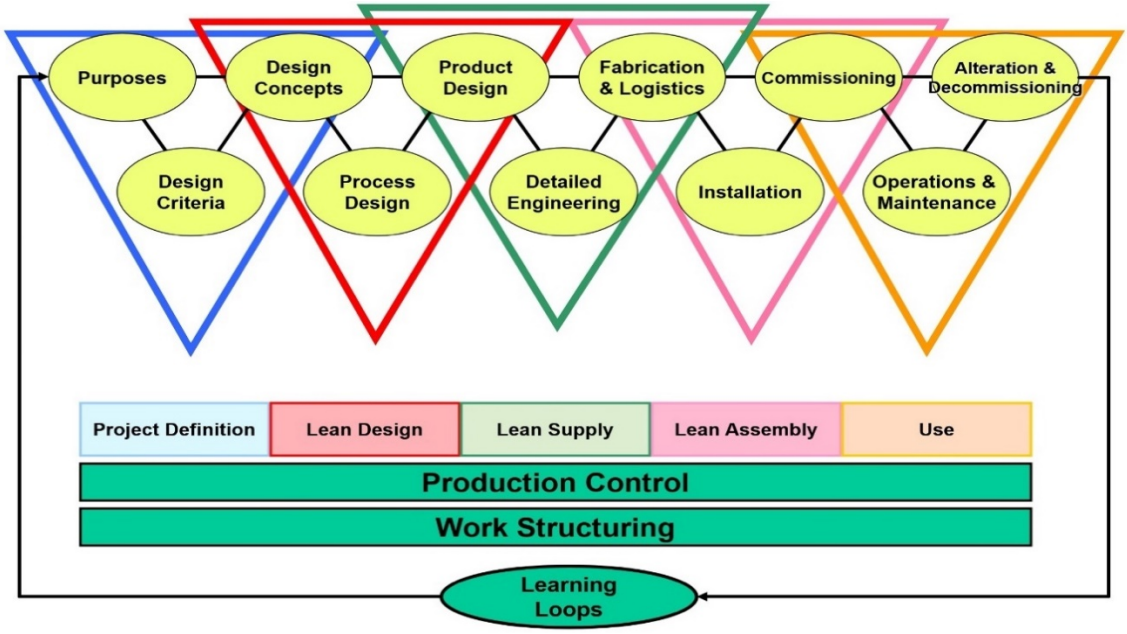


Figure 2.2: Lean Project Delivery System (Figure #3 in Ballard 2008, updated from Ballard 2000a)

In some cases, the level of detail increases from phase to phase. In other cases, the detail may be very high, but the commitment to that design is provisional, pending the involvement of other parties in the delivery process. According to the LPDS, project teams should not only provide owners with what they want (i.e., building a project with the set of specifications and drawings "as is") but help them decide what they want, referring to the means to their ends (e.g., constraints on delivering what is wanted) (Ballard 2008).

During the Project Definition phase, "customer purposes and needs" are translated into product and process design criteria (Ballard and Zabelle 2000a, Whelton and Ballard 2002). Expectations are defined around the customer's business case, local conditions, rough design criteria, budget, and schedule. During the Lean Design phase, customer needs and the design intent are translated into the product design along with preliminary/tentative process design (Ballard and Zabelle 2000b, Whelton et al. 2001). In this phase, the design criteria derived from the expectations in the project definition phase are used along with the applicable codes, standards, and laws to create the engineering specifications of the project and make requirements consistent with one another (Ballard 1999, Ballard and Zabelle 2000b). During the Lean Supply phase, detailed engineering provides the information needed to fabricate or purchase the necessary scopes (Ballard 2000a). In this phase, the agreed expectations guide decisions regarding the engineering, production, and delivery of materials and equipment for any scope of work. During the Lean Assembly phase, all required tools, labor, materials, or parts of a scope are delivered to the site to be assembled and turned over to the customer (Ballard 2000a). In this phase, the requirements concern points for in-process inspections, design of process capability for construction operations, and deliveries to the site of the elements procured in the previous phase.

While GCs and subcontractors may not be involved in the early phases of the project delivery, they need to have a proper understanding of what was done in those phases and have the opportunity to raise questions to get clarifications and suggest changes. This interaction of project participants at

various phases of the project allows them to understand others' expectations and get aligned on the requirements of the end product and the means to achieve them.

Alignment is the "process of incorporating all the distinct priorities and requirements of project participants to create a uniform set of project objectives that meet the business needs of the facility" (Griffith and Gibson 1997 p. 38). This understanding places the "business needs" (often directed by the owner) as primary, and all other requirements are presumably to be met only to the extent that doing so does not reduce meeting business needs. However, (1) some requirements (codes, law, regulations) have priority over business needs, and (2) project participants' expectations appear and influence the project in different phases of the project lifecycle (Cleland 1995, Olander 2007, Ballard 2008, Molwus 2014). Another definition for alignment, which is used for this research, indicates that it means having a "shared understanding of direction" and sharing a "commitment to that direction" (Clark 2020). This direction in construction projects includes, for example, a GC that (1) really understands the architect's design intent, (2) is able to design construction operations to meet such intent, and (3) provides suggestions in instances where the design can be improved to deliver greater value, etc.

Alignment is achieved through conversations in which expectations are spoken. Ideally, the alignment process initiates with the owner stating what they want to accomplish and what constraints they have to do so and continues with input from other project participants (Ballard 2008). These expectations are progressively aligned in the form of requirements (e.g., Juran and Godfrey 1999, Tillmann et al. 2014, Gomez et al. 2019a). In getting alignment, some project participants focus on aligning expectations about cost and schedule, while others focus on defining how work will be done, e.g., shear wall building operations.

The process for aligning expectations varies according to the project's contractual agreement type as project participants get involved in the project at different phases. For example, in relational contracting (e.g., integrated form of agreement, alliancing), the owner and key project participants in project delivery align their expectations in the project definition phase (Tillmann et al. 2014). In this type of contracting approach, teams have incentives to align the expectations for what is best for the project (Matthews and Howell 2005, Thomsen et al. 2009, Darrington and Lichtig 2010), and make decisions and set targets based on consensus (Azhar et al. 2014). Another contracting format, design-build (DB), can be relational within the DB team and foster early alignment when project participants share risk and reward (Matthews and Howell 2005, Darrington 2011). Other more traditional, non-relational contracting forms (e.g., design-bid-build), however, foster individual mindsets instead of encouraging alignment early on in the project (Aapaoja et al. 2013) as project participants get involved late, mostly in the assembly phase.

Alignment of expectations must consider:

1. Owner's needs, project participants' demands, products, processes design criteria, and design concept (Ballard 2000a)
2. Various project participants' expectations and constraints that need to be aligned (Ballard 2000b, Chinyio and Olomolaiye 2010). Not all expectations are likely to be met either because they are not reasonable or achievable (e.g., due to insufficient funds or time), or not consistent or conflicting across the desired characteristics of the project scopes (Sims and Anderson 2001, McManus 2002, Cunningham 2018)
3. Role of language and perspectives when talking about expectations and interpreting quality (Austin et al. 2002, Spencley et al. 2018), e.g., owners', architects', and engineers'

language, perspectives, and concerns may differ and focus on something specific (e.g., costs, aesthetics, functionality, structural design)

4. Stakeholders' involvement at different phases of the project and how these influence the decisions (Ballard 2000a, Whelton and Ballard 2003, Takim 2009)
5. Builders' involvement and the benefits of having operations personnel participate in reviewing designs for feasibility (Juran and Godfrey 1999). In practice, operations personnel involvement varies from none at all (information is just handed over to them for execution), to a structured review (they participate in working on any issue), to co-design (products and processes are jointly developed).

2.2.3 Communicating Project Participants' Expectations

Juran (1995 p. 607) said that "buyers (owners) need to be able to communicate to sellers the nature of what they want to buy," and a major invention to communicate expectations is the written quality specifications found in product catalogs, along with photographs or drawings of the products offered (Ritz 1994). Catalogs[1] exist for construction products that are made-to-stock (MTS) (e.g., floor tiles, desks) and some made-to-order (MTO). MTS products have limited or no customization and are produced based on anticipated demand (Zhang et al. 2013). MTO products may have some level of design already developed to produce the products. MTO products range from (1) engineered-to-order (ETO) (design does not exist before the production process starts) to (2) fabricated-to-order (FTO) (product is made from parts that are produced once an order is placed) to (3) assembled-to-order (ATO) (product is made from existing parts once an order is placed) (P2SL n.d.).

Construction is a project-based production system with unique products (i.e., projects), if only in location, but that can change soil types, land slopes, weather conditions, seismicity, traffic congestion, etc. (Ritz 1994, Koskela 2000, Ballard et al. 2001). Products in construction (e.g., buildings, highways) are ETO products characterized by (1) projects involving the design, procurement, and manufacturing of unique products produced to satisfy a specific owner, and (2) the design and installation of its parts are to be developed once triggered by an order from the owner, without which no product is produced at all. The trigger placed by the owner varies according to their business needs; examples that illustrate this are (1) a university that wants to expand its campus and order the construction of a new building, in which case the building may start operating as soon as the construction is over, (2) real estate developers that order the construction of buildings to rent or sell, and (3) companies building public-private partnership projects such as highways in which the initial investment comes from the company in hopes of getting toll income to generate profits, etc. Differences in conditions and intended use make it impossible to exactly copy and paste (i.e., re-use) a design of a similar project.

Communicating quality expectations requires conversations where the owner expresses their needs and constraints (Ballard 2008) and extends an invitation for feedback to designers and builders who help shape the owner's expectations. Interpreting specifications and drawings "requires a trade-off between assuming reasonable behavior on the part of all the parties concerned in interpreting words such as "sufficient" versus the effort and possible inaccuracy in pre-specifying

[1] IKEA's are well-known catalog examples, which not only include its products with detailed information (e.g., price, dimensions, color, material), but also offer alternatives for how homes and offices can be decorated with these: https://ikeamuseum.com/en/catalogues/ikea-catalogues-through-the-ages/.

all operations" (Hendrickson and Au 1989). Relying on written specifications alone to communicate project participants' expectations might be challenging because (1) agreed expectations might not be clearly captured or communicated to the GC in such specifications, (2) project participants might misinterpret their contents, and (3) specifications might contain vague and conflicting information among disciplines (O'Connor et al. 1991, Stasiowski and Burstein 1993, Assaf et al. 1995). Considering these challenges, project participants' expectations need to be conveyed to everyone involved in a way that all can understand. Clearly communicating expectations helps teams work more effectively, be aware of their team's contribution, encourage openness to ideas, foster creativity, and helps the listener understand and act according to the message (Rock 2009, Azmy 2012, Hersey et al. 2013, Abuhav 2017).

To properly communicate expectations, things to consider are: (1) what will be communicated, (2) when to communicate it, (3) with whom to communicate it, (4) how to communicate it, (5) who communicates it (Abuhav 2017), and (6) how it can be misunderstood to prevent the occurrence of potential mistakes (Shingo 1986). Strategies for communicating agreed expectations include:

1. Make the message personal, consider who the listener is, and convey the message in a respectful manner (Chinyio and Olomolaiye 2010, Zhang et al. 2020).
2. Reduce design batch sizes so specialists can communicate their expectations in small pieces without misleading other project participants (Ballard and Zabelle 2000b, Ballard et al. 2007).
3. Use visuals (e.g., samples of physical goods such as tile materials, virtual model) (Juran and Godfrey 1999, Ballard and Tommelein 2016) to simulate processes, operations, movements, etc. (Jylhä and Junnila 2012, Mahoney 2014, Tovar 2013).
4. Identify project participants needed for specific scopes, listen to their expectations, and pay attention to their concerns, contributions, and the risks they foresee (Chinyio and Olomolaiye 2010).
5. Schedule shop tours, supplier demonstrations, etc., to see different alternatives for products and processes (Chinyio and Olomolaiye 2010).
6. Foster collaborative operations design through virtual prototyping, physical prototyping (i.e., mockups), and first-run studies (Ballard and Tommelein 2016).
7. Have face-to-face interactions as much as possible (Tasmanian Government 2011, Oakland and Marosszeky 2017).
8. Use a language, including idioms and technical terms, that listeners can understand and care about. Language problems (Grill and Nielsen 2019) and the use of technical terms (Blomberg and Henderson 1990) can impede communication if the listener does not know the language/terminology in use. In addition, as Roosevelt said, "nobody cares how much you know, until they know how much you care," showing care about what is discussed might impact communication.
9. Foster psychological safety so that individuals have the confidence to communicate with one another (Huang and Jiang 2012) and ask questions to foster learning, exchange of ideas, and innovation and creativity while creating work environments that are flexible, adaptable, and problem-solving-focused (Brooks and John 2018).
10. Encourage people to reach out for help. One of many supervisors' responsibilities is to guide and help others succeed (CompassPoint Nonprofit Services 2013). Supervisors often

are more experienced and could support others who, due to the lack of experience, might not know when quality might fail.

The process of understanding, aligning, and communicating project participants' expectations is an ongoing work that starts at the project definition phase and continues until the project is delivered. In managing quality, it is imperative to (1) be aware that multiple expectations can arise at different phases of the project development, (2) these expectations can conflict, be vague, or have gaps, (3) alignment of expectations is necessary to determine what needs to be done and how, and (4) once the alignment of expectations is achieved, the "what" to build needs to be communicated in a way that builders can use for execution.

2.3 Assuring Success in Achieving Agreed Expectations

This section is devoted to differentiating the two primary ways of causing conformity: relying primarily on inspection, inspecting-in-quality (IiQ), and building-in-quality (BiQ) (Crosby 1979, Shingo 1986, Juran 1995). The first way, IiQ (i.e., build-inspect-decide), is focused on doing the work and then checking (inspecting it) to determine what happens next (either accept it as is, decide to rework to conform, or redo entirely). The second way, BiQ (i.e., building quality into the product), is focused on reducing the probability of rejection and repair by designing processes to be mistakeproof, or as close to that as possible, and developing process capability, together with learning triggered by process failures. The first way, IiQ, is an approach that lacks emphasis on planning and prevention, resulting in high rejection and rework rates with results that are not fit for purpose (Ireson et al. 1996, Love et al. 1999, Josephson and Hammarlund 1999, Love and Li 2000, Robinson-Fayek et al. 2003, Feng 2009, Feng and Tommelein 2009, Dougherty et al. 2012, Howarth and Greenwood 2018). The second way, BiQ, is an approach that aims to build quality into products to deliver what customers value with no waste (Crosby 1979, Shingo 1986, Ballard and Tommelein 2014). BiQ leverages Deming's work on Plan-Do-Check-Act (PDCA) and focuses on planning the work, preventing defects, or detecting them early in the process, and developing processes capable of achieving the work as planned.

Implementing BiQ can be supported by different methods and tools (Tables 2.3-2.4), which can be used throughout the quality delivery process and are not mutually exclusive. These methods and tools can be chosen according to the project participants' needs or the concerns they wish to address (e.g., learning and continuous improvement, prevention, or planning and execution).

Table 2.3: Methods and Tools that Support the Delivery of Quality (1/2)

Methods and Tools	Reference
Plan-Do-Check-Act (PDCA); Prevent-Detect-Correct-Analyze ($PDCA_B$) cycle: It is a process of hypothesis, experiment, test, and act based on the results. It focuses on learning and continuous improvement through taking corrective actions and preventing the reoccurrence of problems. It is initiated either by planning, acting, and identifying opportunities for improvement or by a failure to deliver quality products.	Shewhart (1939), Deming (1986), Juran (1986), Juran and Godfrey (1999), Ballard and Tommelein (2014)
5 whys and root cause analysis: It is a systematic approach for learning from breakdowns or failures that fosters learning and continuous improvement.	Fischer et al. (2014), Cheng et al. (2016)
Cause and Effect Diagram: It helps to identify various possible causes for a problem and group the causes into categories, including, for example, equipment, process, people, materials, environment, etc.	Ishikawa (1968)
Failure mode and effect analysis (FMEA): It focuses on preventing failure in products or processes by identifying potential failures and implementing countermeasures to prevent them.	Lazor (1996), Juran and Godfrey (1999)
Fault Tree Analysis: It focuses on preventing failure by using a deductive process to discover failure causes. It "traces all possible combinations of causes that could lead to a particular failure."	Lazor (1996), Juran and Godfrey (1999)
Pareto chart: It suggests that 80% of quality issues may be attributed to 20% of causes.	Koch (1998)
Value Stream Mapping (VSM): It facilitates the identification of value and hidden waste. It helps to optimize and standardize processes.	Ballard et al. (2007), Do et al. (2015)
Study Action Teams (SAT): It creates spaces for learning where people exchange ideas and opinions about a topic, and learn from each other.	Hill et al. (2007), Ghassemi and Becerik-Gerber (2011)
Gemba walks: It is a practice used by supervisors to coach their charges to walk the site, see problems, and develop solutions. It allows observing areas to improve.	Poksinska et al. (2013)
Mistakeproofing: It aims to prevent mistakes but, if they do occur, then to detect them as close as possible to the point of origin to limit the damage they may cause and avoid their recurrence.	Nakajo and Kume (1985), Shingo (1986), Tommelein and Demirkesen (2018)
Standardization: It consists of documenting the current best practice for how something should be done and providing the basis for continuous improvement.	Suzaki (1987), Aapaoja and Haapasalo (2014)
Prevention through Design (PtD): It consists of designing a project to prevent potential hazards and preserve workers' health and safety.	NIOSH (2014), Gambatese (2019)

Table 2.4: Methods and Tools that Support the Delivery of Quality (2/2)

Methods and Tools	Reference
Checklists: It helps remind people of things that could have been forgotten while delivering a scope and provides a sense of sequence to perform such steps.	Gawande (2010)
A3 reports: It facilitates problem-solving and decision-making by formalizing, documenting, and evaluating options and reducing the loss of institutional knowledge. It offers a simple way to document agreements regarding expectations to be met.	Sobek and Smalley (2008), Cheng et al. (2016)
First Run Studies (FRS): It prototypes production processes to understand them and find opportunities for improvement. It helps in designing capable operations to meet agreed expectations.	Ballard and Tommelein (2016, 2021)
Collaboratively operations design: It aims to develop alignment about standard processes that consistently produce a product that meets the owner's expectations and provide workers with what is needed (e.g., information, methods, prior work) to facilitate the process to conform to requirements.	Lichtig (2012), Oakland and Marosszeky (2017)
Quality function deployment: It translates the voice of the customer into the voice of the product and process designer, and informs customers to allow them to understand the consequences of their desires.	Akao (1990), Chan and Wu (2002)
Visual management: It focuses on facilitating and simplifying information management and allowing a timely reaction to quality problems.	Laine et al. (2014), Galsworth (2017)
Co-location: It is a space where disciplines work concurrently, exchanging ideas and information while building team cohesiveness. It offers opportunities for conversations where teams can understand, align, and commit to quality expectations.	Kim and Dossick (2011), Do et al. (2015), Franz et al. (2017)
Last Planner® System (LPS): It increases planning reliability and production performance allowing improvement through constant feedback. It increases conversations where the reliable promise is practiced and can be applied to quality.	Ballard and Howell (1994 a/b), Ballard (2000b), Ballard and Tommelein (2016, 2021)
Target Value Design (TVD): It consists of maximizing value generation by enabling the co-creation of value. It fosters value co-creation and alignment regarding quality.	Parrish et al. (2008), Do et al. (2015)
Set-Based Design (SBD): It considers analyzing multiple alternatives to develop a better design and postponing the commitment to a specific design till the last responsible moment.	Ward et al. (1995), Sobek et al. (1999), Ballard et al. (2007)
Choosing By Advantages (CBA): It is a collaborative decision-making system that helps to evaluate decisions by analyzing their advantages.	Suhr (1999), Arroyo (2014), Cheng et al. (2016)

The following subsections expand on related concepts to ensure success in achieving agreed expectations, including a more detailed description of some of the methods described in Tables 2.3-2.4.

2.3.1 Customer Focus and the Delivery of Value

Juran (1995) emphasized customer needs as a top priority, and customer satisfaction is highly determined by the quality they receive (Howarth and Greenwood 2018). A customer in construction is no longer an individual alone, but a cast of project participants (customers and suppliers) who participate in the supply chain. They need to understand what the request is (i.e., expected outputs) and what they need to meet such request (i.e., inputs required). CII (1989, 1990) highlighted that satisfying the needs of the ultimate customer (i.e., owner and users of the facility) requires understanding and satisfying customers' needs of those involved in the delivery process.

Value is a subjective term (i.e., value is in the eye of the beholder) (Holbrook 1999, Salvatierra-Garrido and Pasquire 2011, Drevland and Lohne 2015) that is "generated through a process of negotiation between customer ends and means" (Ballard and Howell 1998 p. 5). The Lean pursuit to create, maximize, and deliver value for customers (Koskela 1992, Howell 1999, Ballard and Howell 2003, Diekmann et al. 2004, Bertelsen and Emmitt 2005) requires understanding the customer's expectations and meeting the expected quality (Liu et al. 2006). The term "customer" in this case must be interpreted over a range, the first sense of customer is the next person after you in a process, but processes can be small or large, ranging from assessing the soil conditions for a building foundation to delivery of the project as a whole, where the customer extends beyond the paying customer to all stakeholders (Ballard 2016). To successfully deliver value, conversations to agree on what requirements are to be met, including DFOWs, and their MAC among the project participants needed for a scope, need to be part of planning and executing construction projects.

BiQ is tightly linked to Lean construction. For instance, Ballard (2016 p. 272) said that "The Lean Ideal is to deliver value to customers with no waste [which resonates with the BiQ pursuit of value delivery]. Value, in this case, is instrumental value (i.e., enables customers to accomplish their objectives). Waste is anything with a cost of any kind (e.g., stress to personnel) that can be eliminated without reducing customer value. Customers include the paying customer, which is the immediate customer of those delivering the project, other project participants, both internal and external, and arguably the human species; e.g., consider the environmental and aesthetic impacts of projects (Ballard et al. 2001)." Similarly, Gryna et al. (2005 p. 127) provided suggestions that are consistent with Lean principles such as "respect for people," by suggesting to "answer suggestions from workers promptly and in a manner that shows respect for the worker," and to "treat all people with dignity." The Lean principle "respect for people" also resonates with Deming's principle (1986) "eliminate fear from the workplace," which requires much more than just telling craftworkers or engineers that there is no reason to fear, but rather fostering psychological safety. Other areas where Lean and quality are linked are in the (1) pursuit of continuous improvement, and (2) Lean methods and tools used to support the delivery of quality for a scope of work.

To fully implement BiQ, teams need:

1. Leadership who understands how to deliver value (e.g., is aware of the various expectations that need to be understood and aligned before designing operations) and is able to determine and build the competencies needed within their teams to do their work as expected (Juran and Godfrey 1999, Oakland and Marosszeky 2017).
2. People feeling psychologically safe to speak up when mistakes occur and report defects to their supervisors. When project participants in a team feel psychologically safe, learning behaviors are fostered, and this is evidenced by people speaking up so that defects can be fixed, and their impact mitigated.
3. Project participants breaking down barriers, increasing familiarity among them, and collaboratively designing operating procedures to optimize the work as a whole (e.g., minimize rework, increase production rates) (Crosby 1979, Deming 1982, Goodman and Leyden 1991, Alexander et al. 2017, Gomez et al. 2019b).

2.3.2 Psychological Safety and its Relationship with Lean and Quality

Schein (1985) explained that the essence of psychological safety is that "we can imagine [and potentially express] a needed change without feeling a loss of integrity or identity." In his approach, he described that psychological safety is a key piece in learning, a centerpiece for the Lean principle of continuous improvement, because it is a state where people feel their "self" is not threatened in any way (i.e., their identity, integrity, or membership in groups they care about will not be damaged). Schein seems to be mainly concerned with the individual's attitudes toward organizational change, meaning how people would approach change. Kahn (1990 p. 708) broadened the concept beyond organizational change, and defined psychological safety as "feeling able to show and employ one's self without fear of negative consequences to self-image, status, or career." Psychological safety, then, fosters employees' engagement and facilitates a work environment where they can express themselves without fear of retaliation. Kahn's definition covers any kind of interaction between individuals, but still considers psychological safety as an attribute of individuals. Edmondson (1999) extended the concept to teams and defined psychological safety as "the belief that the work environment is safe for interpersonal risk-taking," meaning that individuals in teams will mutually respect each other and not get embarrassed, rejected, or punished for speaking up. These definitions converge on the idea of people caring about (1) their image, status, or career, and (2) how people with hierarchical power, peers, subordinates, or someone they care about would regard and treat them.

From Schein positing psychological safety as an attribute of individuals in situations of organizational change, to Kahn understanding it as an attribute of individuals in all types of situations, to Edmondson positioning it as an attribute of teams, psychological safety is about candor and openness; it is creating an environment where productive disagreement and the free exchange of ideas are welcome, it is what "takes off the brakes that keep people from achieving what is possible" (Edmondson 2018).

Edmondson (2011) said, "we are programmed at an early age to think that failure is bad. That belief prevents organizations from effectively learning from their missteps." Psychological safety allows for constructing a work environment where "trust and respect thrive" (Edmondson 2012, Edmondson 2018), learning flourishes (Edmondson 1999, Roberto 2002, Wilkens and London 2006, Carmeli 2007, Tucker et al. 2007, Carmeli and Gittell 2009, Ortega et al. 2010, Liu et al.

2014, Edmondson and Lei 2014), and performance improves (Edmondson 1999 in Figure 2.3, Carmeli 2007, Huang and Jiang 2012).

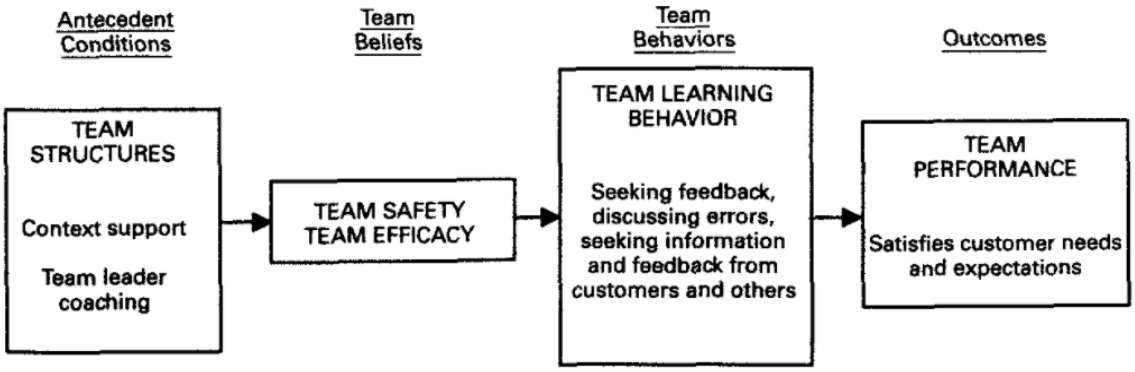


Figure 2.3: Psychological Safety Relationship with Learning Behaviors and Team Performance (Figure #1 in Edmondson 1999)

Psychological safety aims to break down some taken-for-granted rules (e.g., speaking up brings career consequences, don't speak up if the boss's boss is present, don't criticize something the boss may have helped create) that have governed people's behaviors about when to speak up or remain silent when interacting with others (Edmondson 2018). Other reasons for remaining silent include, for example, disinterest, overthinking, lack of knowledge, and political correctness (e.g., thinking that it would be good to tell my boss about a mistake but not in front of a large audience) (Milliken et al. 2003, Karaca 2013, Morrison 2014).

Psychological safety is not a tradeoff for accountability or excellence; Edmondson (2018) described them as separate dimensions (Figure 2.4) in which the ideal estate would be to aim for a learning and high-performance zone. In managing quality, leaders are responsible for promoting psychological safety for their organizations to develop and continue to improve capability.

	Low Standards	High Standards
High Psychological Safety	Comfort Zone	Learning & High Performance Zone
Low Psychological Safety	Apathy Zone	Anxiety Zone

Figure 2.4: Psychological Safety Relation to Performance Standards (Figure #1.1 in Edmondson 2018)

Argyris and Schön (1978) and Edmondson (1999) treat learning as a process in which outcomes allow greater understanding of a subject, adaptation to change as needed, and, therefore, where performance improvement can be achieved. Psychological safety can facilitate achieving the goal of avoiding surprises by working upstream to uncover and align expectations and setting up clear objectives and criteria to measure success in achieving quality.

Deming (1986 p. 26) said, "top management should publish a resolution that no one will lose his job for contribution to quality and productivity." Contributions to quality can be evidenced in many

ways, for example, a worker reporting a mistake before it becomes a defect, asking for information or guidance to execute work that is not clear to him, or finding a way to get around some difference between the plan and actual conditions. Today, however, construction craftworkers fear the consequences (e.g., getting fired or being sent to do physically demanding work as punishment) they would face if they or someone else made a mistake and reported it (Chapter 4). This fear can impact quality as people may hide mistakes in exchange for self-protection (Edmondson 2003).

2.3.3 Lean Principle of Respect for People for the Delivery of Quality

One of the earliest milestones of the quality movement in the US was Frederick Taylor's publication "Principles of Scientific Management." He suggested separating planning from execution; engineers would do the planning while shop supervisors and the workforce would just carry out the plans (Goetsch and Davis 2014). Due to this separation, craftworkers are limited to contributing only a little to the early phases of a project because all the planning and design are done elsewhere, i.e., by project staff in the construction projects (Crosby 1979). This broken planning and execution approach negatively affects human relations and quality because of its premise that the workforce lacks the "literacy" needed to plan the work (Juran 1995). This overlooks that quality is directly connected to the people performing the operations in the field.

Respect for people, a cornerstone principle of the Lean philosophy (Ohno 1988), means treating individuals in a team courteously and respectfully and engaging them in improving their capabilities. As people advance their understanding of quality, part of planning for it includes the "recognition that you cannot, and should not, fool the people" (Crosby 1979 p. 55). The principle of respect for people applied to quality management fights against some stereotypes about workers being completely predictable and reinforces the idea of having all those needed participate in planning and executing the work.

Howell et al. (2017) proposed that behaving according to the Lean principle of respect for people can foster psychological safety, which, in turn, impacts performance in quality. Making reliable commitments demonstrates respect for others and is key in planning and building-in quality. Ballard and Tommelein (2016) explained that an essential prerequisite for reliable promising is that suppliers can say "no" to a request. Reasons for saying no can be tied to task appropriateness (sequence), readiness to be performed (task definition, soundness, or size relative to the capacity of performers) (Ballard and Tommelein 2016), expertise on the specific subject, or project constraints (budget, time). In a psychologically safe work environment where respect for others thrives, workers can (1) identify problems that might lead to defects and/or the defects themselves, and (2) figure out ways to solve problems and learn how to prevent repeating mistakes.

2.3.4 Language Action Perspective and Reliable Promising for Delivering Quality

Macomber and Howell (2003) connected the Language Action Perspective (LAP) with Lean, pointing out the study of speech acts and the commitment workflow described by Flores (1982). They argued that LAP describes the very human processes, the purposeful ways people communicate, by which projects are conceived and delivered. Gomez et al. (2020) described the importance of LAP theory in delivering quality. LAP describes the different speech acts that can be part of a conversation. Among those speech acts, reliable promising consists of conversations in which a request is being made, and parties commit to certain CoS (Austin 1975).

Macomber and Howell (2001) identified five elements of reliable promises:

1. Defining and committing to CoS: relevant for defining and committing to DFOWs and MAC for the delivery of quality
2. Competency to perform the task: relevant for project participants talking about their expectations (including their limitations regarding competencies)
3. Capacity available and allocated to perform the task: relevant for developing capable operations to meet project participants' expectations around quality
4. Sincerity: relevant for people feeling psychologically safe to speak up and accept a request only to the extent it is achievable, or decline, or make a counterproposal
5. Clean up the mess: relevant for continuous improvement to learn from what happened (e.g., failed to deliver as promised) and make things better now and the next time.

Reliable promising can be understood as a behavior enabled by psychological safety; namely, to speak truth to power, feel free to ask questions and make suggestions and ask for help, and be confident that mistakes you make will be met not with punishment but with help. Reliable promising is key in any situation in which one or more people are responsible for delivering or providing something to someone else and improving teams and organizations' operations (Macomber and Howell 2003, Feliz et al. 2014, Parrish 2014, Ballard and Tommelein 2016).

Ballard and Tommelein (2016) said that "the probability that commitments can and should be kept is increased when both parties, customer and supplier, practice reliable promising – they take their promises seriously and engage in a conversation to align the interests and capabilities of both parties." Project participants deserve to know exactly what they are committed to delivering and must deliver exactly that, following a cycle of reliable promises (Figure 2.5).

Figure 2.5: Basic Action Workflow or Reliable Promise Cycle (No Figure Number in Flores 2012)

Reliable promising start by making a request (i.e., expressing expectations), followed by a process of clarifying the request through negotiation (i.e., aligning and agreeing on MAC with a thoughtful consideration of the capability to deliver on that commitment) and executing work, and finalized by declaring satisfaction (i.e., completing the request and measuring as per the agreed MAC). Reliable promising applies, for example, to releasing workspace from one trade to the next, notifying suppliers of payments due, and delivering quality scopes of work. In all cases, deliverables must satisfy the agreed expectations.

2.3.5 Servant Leadership

Servant leadership proposes that those in a leadership position can "help, support, encourage, and lift up others" by seeing leadership as an opportunity to serve others and wanting to serve by helping them succeed (Greenleaf 1977). Greenleaf said that those served, become "become healthier, wiser, freer, more autonomous."

This type of leadership style is important for employees' psychological health (Rivkin et al. 2014). It consists in putting yourself in others' shoes and trying to understand them to support them and help them thrive. Servant leadership shares ideas with the Lean principle of respect for people, and it influences psychological safety and the delivery of quality in different ways, e.g., GCs trying to understand design intent and, when possible, offering them better alternatives than those initially planned to achieve).

2.3.6 Collaborative Design of Construction Operations to Meet Expectations

Juran (1986) suggested that an inherent part of the quality planning process is assuring that the operations to produce products are capable of meeting quality goals under operating conditions. When problems with quality arise, it may be assumed that rejections are mostly due to poor workmanship, but rather, they might be due to not properly estimating its process capability (Milberg 2006). Juan and Gryna (1988) defined process capability as a "quantified prediction of process adequacy," meaning whether the designed process will hold the tolerances and satisfy requirements. Process capability makes it feasible to use statistical process control for improving repetitive operations (common in manufacturing), but current practice and the uniqueness of the projects in construction make it hard to collect data for this purpose in the architecture, engineering, and construction industry (Milberg 2006). In a broader view of the concept, process capability is the "effectiveness of the process in meeting customer needs," and its prime application is during operations design (Juran and Godfrey 1999).

The ontology I use is that (1) processes in construction projects are a series of steps executed by multiple subcontractors to build any scope of work (e.g., building a concrete wall involves the steel subcontractor to install the rebar and a concrete subcontractor to install formwork and pour concrete), and (2) operations are the steps executed by one of the subcontractors (e.g., every step a drywall subcontractor takes when building a partition wall; operations of the drywall subcontractor do not consider other subcontractors' steps for building the partition wall such as installing MEP systems).

The design of operations capable of meeting specific quality requirements needs to consider (Howell and Ballard 1999, Ballard and Tommelein 2021), at a minimum:

1. Requirements to be met.
2. Skills and knowledge of the performers to meet them.
3. Steps to be performed, durations, and sequence.
4. How the information is transferred throughout the chain (e.g., from staff and supervisors to the crews that carry on the activity).
5. Applicable planning and control processes that generate and provide that information to whom and when needed.

Ballard and Tommelein (2016, 2021) stressed the importance of engaging direct workers in operations design and described three ways to develop the design of construction operations:

1. Virtual prototyping involves using a computer-based model (e.g., virtual mockups) to test and refine the design of an operation. It reduces the cost and impact of a flawed design. The more hazardous or unfamiliar the operation, the more virtual prototyping is needed. For example, for placing a tower on its foundation, learning from failure that a design needs improving is not the best option. Operations that have not been performed previously benefit from virtual prototyping as it does not require significant investment in materials, equipment, labor, etc.
2. Physical prototyping, known as mockups, introduce materiality and, thus, aspects of the operation that might not be captured in virtual prototypes. Craftworkers can add their skills and knowledge in devising and assessing virtual prototypes, but their contributions are perhaps even more valuable in physical prototyping.
3. First-run studies (FRS) use the first instance of performing an operation to test its capability. Doing so is only a matter of mindset; being alert to opportunities for improvement. As such, FRS should be done to test and improve all operations.

Many operations can be designed using all three methods. Operations design is a fundamental piece of the quality delivery process because it assures that processes are capable of meeting the agreed DFOWs and MAC. It defines the means by which the work is to be executed to meet project participants' agreed expectations.

2.3.7 Continuous Improvement and Standardized Work

The American Society of Quality (ASQ n.d.) highlighted continuous improvement as an ongoing effort to produce better products, services, and processes. Continuous improvement is a challenging approach toward execution because (1) people enjoy the certainty of having a pre-established process to follow, but changes are likely to come up, and breakdowns are inevitable (Winograd and Flores 1986), and (2) it requires us to accept our individual and collective fallibility (Edmondson 2012).

As social creatures, humans enjoy creating, sharing, or implementing new ideas (Edmondson 2012). However, fear inhibits learning, cooperation, and continuous improvement because fear impairs analytical thinking, creative insight, and problem-solving capabilities (Fox and Shonkoff 2011). For continuous improvement, the world needs people who are able to (1) share "concerns, questions, mistakes, and half-formed ideas" without "fear of embarrassment or retribution," (2) speak up with confidence that they "won't be humiliated, ignored, or blamed," and (3) "ask questions when they are unsure about something" (Edmondson 2018). A concern regarding quality is people not reporting mistakes when discovered, and not speaking up even though doing so would benefit the team. For instance, Milliken et al. (2003) found that employees remained silent mainly because of self-image as they did not want to be viewed or labeled negatively or damage valued relationships. If people feel that their saying could be interpreted as negative or threatening to their superiors, they will likely keep silent (Ryan and Oestreich 1991) or behave in a self-protective manner (Athanassiades 1973). Continuous improvement can occur by learning from experiments or breakdowns; "Experiments are intended deviations from the standard. Breakdowns are unintended deviations from the standard" (Ballard 2008 p. 11). In either case, learning requires a

"safe zone in which participants can openly speak" (Seed 2014), a zone that can be fostered by building psychological safety.

Learning and continuous improvement are linked to standardization. Standardized work evolves through continuous improvement, which helps to eliminate waste and redesign tasks to continuously establish a new current best way of doing things (Liker and Meier 2007). Standards embrace product standards, such as using the same materials to improve production (Tommelein 2006), and process standards, such as standard work design developed in FRS (Gallardo et al. 2006, Feng and Ballard 2008, Hackett et al. 2015). To foster the use of standardized products and processes in construction, some challenges need to be overcome, e.g., from low process discipline and the lack of standard methods that affect predicting and measuring quality (Aapaoja and Haapasalo 2014), to the misbelief that the uniqueness of every part of a project contributes to adding value (Tommelein 2016).

2.3.8 Mistakeproofing

In construction, the uniqueness of the projects and the challenges in developing requirements provide ample opportunity for making mistakes. Nakajo and Kume (1985) said that "humans are liable to make mistakes when the information is complex or subject to various possible interpretations," and offered mistakeproofing as a method that "makes it impossible for an error [mistake] to occur or makes the error [mistake] immediately obvious once it has occurred" (ASQ n.d.). Mistakeproofing involves investigating mistakes and analyzing their consequences to prevent their reoccurrence (Nakajo and Kume 1985, Shingo 1986, Godfrey et al. 2005, Tommelein and Demirkesen 2018).

Mistakeproofing principles are described in Figure 2.6. If a mistake occurs during the execution of the operation, then the intent is to detect the mistake as close as possible to the time of occurrence to mitigate the associated damages.

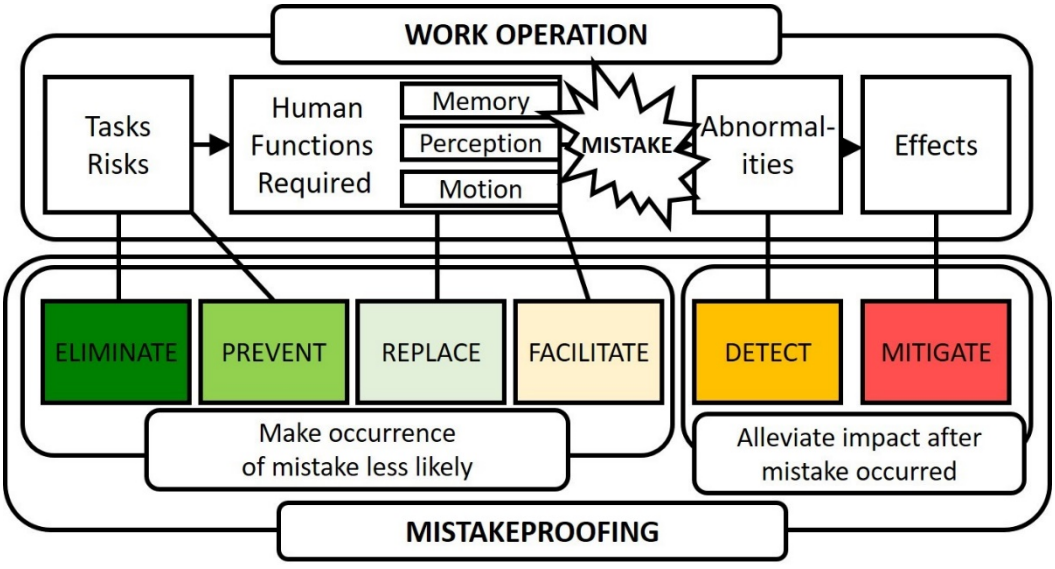


Figure 2.6: Mistakeproofing Principles Applied to Work Operations (Figure 6 in Tommelein and Demirkesen 2018, after Godfrey et al. (2005))

Tommelein and Demirkesen (2018) described the purpose of each principle:

1. Elimination is "to remove the possibility of a mistake occurring in a task of a process by redesigning the product or process so that the task (or associated product part) is no longer necessary."
2. Prevention is "to design and engineer the product or process so that it is impossible to make a mistake at all."
3. Replacement is "to substitute one process with a more reliable process to improve consistency."
4. Facilitation is "to use various means (e.g., sensory input) to make tasks easier to perform."
5. Detection is "to identify a mistake promptly so that a person can quickly correct it and thereby avoid that the mistake may turn into a defect."
6. Mitigation is "to minimize the effects of mistakes."

In construction projects, misinterpretation of information (Juran and Godfrey 1999, Mitropoulos et al. 2005) and an individual's judgment (Howarth and Greenwood 2018, Alomari et al. 2018) can cause mistakes. Considering this, construction teams are challenged to plan ahead to eliminate or prevent them from happening. For any operation (e.g., pouring a concrete wall, assembling an IKEA desk[2]), the ideal is to take the best possible action depending on the problem dealt with, from eliminating the possibility of the mistake occurring in the first place to mitigating its effects once it occurs.

Mistakeproofing facilitates the process of assuring quality because mistakes are eliminated or detected and mitigated before becoming defects. BiQ, through mistakeproofing principles, builds a culture of prevention and develops people's alertness to opportunities for further improvement (Shingo 1986, Tommelein and Demirkesen 2018). BiQ requires:

1. A process to understand, align, and communicate expectations to determine which operations need to be executed and what the expected outcomes are
2. Operations capable of meeting the agreed expectations
3. Operations that are designed to be mistakeproof, when possible, or where mistakeproofing principles are applied to the extent possible.

2.4 Methods Used to Assess Success in Achieving Expectations

Assessment is needed of the quality management system itself, of individual systems and scope, of the product design, of process capability, and finally, of performance of the constructed asset (CII 1990, Juran and Godfrey 1999, CII 2001, Von Collani and Baur 2006, Abuhav 2017, Oakland and Marosszeky 2017, Howarth and Greenwood 2018, Construction Quality Executive Council (CQEC) 2020). The scope of this research is limited to the assessment of specific scopes conforming to the agreed expectations (e.g., architectural shear walls, metal doors, cabinets). Determining if a delivered scope is acceptable (i.e., meets the agreed expectations) requires being aware that:

[2] IKEA's assembly instructions are examples of operations designed to be mistakeproof. These instructions show the step-by-step process for assembling the purchased furniture without words (https://michelbaudin.com/tag/ikea/).

1. Relying on inspections alone to assess the delivered scope is not sufficient for delivering quality because their timing is too late in the process (Deming 1986). Applying source inspection (Shingo 1986) all through the design and construction process when operations get executed can increase the probability of delivering non-defective scopes that are assembled from multiple parts.
2. Methods for assessing conformity vary (e.g., inspections, control charts, testing) (Shingo 1986, Marrero et al. 2014), and evaluating quality requires project participants to agree on how to assess conformity. The method chosen to assess a delivered scope needs to be clear about the specific steps (i.e., activities needed) to perform such assessment (e.g., visual inspection to assess color at a certain distance and lighting conditions, knocking on the formwork panels, and listening to the sound it makes after pouring concrete to make sure there are no empty holes or spaces in the poured wall panels).
3. Assessing conformity when it depends on an individual is a subjective process based on the interpretation of the person conducting the assessment (Dougherty et al. 2012). Different perspectives of those involved in conducting the assessment need to be aligned. For example, if the architectural concrete shear walls of an exploratory study I conducted (Gomez 2019a) had been built with the specification that asked to have a "mirror-like" surface, at the time of assessing the built walls, it would be very unlikely that project participants conducting the evaluation (e.g., the person who built it, the architects who designed it, the owner who paid for it) would have the exact same thing (i.e., assessment criteria) in mind.

Considering the challenges faced, remedies for these include (1) defining MAC to reduce subjectivity, (2) defining an assessment method appropriate for the purpose, and the different steps this method requires to perform the assessment, and (3) conducting inspections at every step of the production process before work is handed over to the next person or process, and not delaying the inspection until the final delivery of the scope.

2.4.1 Define an Assessment Method Fit for Purpose

Different assessment alternatives (e.g., control charts, inspections, testing) are suitable for specific purposes. In fabrication processes, for example, one way to assess conformity is through process control charts, which can be used to determine if the manufacturing process is itself in control and the products are meeting the intended specifications (Shewhart 1939, Gryna et al. 2005, Marrero et al. 2014, Oakland and Marosszeky 2017, ASQ n.d.). In construction, assessment of conformity is done through inspections, which can be done in different ways (e.g., testing, visual inspection). Various project participants conduct inspections (e.g., first the person who performs a task, then the company that builds the scope, then architects, owners, city inspectors) and serve to reveal defects, though they play a passive, wasteful role (Shingo 1986). Inspections cannot be eliminated until the entire process is fully mistakeproof at any given time (Shingo 1986). Even in the case that products pass 100% inspection, a customer might still reject it for various reasons (e.g., not fit for purpose, change opinion such as customers returning purchased products using the return time window offered for most sales).

One approach for conducting inspections is using sampling inspections. Sampling inspection relies on extrapolating samples and assumes that inspection is made without mistakes and that inspectors follow the prescribed sampling plan (Shingo 1986, Juran and Godfrey 1999). However, this type of inspection allows for some defects to be delivered because of the products that are not assessed

in the process. The accuracy of estimates made by inferring from a sample increases with the number of items in the sample, but falls short of 100% until the entire population is sampled. Another approach for inspections is using 100% inspection (Shingo 1986), but even then, there still remains the risk of failing to detect defects when humans perform inspections (making the inspection memory, perception, and motion dependent). Another approach for inspections is source inspection, which allows the detection of mistakes at the source (Shingo 1986, Juran 1995, Juran and Godfrey 1999). For any inspection approach, the inspection itself may not be 100% correct, which may lead to mistakes. If mistakes are discovered as close in time to their occurrence as possible, that prevents the defective product from being handed off to the next step in the production process. Detection of mistakes relies on all project participants speaking up once mistakes are detected, which is a behavior characteristic of psychologically safe work environments (Edmondson 2018).

2.4.2 Define Measurable Acceptance Criteria (MAC) to Reduce Subjectivity

Clarity in the context of quality involves clearly understanding project participants' expectations, aligning them into a set of requirements to meet, and defining a clear way to check for conformity (Wallace 1986, Hendrickson and Au 1989, Wallace and Cherniavsky 1990, CII 1990, Lowe 2001, US Army Corps of Engineers 2018, CQEC 2021). Juran and Godfrey (1999 p. 85) said that "specifications must be unequivocally clear." Gomez et al. (2019a) introduced the concept of MAC in construction projects as "an objective way to evaluate a deliverable" that allows for assessing whether the deliverable meets the agreed expectations. This case described the process to define MAC for architectural shear walls (e.g., GC and concrete subcontractor searched industry standards, means, methods, tolerances for mix designs, formwork materials, vibration techniques, etc. to provide measurable solutions for each feature identified). MAC for this scope included details about rustication and reveal strips, aesthetics of formwork, slag, color, texture, etc. Establishing DFOWs and MAC for a scope is a way of reconciling the technical aspects of building these with how the owner's objectives are expressed. MAC help define what is in project participants' minds, and it can be set for any input, process, or output before the development begins. Developing MAC considers:

1. Any pre-established requirement
2. Project participants' expectations that might help to find new information
3. Agreements reached in the alignment process to assess that a product is "well done."

MAC need to be written as statements with clear and simple language. Though, when it becomes challenging to express the MAC by speech alone, supplemental materials (e.g., instructions on where to stand, in what lighting conditions, submittals, materials samples) can be used to establish a clear understanding of expectations and how to assess product conformity to them. MAC needs to have enough detail to be useful and define what is acceptable (e.g., in regard to functionalities, aesthetics, time of completion).

2.5 Leading Quality in Construction Projects

Similar to safety management, in which old approaches designated most of the responsibility to the "safety person," more enlightened approaches emphasize the importance of every person, including, for example, all staff members and the owner, to take ownership of safety, their own,

and others around them (Liska et al. 1993, Levitt and Samelson 1993, Hinze 1997, Hislop 1999, Gambatese 2000, Huang 2003). Project participants participate in different ways in the implementation of quality delivery processes. However, the responsibility for leading quality (i.e., guiding the implementation of the process) and the project participants' role in the process are not clear from the literature.

2.5.1 Quality is Everyone's Responsibility

Deming's principles (1982) placed the responsibility for quality on management. He said that "the quality desired starts with the intent, which is fixed by management. The intent must be translated into plans, specifications, tests, in an attempt to deliver to the customer, the quality intended, all of which are management's responsibility." This focus on management for leading quality works at the systems level because it is the leader who decides (1) if to pursue an IiQ or a BiQ approach, (2) if to value or disregard the expectations of other project participants, and (3) if to pursue the Lean ideal or rather whatever increases today's profits. Taguchi and Clausing (1990) critiqued how managers implementing traditional approaches towards quality often think that quality results are the responsibility of a few quality control people. Other approaches, such as total quality management (TQM) and robust quality, shifted this view and suggested that everyone is responsible for quality (Imai 1986, Taguchi and Clausing 1990). Responsibility to manage quality requires judgment, coping with uncertainty, implementing new ideas, coordinating, and communicating with others (Juran 1995, Antillon et al. 2011, Abuhav 2017).

At the systems level, in construction, the responsibility for quality is relegated from the GC to the subcontractor and sub-subcontractor, often through contracts including penalties for non-performance (Arditi and Gunaydin 1997). Quality depends on multiple operations performed by different trades. For example, when building reinforced concrete walls, the quality depends at a minimum on the GC, steel subcontractor, concrete subcontractor, steel and concrete suppliers, and formwork suppliers. When implementing a quality management process, some individuals need to make sure that the system is functioning as intended (i.e., assuring system performance), some for taking steps to improve its functioning where possible (i.e., improving steps within the system), and some for performing the steps and for improving its functioning.

At the execution level, people in different roles are involved in the delivery of quality deliverables (e.g., members who participate in the delivery of the architectural shear walls go all the way from the market to the owner, to the architect, to the construction engineers, to the suppliers). However, the responsibility to deliver quality in practice is currently fragmented and needs improvement (CII 1989, Hoonakker et al. 2010, ASCE 2012, Gomez et al. 2019a). For example, CII (1989) identified that most of the responsibility for quality outcomes lies on the inspectors. Gomez et al. (2019a) reported that most project participants in a construction project attribute most of the responsibility to the "quality champion" of the project. In a more extensive study with 208 contractors, Hoonakker et al. (2010) identified that only 13% of respondents require the suppliers and subcontractors to use some quality program.

Ballard and Howell (1998) highlighted that it is common for upper levels of supervision and management to monitor productivity and progress, while lower levels and direct workers are expected only to push and work harder. From that division of responsibilities, the activity of defining quality and planning to achieve it relies heavily on the staff (project manager and site engineers), leaving only execution, as per the plan, to craftworkers.

Planning the quality delivery process requires clarity on the level of involvement of project participants at the systems and execution level. Both are necessary to clearly define what quality is (i.e., requirements, DFOWs, and MAC) and how to achieve it (i.e., means and methods) for any deliverable. Considering the dependency between the GC, subcontractors, and suppliers to ensure meeting expectations, every participant is expected to manage quality to the extent possible. Responsibility for managing quality at this level includes collaborating and coordinating with multiple project participants. For example, for building concrete shear walls, there cannot be just one person responsible for all of the quality of sheer walls, but there might be someone who has that role (e.g., concrete project engineer, concrete project manager) and someone who has leadership responsibility for actually doing the work (e.g., concrete general foreman, craftworkers who install the formwork and pour the concrete).

2.5.2 Managerial Actions to Increase Psychological Safety

Edmondson (2008) described that in order to foster psychological safety, the team has to start small and identify specific areas where to focus and then expand through emulation, imitating behaviors of those fostering psychological safety. In industries other than construction, studies have documented different means or practices to increase psychological safety. In addition, extensive research has been done in the area of construction safety that is relevant and applicable to fostering psychological safety (Table 2.5). The applicability of these practices needs to be tailored to the context (i.e., based on the needs of each team).

2.5.3 Offering Recognition for Desired Behaviors

Saunderson (2004) and Peterson and Luthans (2006) describe different types of recognition programs. First, formal recognition is a structured recognition program that focuses on specific objectives (i.e., it has a defined criterion to meet). Second, informal recognition focuses mostly on recognizing good performance, often awarded monthly or quarterly. Third, everyday recognition (aka. Social recognition), focuses on giving immediate recognition to people displaying the desired behaviors and setting an example for others.

Various programs for recognizing desired behaviors for safety have been implemented in construction projects, and these can be adapted to foster behaviors desired for quality. For example, Sparer et al. (2015) describe a program that recognized subcontractors who met desired safety performance based on a weekly assessment of safe or unsafe site conditions through visual inspections. In this program, each subcontractor's performance was communicated to all workers and their supervisors using visuals and orally during the project's weekly group meeting. Similarly, Abas et al. (2020) describe a program that recognized desired housekeeping and injury-reporting behaviors. It rewarded cleanliness and reporting of unsafe behaviors and site hazards. It can take the format of a point-based assessment where subcontractors gain points based on the number of unsafe behaviors or hazards their workers report.

Table 2.5: Practices to Foster Psychological Safety

Practices to Increase Psychological Safety	Reference
Purpose: Establish a bond and break down walls between workers and staff, strengthen supervisors–frontline employee relationships, and lower interpersonal threats.	
1. Put people in contact with someone they believe; facts shared by peers have a more powerful impact. 2. Stop, look, listen, and talk to frontline employees about what is happening on the floor. 3. Practice conversational turn-taking, so that team members have the chance to speak. 4. Practice empathy and social sensitivity to identify how others feel based on their behaviors. 5. Establish a committee and bring management closer to support.	Levitt and Parker (1976), Hinze and Parker (1978), Crosby (1979), Sanna and Shotland (1990), Hallowell and Gambatese (2010), Komaki (2015), OSHA (2016)
Purpose: Practice active caring to facilitate, motivate, encourage speaking up, and model desired behaviors.	
1. Compel rationale for speaking up and let others know why it is important for themselves and their organizations. 2. Recognize leaders and your own fallibility and mitigate the intimidating effects of power. 3. Appreciate vulnerability and acknowledge ignorance or the lack of answers to some questions. 4. Ask questions that are not leading or rhetorical. 5. Model curiosity to foster openness and collaboration. 6. Help people believe they will not be rejected and that the newly uncovered information will be used to learn. 7. Incentivize workers' participation (e.g., by reporting their concerns) to strengthen communication. 8. Do housekeeping to show respect for other trades who will work in the same zone.	Hinze and Harrison (1981), Liska et al. (1993), Edmondson (1999, 2003, 2008, 2012b), OSHA (2016)
Purpose: Build a growth mindset with servant leadership and encourage to take on new challenges with confidence.	
1. Lead by example, use servant leadership and emphatic listening. 2. Involve workers in accident/defect case analysis. 3. Praise wisely, praise the process people get engaged in, and foster perseverance, strategies, and improvement. 4. Provide training based on the team's needs.	Hinze and Harrison (1981), Dweck (2006), Hinze et al. (2013), OSHA (2016), Awwad et al. (2016)

2.6 BiQ Frameworks used in Construction

Two BiQ frameworks are widely known, one in the industry and one in the academy sector. These are from the Boldt[3] company and the P2SL, respectively.

2.6.1 Boldt's BiQ Framework

Figure 2.7 depicts Boldt's BiQ framework. In practice, project teams implement this framework to some extent based on risk analysis for a particular scope of work. I present a description of the application of this framework based on personal experience[4] and internal communications with some Boldt employees.

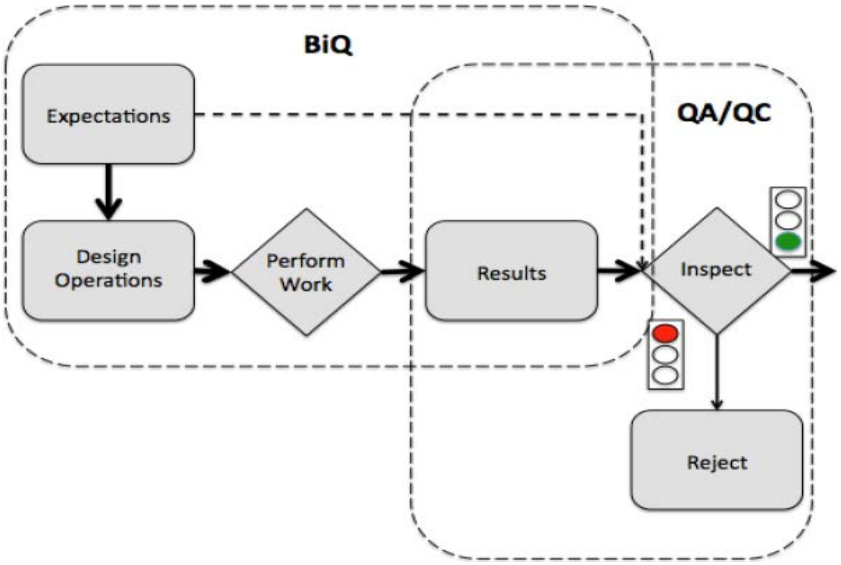


Figure 2.7: Boldt's BiQ Framework (No Figure Number in Lichtig 2012)

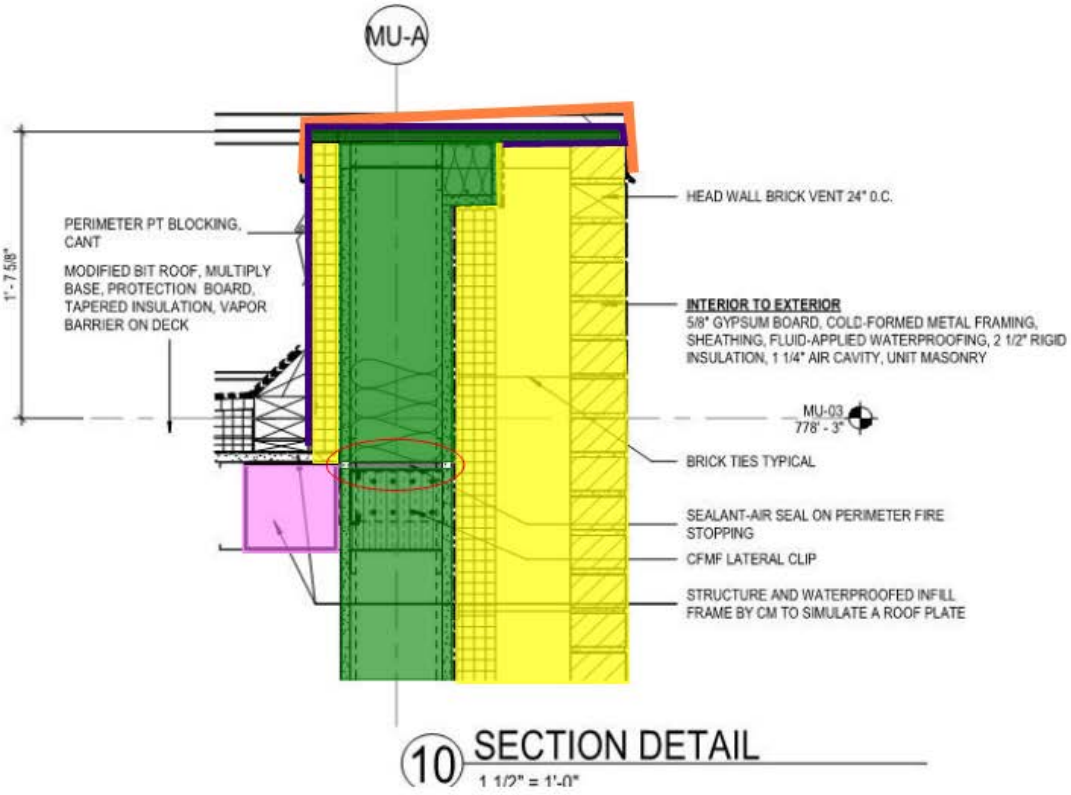
For the "Expectations" step, Boldt holds "Make Work Ready" meetings with subcontractors to discuss the project specifications and start planning the work.

For the "Design Operations" step, Figure 2.8 presents a diagram created through coordination meetings between Boldt and subcontractors for enclosure details. In these meetings, the GC and subcontractors defined the work sequence (i.e., steps) to build this scope and specified the trade in charge of executing such steps. In this case, the GC and subcontractor participated in the coordination meeting to design operations. Questions or concerns that needed the architects' or owner's input were highlighted in the "Notes" section.

[3] The Boldt Company (aka. Boldt) is a GC known for its BiQ focus (www.theboldtcompany.com/boldthinking).
[4] I interned at Boldt in Summer 2017 and attended some of Boldt's presentations at the Lean Construction Institute (LCI) annual conferences from 2017-2020 where teams shared their experiences implementing their BiQ framework.

Work-Step Sequences:

Done?	Step #	Description	Installer	Color
Y/N	1	Erect Structural Steel	Crystal Steel	Pink
Y/N	2	Install blocking, CFMF, sheathing, AVB	Valley	Green
Y/N	3	Perimeter firestopping		
Y/N	4	Install rigid thermal insulation	Boldt Masonry	Yellow
Y/N	5	Install face brick	Boldt Masonry	Yellow
Y/N	6	Install plywood at top of parapet	Valley	Green
Y/N	7	Install Roof Membrane/Flashing	K&W	Purple
Y/N	8	Install metal coping	K&W	Peach

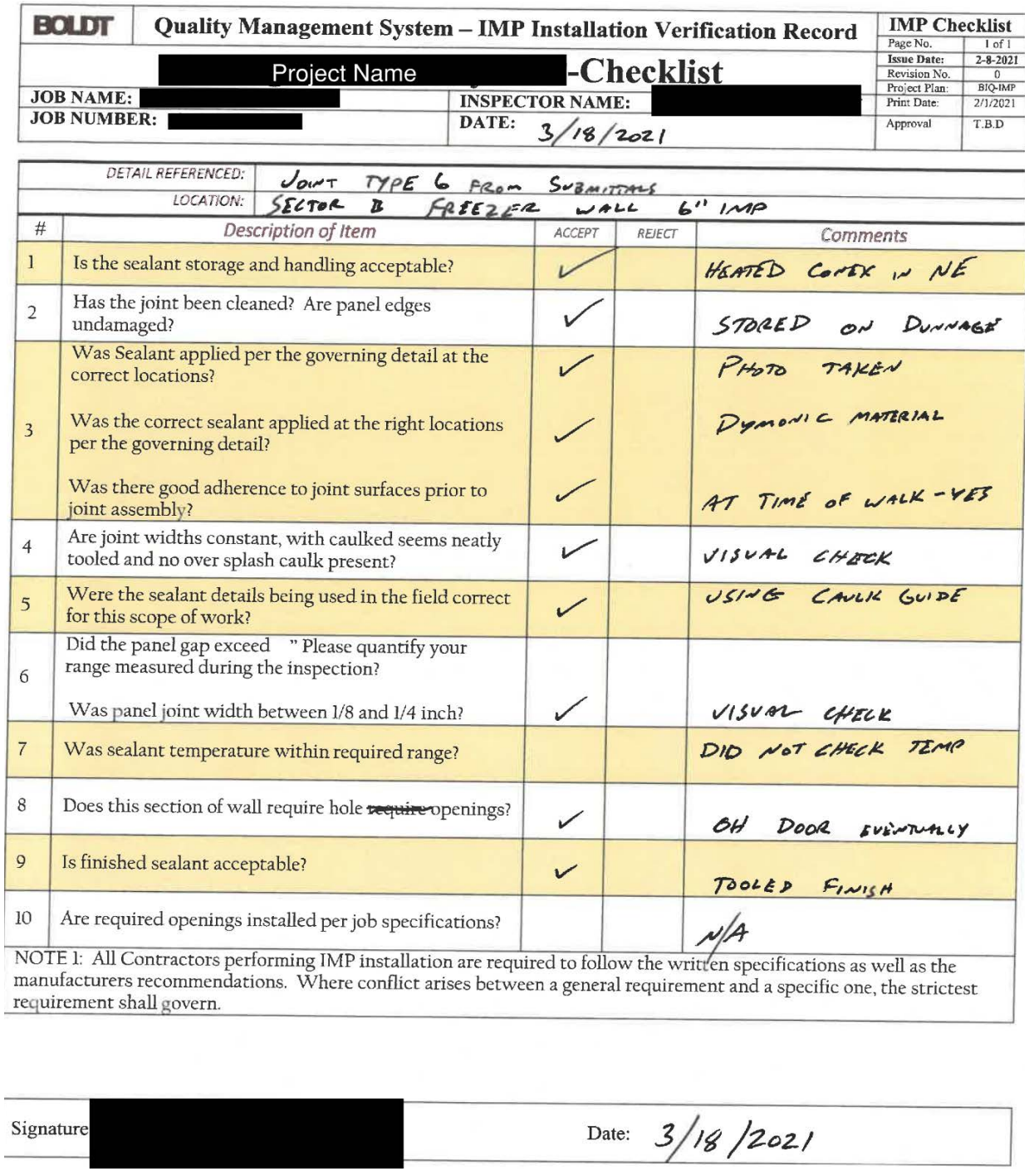


Notes:

1. Rigid insulation coordination between K&W vs. Boldt Masonry.
2. Design Team - is perimeter firestopping required at circled location?
3. Rigid insulation behind parapet - Boldt Masonry did not include

Figure 2.8: Diagram Created in Operations Design Step by Boldt and Other Project Participants (Courtesy of Boldt)

After the work is performed and a deliverable [i.e., results] is produced, the last step in Boldt's BiQ is the "Inspect" step. For inspections, Boldt uses standard forms (e.g., Figure 2.9) that are included in Boldt's Quality Management System (QMS) manuals. The items listed on the checklist are developed for each project and then added to their QMS manuals.



BOLDT | Quality Management System – IMP Installation Verification Record | IMP Checklist

Page No. 1 of 1 | Issue Date: 2-8-2021 | Revision No. 0 | Project Plan: BIQ-IMP | Print Date: 2/1/2021 | Approval T.B.D

Project Name -Checklist

JOB NAME: [redacted] INSPECTOR NAME: [redacted]

JOB NUMBER: [redacted] DATE: 3/18/2021

DETAIL REFERENCED: JOINT TYPE 6 FROM SUBMITTALS

LOCATION: SECTOR B FREEZER WALL 6" IMP

#	Description of Item	ACCEPT	REJECT	Comments
1	Is the sealant storage and handling acceptable?	✓		HEATED CONEX IN NE
2	Has the joint been cleaned? Are panel edges undamaged?	✓		STORED ON DUNNAGE
3	Was Sealant applied per the governing detail at the correct locations?	✓		PHOTO TAKEN
	Was the correct sealant applied at the right locations per the governing detail?	✓		DYMONIC MATERIAL
	Was there good adherence to joint surfaces prior to joint assembly?	✓		AT TIME OF WALK - YES
4	Are joint widths constant, with caulked seems neatly tooled and no over splash caulk present?	✓		VISUAL CHECK
5	Were the sealant details being used in the field correct for this scope of work?	✓		USING CAULK GUIDE
6	Did the panel gap exceed " Please quantify your range measured during the inspection?			
	Was panel joint width between 1/8 and 1/4 inch?	✓		VISUAL CHECK
7	Was sealant temperature within required range?			DID NOT CHECK TEMP
8	Does this section of wall require hole ~~require~~ openings?	✓		OH DOOR EVENTUALLY
9	Is finished sealant acceptable?	✓		TOOLED FINISH
10	Are required openings installed per job specifications?			N/A

NOTE 1: All Contractors performing IMP installation are required to follow the written specifications as well as the manufacturers recommendations. Where conflict arises between a general requirement and a specific one, the strictest requirement shall govern.

Signature [redacted] Date: 3/18/2021

Figure 2.9: Inspection Checklist Example used in a Boldt Project (Courtesy of Boldt)

2.6.2 P2SL's BiQ Framework

Boldt's BiQ framework was expanded by the Project Production Systems Laboratory (P2SL) researchers to align with the levels of the Last Planner System (Figure 2.10). P2SL's BiQ emphasizes the continuous improvement portion of quality. After the work is inspected, it can be either accepted or rejected. In both cases, the "Give Feedback" step is a parallel to the "learning" portion in the LPS, in which the work done is compared to the work as planned. For quality, the delivered scope is assessed against the expectations defined. The feedback received in this framework feeds other steps with input on how to do things better or repeat.

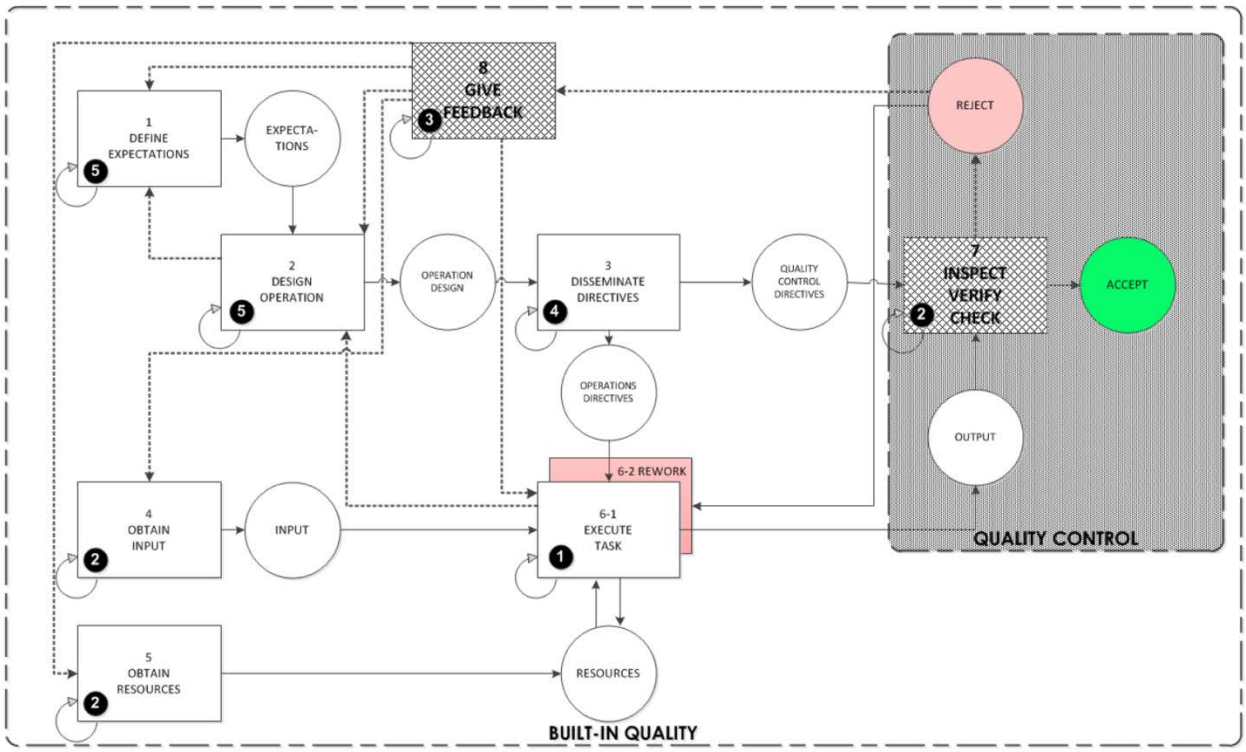


Figure 2.10: P2SL's BiQ Framework (Figure 3 in Steinhaeusser et al. 2014)

2.7 Focusing on Behaviors for Managing Quality in Construction Projects

Deming (1986 p. 18) said that "transformation can only be accomplished by man, not by hardware. A company cannot buy its way into quality." Traditional quality management processes are developed under the expectation that "human beings will automatically behave in accord with a newly designed quality procedure" (Pounds et al. 2015). Moreover, in the design of production systems, Edmondson (2012a p. 286) highlighted that "underlying the notion of a simple, controllable production system was the notion of the simple, controllable employee." However, in reality, people behave according to their beliefs and preconceived ideas, often grounded in previous experiences (Flores 2016). People's behaviors can significantly determine the quality of products and services delivered (Imai 1986, Flynn 2001, Spigener and Angelo 2001).

The process through which deliverables in construction projects are produced may vary from one to another (e.g., building concrete walls, installing terrazzo flooring), but often a process is

repeated many times (e.g., pouring dozens of concrete walls) in a single project. All deliverables go through the same set of fundamental steps prior to production:

1. Understanding expectations
2. Aligning expectations and defining requirements
3. Agreeing on MAC
4. Designing the work as per the agreed MAC
5. Agreeing on how conformity to those expectations will be met, including assuring operations capability
6. Agreeing on how that conformity will be assessed.

Various project participants interact throughout this set of fundamental steps to deliver quality scopes. For example, in the case of concrete shear walls, some of the project participants in the process are (1) structural designers (who define the loads the wall can bear), (2) architects (who may have a preference for the aesthetics of the wall's surface or dimensions), (3) GC and concrete subcontractor (who have experience on the means and methods to build walls and related constraints such as cost and time), (4) carpenter crews (who have similar skills and directly participate in the execution of the operation), and (5) suppliers of concrete and formwork. Defining what behaviors are expected from these people while they participate in the delivery process is key to having clarity throughout the different steps of a process.

2.7.1 Culture and Behaviors

Extensive research has been conducted on Behavior-Based Safety (BBS) in construction (Geller 2001, 2005, Li et al. 2015). A search on the topic of "behavior-based safety" in the Web of Science database and Google Scholar shows 366 and 7,080 articles by March 2023, respectively. BBS foundations suggest that safety on a project can be improved by fostering behaviors needed for safety, such as wearing protective gear or using an equipment guard (Geller 2001). Just as occurs with BBS, quality can be managed from a behavior-based perspective (Krause 1994, Spigener and Angelo 2001). BBS uses a behavioral approach to lead to a culture based on accident prevention (Lingard and Rowlinson 1997, Chen and Tian 2012, Choudhry 2014). Similarly, BBQ uses a behavioral approach to lead a culture that minimizes surprises and delivers quality as per the agreed expectations (Spencley et al. 2018). This culture for quality can be described by four attributes: (1) beliefs, (2) intentions, (3) attitudes, and (4) behaviors (Johari and Jha 2020). Figure 2.11 shows my interpretation of how these attributes connect to people behaviors.

Beliefs refer to how we understand the world and the people in it (i.e., a person's subjective understanding of the environment) (Fishbein and Ajzen 1975). If related to bad experiences (e.g., someone getting fired for reporting a mistake), beliefs may make people feel constrained and afraid of speaking up, inhibiting learning (Edmondson 1999, Jervis 2006, Flores 2016). Beliefs can be explored from the perspective of the presuppositions (what is assumed to be true about quality management processes; e.g., "quality lies in the eyes of the beholder," "information is ambiguous, inconsistent, or conflicting," "we are always making assumptions").

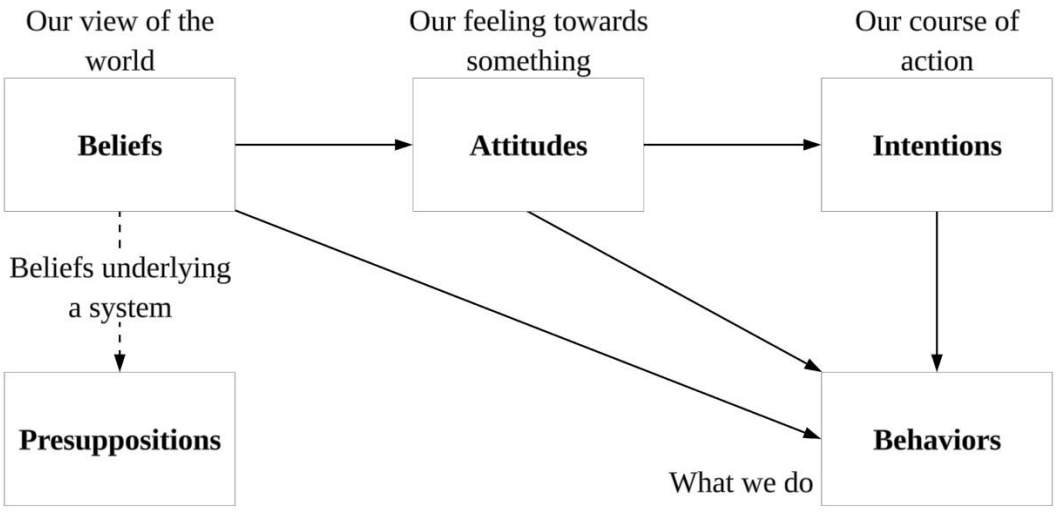


Figure 2.11: Culture Attributes that Drive Behaviors

Attitudes refer to how we feel towards something (i.e., favorable or unfavorable evaluation of anything, e.g., an object, a person, or an abstract idea) (Katz 1960, Eagly and Chaiken 1993, Ajzen 2001, Albarracin et al. 2005). Attitudes can be influenced by people's beliefs (Wyer and Goldberg 1970, Wyer 1974, Johari and Jha 2020). Managing quality requires people with positive attitudes toward others' expectations (e.g., GC understanding the architect's design intent), collaborative work to understand, align, and meet expectations, etc.

Intentions refer to what we aim to accomplish (e.g., delivering quality, and having a clear way to evaluate delivered scope) (Bratman 1987). Intentions are driven by attitudes (Ajzen and Fishbein 1973, Eagly and Chaiken 1993, Johari and Jha 2020). In the presence of favorable attitudes towards quality, intentions can embrace BiQ steps; for example, project participants' intentions might be to understand and align others' expectations to make sure that their plans have clarity about what to build.

Behaviors refer to what we do (i.e., acts of an individual) (Albarracin et al. 2005). Behaviors are "neither negative nor positive" (Spigener 2001). These are influenced by the person's beliefs, attitudes, and intentions (Ajzen and Fishbein 1973, Feinfield et al. 1999, Glasman and Albarracin 2006, Johari and Jha 2020); and in turn, behaviors greatly influence the resulting performance (Spencley et al. 2018, Johari and Jha 2020). The focus on behaviors aims to position project participants with a certain mindset to highlight the consequences of their actions in achieving the intended outcomes. A repetition of behaviors in a context leads to the formation of habits (Lally et al. 2010).

Flynn (2001) described how some employees would skip certain steps in a defined process to ease their work and how these behaviors that may put quality at risk can be replicated (i.e., followed) by other employees if actions are not taken. Crosby (1979) realized that the "conventional approach [to quality] was not effective," but "some beliefs are so ingrained that they cannot be changed just by suggesting they are wrong." Identifying and clarifying the behaviors desired to deliver quality is important.

2.7.2 Behavior-Based Quality (BBQ)

The term BBQ was first introduced in construction by Spencley et al. (2018), who expanded Steinhaeusser et al.'s (2014) work on BiQ. BBQ is a form of BiQ that extends current approaches by emphasizing the human factor in quality management. The human-oriented literature in quality pertains, for example, to management practices (e.g., Crosby 1979, Deming 1986, Juran and Gryna 1988), methods and tools to minimize mistakes due to human error (e.g., Shingo 1986, Godfrey et al. 2005, Tommelein 2019), and the culture and behaviors of those involved in the quality process (Flynn 2001, Spigener 2001, Thomas et al. 2002, Howell et al. 2004, Pounds et al. 2015, Spencley et al. 2018, Gomez et al. 2019, 2020). Spigener (2001) said that BBQ is mainly focused on:

1. Improving the "likelihood that the right behavior will occur"
2. Engaging personnel in quality
3. Assuring upstream diagnosis of deficiencies
4. Shifting and moving away from the disciplinary action as a tool for improvement
5. Encouraging positive feedback for improvement.

Spencley et al. (2018) unraveled the first step of BiQ, "define expectations," into a framework that includes first understanding expectations, then aligning the team, agreeing on MAC, and designing capable operations before the execution of work. For this research, BBQ is defined as *a people-oriented approach toward quality delivery that highlights the role of people's behaviors in understanding, aligning, and communicating expectations, and developing operations capable of meeting such expectations*.

Some of the behaviors that Lean fosters for delivering quality are:

1. Reliable promising: Subdivided into (1) look for alignment (understand and align expectations in the form of DFOWs and MAC), and (2) execute as per the agreed expectations. Clarity of requests and commitments is key in the planning process for delivering quality scopes.
2. Respect for people: Individuals can have the confidence to talk about mistakes, prevent their reoccurrence, innovate and try new ways to make things better, and show vulnerability and clarity in their work. For quality, respect for people can be observed, for example, when people listen to others' ideas for how an operation can be executed (i.e., design of operations).
3. Pursuit of learning and continuous improvement: Consists of learning and improving current processes and performance from experiments and breakdowns. When delivering any scope, mistakes can happen, but the intent is to prevent these mistakes reoccurrence and improve the way things are done.

Foundational behaviors fostered through psychological safety for BBQ are those related to learning behaviors and speaking up. Edmondson (1999), Pearsall and Ellis (2011), and Edmondson (2018) described valuable forms of speaking up (e.g., seeking feedback, asking for help, experimenting) that would allow people to detect unexpected changes, learn and understand owner's requirements, or discover unexpected consequences of their actions. An application of these behaviors for delivering quality, is illustrated below:

1. Communicate challenges, concerns, and opportunities about a specific scope of work
2. Admit that the expectations regarding a scope go beyond the estimated budget or might make the project fall behind schedule

3. Report mistakes or rework to avoid their reoccurrence
4. Addressing employee's observations, questions, ideas, and concerns to provide clarity of the work to be performed
5. Raise concerns about conflicting expectations about a scope
6. Ask a colleague for feedback on a built product in case of doubt
7. Provide constructive feedback when expectations are not met to foster continuous learning
8. Listen to one another to understand other's expectations about a scope and show sensitivity to feelings and needs
9. Encourage others who might otherwise be uncomfortable speaking up to be part of the discussions
10. Design operations capable of achieving expectations considering that expectations need to be clear and can be achievable by craftworkers.

Crosby (1979) highlighted the need to design systems to manage quality that prevent defects. Despite the need to improve the delivery of quality, Koskela et al. (2019) described a decline in the quality movement due to apparent weakness in the theoretical and philosophical foundations of the subject. With this system, the Behavior-Based Quality System (BBQS), I aim to contribute further to those foundations of quality. Gomez et al. (2023) presented a high-level description of the BBQS features developed in this dissertation and illustrated some features in detail using a case study.

2.8 Ways to Assess the Effectiveness of Quality Implementation

The International Standard for Quality Management Systems (QMS), ISO 9001:2015, covers a variety of topics to ensure that companies consistently deliver quality products and services (Abuhav 2017). A QMS needs to be measurable to satisfy ISO 9001 standards. ISO establishes that when evaluating a QMS's effectiveness, the organization needs to define what needs to be monitored and measured, how the monitoring and evaluation process will be conducted, when it will occur, and how and when the results will be analyzed and shared. ISO 9001-2008 was heavily focused on products, whereas ISO 9001-2015 expanded its focus to products and services. ISO's measurement focus has changed toward assessing process inputs, outputs, and the information conveyed in the production process.

Common quality-related metrics in the literature are, for example, rework cost, number of inspections pass/no pass, number of items in the project's punch list (CII 1990, CII 2001, Abuhav 2017, Oakland and Marosszeky 2017, CQEC 2020). Measuring quality management effectiveness enables continuous improvement as metrics allow improvement to occur and be quantified. Measuring enables establishing a baseline of where a project or a company is in terms of quality and identifying opportunities for improvement. Metrics to assess quality can be divided into two categories, those that focus on assessing the outcomes and processes, and those that focus on assessing the current conditions versus predictors (Table 2.6). The implementation of a quality system can be assessed in terms of the effectiveness of its steps (i.e., understanding expectations, assessing success in meeting such expectations, developing operations capable of meeting them, procuring and producing them, and assessing its conformity with expectations) and the outcomes achieved through such steps.

Table 2.6: Quality-Related Metrics

Type of Quality Metric	Examples of Metrics Applied to Quality
Metrics that focus on assessing results and processes (Juran and Godfrey 1999, Gryna et al. 2005, Spear 2010).	
Outcome metrics: Show how well the project has delivered quality.	1. Rework[5], cost of redoing work 2. Delays 3. Frequency that mistakes and defects reoccur
Process metrics: Show how well the quality management processes have been implemented.	1. MAC was agreed between all the project participants needed 2. Delivered scopes are assessed to the agreed MAC
Metrics that focus on current conditions or predictions (Juran and Godfrey 1999, Toellner 2001, Loushine et al. 2006, Choudhry et al. 2007, Grabowski et al. 2007, Hinze et al. 2012).	
Lagging indicators: Linked to aspects of quality that had occurred (reactive approach that looks at past performance; respond to the question: how are things going?).	1. Rework rate 2. Lost time due to rework 3. Rework impact (severity) 4. Number of failed inspections 5. Owner's callbacks
Leading indicators: Linked to preventive actions (proactive approach that looks at possible future performance; respond to the question: what needs to be done to achieve the intended objectives).	1. Commitments kept 2. Countermeasures taken to broken promises 3. Quality of meetings

2.9 Conclusions

The following conclusions are drawn from the literature:

1. Definitions of quality in construction focus on conforming to requirements as a sign that quality is met. For that to be the case, project participants' expectations need to be included in these requirements to properly convey what needs to be done, how to do it, and how to assess that quality has been met.
2. DFOWs are a subset of requirements that need more attention to meet the intended results.

[5] Rework cost can be as high as 12% of the total project costs (Love et al. 1999) and can impact project with a delay of 9.8% from the original schedule (Dougherty et al. 2012). Even though its impact is significant, rework (and other types of waste) is not often tracked and becomes an accepted part of the construction process (Love et al. 1999, CII 2001, Ford and Sterman 2003, Formoso et al. 2011). Reasons for not tracking it vary, for example, from considering that it is unavoidable and not worth tracking, to not having a system in place track it (CII 2001) to seeing it as something that might negatively impact a company's reputation (Arditi and Gunaydin 1997).

3. All requirements, including DFOWs, need to have a clear MAC before construction starts. MAC help reduce subjectivity or bias from the project participants assessing the delivered scope.
4. Project participants may have different (1) expectations (e.g., regarding performance, usability, appearance, functionality), (2) influence on the project (e.g., financial, decision-making power), and (3) contractual relationships (e.g., direct participants such as subcontractors and indirect participants such as surrounding communities) that need to be considered when planning for BiQ.
5. The process of understanding, aligning, and communicating project participants' expectations is an ongoing work that considers that expectations are discovered at different project phases.
6. Project participants have different and sometimes competing interests, and therefore defining quality requires alignment, and once expectations are aligned, they need to be expressed in a way that builders can use them for execution. This process consists primarily of allocating time and money to objectives, the accomplishment of which is in the best interest of all project participants, even if they do not get everything they want for themselves.
7. There are two ways of doing the work and causing conformity. First, a reactive approach that consists of building and checking (IiQ). Second, a proactive approach that aims to build quality into the product (BiQ). The first one assumes that rework will just happen, and the second tries to use different strategies to reduce the probability of rejection and repair by designing the processes accordingly.
8. People behaviors play an important role in quality. Such behaviors can be influenced by their beliefs, attitudes, and intentions. Beliefs refer to how people understand the world, and it is tightly linked to presuppositions (i.e., what is assumed to be true). Attitudes refer to how people feel towards something, and these are highly influenced by people's beliefs. Intentions refer to what people aim to accomplish, and these are highly influenced by people's attitudes. Behaviors refer to what people do, and this highly impacts performance.
9. The effectiveness of a quality management system can be assessed in terms of the quality of its products and how well the system itself was implemented. Both assessments are important for continuous improvement. A project might deliver quality scopes (assessed by the outcomes metrics), yet also find opportunities for further improving the steps in its processes (assessed by process metrics).
10. Quality, lean, and psychological safety are linked if various ways. Lean principles, tools, and methods are aligned with (1) pursuing the delivery of quality products of any type, and (2) fostering psychological safety. Lean aims to deliver value and minimize waste. To deliver value, one must understand what it is for the customer (i.e., define expectations). To minimize waste, one can reduce, for example, the potential quality issues by raising concerns about parts of the work as they arise and not feeling embarrassed or intimidated about asking questions. Speaking up does not mean that everything will be perfect, but it collaborates in steering toward that objective.
11. Psychological safety can be seen as a Lean concept itself, resident in the principle of respect for people.

3. RESEARCH METHODOLOGY

This chapter presents my research methodology to design, test, and refine the Behavior-Based Quality System (BBQS) and its features to meet quality expectations.

The chapter is organized as follows. Section 3.1 introduces an overview of the design science research methodology and its artifacts. Section 3.2 summarizes the way I designed my artifact, the BBQS. Section 3.3 describes the iterative process I designed to test and refine the BBQS. Last, Section 3.4 describes how I demonstrated the utility of the BBQS.

3.1 Design Science Research

Holmström et al. (2009) contrasted two types of research approaches, explanatory research (also known as theoretical or natural sciences) and exploratory research (also known as constructive research or design science research (DSR)). On the one hand, natural science research seeks to understand a phenomenon that exists out there and seeks to develop theoretical explanations and predictions. On the other hand, DSR seeks to solve a problem through the creation of an artifact that can be evaluated for its utility and contributes to existing theory (March and Smith 1995, Simon 1996, Lukka 2003, Van Aken 2004, Hevner et al. 2004, Vaishnavi 2007, Holmström et al. 2009, Vaishnavi et al. 2014/2019).

Simon (1996 p. xii) suggested that fields such as engineering and architecture "are concerned not with the necessary but with the contingent, not with how things are but with how they might be, in short, with design." Van Aken and Romme (2012) said that DSR consists of "describing and explaining what is and designing and evaluating what can be." They highlighted DSR to be driven by field problems where there is a possibility for improvement. Since the objective of my research is exploratory in nature and involves the design, testing, refinement, and validation of a new artifact (i.e., a system to deliver quality), I use DSR as my primary methodology.

March and Smith (1995) proposed four artifacts for DSR: constructs, models, methods, and instantiations. Vaishnavi et al. (2004/2019) suggested a broader list, including novel or innovative things or processes as DSR artifacts. In addition, Van Aken and Romme (2012) introduced a more generic perspective on DSR outcomes, calling them "solution concepts," referring to solutions that can solve field problems. DSR artifacts are developed to solve specific needs. For example, contracts and procedures that create cooperative arrangements in management or drugs that treat particular illnesses (Van Aken and Romme 2012). My artifact, the BBQS, is a system for managing quality in construction projects.

Researchers use various methods under the umbrella of DSR. I used action research for testing and refining my artifact, and combined methods for data collection (Zelditch 1962, O'Donovan and McAuliffe 2020). Through this combined approach, I:

1. Collected quantifiable information through a written survey to assess my research variables.
2. Interviewed participants to gather anecdotal evidence in the form of testimonials, and gather feedback from study participants about how quality is managed on their projects.
3. Visited project sites to describe the conditions before and after implementing the BBQS.

I developed the BBQS in three phases (Figure 3.1). Each of these phases includes a series of activities described in Figure 3.2. Each of the activities described in the colored boxes is explained in designated subsections in parentheses.

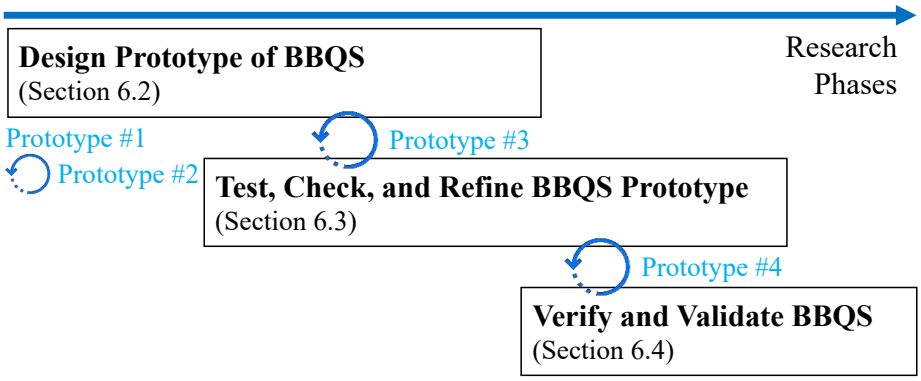


Figure 3.1: Research Phases for Developing the BBQS

3.2 Design Prototype of the BBQS

3.2.1 Conduct Literature Review

Chapter 2 presented findings from the literature to understand how quality is being managed and how it should be managed to identify areas to improve quality management in construction projects. For testing the BBQS, I also explored literature relevant to the scope of my study (e.g., drywall and framing standards and code requirements) to guide my discussions with the project teams.

3.2.2 Identify Potential Biases and Define Mitigation Strategies

Knowledge production can be influenced by factors such as the researcher's position, race, gender, and religion (Scheurich 1994), all of which may bias the researcher. For example, when interviewing, the choice of words of the interviewers (that might be based on their culture, experience, etc.) can bias respondents (Sreejesh et al. 2014) and alter the research findings. Therefore, to conduct valuable research, these biases need to be identified so that the researcher is aware of potential conflicts and plans how to deal with them (Denzin 1989). Table 3.1 describes the biases I foresaw and the corresponding mitigation strategies I took.

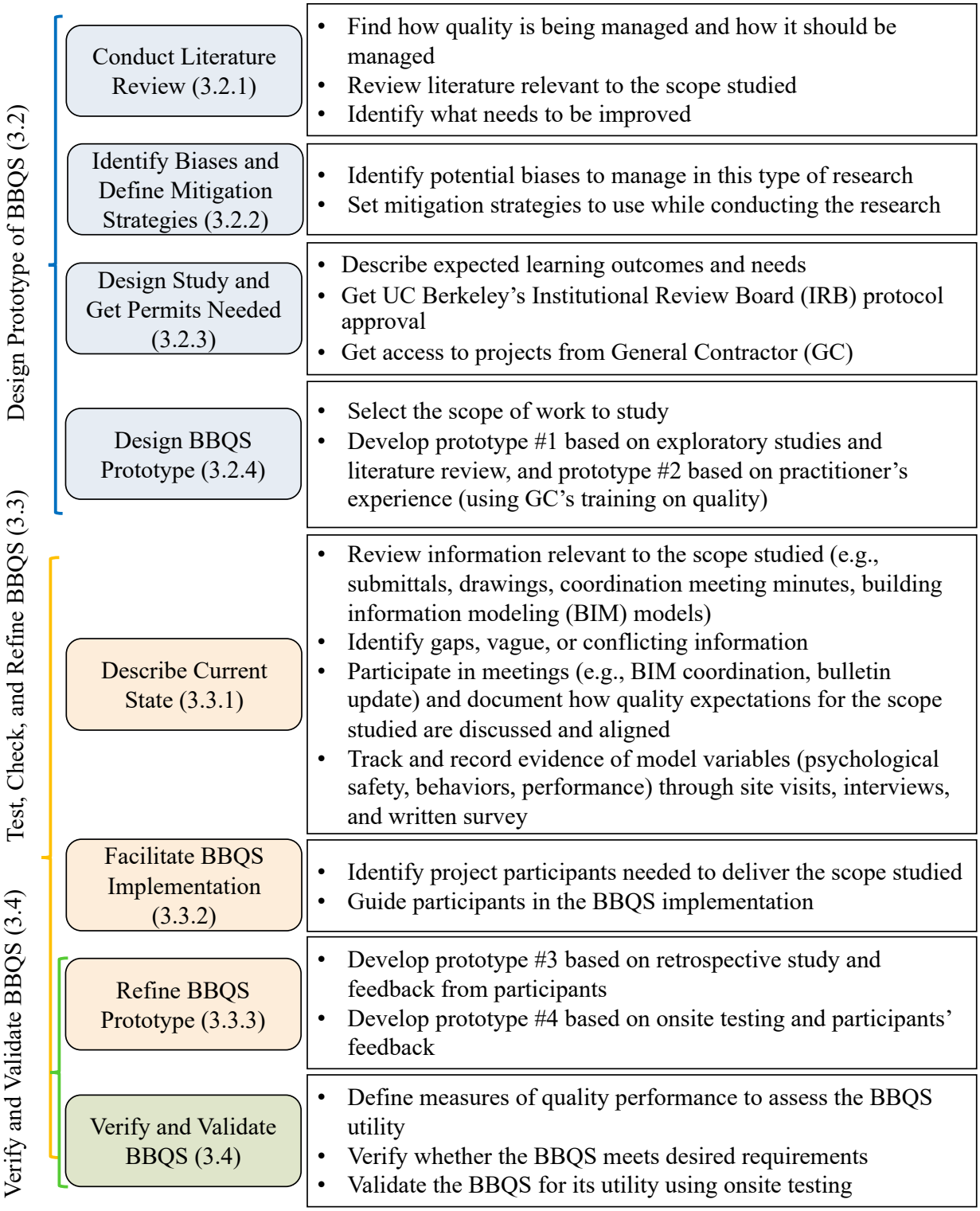


Figure 3.2: Research Activities for Developing the BBQS

Table 3.1: Potential Biases and Mitigation Strategies

Potential bias	Mitigation strategy
Design bias: incongruence between research objectives and methods (Smith and Noble 2014).	Develop a research design that adopts methods that respond to the research objectives.
Sample-size bias: preference for a larger sample size in an attempt to increase precision (Mouselli and Massoud 2018).	Use a purposive sample and include (1) at least one person from each stakeholder group for the interviews, and (2) the largest possible sample for the written surveys.
Selection bias: related to recruitment and inclusion criteria of participants in the research (Smith and Noble 2014, Sreejesh et al. 2014)	Recruit participants that meet the research objectives and have a wide range of roles and experiences in relation to the research topic.
Interviewer bias: occurs when the interviewer's behavior (verbal and non-verbal) influences how interviewees react or respond (Saunders et al. 2009, Sreejesh et al. 2014, Mouselli and Massoud 2018).	Inform participants about the study and emphasize that this is done for learning purposes and will not negatively affect their individual work. For oral interviews and written surveys, create rapport before these are conducted. For observations, conduct these in a way that does not disturb participants' work.
Confirmation or analysis bias: look for data that confirms the researcher's hypotheses (Smith and Noble 2014).	Use neutral questions to avoid leading respondents towards confirming or disconfirming hypotheses.
Interviewee or response bias: inclination to mislead researchers either through "deliberate misrepresentation" or "unconscious falsification" (Saunders et al. 2009, Sreejesh et al. 2014).	Inform that data is confidential for research purposes, and no identifiers will be linked to specific individuals. For surveys, use simple statements to minimize misinterpretation. For interviews, use open-ended questions and elicit examples and stories from the respondents to illustrate their responses.
Cultural bias: misinterpretation of responses due to cultural differences between interviewer and interviewee (Marshall and Rossman 1999).	Have data collection methods revised by advisors and practitioners collaborating in the study to check clear questions for the intended purpose.
Social desirability bias: tendency for respondents to provide answers that are socially correct or acceptable (Sreejesh et al. 2014).	Explain to the participants the importance of collecting reliable information to build the research artifact in a way that the artifact can add value and support quality delivery.

3.2.3 Study Design

Table 3.2 describes the two types of studies I conducted for testing and refining the BBQS.

Table 3.2: Case Study Details

	Project 1	Project 2
Project description	Study took place on a project about to finish construction, using a retrospective approach.	Study took place on a project under construction where I implemented the BBQS.
Objectives	To inform and refine the BBQS prototype 2.	To test, check, and refine BBQS prototype 3.
Learning Outcomes	To understand how a best-in-class project was achieved and improve the BBQS prototype 2.	To test, check, and refine BBQS prototype 3, including its features and managerial actions to foster behaviors desired for quality and psychological safety.
Data Collection Tools and Procedures	Written survey, oral interviews, and site visits. Swimlane diagram of how quality was managed to depict processes, participants, and handoffs.	Written survey, oral interviews, and site visits pre- and post-BBQS. Swimlane diagram of how quality was managed to depict processes, participants, and handoffs.

My data collection instruments were approved by the University of California Institutional Review Board (IRB) with protocols number #2019-02-11805 (for the exploratory studies) and #2022-03-15165 (for the BBQS testing studies).

3.2.4 BBQS Prototype

3.2.4.1 Select Scope of Work to Study

I selected the scope of work for this research by analyzing the advantages of studying one scope over others, lessons learned in the exploratory studies, and recommendations from practitioners. I used Choosing by Advantages (CBA) to identify which scope provided the most advantages to the study. By using CBA, I followed the steps in Suhr (1999): (1) identify alternatives, (2) define factors, (3) define must/want have criteria for each factor, (4) summarize the attributes of each alternative, (5) decide the advantage of each alternative by underlining the least-preferred attribute for each criterion and identify the advantage of each of the other attributes relative to the least preferred attribute, (6) decide the importance of each advantage based on the selected paramount advantage and the established scale of importance, (7) calculate the total importance of advantages of each alternative, and (8) make a recommendation. I chose to focus on vertical elements of drywall work (e.g., partition walls, exterior metal framing) (Appendix 2).

3.2.4.2 Design BBQS Prototype for Testing

The BBQS prototype I designed for testing includes the following elements:

1. Functions that are to be performed in sequence in the service of delivering quality.
2. Presuppositions that are the basis for the system; things assumed to be true about quality management.

3. Principles that are foundations for the BBQS and the behaviors that support it.
4. Processes that are used to perform the BBQS functions and the steps needed to produce the expected outcomes.
5. Methods and tools that are used to support the BBQS processes.

I refined this initial prototype through an iterative cycle by having project participants test it to deliver the scope selected (Section 3.3). I verified and validated my artifact based on its utility to deliver quality for this scope (Section 3.4).

The elements of the BBQS are designed from a combination of existing and new knowledge. I studied existing knowledge following the structure of the system, e.g., presuppositions relevant to quality management. New knowledge built on existing knowledge, for instance, some functions that BBQS uses have been recognized in the literature; other functions, such as "supporting consistent execution in the field" or "agreeing on methods of assessment," however, have not. I propose these as fundamental functions for delivering quality. For example, construction project specifications include a certain level of detail for the end goal of a building's element (e.g., fire rating levels for cladding materials, assembly's R-value), tests needed (e.g., sound insulation testing), and the type of material required (e.g., type X drywall for fireproofing). However, specifications such as "mirror-like" for concrete wall finishes need further clarification. Once the requirement is clarified, project participants need to determine how they will assess whether the agreed requirements are met (e.g., by looking at the wall from a certain distance at a certain angle with certain lighting). These detailed methods for assessing delivered work are part of implementing the BBQS function. For instance, inspections may fail because of a lack of alignment about how the delivered scope will be assessed (e.g., looking at a painted wall from 10 ft away and a certain height range to assess its finishes, instead of looking at the wall from 1 ft away, from where a small inconsistency might be more apparent and perceivable to the eye).

3.3 Test, Check, and Refine the BBQS: Action Research

Design processes by which DSR artifacts are developed are iterative in nature (Van Aken and Romme 2012). Action research is an appropriate method for creating DSR artifacts because it follows the Plan-Do-Check-Act (PDCA) cycle for continuous improvement (Shewhart 1939). Lewin (1946) and Somekh (2005) suggested that action research helps test and refine a concept or a process by applying a set of improvements. Baskerville (1999) proposed five phases for conducting action research. The application of these phases for the development of the BBQS is described below:

Defining the problem and its boundaries:

Explore opportunities in the literature and diagnose a problem the BBQS aims to address. First, by conducting a review of the literature (Chapter 2). Second, by studying the specifics of the scope selected and consulting trades literature and experts in the field for process steps and common quality issues.

Action planning or planning intervention:

Customize BBQS with the project participants who are involved in building the scope studied.

Action taking or conducting intervention:

Implement the BBQS for the plan selected in a real-world setting using a mixed-methods approach for data collection, including site visits, surveys, and interviews.

Evaluating outcomes and reflecting on intervention:

Assess the BBQS implementation and its outcomes through a combination of qualitative (perception-based metrics for which project participants assess the research impact) and quantitative metrics (measurable outcomes of the implementation).

Reporting findings to re-engage in future iterations:

Redirect the knowledge gained to use it as a basis for future interventions.

3.3.1 Describe Current State

I used case studies (Yin 1993) where I described how quality is managed, emphasizing the scope selected, pre- and post-BBQS implementation. I used this description, developed from site visits, interviews, and surveys, to assess the effectiveness of the system.

3.3.1.1 Study Project Documents

Delivering quality in construction projects involves information management tasks such as elaborating submittals, consulting industry standards, vendor catalogs and orders, contracts, etc. I reviewed these project documents (Table 3.3) to corroborate, refute, and expand the study findings based on project information (Frey 2018).

Table 3.3: Project Information Consulted

Information	Use to Understand
Sample of contract documents	Initial requirements (expectations) for the scopes studied and how these change by using the GC's involvement in leading the quality process.
Sample of RFI and submittals	Changes and questions posed by the GC as well as responses from designers.
Orientation and training materials that project participants received	1. Quality-related information that every project participant receives during onboarding when joining the project. 2. Quality-related training that participants have gone through to understand how quality is to be managed. 3. Training that craft received onsite to assure process capability.
Instructions craftworkers receive	Ways expectations are conveyed to craft for operations design, and later for production after operations are designed.
Sample inspection reports and project inspection statistics	1. Inspection items and details about how these will be inspected. 2. Opportunities for continuous improvement by analyzing failed inspections, and what went well through the process.

3.3.1.2 Conduct Site Visits

Lammers and Badia (2004) said that observations "involve the use of our sensory systems (including eyes and ears) to record behavior." Observations are used to gather information about behavioral patterns in the phenomenon of interest (Malhotra and Birks 2006). Table 3.4 summarizes common observation approaches described in the literature.

Table 3.4: Types of Observation Approaches

Observation Approach	Description
Reference: Lammers and Badia (2004), Sreejesh et al. (2014)	
Participant	Researcher is part of the observed environment and establishes a relationship with the research participants in their natural settings.
Nonparticipant or Direct	Researcher does not interact with those being observed, and information is gathered without the observer being noticed.
Contrived	Participants are aware they are being observed.
Reference: Malhotra and Birks (2006)	
Structured	Involves knowing what is to be observed and how to measure it.
Unstructured	Involves monitoring all aspects of the phenomenon that seem relevant to the problem at hand.
Disguised	Involves that the participants are unaware that they are being observed.
Undisguised	Involves that participants are aware that they are being observed.
Natural	Involves the observation taking place in its natural environment (e.g., at the sites where project is built) to accurately reflect the phenomenon (e.g., how construction operations are performed).
Contrived	Involves creating an artificial environment (e.g., a laboratory) to test the outcomes.

Researchers using a DSR methodology typically adopt a participant observer role because of the interventions to test and refine the artifacts developed (Van Aken and Romme 2012). I conducted site visits taking a participant role because I interacted with people onsite for the testing and refinement activities of the BBQS. Challenges I anticipated included (1) subjectivity because a single event can be "perceived differently by different people," (2) reasons for the observed behavior are difficult to determine, and (3) limitation of the observer to evaluate and mitigate their biases (Malhotra and Birks 2006). To mitigate these challenges, I used previously defined items to assess (e.g., behaviors desired for quality for the BBQS) and took notes to compare how what I observed happening onsite equals or differs from participants' responses in surveys and interviews. In addition, I used supplementary information such as excerpts of specifications or drawings relevant to the discussion, photos of what comes out as a result of the discussion that had not been previously included or clearly conveyed in the project documents, and photos of different techniques and tools used in the process of building the scope studied.

After documenting my observations, I validated these with project participants by sharing the description of my observations and making the adjustments needed considering their feedback.

3.3.1.3 Conduct In-Depth Interviews

A qualitative interview methodology is suitable for explaining why and how certain events occurred and how these influenced outcomes. Interviewing is among the most used methods in social science research (Hermanowicz 2002, DiCicco-Bloom and Crabtree 2006). Kvale (1996) said, "knowledge is understood as buried metal, and the interviewer is a miner who unearths the valuable metal." DiCicco-Bloom and Crabtree (2006) and Guion et al. (2011) highlighted that in-depth interviews aim to elicit detailed narratives and stories from relatively few people. By interviewing participants who are part of the BBQS implementation, I captured the characteristics of the BBQS with examples that illustrate its elements.

3.3.1.3.1 Participants for Interviews

Sampling methods are divided into probability and non-probability methods (Wretman 2010, Shorten and Moorley 2014, Taherdoost 2016, Engel and Schutt 2017). Probability methods consider that every unit has an equal chance of being selected. In contrast, non-probability sampling methods consider a sample chosen based on the researcher's judgment. Table 3.5 shows examples of common probability and non-probability sampling methods and describes how the sample is chosen.

Table 3.5: Probability and Non-Probability Sampling Methods

	Sampling Method	Description of How a Sample is Chosen
Probability methods	Simple random sampling	Sample is randomly selected, and it is used to represent the entire data population.
	Stratified random sampling	Sample represents members from each population's subgroup. For this, the population is divided into smaller subgroups based on common characteristics.
Non-probability sampling methods	Purposive sampling	Sample is chosen based on the judgment of the researcher.
	Snowball sampling	Sample is built by word of mouth. It starts with a few participants who the researcher invites, and then these participants invite others to also join.
	Convenience sampling	Sample is chosen based on the most easily accessible participants to include in the sample.

I selected "purposive sampling" as my sampling technique, in which the sample population is chosen based on the researcher's judgment. I aimed to capture the perspective of each project participant's group involved in the quality delivery process. However, the generalization of findings is limited (Malhotra and Birks 2006). The number of participants varied according to the project and the phase when I conducted the study. I described who participated in each project in their corresponding chapter.

3.3.1.3.2 Analyze Interview Responses

I analyzed the interview transcripts by codifying individual responses to identify patterns in the responses (Auerbach and Silverstein 2003). This coding process consists of tagging the responses

and then sorting the segments with similar content that would provide patterns, if any, in interview responses (Miller and Crabtree 1999, DiCicco-Bloom and Crabtree 2006).

3.3.1.4 Conduct Written Survey

I conducted a written survey to assess the behaviors desired for the BBQS, the team's level of psychological safety, and the team's performance in terms of quality for the scope studied. I gathered the largest possible number of participants between those who are part of building the scope selected. In analyzing the responses, I adopted the following strategies:

1. In my exploratory studies, I added reverse control questions to clean data by removing sets with responses inconsistent with specific pre-established criteria, similar to what was done in the exploratory studies.
2. In my testing case, I used Cronbach's Alpha to measure the internal consistency of the data collected. This consistency represents the reliability of the data (Cronbach 1951).

3.3.2 Facilitate BBQS Implementation

Following the action research method, I actively participated in implementing the BBQS for testing and improving the system using the scope selected. I improved my prototype by:

1. Testing the BBQS elements with the project participants who are needed in the quality delivery process and determining what elements or parts could be improved.
2. Training these project participants in the BBQS, including provoking discussions around quality for the scope studied and using their feedback to improve the system.
3. Practicing behaviors that support the BBQS to deliver quality, implementing actions to foster such behaviors, and identifying how these actions can be improved.

3.3.3 Refine BBQS Prototype

I developed the BBQS through a series of four iterations (Figure 3.3).

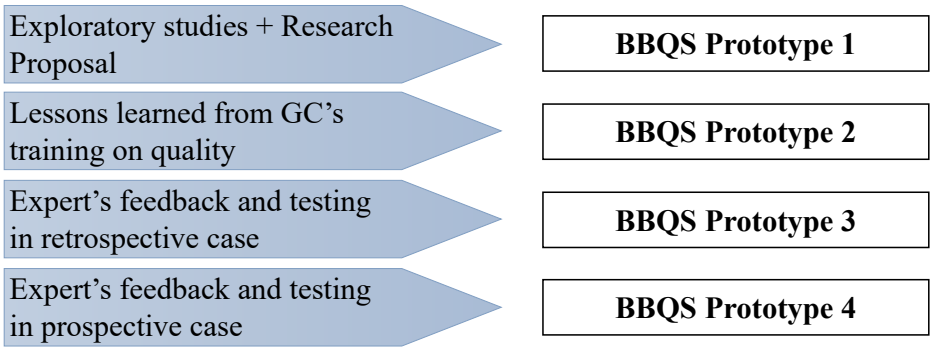


Figure 3.3: Prototyping Iterations for Developing the BBQS

I designed Prototype 1 through exploratory studies and literature review. Using Prototype 1 and lessons learned from a training program that the GC conducts on quality management, I built Prototype 2. I built Prototype 3 using a retrospective study on a project that has successfully managed quality, and the feedback from the GC building this project on Prototype 3. Last, I built Prototype 4 based on an instantiation where I applied the BBQS in a project during construction

to improve the management of quality on the project, and feedback from the GC building the project and its quality leadership team on Prototype 4.

3.4 Verify and Validate BBQS: Demonstrate Utility

The evaluation of the artifacts has been highlighted as a key piece of the process to provide DSR needed rigor for research (Hevner et al. 2004, Peffers et al. 2008). According to March and Smith (1995), evaluation refers to the "development of criteria and assessment of artifact performance against those criteria." I used verification and validation (Boehm 1981, Bahill and Henderson 2004, ISO/IEC/IEEE 2010) as procedures to evaluate if the BBQS fulfills its intended outcomes. Through verification, I evaluate whether I am building a system right, whereas, through validation, I evaluate whether I am building the right system.

3.4.1 Verify BBQS Composition and Functionality

Verification evaluates whether the BBQS meets certain design specification requirements (i.e., attributes defined for the system) (Bahill and Mandi 2017). BBQS, as other DSR artifacts, was first evaluated "on paper" by assessing these requirements, and then it was implemented in the field to validate it for its expected utility (Van Aken and Romme 2012).

Requirements can be seen as a way to predict user acceptance and adaptation (Davis 1989). I defined the requirements to evaluate the BBQS (Table 3.6) considering the customers (GCs) and my own expectations as a researcher to deliver a quality product.

Table 3.6: Verification Requirements and Procedure

Requirement	Verification Technique Description
Perceived ease of use (Davis 1989, Plaisant 2004) and clarity (Preece 2001, Eppler and Bresciani 2013)	Reviewing the BBQS with industry practitioners to verify they can understand and apply it. In addition, having one of the GC's quality corporate members inspect it to verify this requirement considering whether it has a reader-friendly structure and content, and make sure it is self-explanatory with low cognitive effort.
Perceived usefulness (Davis 1989)	Reviewing the BBQS with industry practitioners and one of the GC's quality corporate members to determine to what extent they can help users do their job better.
Adaptability (Norman 2002, Andresen and Gronau 2005)	Applying the BBQS to more than one scope with different project conditions.
Consistency (Cronbach 1951, Cortina 1993)	Using an analytic test (Cronbach's alpha) to assess the reliability of my survey, argue for compliance, and establish confidence in my data.

3.4.2 Validate BBQS for its Utility

Validation evaluates whether the BBQS meets the functionality it is intended to achieve. In this case, I validated the BBQS based on its utility (March and Smith 1995) in a real-life setting. The utility of the BBQS is to deliver quality in construction projects significantly better than current BiQ and IiQ approaches, described in the literature. Its utility can be demonstrated by analyzing its pragmatic validity, which requires implementing it in the real world and evaluating its outcomes (Worren et al. 2002). Different evaluation methods have been proposed for DSR artifacts, from action research to case studies to optimization to controlled experiments, to expert evaluation, etc. (Hevner et al. 2004, Vaishnavi 2007, Holmström et al. 2009, Peffers et al. 2012).

I chose action research to design and evaluate BBQS in iterative cycles. I demonstrate pragmatic validity in action research by comparing how well quality is managed when implementing the BBQS versus when not. I used a combination of process and outcome metrics (Table 3.7) to assess the BBQS utility.

Table 3.7: Metrics to Validate the BBQS

Metric		Description
Process Metrics		
	Engagement of project participants	Were all the project participants needed engaged in the conversations about quality for the scope studied?
	Behaviors in the system	What is the impact of the behaviors desired for delivering quality?
Outcome Metrics		
	Psychological safety, behaviors for quality, and performance	Perception-based metric to assess the study variables using a pre-defined data collection tool.
	Number of quality issues identified at the different tiers of quality control (Figure 3.4)	Timing when issues are identified. Tiers numbering may change as not all projects have the same participants involved, but the logic is maintained from bottom to top (the lower the number, the closer the participant is to the work being installed).
	Distribution of quality issues documented in rolling completion list (RCL) items by tier of quality control	RCL list quality issues typically identified by various parties. The number of items in the RCL provides an idea of the number of quality issues but is not a complete representation of it since some issues may be just verbally communicated to the person who needs to fix them but may not be added to the list.

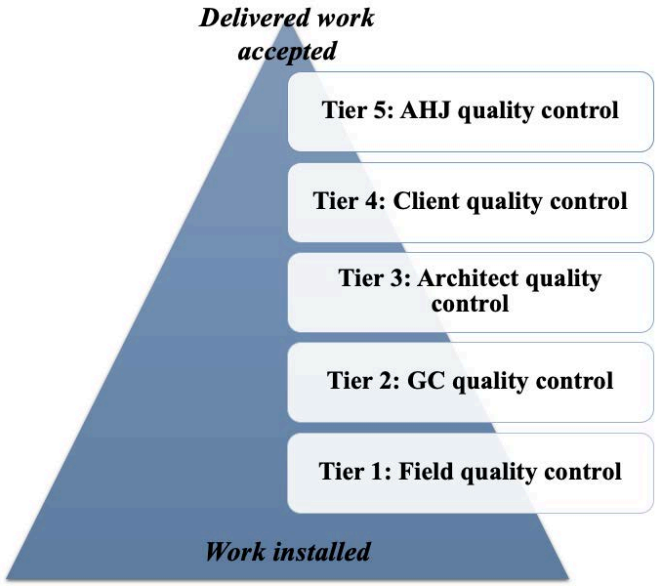


Figure 3.4: Tiers of Quality Control

In my findings in the following chapters, I describe how some metrics in Table 3.7 correlate.

4. EXPLORATORY STUDY ON PSYCHOLOGICAL SAFETY

This chapter presents the findings of a study I conducted to explore the psychological safety construct and its connection to learning behaviors in two University of California San Francisco (UCSF) construction projects. The UCSF operations leadership encouraged two of the GCs working with them to participate in the study to measure this construct and implement managerial actions to foster it within their project teams.

The chapter is organized as follows. Section 4.1 introduces the projects background. Section 4.2 describes the methods used to analyze the study data. Section 4.3 summarizes some of the projects' standards practices and GC's efforts connected to psychological safety. Section 4.4 describes the team psychological safety, learning behaviors, and its connection. Section 4.5 summarizes suggestions to foster psychological safety. Section 4.6 presents the managerial actions the teams implemented in their projects as part of this study. Section 4.7 presents a discussion of the findings. Last, Section 4.8 concludes this chapter.

4.1 Projects Background

The two projects I studied are:

1. **UCSF Block 23A:** A 154,000 square feet lab research building that features three levels of patient treatment clinics, two levels of wet and dry research space, and a vivarium.
2. **UCSF Block 33:** A 359,703 square feet lab research building that features teaching, research, conference, and administrative spaces.

Although UCSF is a public entity, because of its connection to Lean construction and the support of its operations team, the contract with both projects was designed as a hybrid contract. The contracts used a guarantee maximum price (GMP) while fostering an integrated team approach having all stakeholders working from a big room.

4.2 Methods

I used a combination of quantitative and qualitative methods to assess the team psychological safety and test managerial actions to foster its improvement. My primary contacts in both projects were the safety managers.

The study involved four phases of data collection. First, I visited the site and participated in project meetings to become familiar with the team. Second, I designed and administered a survey to assess psychological safety and learning behaviors. Third, in collaboration with the study participants, I designed managerial actions to foster psychological safety. Fourth, I re-assessed the team psychological safety and learning behaviors.

4.2.1 Site Visits

I visited both projects from August 2018 to December 2019. During these visits, I documented some of the projects' practices that were relevant to psychological safety. In the following sections, I discuss how these practices may relate to the survey results.

Once I presented the initial survey results to the project teams, and we aligned on what managerial actions we wanted to implement in each site, I continued visiting the project sites to implement such actions, and re-administered the survey at the end of the study.

4.2.2 Survey

In 2018, when I joined the Construction Safety Research Group, Dr. Ballard and I designed a survey to measure psychological safety and learning behaviors (Appendix 3) in construction projects based on our understanding of the construct and how it was measured in other industries.

I invited the projects' staff and craft to participate in the survey in four rounds. Table 4.1 describes the participation rate per round. Considering all rounds, 169 participants took the survey (Appendix 4), with a 73% response rate, including 17 staff and 152 craftworkers. The survey included 13 numerical questions that used a 7-point Likert-type scale, 1 reverse numerical question, 3 yes/no questions, and 3 open-ended questions.

Table 4.1: Participants' Description of Psychological Safety Exploratory Study

	Round 1	**Round 2**	**Round 3**	**Round 4**
Project	Block 33	Block 33	Block 33	Block 23A
Participants Population	Craft	Craft supervisors	Craft	Staff
Number of Participants	64	11	77	17
Participation Rate	64%	100%	77%	85%
Date	Jan 2019	Mar 2019	Jun 2019	Aug 2019

I intended to establish a level of trust between myself and the study participants through continuous interaction in the field. Before administering the surveys, I explained to the participants the study's purpose and the benefits expected from their collaboration for themselves and the overall construction community. I communicated the purpose through group and one-on-one conversations. In addition to sharing the importance of the study and encouraging them to respond to the questions honestly, I included one reverse question in the survey to identify when respondents may have answered carelessly.

4.2.2.1 Survey Processing

Using the reverse question, I defined the pair of responses that might indicate attempts to say what they think is wanted (Table 4.2) to remove the noise in my data. If a respondent had any of these pairs in their response, I removed such responses for the analysis I present in the following sections.

Table 4.2: Pair of Numerical Responses Removed

Question 2	7	7	7	6	6	6	5	5	3	3	2	2	2	1	1	1
Question 11	7	6	5	7	6	5	7	6	1	2	1	2	3	1	2	3

From the 169 responses, I removed 48 responses with these pair criteria, leaving a total of 121 responses for my analysis. Figure 4.1 shows the correlations of the numerical questions responses before the removal of noisy data. Figure 4.2 shows the correlations after the removal of noisy data. After removing noise, Q2 and Q11 show the expected negative correlation of a reverse question.

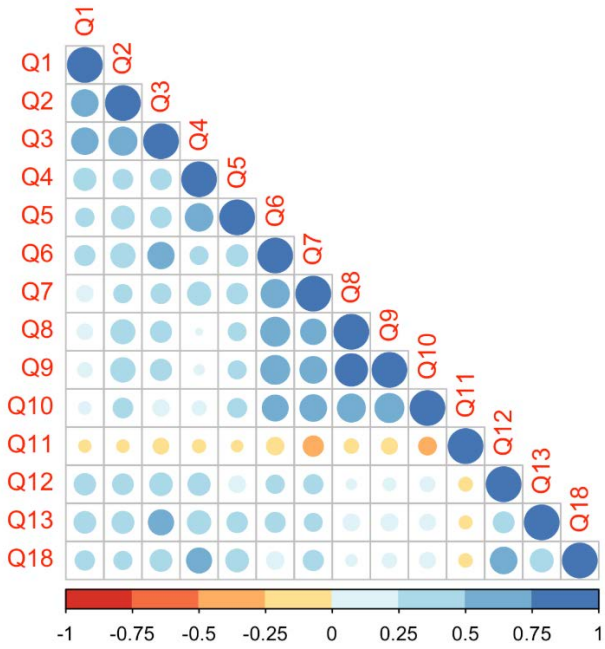


Figure 4.1: Survey Responses Correlation Among Questions Prior to Removing Noise

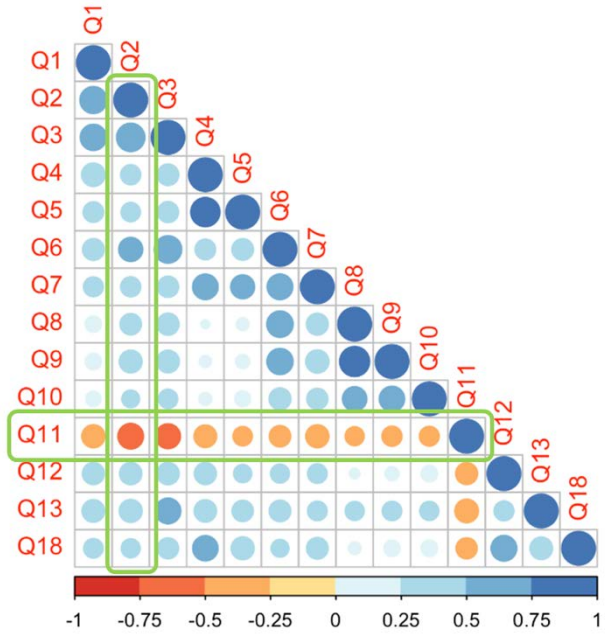


Figure 4.2: Survey Responses Correlation Among Questions After Removing Noise

4.2.2.2 Survey Measures

Using the numerical questions, I defined the following scores:

Learning behaviors score = mean (Q1, Q2, Q3, Q6)

Psychological safety score = mean (Q4, Q5, Q7, Q8, Q9, Q12, Q13, Q18)

The output of each of these scores is a numerical value between 1 and 7 for each of the respondents, where 1 is representative of "very rare occurrence of learning behaviors" and "very low psychological safety" respectively, and 7 is representative of "very common occurrence of learning behaviors" and "high psychological safety" respectively.

4.3 Projects' Standard Practices and GCs' Efforts to Foster Psychological Safety Before Study

4.3.1 Projects' Practices

The GCs building Block 23A and Block 33 had some standard practices in place before I conducted the study. The extent to which each led these practices varies slightly in terms of implementation. I describe these practices and how they may influence the team psychological safety below:

1. **Onboarding orientation:** Designed for both staff and craft personnel. During the onboarding, the safety manager introduced (1) general information about the client, (2) the project scope, (3) Lean fundamentals that the team aimed to foster, such as respect for people and 5S, (4) site-specific hazards associated with the work, and (5) examples of how others speaking up helped the team and did not lead to negative consequences for the person speaking up, which can foster psychological safety.
2. **Near miss and incident reporting:** Designed for both staff and craft. This practice consisted in encouraging and incentivizing the reporting of near misses or incidents onsite. The purpose was not only to record what happened but avoid its recurrence. Figure 4.3 is a poster excerpt displayed at Block 33, showing what the team considers a near miss and an incident, and some examples of each. The message of this poster was positively reinforced by the safety manager, who often encouraged team members to speak up, assuring them that reporting would not result in negative consequences but rather create learning opportunities.

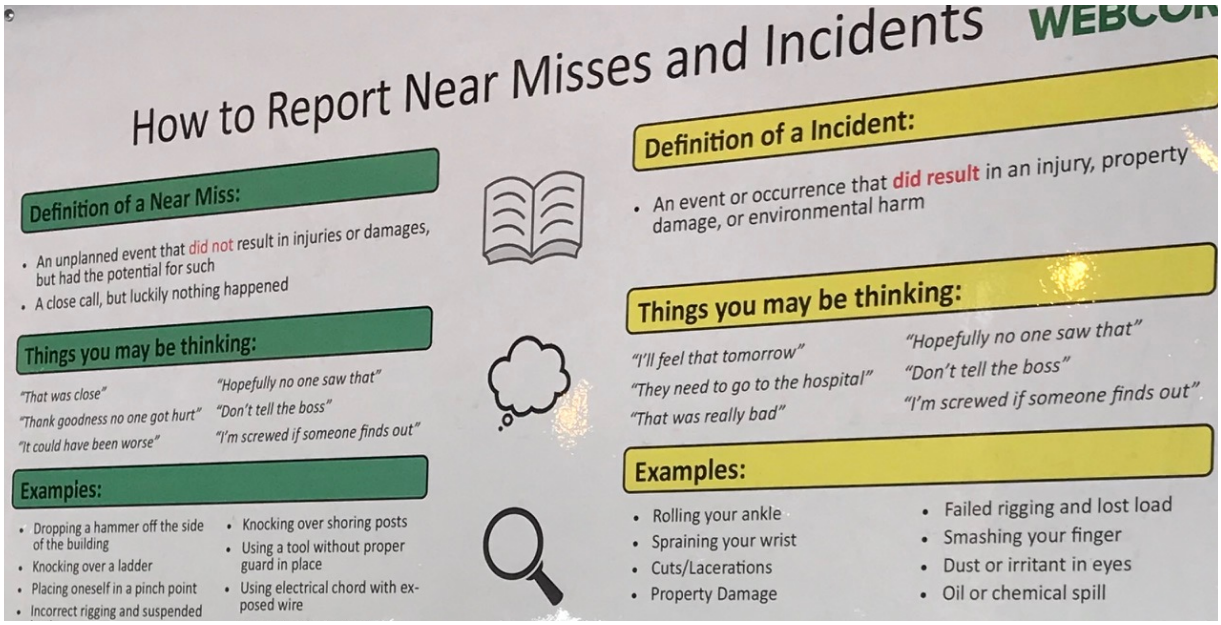


Figure 4.3: Excerpt of Near Misses and Incidents Reporting Poster (Photo: © Sulyn Gomez, 2018-08-15)

3. **All-hands weekly meetings and stretch and flex:** Designed for both staff and craft. During these 1-hr meetings, the GCs' safety manager or Pes shared the major activities and changes happening on the project during that week, lessons learned and near misses reported during the week, and stretching for a few minutes before starting their work for the day. An executive decision of the GC building Block 33 included a modification on the occurrence and format of these meetings. The new format started in May 2019 and consisted of each contractor hosting their own small weekly group meetings. I describe in later sections some of the consequences of this directive on the project team dynamics. This practice allowed everyone on site to learn of examples in which people speaking up and reporting incidents led to the project learning and did not carry negative consequences for the person who spoke up. It also allowed them to be up to date about events occurring on the project and increased people's awareness of their surroundings.
4. **Visual management and signage:** This practice was designed to facilitate the communication of relevant information. For instance, the team used visuals to communicate the project layout and show the tower crane, access gates, evacuation zones, etc. Other visuals serve to alert people about hazards in the work areas (e.g., areas below overhead work delineated with hard barricades or danger tape). Visuals can foster psychological safety, from simple messages such as "We value your opinion, help us improve" to pictures displaying unity and teamwork among peers and workers and their supervisors.
5. **Clean as you go:** This practice consisted of encouraging all contractors to clean their work area before moving to another area. The teams expected that by maintaining clean work areas, they would have a more productive and safer work environment. Although both projects encouraged this practice, in my site visits, I found that one of them did better at enforcing it than the other. Cleaning the area once the work is completed is a sample of respect for others; showing respect for others is a way to foster psychological safety.

6. **Nothing hits the ground:** This practice consisted of having all materials on wheels or pallets so these can be easily moved from one place to another (Figure 4.4). This practice intends to facilitate the transportation of materials so that workers do not have to carry heavy materials by hand for long distances. It is a way to show appreciation for workers by easing a task that would otherwise be very tedious and exhausting. Showing care for others is also another way to increase psychological safety.

Figure 4.4: Drywall Studs on Wheels for Easy Transport (Photo: © Sulyn Gomez, 2019-04-24)

7. **Right to stop work and speak up for safety:** Designed for both staff and craft. This practice was communicated in the onboarding session to all workers. This practice encouraged workers that if they see an unsafe act being performed, they have the right to speak up, stop the work, and talk to the worker or their supervisor. While this practice requires some level of psychological safety for the person to speak up, it also fosters it by making it explicit that it is Ok to say something, especially when someone is at risk.
8. **Pre-task plans (PTP):** Designed for craft. This practice allows the person building to assess the potential risks of the work that is to be performed and plan how to perform the task safely. While an important practice, in my site visits, I observed some inconsistencies in how some workers filled out the PTP. Some included detailed information about the task and associated risks, while others included only a high-level description of the task. Filling out this form helps a worker analyze the hazards associated with the task. By doing so, this person is more aware of such hazards and may be more prone to speaking up when seeing someone doing something unsafe.
9. **Right to know the area:** Designed for craft. This practice consisted in having a designated space where workers' rights (e.g., OSHA posters, workers' rights mandated under the law, wage requirement) were displayed. The information shared on this wall was posted in English and Spanish. Implementing an area to help workers be informed of their right help increase the feeling of care from staff to craft, fostering psychological safety.
10. **Personal Protective Equipment (PPE):** Designed for both staff and craft. This practice, guided by laws in the USA, consisted of enforcing every person on site to comply with PPE requirements according to their work. At a minimum, required PPEs include a hard hat, safety vest, safety glasses, work boots, pants, gloves, and shirt with sleeves. Considering the inherent hazards associated with construction activities, having all people

wear equipment for their protection gives them a sense of being taken care of and appreciated, which ties to fostering psychological safety.

4.3.2 GCs' Efforts

The GCs, independently, had each launched an effort (Table 4.3) to assess their project's culture and identify opportunities for improvement.

Table 4.3: Summary of GC's Efforts to Assess and Improve Project's Culture

Effort	Highlights and Possible Connections to Psychological Safety
Block 23A's GC: Craft Engagement Survey *Measured internally for the 1st time when the study took place in 2018 with 2,500 participants in the central region. The GC planned to survey other regions in the future.	Measures craft engagement with an intent to identify opportunities to foster craft engagement and participation in the project activities. Opportunities for improvement from this survey outcome that the GC may explore can foster psychological safety in the following ways: 1. Use a language craft speak: The study identified that around 90% of people in the offices speak English, while 90% of craftworkers speak Spanish. Communicating with craft in a language they can really understand can help. 2. Recognize and help them keep growing: Craft reported they want to be seen, included, respected, appreciated, and trained. They play a key role in the successful execution of projects, and they want to feel valued as such. Showing appreciation for their work is a way of acting caring, which can increase psychological safety.
Block 33's GC: Safety Culture Survey *Measured by an external consultant, Safety Performance Solutions (SPS), every 2 years since 2014 – last assessment conducted in 2018 with 1,007 respondents (250 craft and 757 staff)	Measures safety culture as a result of four elements; (1) safety is held as a value by all employees, (2) each person is responsible for their own safety and others' safety, (3) each person is willing to do "beyond the call of duty" on behalf of safety, and (4) everyone actively cares for others (SPS 2015). Considering these elements, SPS suggested opportunities for improvement to the GC. Some of these opportunities could foster psychological safety in the following ways: 1. Combat the perception that "schedule is king" and design a system to encourage feedback: Building psychological safety requires the space and time for people to speak up and communicate requests, questions, and concerns without fearing consequences. 2. Enhance project staff involvement in the field: Working on closing the gap staff-craft can positively impact psychological safety by strengthening staff-craft relationships and breaking down silos. 3. Recognize desired behaviors: Personal recognition or reward can reinforce the message that the team values the individual and appreciates his contribution to the project, encouraging them to participate actively in speaking up.

4.4 Team Psychological Safety – Learning Behaviors

4.4.1 Team Psychological Safety

I reported the team psychological safety score for each round of analysis in Table 4.4 using a 1-7 score where 1 and 7 represented a low and high psychological safety environment, respectively:

Table 4.4: Psychological Safety per Round

	Round 1 (Craft)	**Round 2 (Craft Super.)**	**Round 3 (Craft)**	**Round 4 (Staff)**
Psychological Safety Score	6.145	6.376	6.034	6.326
Std. Dv.	0.756	0.511	0.745	0.472

My takeaways per round, from the survey, interviews, and my observations, are:

Round 1 (Figure 4.5):

1. Craft were more willing to speak up within their own crews rather than with other companies, even when they saw the other person doing something unsafe. The team had an opportunity for improvement by increasing familiarity among subcontractor workers so that they feel more confident to speak up whether they work together or not.
2. Craft felt they were not as engaged during the operations design (how work is to be built). Supervisors could start engaging their crews more in operations design, helping them be more aware of the hazards and quality expectations for such tasks.

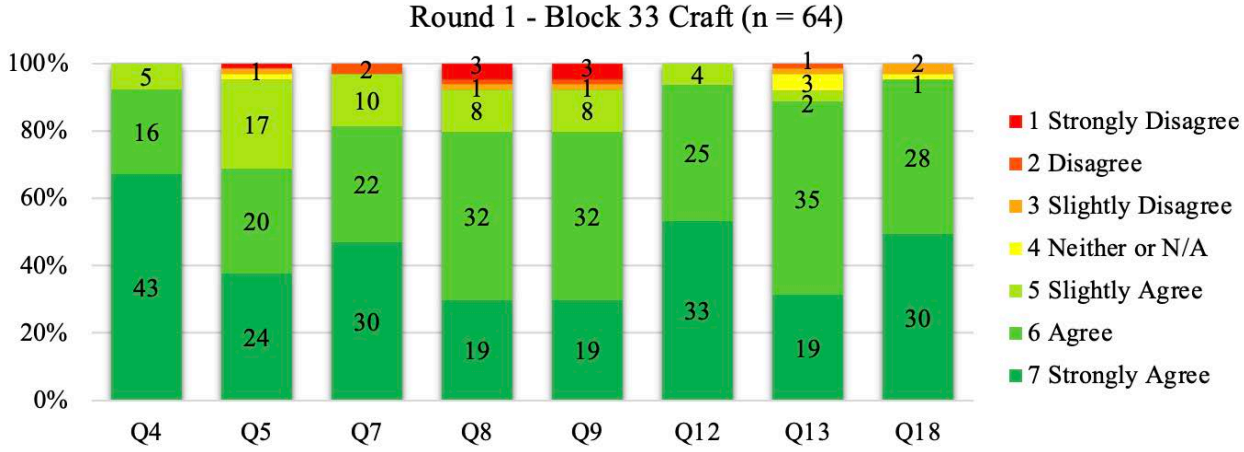


Figure 4.5: Count of Participants' Scores per Question in Round 1

Round 2 (Figure 4.6):

1. Craft supervisors scored slightly higher than craft in psychological safety. However, the same tendency observed in craft of the willingness to speak up among their own crews rather than with others is also observed among supervisors.
2. Craft supervisors reported more confidence than craft when having to reach out to their supervisors to share their ideas or raise concerns.

3. Craft supervisors actively participate in designing how the work is to be done. Around 70% of supervisors rated 7 points to the statement, "I participate in designing the operations of the activities I am going to execute onsite and I feel safe about how we execute them." In comparison, only 30% of craft rated 7 in this question in Round 1.

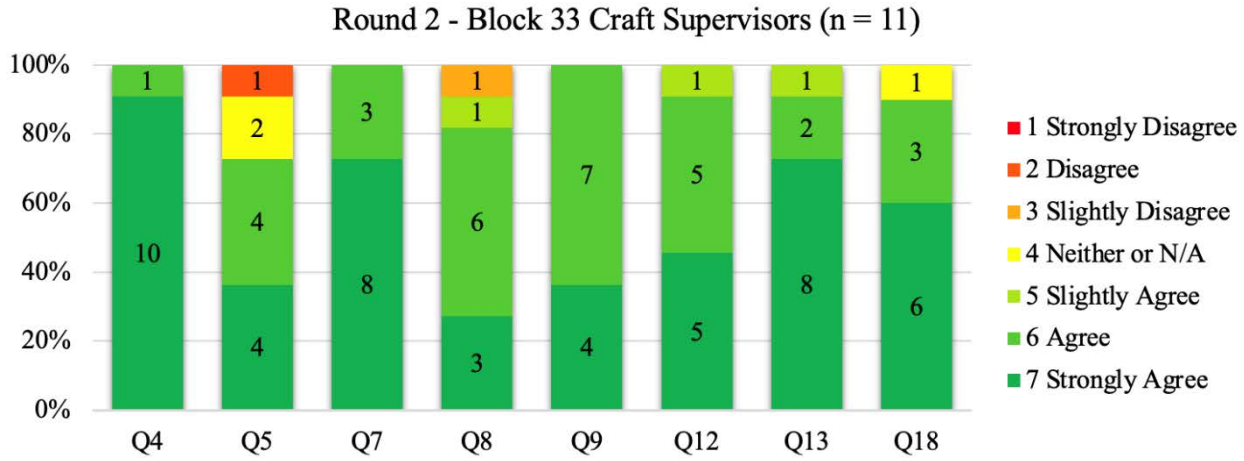


Figure 4.6: Count of Participants' Scores per Question in Round 2

Round 3 (Figure 4.7):

1. Although the overall psychological safety score for Round 3 is slightly lower than Round 1, I identified that the areas that have shown improvement relate to the managerial actions the project team and I implemented (Section 4.5) after analyzing Round 1 results. From my interviews with craft, this decrease may be tied to one significant change directive in the all-hand meetings that occurred when the study started. Because the number of craft peaked at some point in the project, the staff leadership decided that instead of having one all-hand meeting, each subcontractor was responsible for holding their own small all-hand meetings. This motive was not communicated to craft, who felt that the group meetings were just canceled from one week to the other, and they were no longer informed of the key things happening during that week. The large group all-hands meetings were a space where lessons learned (mistakes and near misses) were shared, encouraging people to speak up. I participated in a number of small all-hands for different trades I randomly selected and observed that the quality of the conversation content significantly decreased.
2. Craft reported a more balanced willingness to speak up within and outside their crews, especially if they observe someone in a hazardous situation.
3. Craft reported a better relationship with their supervisors than that in Round 1. More people felt that their supervisors were willing to listen to their ideas, and they were comfortable talking to them about their concerns.

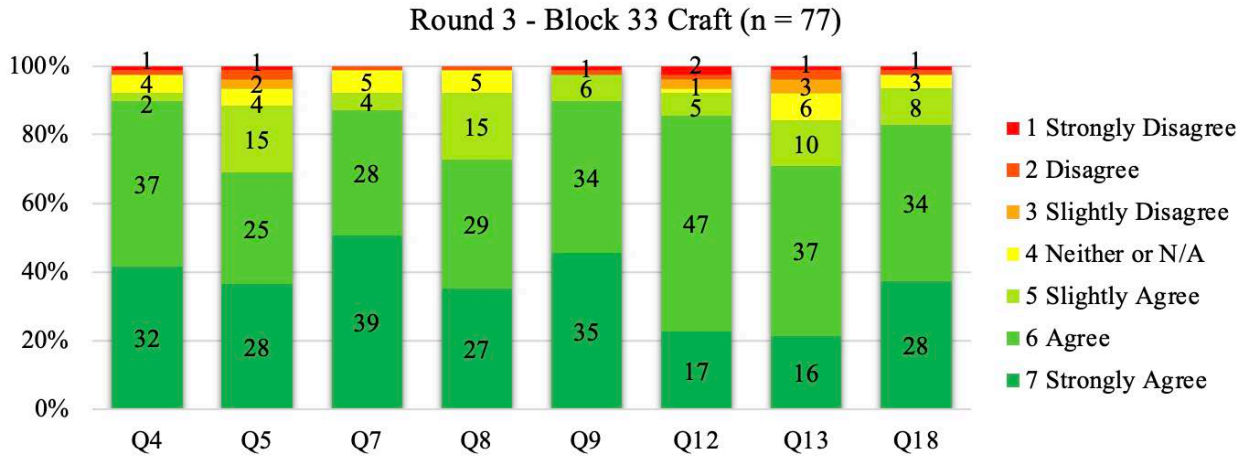


Figure 4.7: Count of Participants' Scores per Question in Round 3

Round 4 (Figure 4.8):

1. Staff scored slightly higher than craft in almost all psychological safety questions, supporting my observations and conversations with both staff and craft participants that suggested staff felt safer to speak up and bring up concerns while craft felt more constrained to accepting directives from staff.
2. A similar tendency to that of the craft group in Round 1 occurred; staff was more willing to speak up within their crews (which, in this case, it would include the members of their company assigned to this project), rather than with other crews (other companies), even though they all work together in the same project.

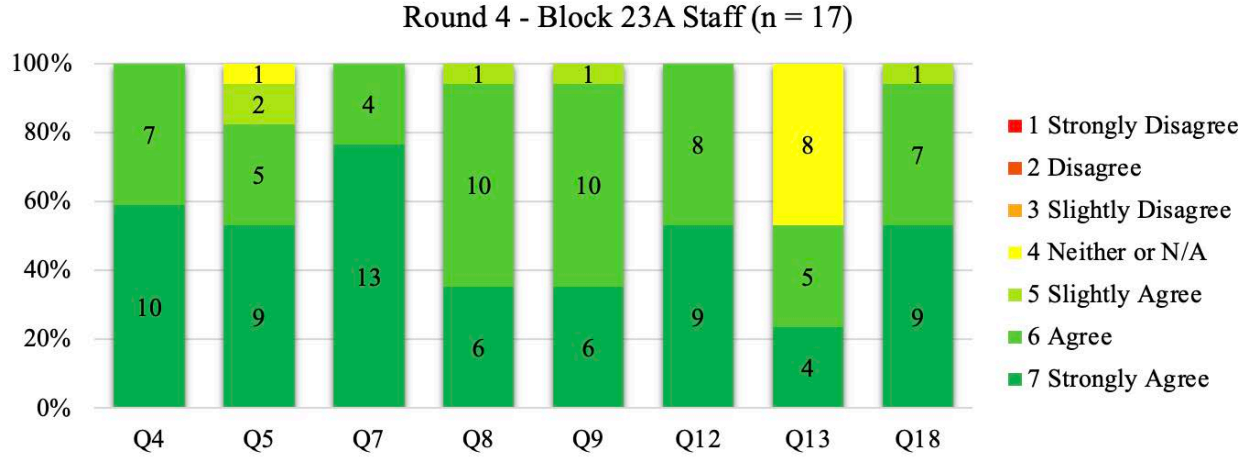


Figure 4.8: Count of Participants' Scores per Question in Round 4

I analyzed the responses of the four rounds together to explore the trends in my sample. I summarize the trends I identified in the following subsections.

4.4.1.1 Psychological Safety by Organization Type

In this exploratory study, I included the GC and subcontractors only. Typically, the GCs select the subcontractors who work on the project, so I analyzed psychological safety divided into these

categories. Figure 4.9 shows the score distribution. The areas where the vertical axes are broader represent where the number of data points is denser (i.e., where most responses fall). Psychological safety in the GC group has less variance than in the subcontractor's group; this can be explained by the various subcontractors who participated in the study compared to only one GC.

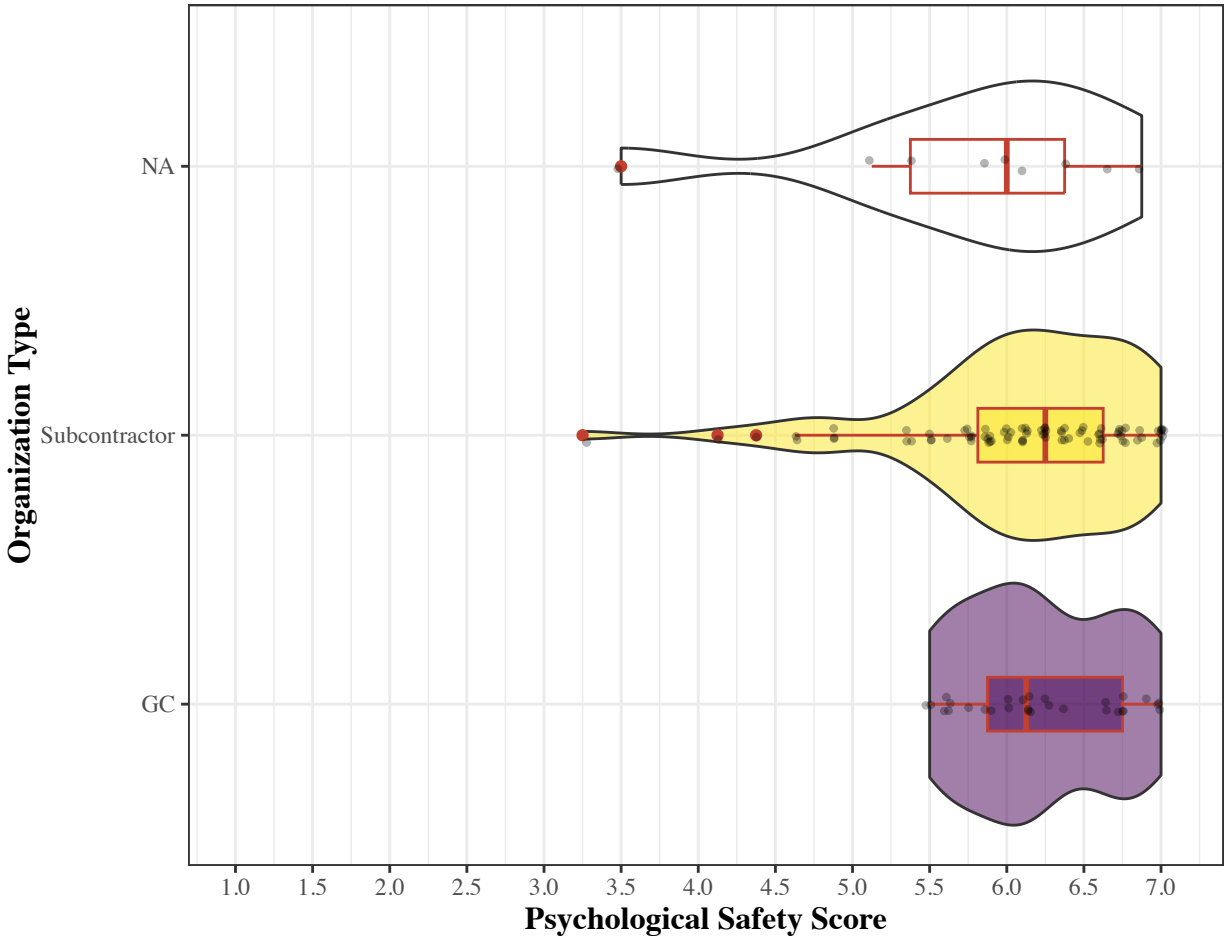


Figure 4.9: Psychological Safety Score by Organization Type

4.4.1.2 Psychological Safety by Trade

Because of the number of trades participating in the study (Figure 4.10) and the small sample, I did not observe solid trends for psychological safety per trade. Some trades have more variance than others (e.g., carpenters), but it may also result from the low number of participants per trade in the study.

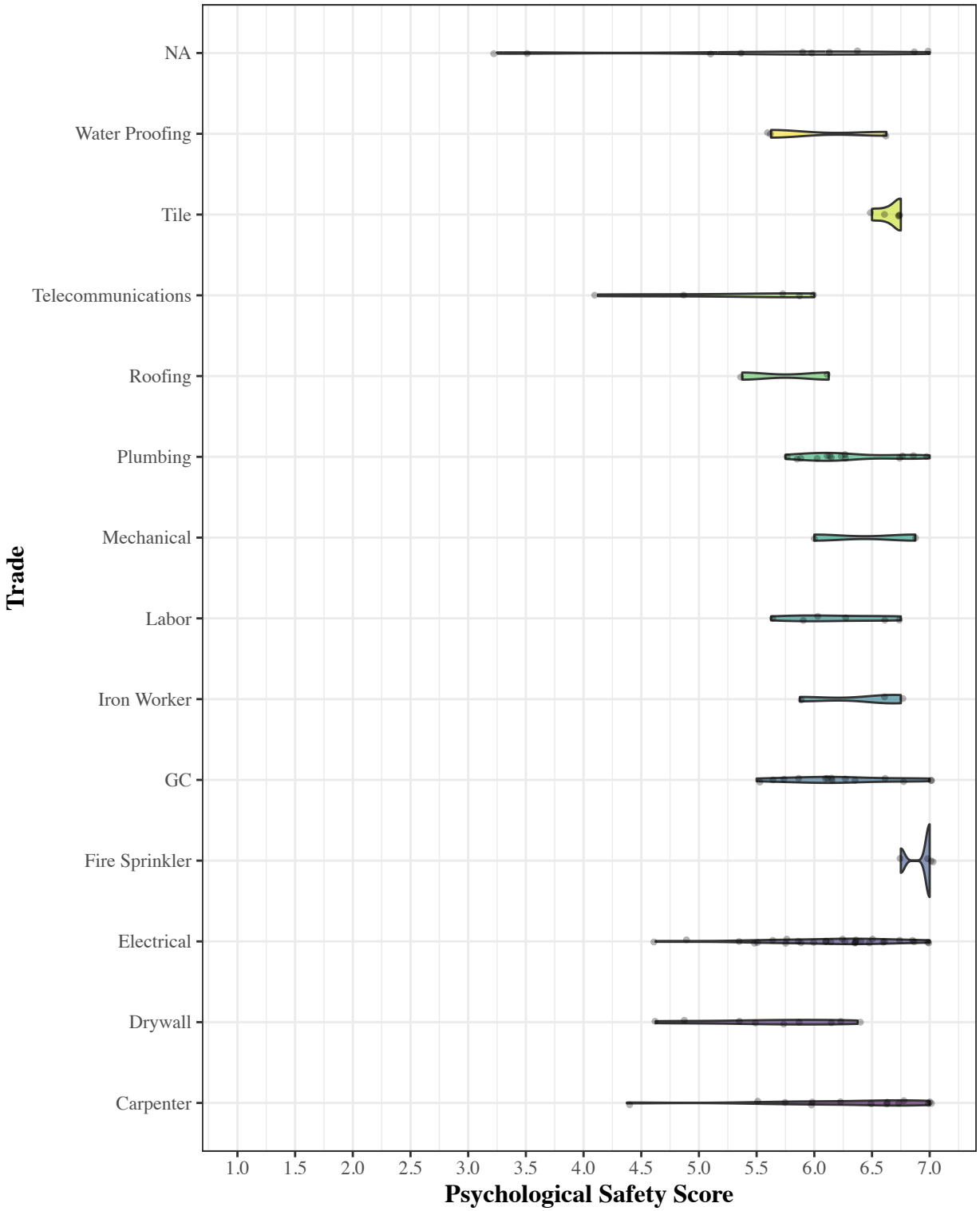


Figure 4.10: Psychological Safety Score by Trade

4.4.1.3 Psychological Safety by Time in Project

From Figure 4.11, I observed that the newest team members had less variance in their responses, causing the distribution to be narrow. The longer they spent on the project and became familiar with the project dynamics (i.e., how other team members behave in the project), the more this distribution expanded. While some felt psychologically safer after spending time with the project team, others felt more unsafe. On average, however, the mean shifted right, meaning higher psychological safety.

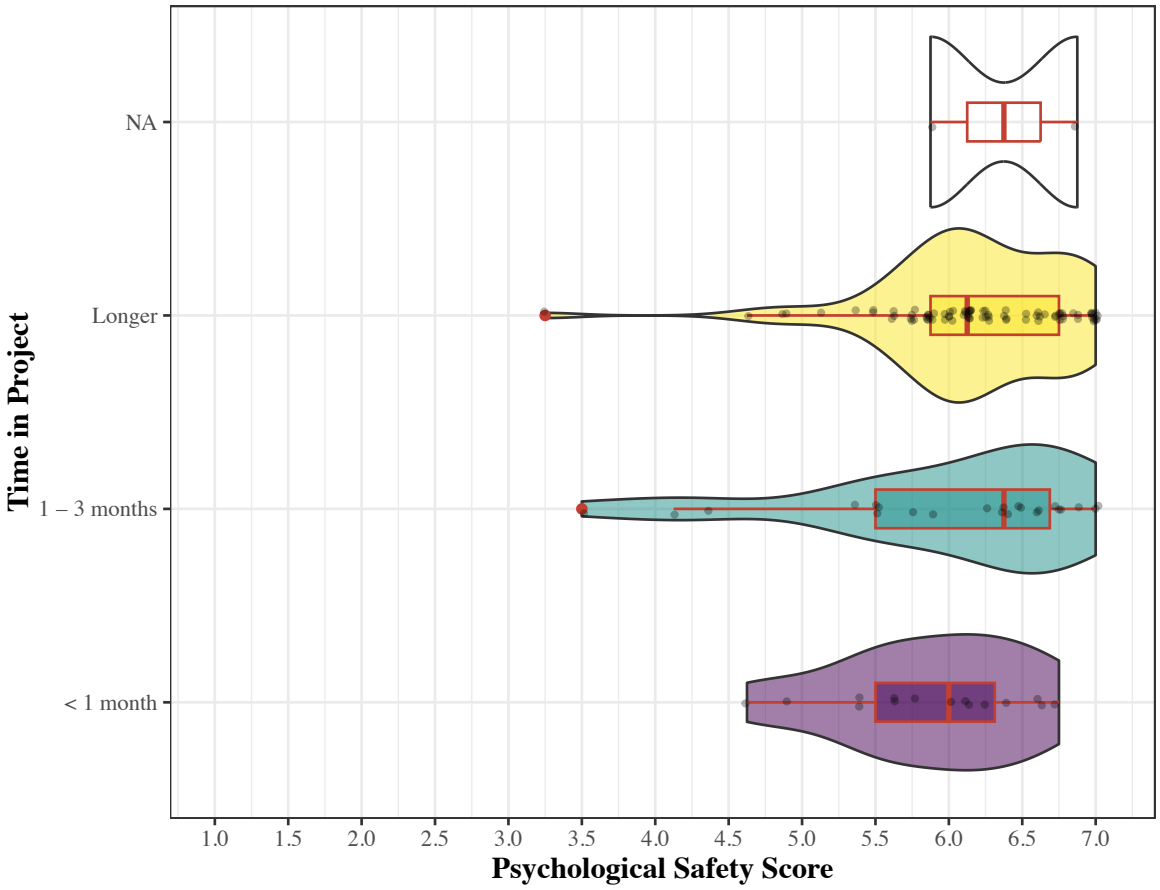


Figure 4.11: Psychological Safety Score per Time in Project

4.4.1.4 Psychological Safety by Position

Figure 4.12 shows the psychological safety score distribution by position. Staff participants (e.g., PMs, PEs) have less variation and higher psychological safety than craft (e.g., journeyman, apprentice).

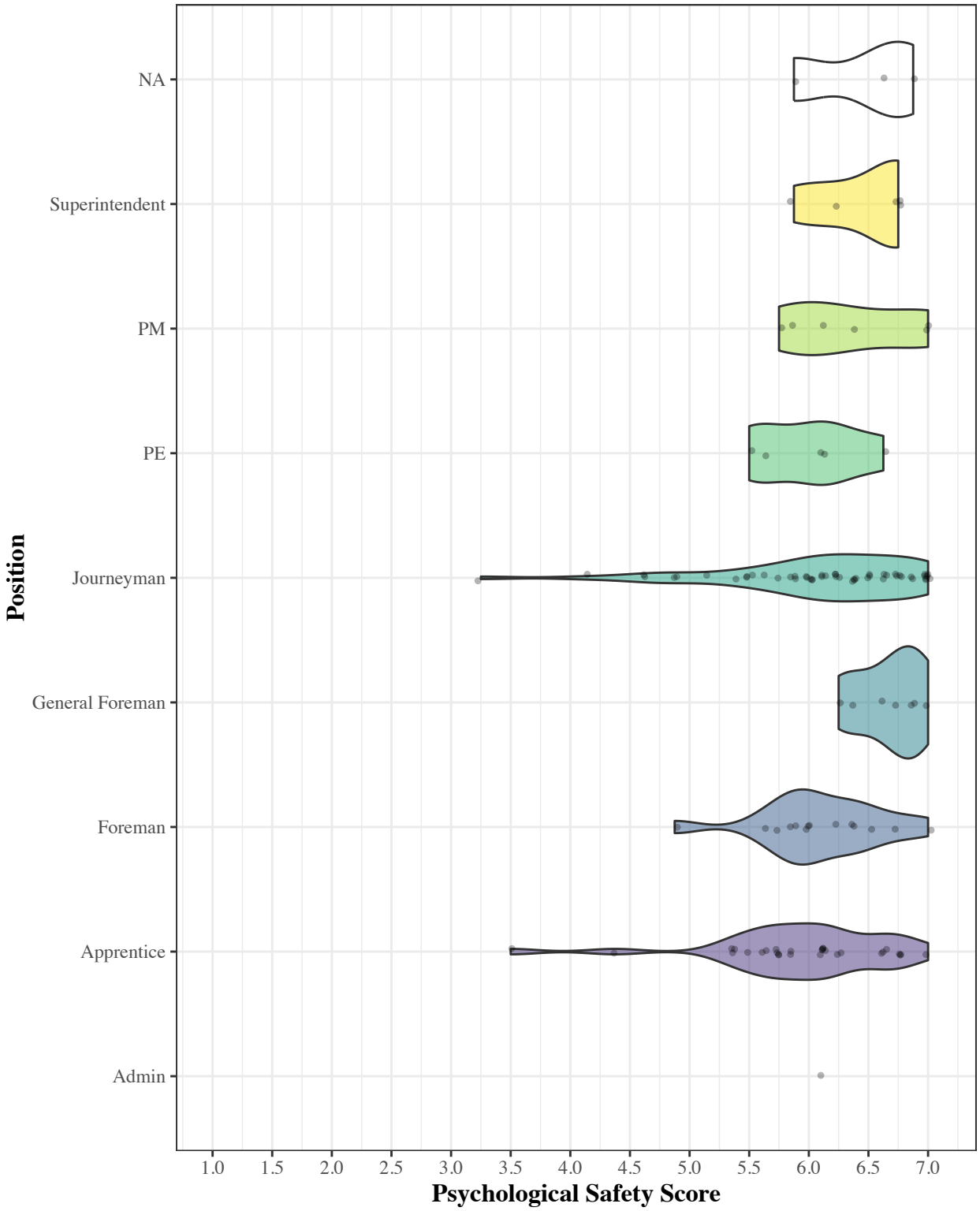


Figure 4.12: Psychological Safety Score by Position

4.4.2 Team Learning Behaviors

Table 4.5 shows the project's team learning score for each round of analysis in a 1-7 score where 1 and 7 represented an environment where the team could learn very little or very much, respectively:

Table 4.5: Learning Score per Round

	Round 1 (Craft)	Round 2 (Craft Super.)	Round 3 (Craft)	Round 4 (Staff)
Psychological Safety Score	6.121	6.333	5.863	6.279
Std. Dv.	0.712	0.533	1.051	0.506

Literature describes a strong relationship between psychological safety and learning. In the next section, I explore this connection in construction teams.

4.4.3 Psychological Safety – Learning Relationship

I identified a correlation of 0.60 between psychological safety and learning behaviors. From my observations in the field and interviews with study participants, as shown in Figure 4.13, the less interpersonal-risk they perceive in the work environment (e.g., not thinking they would get fired for raising a concern), the more prone they are to speak up (e.g., report mistakes or near misses), and the more the teams can learn (e.g., know what went wrong and plan to prevent it in the future).

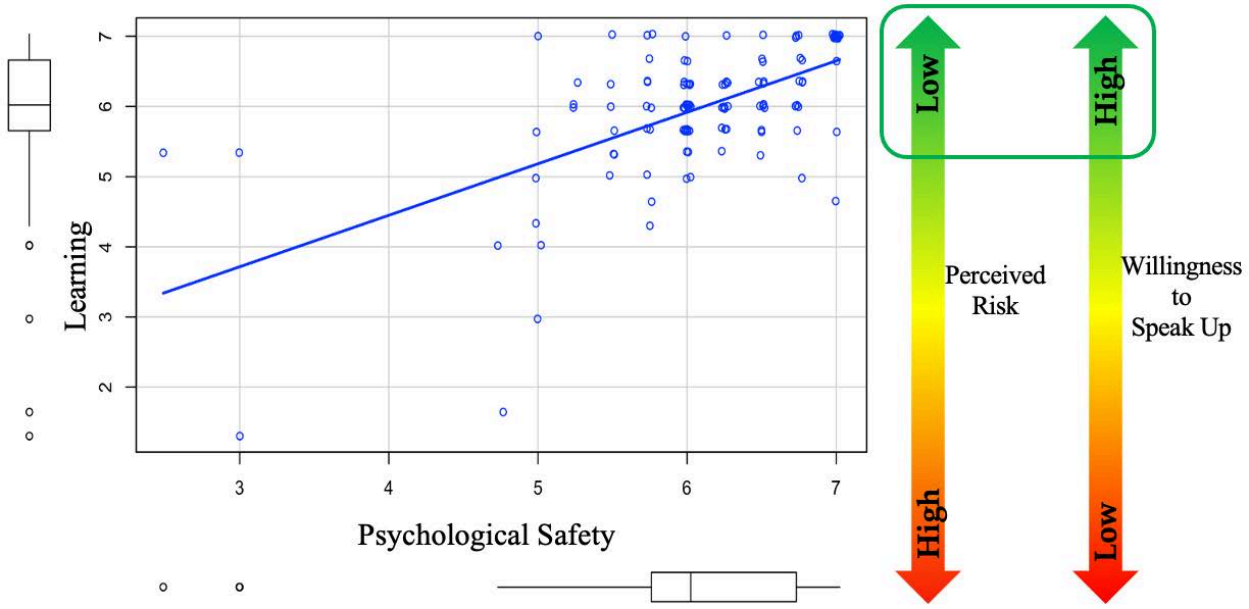


Figure 4.13: Psychological Safety – Learning Correlation

In the next section, I describe what participants described as opportunities to foster psychological safety in construction projects.

4.5 Actions to Foster Psychological Safety in Construction Project Teams

I gathered participants' ideas for fostering psychological safety in their projects and grouped them into action categories, as shown in Table 4.6. These actions are meant to contribute to building an environment where people are confident about asking questions and getting clarity on the work, speaking up when errors occur, expressing concerns, providing feedback, and avoiding getting into hazardous situations.

Table 4.6: Participants' Suggestions to Facilitate and Foster Speaking Up

Participants Expectations	Round 1 (Craft)	Round 2 (Craft Sup.)	Round 3 (Craft)	Round 4 (Staff)	Total
Strengthen relationships with supervisor	4		10	3	17
Be trained (e.g., participate in all-hands where examples of speaking up are shared)	6		7	4	17
Be able to provide anonymous suggestions	3		5	5	13
Strength relationships within and among trades	8		4		12
Not be punished for speaking up	7		5		12
Be recognized and rewarded	6	1	2		9
Be heard and know that their concerns will be addressed	6		2	1	9
Have everyone caring for common areas (e.g., cleanliness)			7		7
Be involved in planning work	4		1		5
Have time and means to raise concerns			2		2
Have staff actively participate in the field				2	2

Once I completed Round 1 and 2, I presented the results to the project team's leadership, and we designed some managerial actions that were able to implement in the projects. I summarized these actions in the following section.

4.6 Managerial Actions to Foster Psychological Safety

Based on the survey responses, observations from site visits, and the interviews with the study participants, I provided feedback to the project team leadership; together, we designed and implemented the actions described in this section.

4.6.1 Onsite Safety Committee

The project team and I designed the onsite safety committee to systematically increase strength and cohesiveness within the project team, particularly between craftworkers from different subcontractors. We run the committee (Figure 4.14) in the following way:

1. The committee was composed of one member from each subcontractor. We asked the committee to identify things that were going well and things that needed improvement
2. The committee met monthly for 1 hr., which included a 40-minute site walk and a 20-minute team discussion about the observations made by the participants during the walk
3. Takeaways of the committee were shared with all the project in the subcontractor coordination and all-hands meetings
4. The PE leading the committee held weekly check-ins to follow up on actions decided during the last committee meeting
5. For the committee walks, we assigned people pairing those with different experience levels, from apprentice to foreman to PEs. Cross-pollination of trade knowledge and experiences played a key role in breaking barriers within trades
6. Preparation for the meetings included having every contractor on site to encourage at least one person from their team to participate, and identifying areas of focus for the site walks.

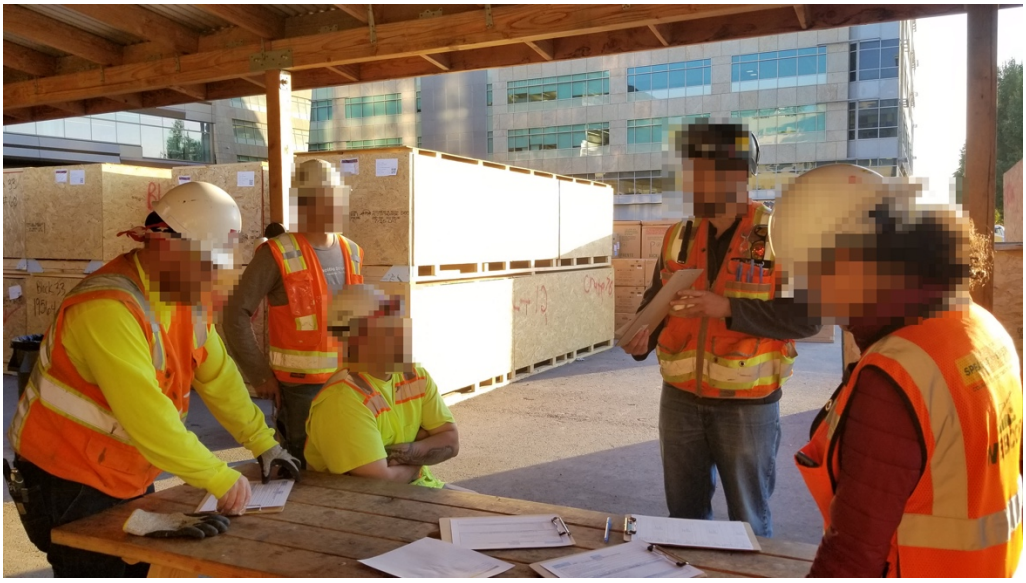


Figure 4.14: Safety Committee Members Sharing Takeaways and Opportunities for Improvement (Photo: © Sulyn Gomez, 2019-10-30)

Leadership, or a lack thereof, played a key role in the committee's success. The committee's objective was not to push a single agenda but to empower members to look out for one another. The committee encouraged reporting by sharing examples of things reported that did not negatively affect the individual. Safety concerns that were not brought up before often started to surface.

4.6.2 Doing it Right Recognition Program

The project team and I designed this program to recognize and show appreciation for the workers' commitment to continuous improvement. The recognition program was directly supported by day-to-day conversations, having suggestion boxes on the job, and sharing the team's contact information, such as cell phone numbers on their hardhats, so every worker could reach out for help, suggestions, or requests to improve the site. We recognized people in the following ways:

1. Installing a workers recognition wall and posting a picture and a description of how the worker contributed to the team
2. Having the Pes giving away recognition stickers (Figure 4.15) and free lunches to those who contributed to the team, especially during their site walks, which was deliberately planned to have staff members participate in the field more often
3. Making recognitions public so workers are inspired by their peers to speak up.

Figure 4.15: Worker Holding Work Recognition Sticker (Photo: © Sulyn Gomez, 2019-06-04)

4.6.3 Leadership Coaching for Supervisors

This action was a combination of sessions I led with the supervisors of all the trades in the project (Figure 4.16), and some others that the GC's leadership assigned to their superintendents independently of the study. After survey Round 1, the GC's superintendents completed their independent leadership training and started sharing their takeaways with all the supervisors onsite. Through our study and the leadership sessions, the GC's project leadership understood the various ways they had to get the work done (e.g., by threatening, inspiring, and motivating) and the potential consequences of doing one or the other. For instance, if a supervisor asks a worker to get the job done, they will probably do it, but this supervisor can also ask their workers if they need anything (any help) to get the job done and involve them in the planning process. Both behaviors get the job done, but in one scenario, the worker probably feels more psychologically safe and valued and can contribute more to designing and executing the tasks.

Figure 4.16: Meeting with Project Supervisors to Report Round 1 Study Findings (Photo: © Sulyn Gomez, 2019-03-20)

4.6.4 Use of English and Spanish in Weekly All-Hands Meetings

In 2015, more than 31% of workers in the construction industry were Hispanic workers, more than 7% European, and more than 6% Asian (CPWR 2018). Language limitations in the context of construction projects could cause difficulties in understanding expectations and work processes to meet these (Ruttenberg and Lazo 2004), putting themselves in hazardous situations and increasing the likelihood of being killed or injured (National Research Council 2003).

While I was aware that many craftworkers in construction are Spanish speakers, before this study, I did not know some of them barely understand English, if at all. Not understanding what is being said to us can impact how safe or unsafe individuals can feel working in a team. Having realized this during my conversations with them, I suggested bringing the use of Spanish onsite to a higher level. When the study started, I observed some posters and signs onsite that used English and Spanish. However, meetings such as the all-hands meeting, where important messages were communicated and everyone participated, were held in English.

As part of our study, the project team started using Spanish during the all-hands. The safety manager would deliver the messages in English, and one of the Pes would simultaneously translate them into Spanish. This helped to communicate the message during the meetings and improve participants' engagement.

4.6.5 Craft Appreciation Lunch

The project team and I re-designed the format the project had for craft lunches before the study. The existing format was purely a lunch, and very few trades showed up. While the PE hosting the lunch asked for verbal feedback, participants rarely spoke up. In the new design, we aimed to create a safe environment and use this space to hear their feedback on things that could be improved. We run the appreciation lunches with the new format in the following way:

1. The lunches were scheduled once a month, and the date was reminded during the all-hands meeting the week before
2. GC's leadership encouraged all subcontractors to participate by having at least one person from their team in the meeting. This helped improve attendance
3. All the attendees received post-its at the beginning of the meeting, and we asked them to write as many suggestions as they had. Then we collected all the post-its and put them on a board. No individual post-it was linked to a specific person
4. We asked for things they would like to see changed (constructive feedback so the team can improve) and things they liked so the team could keep doing it
5. Once all post-its were on the board (Figure 4.17), the PE and I read each post-it out loud and guided the discussion in the room so no one person was put in the spot. For each idea discussed, many participants provided comments and shared their perspectives about the issue
6. To wrap the discussion up, the PE would summarize key points and share actions that are to be taken based on the feedback collected
7. The PE shared the key takeaways of the discussion with the staff members during the weekly coordination meetings.

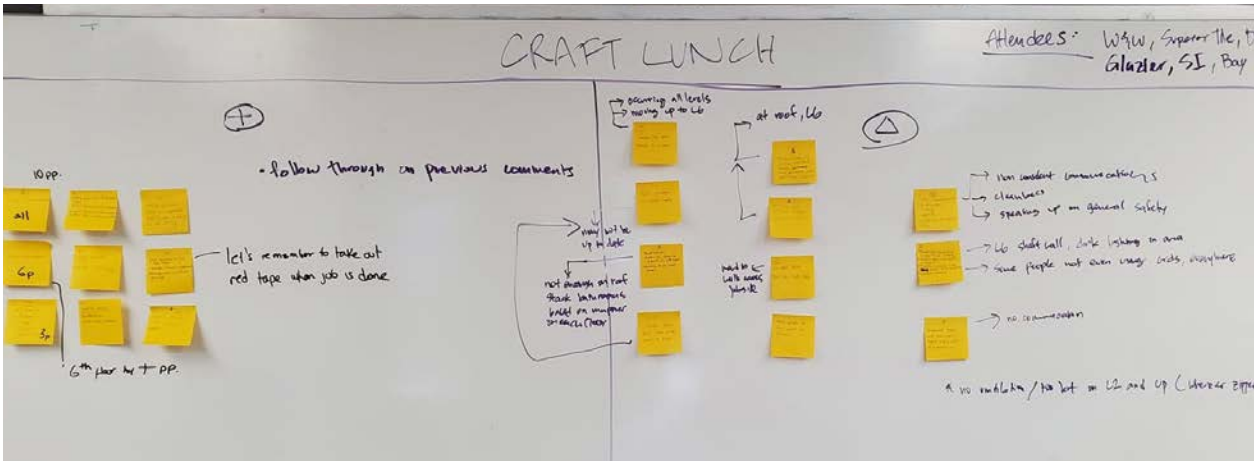


Figure 4.17: Board Sample where Feedback from Craft was Documented during Craft Lunches (Photo: © Sulyn Gomez, 2020-02-27)

4.7 Discussion

Using standard practices to foster psychological safety, and psychological safety to successfully implement such practices

While this chapter describes how some of the standard practices implemented could foster psychological safety, it also highlights that for some of these practices to succeed, the team requires psychological safety to drive the behaviors needed. For example, practices such as all-hands meetings and onboarding sessions foster psychological safety. However, the practice of reporting near misses strongly depends on people feeling that they can speak up and report without negative consequences.

Leveraging psychological safety through current company efforts

While psychological safety as a construct has not been studied much in construction yet, other related topics had been explored in detail. For instance, safety culture and engagement are examples described in this chapter of existing things led by the GCs to improve the existing work environment and involvement of its team members.

Identifying relevant factors influencing psychological safety in construction teams

When exploring the trends of psychological safety considering the organization type, trade, time in the project, and position, I found that the time the person had been working on the project is a relevant factor contributing to how psychological safety the person felt; however, because of the small sample, I cannot generalize this finding.

4.8 Conclusions

In this chapter, I explored the construct of psychological safety in construction project teams. I identified a similar positive correlation in construction teams between psychological safety and learning than the one described in the literature for industries such as healthcare and manufacturing. The sample I collected showed that the staff and craft supervisors reported slightly higher psychological safety scores than craft did. I also identified some managerial actions construction teams could implement to foster psychological safety. Then I customized some of these actions with the project teams' collaboration and tested them on the projects studied.

5. EXPLORATORY STUDY ON QUALITY MANAGEMENT

This chapter presents the findings of a study I conducted to explore how a GC applied the Behavior-Based Quality (BBQ) notion to manage quality in the Block 23A project described in the previous chapter.

The chapter is organized as follows. Section 5.1 introduces the project background and the scope used to illustrate how the team applied BBQ in this case. Section 5.2 describes the methods used to analyze the study data. Section 5.3 describes BBQ implementation from the perspective of the project participants. Section 5.4 illustrates BBQ implementation through a specific scope. Section 5.5 presents a discussion of the findings and opportunities for improvement. Last, Section 5.6 concludes this chapter.

5.1 Project Background

Around the time this study started, the GC's quality leadership team published a paper describing their BBQ approach to quality (Spencley et al. 2018). This GC highlighted the need to shift from focusing on quality as a control mechanism towards BBQ so their teams can better plan to understand quality expectations and meet them. This GC's adoption of BBQ varied from project to project.

When the study took place (Figure 5.1), concrete and MEP were the larger scopes of the project. I chose to study concrete because it was one of this GC's self-performed work (SPW) scopes. SPW employees often have a longer tenure than subcontractors, and the study offered longer-term benefits for the GC and its SPW concrete group. SPW concrete was delivered on a lump sum basis. Among the SPW concrete scope, I focused on architectural concrete shear walls because these were designed to be exposed walls in a central location in the building, making them key features of the project.

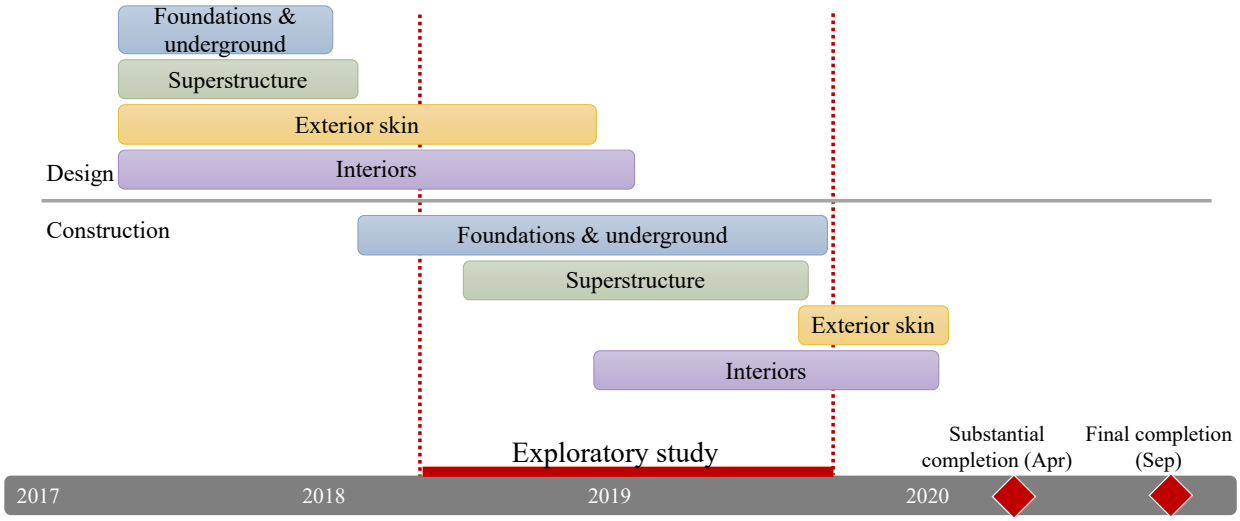


Figure 5.1: Time when Study Took Place

The project team, including the client's representative, architects, and contractors, worked in a big room (Figure 5.2), some for up to 3.5 years. Working co-located helped the team reach out to each other and facilitate quality conversations occurring:

> *"There is an ethos that is created that we are all part of one big team… There have been many instances where a question will come up a code compliance issue and it can only be answered for example by the fire sprinkler engineer. Because they're resident here [in the big room] and working with us, it's very easy for us to bring them into a meeting to meet with the fire marshal and say, 'hey how do we work out this particular?' I think there have been numerous examples of that working quite well." – Architect B*

Figure 5.2: Project Big Room (Courtesy of DPR)

5.2 Methods

I studied this project using qualitative methods, including observations and interviews. My primary contact in this project was the quality champion, fulfilling the function of quality manager.

The study involved two phases of data collection. First, I visited the site to describe how the team implemented the BBQ approach. Second, I interviewed key project participants to refine my description of the process and how this project differed from what they had experienced on past projects.

I visited the project site over the course of 1.5 years and observed the process of delivering the scope studied, architectural concrete shear walls. I observed the conversations the team had to define the quality expectations, the testing of operations through mockups, the construction in the building, and the inspection to assess the walls built.

I interviewed 8 participants, using the questions in Appendix 5, to gather their perspectives on the project's quality process, from the owner's representative, architect, GC, and SPW concrete.

5.3 BBQ Implementation from the Project Participants' Point of View

This section describes the participants' experience implementing BBQ in this project, including what went well and their struggles.

5.3.1 Going Beyond Plans and Specs

Participants described why it was important not only to rely on the project documents as they were first developed:

> *"The project's program document did not necessarily reflect every constituent groups goals and demands and technical requirements, and of course, those might have changed a bit over time." – Architect B*

> *"Sometimes we do not communicate well our priorities to the people building the projects." – Client's Representative*

One example that illustrates the need to get a better understanding of the original design documents is:

> *"There were only like 3 words in the specs [referring to the bench welding details included in the specifications of the project], but that's the very first thing they [the client end users] went to when inspecting the bench mockup. They took the table and went like this [slide his finger throughout the corner of the table to show me what the people revising the mockup did]. If that's important, don't make it 3 words, but make its own entire section, make it the first thing." – PE*

Designers are typically challenged to convey the expectations of multiple end-users and translate them into drawings and specifications that contractors use to build, and contractors are challenged to understand that design intent and plan to build a project meeting quality requirements:

> *"So, within the clinical area we met with nurses, the doctors, the environmental health and safety people and then the campus fire marshal who is designated as the authority having jurisdiction. In the research facilities, we met with a series of representative principal investigators. Then we met with the laboratory animal research lab laboratory animal resource. Then the final overall play was a group that was called the executive design committee, which included representatives of the primary donor. That's just on the architectural design side. Then we translate all of that into construction." – Architect B*

> *"The lab casework mockup had a lot of different elements. There're benches, a sink, ceiling service panel, all the utilities that come down; it even has the owners' mockups for the chairs. They are the main lab benches that a lot of the people in the building will be working on for the neuroscience dry labs. We identified that the cabinets were important to certain stakeholders even though it's a cabinet. [When inspecting the mockup, for example,] we had some people from the UCSF's ergonomics department. They sat down and they actually pull the drawer out and they said 'oh is that really what we want our scientists to do? – No.' [We realized these details] were really important to them." – PE*

In addition to the typical challenges of construction projects, this project had 2 different construction firms collaborating in the design of the project and a large number of end-users whose quality expectations needed to be understood for delivering quality:

"The project has a design architect [Architect A firm] who was chosen independently of [Architect B firm], who created the essential conceptual design approach to this project. Architect B was brought in to actually realize and deliver the project according to that design intent. So that was the first step in the quality process embracing the intent and understanding the intent of the design and then coordinating our efforts with the design architect to make sure that what we do reflects their level of quality expectation." – Architect B

"[Architect B firm] was engaged in coordination sessions with I think about 35 different user groups from the Client to make sure that what the building program as well as the realization of the documents reflected what the Client A intended as well." – Architect A

BBQ helped contractors understand the design intent and focus their quality plans accordingly:

"You're trying to communicate [quality expectations] to a wide variety of project participants [i.e., contractors building what the design says] who want to be able to see the big picture of what the design intent is, and focus the quality program [to understand and meet such intent]. I think it [BBQ] was quite valuable." – Architect B

5.3.2 Understanding of BBQ Among the Project Participants

Some participants reported having a very limited understanding of what the BBQ approach was for this project, while others reported that it became clear over time, suggesting that some orientation could have helped the team understand what it takes to manage quality using a BBQ approach:

"[when we started] I didn't have a complete understanding of what the behavioral based quality approach was." – PE

"I don't think it [BBQ process] was very explicit. It became clear to us over time… but there was no single point at the beginning of the project where that [BBQ] was necessarily explained." – Architect B

This limited understanding of BBQ and how project participants were to implement it created confusion for some as to what they were expected to do:

"A little bit of me was like, 'Well, I'd like some type of guidance.' It's easy to say go out there and do it [quality]. We should have quality just as high of a standard as safety is, but with safety there comes a lot of regulations, and there's a lot of oversight. We have a safety coordinator on every project, we have safety meetings every morning in the field, we have a project-wide safety meeting every week that everybody is mandatory to go to. Why don't we have that with quality? That's what is kind of confusing to me, we say that we should emphasize it, but nobody is telling me honestly what to do with it." – PE

Even though some participants reported that the GC's quality corporate team visited the project and described the BBQ approach, the explanation was only given at a high level. Training and role modeling could support the implementation of BBQ. Things such as standardizing a language are also as important when building a sustainable change; while some participants were familiar with BBQ, distinguishing features of work (DFOWs), and measurable acceptance criteria (MAC), others reported to have not heard the terms, but they still participated in the quality process.

5.3.3 Owning the Process: Who is Responsible for Quality?

Because of the nature of BBQ, which emphasizes the behaviors of all those involved in the quality process to plan and meet quality requirements, I explored the participants' perceptions of who led the process. When the study started, many responses placed most or all the responsibility for achieving the agreed quality requirements on the quality champion. This changed over time as Pes got more involved in quality planning.

> *"I don't think [the quality champion]'s scope was defined very well. He was told he was the quality manager and I think he had to figure his job out on the way. We kind of figured it out along the way." – PE*

The role of the quality champion transitioned to that of a facilitator who supported the BBQ implementation. Once participants were involved in the process, they soon realized the benefits:

> *"There are aspects of it [BBQ implementation] that are very important and useful. Trying to get people really early to have feedback [in the design] is valuable." – Architect A*

> *"I think that that approach [BBQ] works quite well. It's very important that the people are involved and lose the psychology of the old ways [all competing against each other]." – Architect B*

> *"Yeah I would use it [BBQ] again. I think having to identify [DFOWs] early on and getting everybody engaged on it was great." – PE*

As project participants were engaged in BBQ implementation, they planned discussions and committed to such plan:

> *"We very much defined times in the schedule where the appropriate stakeholders can review [the project information] and we identified beforehand what to review. Everybody had a say in it before we completed the review." – PE*

The quality champion developed a poster describing the high-level process steps of what BBQ encompasses in this project (Figure 5.3).

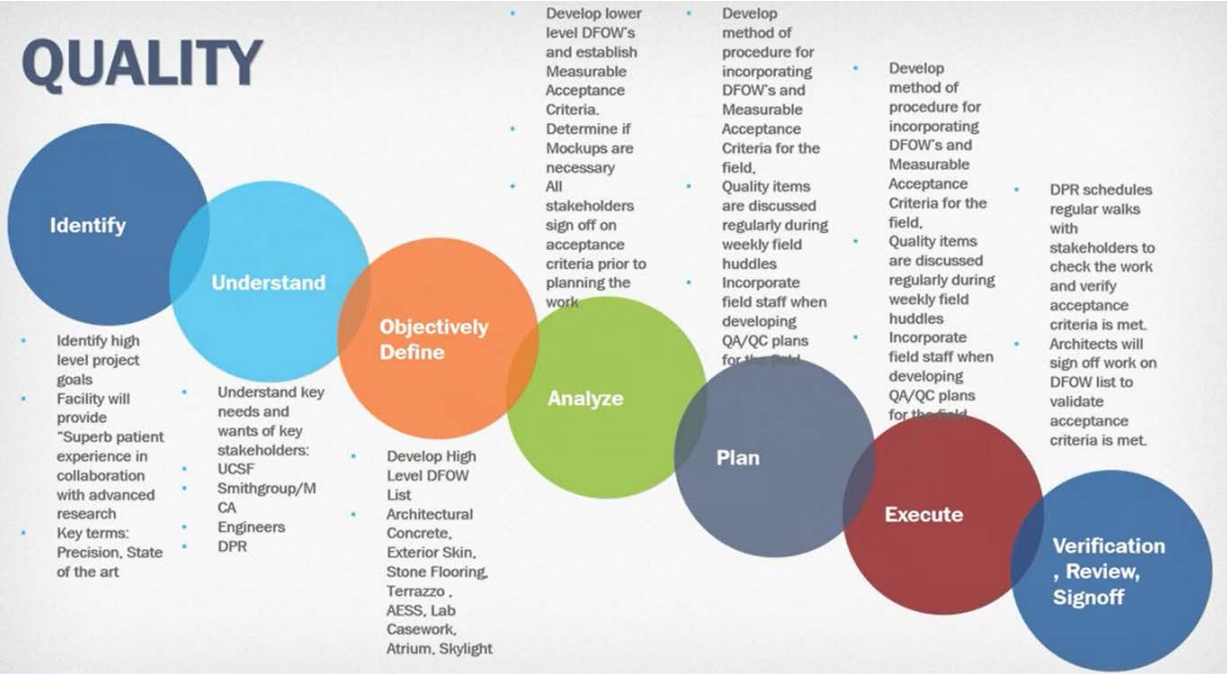


Figure 5.3: Poster Describing the Team's Implementation of BBQ in Sequential High-Level Steps (Courtesy of DPR)

In the next section, I illustrate how participants were engaged in the process and the outcomes of their engagement.

5.3.4 Engaging All Participants Needed in Quality Conversations

At the onset of the project, the client engaged various project participants (design leads, GC, donor, and end-users) to participate in the definition of the project's goals. The GC, following the BBQ approach, engaged the project participants in a series of meetings to plan how the client's goals could be met and start identifying the project's DFOWs:

> *"I think for the most part the right people were involved in these [DFOW] meetings. In terms of being able to predict the outcome we've been doing really well and having the subcontractors here in the big room is enabling that quite well." – Architect A*

> *"I think that bringing in the actual trade people and the crafts people early in the process allowed us to incorporate their constructability suggestions and in some cases, they suggested solutions that exceeded what we thought they could do. That's always a nice thing. Like for instance, we just met with the Terrazzo subcontractor, and he made a few suggestions of changes that would result in a better job, in a better installation that we had anticipated." – Architect B*

The BBQ supported project participants' engagement and the involvement of craft in the quality process:

> *"It's important that the expectations of quality are conveyed to the subcontractors and the people who are actually doing the work in the field… I think it [BBQ process] engages everybody at a deeper level. [BBQ] implies that all project participants are focused on*

achieving the best result for the client based on the known and unknown factors of the project" – Architect B

The DFOW meetings were an essential part of the quality conversations in this project; not only did they allow the team to gain a better understanding of the quality requirements, but they helped strengthen the team relationships:

"I think the DFWO meetings are essential in making sure that we have communicated our quality intent and that the objective of the work is reflected in the people who are going to actually realize it. The DFOWs represent a bridge for the contractor to understand what the design intent is and how they are intended to achieve a specific result" – Architect B

These meetings also helped make informed decisions regarding the requirements expected and the associated costs and schedule:

"[In the DFOW conversations] we can come together with a general ROM [rough order of magnitude]. That's good because the owner has a chance to say something. We may say 'hey we have this change that is going to cost you a million dollars', the owner might have something to say like 'do we really need to do all this?' or 'no I don't necessarily want to if I don't have to'." – PE

5.3.5 Getting Alignment on Quality Expectations

The DFOW meetings allowed the team to discuss and agree upon the MAC to assess the work once completed:

"There are certain things that might not be as clear in the drawings and that you explicitly write down during those [DFOWs/MAC] meetings." – Architect B

"We sat down initially with the subcontractors, [client], and [architects] and we said basically, 'what do you guys care about? What else are you guys going to look at?'. [Through the DFOW meetings] We developed this list of items that we used as a checklist initially when we did the lab casework mockup. Things like the welded assembly of bench frames, well, that's not in the specs, the details don't show anything, the drawings just show a bench. It might say this high, this color, this finish and this material. It also said generally how it's put together, like some legs are bolted, some frames are welded. But we identified that they care a lot about the welds. The first thing they [client and end users] looked at was the welds and craftsmanship of the metal frame at the table." – PE

BBQ implementation can thrive in a psychologically safe work environment, where project participants can freely talk about their expectations, concerns, limitations, capabilities, and even about mistakes made to foster learning and improvement and minimize the reoccurrence of such.

Table 5.1 summarizes my understanding of BBQ based on the participants' experience with BBQ compared to what they had typically experienced in past projects.

Table 5.1: Traditional Quality Management Focus Versus Behavior-Based Quality (Adapted from Gomez et al. 2019a)

Traditional Quality Management	Behavior-Based Quality (BBQ)
Build it – Check it	Seek a common understanding of quality expectations before building
Low confidence to speak up or raise concerns	High confidence to speak up in a psychologically safe environment
Culture of knowing and assuming	Culture of learning and asking questions
Quality is the responsibility of one person	Quality is my responsibility Every person is responsible for delivering quality products
Blame others when mistakes happen	Seek to understand what could have caused the mistake and plan to avoid its reoccurrence
Workers are not involved in defining quality expectations nor planning how to achieve them	Workers are encouraged to participate in shaping quality expectations and designing capable operations actively
Fragmentation and miscommunication between design and construction	Fostering communication and alignment between design and construction

In the next section, I describe how the GC applied BBQ to the shear walls scope designed as architectural exposed elements of the building.

5.4 Architectural Exposed Concrete Case

The project was designed to have exposed concrete walls in a central location (Figure 5.4). The GC identified these walls as a DFOW for the project and started conversations to better understand expectations and define quality requirements to be met:

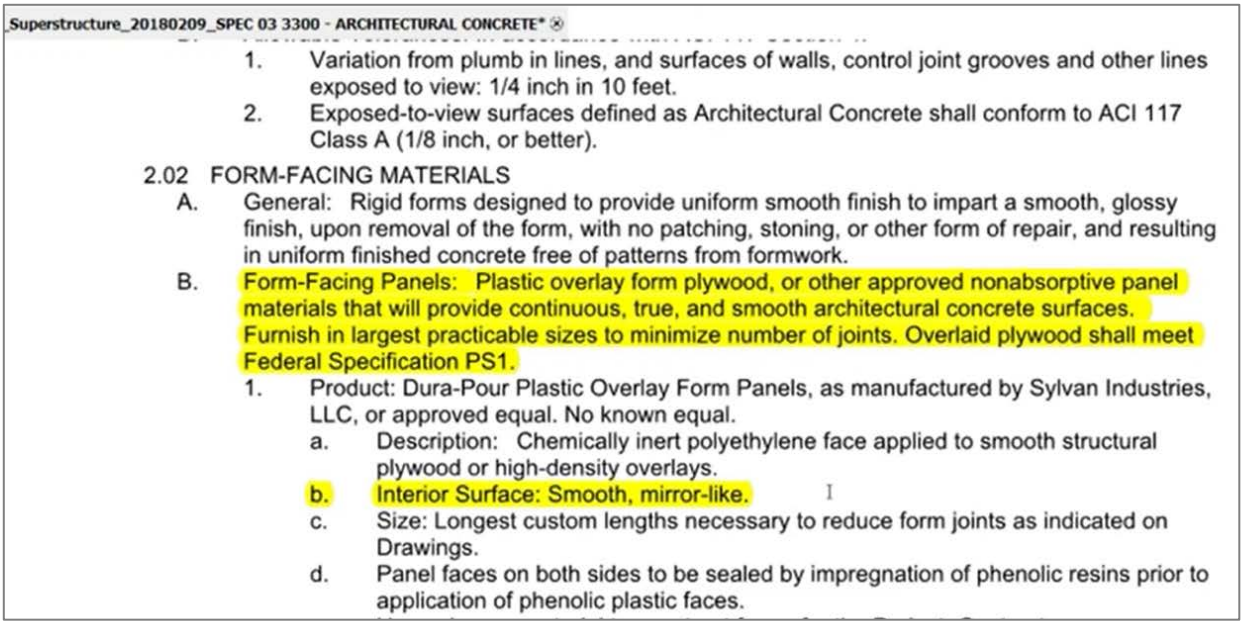
> *"We had very early on DFOW discussions when the concrete was starting. I remember in the big room the client and the user groups coming in and even attending just to get an idea of the progress of the job. We introduced quality, I remember [the quality champion] speaking specifically to that group… Everybody in the big room was engaged in the [BBQ] process. The process probably took a lot longer, but everyone was very engaged." – PE*

Figure 5.4: Atrium View to Architectural Concrete Shear Walls (Courtesy of DPR)

5.4.1 Moving the Unknowns to Knowns: Understanding DFOWs and Defining MAC

> *"[architectural concrete] was a part of the project that we worked quite extensively with the team through a DFOW process bringing in the people who would actually be managing and building the work on site." – Architect A*

As part of BBQ, the GC reviewed the project specifications and drawings in preparation for the work, and highlighted areas that needed more clarity. Figure 5.5 shows an example the GC called out in the project specifications for architectural concrete that required alignment conversations to really understand the quality expectations for the scope. The specifications called for a wall surface "smooth" and "mirror-like concrete." Because such details were not clear, the quality champion asked questions to understand the expectations for the surface finish, color, location of form joints, and construction tolerances for the DFOW of architecturally exposed concrete walls.


Superstructure_20180209_SPEC 03 3300 - ARCHITECTURAL CONCRETE*

1. Variation from plumb in lines, and surfaces of walls, control joint grooves and other lines exposed to view: 1/4 inch in 10 feet.
2. Exposed-to-view surfaces defined as Architectural Concrete shall conform to ACI 117 Class A (1/8 inch, or better).

2.02 FORM-FACING MATERIALS

A. General: Rigid forms designed to provide uniform smooth finish to impart a smooth, glossy finish, upon removal of the form, with no patching, stoning, or other form of repair, and resulting in uniform finished concrete free of patterns from formwork.

B. Form-Facing Panels: Plastic overlay form plywood, or other approved nonabsorptive panel materials that will provide continuous, true, and smooth architectural concrete surfaces. Furnish in largest practicable sizes to minimize number of joints. Overlaid plywood shall meet Federal Specification PS1.

1. Product: Dura-Pour Plastic Overlay Form Panels, as manufactured by Sylvan Industries, LLC, or approved equal. No known equal.
   a. Description: Chemically inert polyethylene face applied to smooth structural plywood or high-density overlays.
   b. Interior Surface: Smooth, mirror-like.
   c. Size: Longest custom lengths necessary to reduce form joints as indicated on Drawings.
   d. Panel faces on both sides to be sealed by impregnation of phenolic resins prior to application of phenolic plastic faces.

Figure 5.5: Excerpt of Project Specifications for Architectural Exposed Concrete Walls (Courtesy of DPR)

The DFOW meetings provided the team a place to gather input to shape the quality requirements:

> *"With the DFOWs, we can identify things that we can do very well, but more importantly, there are things that you identify that are too difficult to achieve or not realistic. One aspect was the corner of a wall for the architectural concrete. They said, 'oh I want to see a corner of a concrete that is 90 degrees sharp'. You know with concrete that's very hard, and we told them 'we cannot guarantee that we can achieve that, you can get it in a lot of places, but we can't guarantee that it will be everywhere.'." – PE*

DFOW conversations were informed by site visits organized by the GC and SPW concrete to past projects where the architect or client saw alternatives of finished work. Figure 5.6 shows an excerpt of the DFOW tracking log used by the team to document their agreements during quality discussions.

Scope	Ref. No.	DFOW Details	CD Reference (*state if UNSPECIFIED)	MAC
Architecturally Exposed Walls	1	Walls - Rustication and Reveal Strips	Bulletin 2	Birch, Select and Btr Grade per NHLA; mill straight to profiles shown. Nail to form where shown. Use finish nails only.
	2	Walls - Aesthetics of Formwork	Bulletin 2	Material type Panel Size Plywood orientation Form Joints (see below) Corners Aesthetics of Formwork
	3	Cold Joints/ Interface with Floors (wall/ slab interface)	Bulletin 2	Plan for CJ to be at top of reveal/ top of slab. Avoid middle of pour CJ. Joint locations on CD's.
	4	Form Edges / Form Joints	Bulletin 2	Factory seal with aluminized polyurethane sealer to prevent moisture penetration. Lap and seal joints, gaps, and apertures in forms to withstand full hydraulic pressure and remain watertight and flush
	5	Form Ties and Plugs	Bulletin 2	Dywidag System International Threadbars 5/8 in. in diameter in 3/4 in. PVC sleeves, or equal. Locate as shown. Accurately place and align Lead discs, 1/8-inch thick. Plugs to be semi-recessed, as shown.
	6	Wall Corner Conditions	N/A	1/8" Radiused 5/A5511, Bulletin 2. ACI 303R-12, 117
	7	Wall Plumb	Bulletin 2, 03 30 00 Cast in place Concrete	ACI 117
	8	Coverage	Bulletin 2	Minimum 1" for exposed walls, 1-1/2" for columns exposed to weather

Figure 5.6: Excerpt of DFOW List for Architecturally Exposed Walls (Courtesy of DPR)

The project participants developed this list over a number of meetings through an iterative process enriched by the participation and feedback of multiple parties:

> *"A person from UCSF was like 'what if a kid comes and runs his fingers right down like the corner of this [90-degree sharp wall corner]' and nobody had really thought of that. And that was part of our DFOW, the safety of the corner. It wasn't identified early on. Everyone talked about the aesthetic of the wall. Everyone talked about whether we were aligned with a joint somewhere or how visible it is, but nobody talked about the safety of it, does it violate a code issue? Is there something like the university will get sued over? No one talked about that at the beginning." – PE*

The team achieved great results as they worked together, ensuring everyone's expectations were aligned and that construction documents reflected what these expectations were:

> *"[through the BBQ process] Decisions were made as to how we were going to review the quality of work in the field. I thought that [MAC] was quite clear." – Architect B*

In the next section, I describe some of the key subprocesses the team used as part of BBQ implementation.

5.4.2 Quality Processes within BBQ

Figures 5.7-5.11 describe the process steps this team followed to build the architectural exposed concrete walls scope, including the design development, mockups, and installation. As a convention, I numbered each activity describing who performed the step and what activity it was. Circle marks show the involvement of project participant(s) from a stakeholder group in an activity led by another. I explain these activities in Appendix 6 and highlight key activities with a detailed explanation in the following subsections.

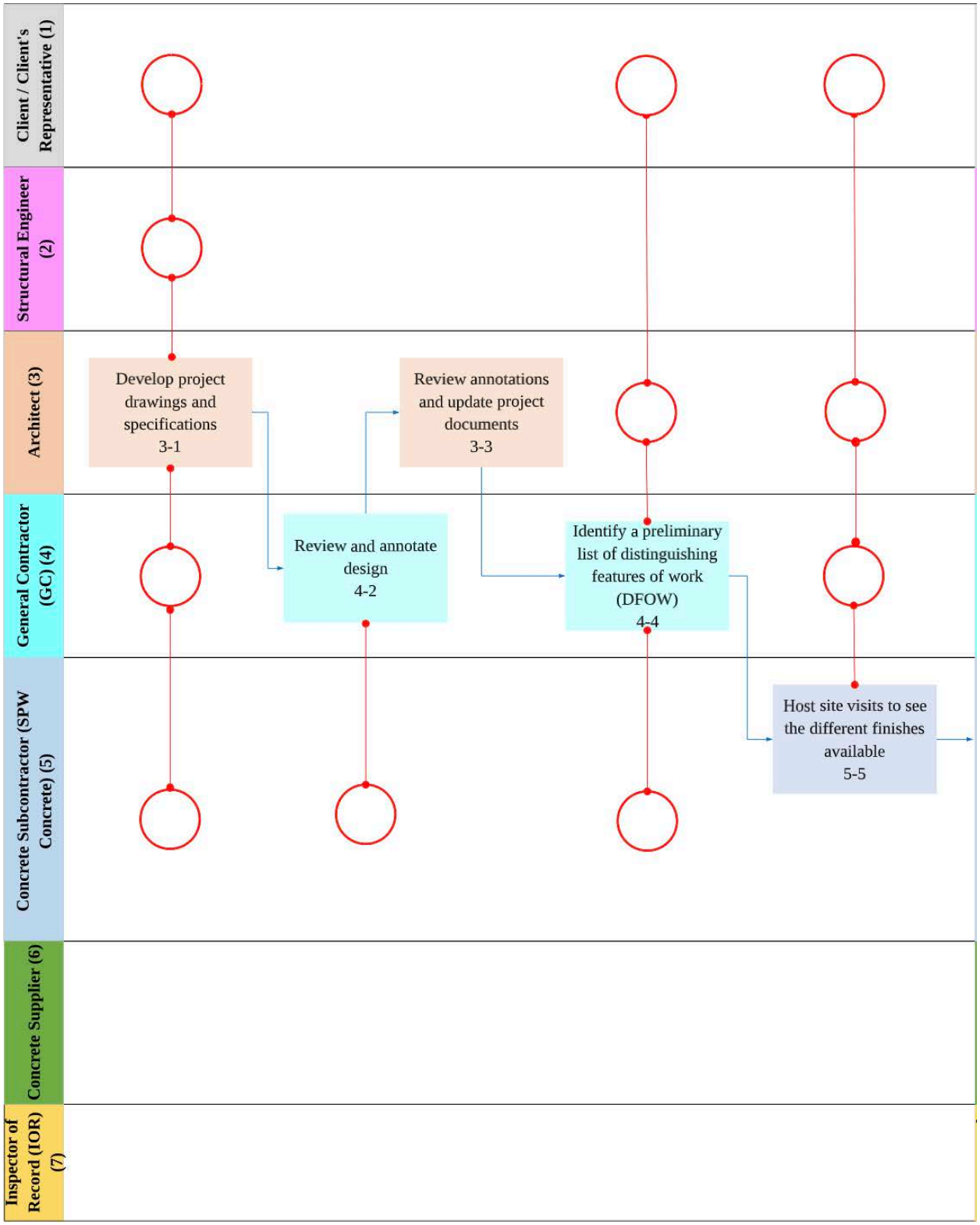


Figure 5.7: BBQ Process for Architectural Concrete Shear Walls (1/5)

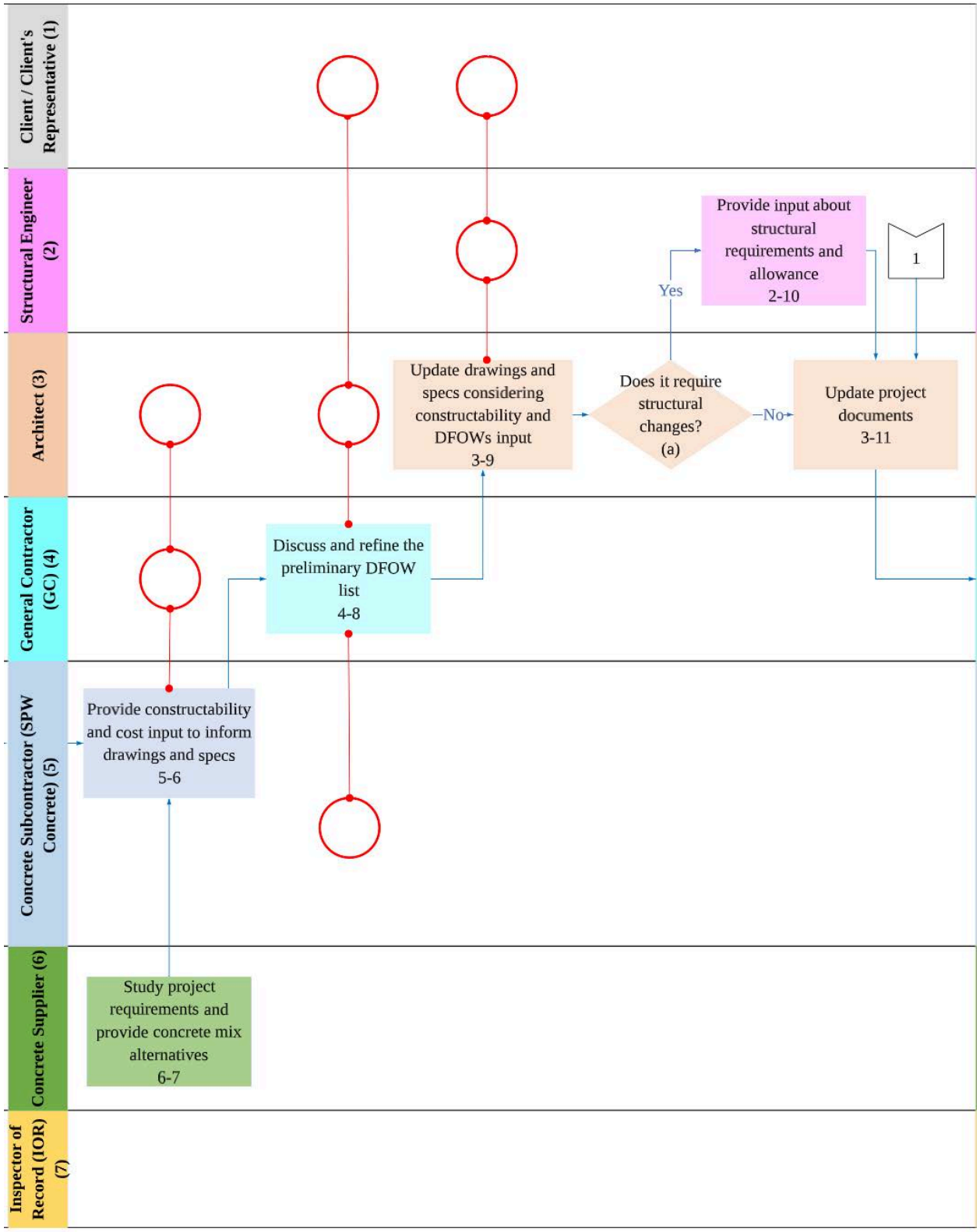


Figure 5.8: BBQ Process for Architectural Concrete Shear Walls (2/5)

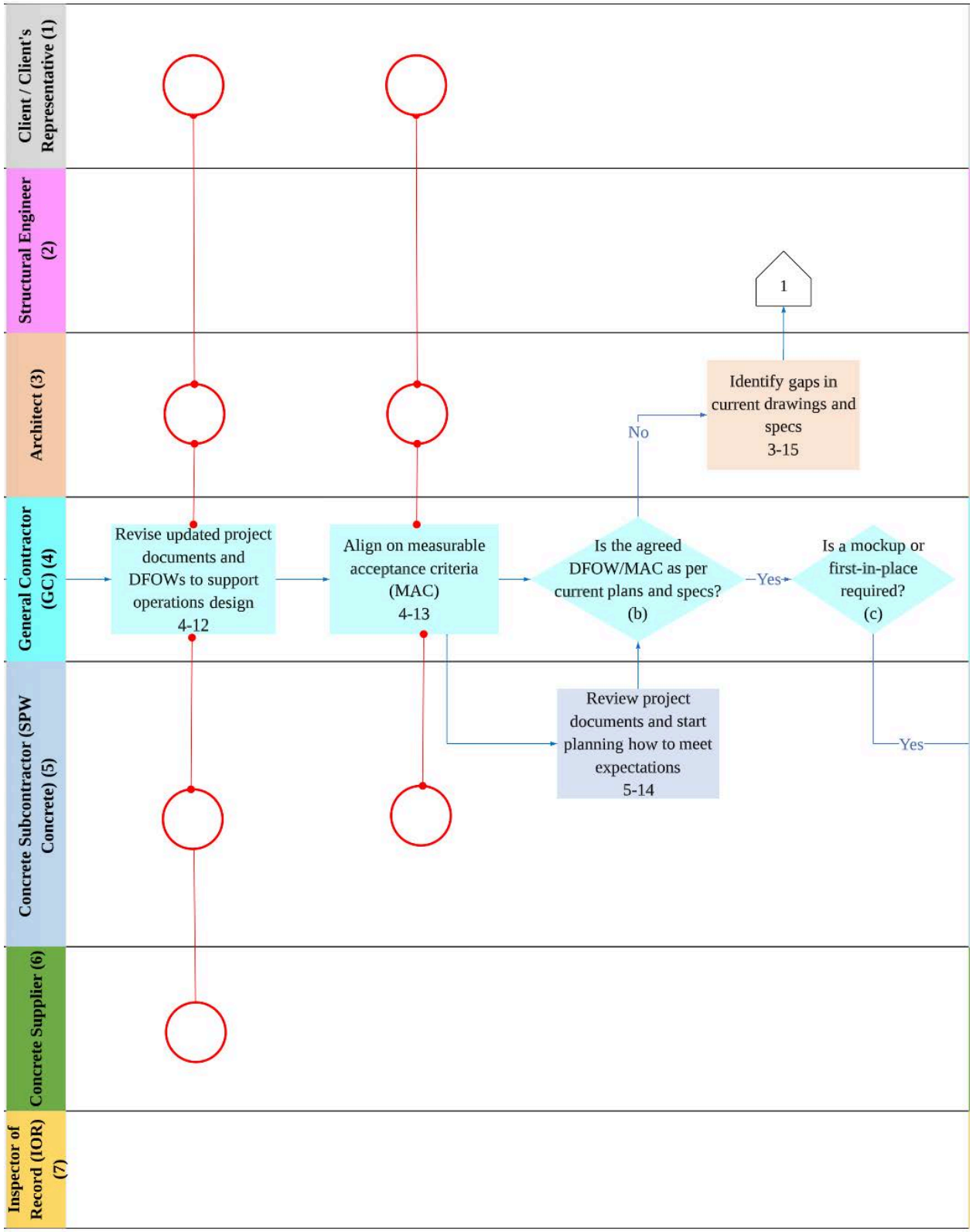


Figure 5.9: BBQ Process for Architectural Concrete Shear Walls (3/5)

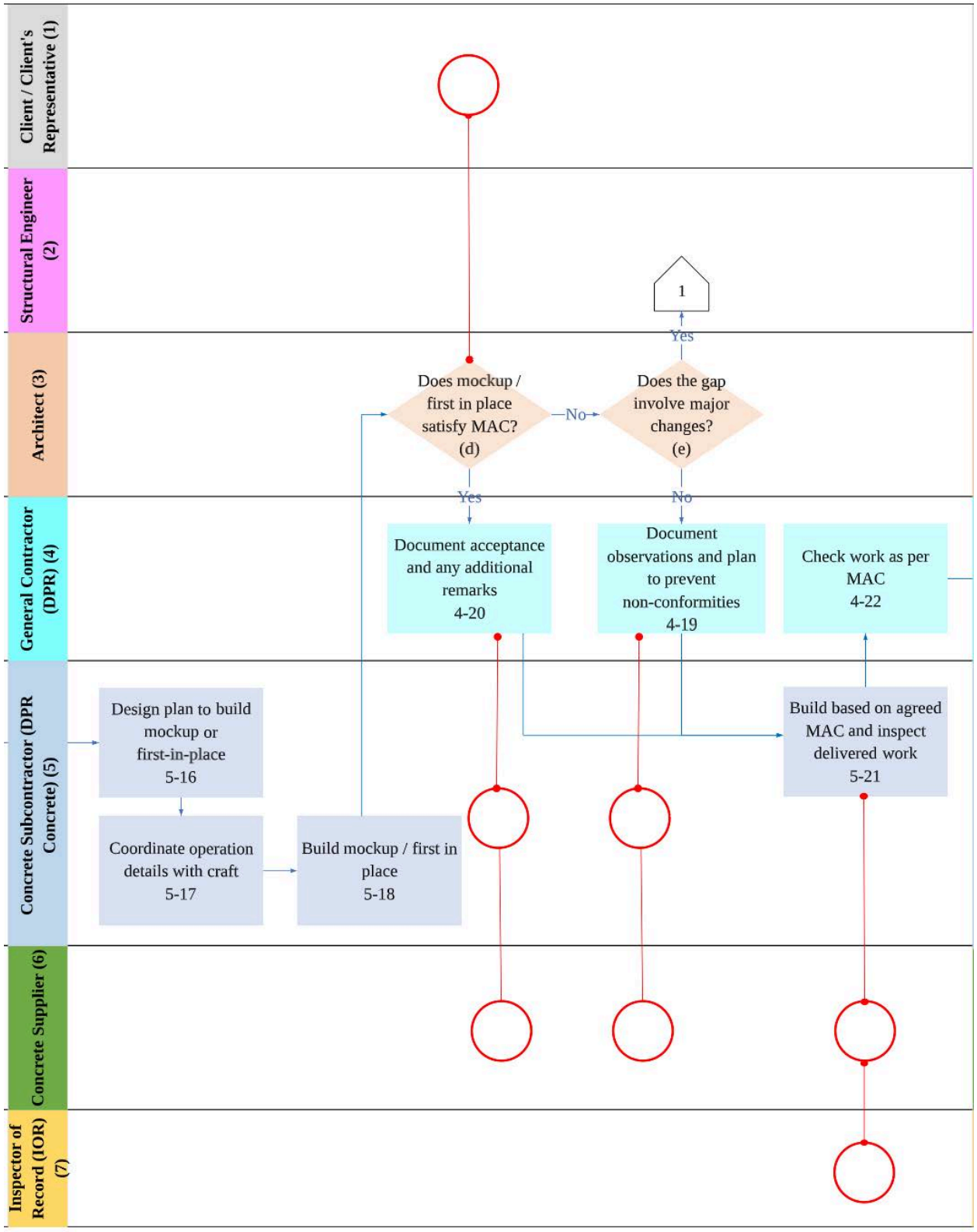


Figure 5.10: BBQ Process for Architectural Concrete Shear Walls (4/5)

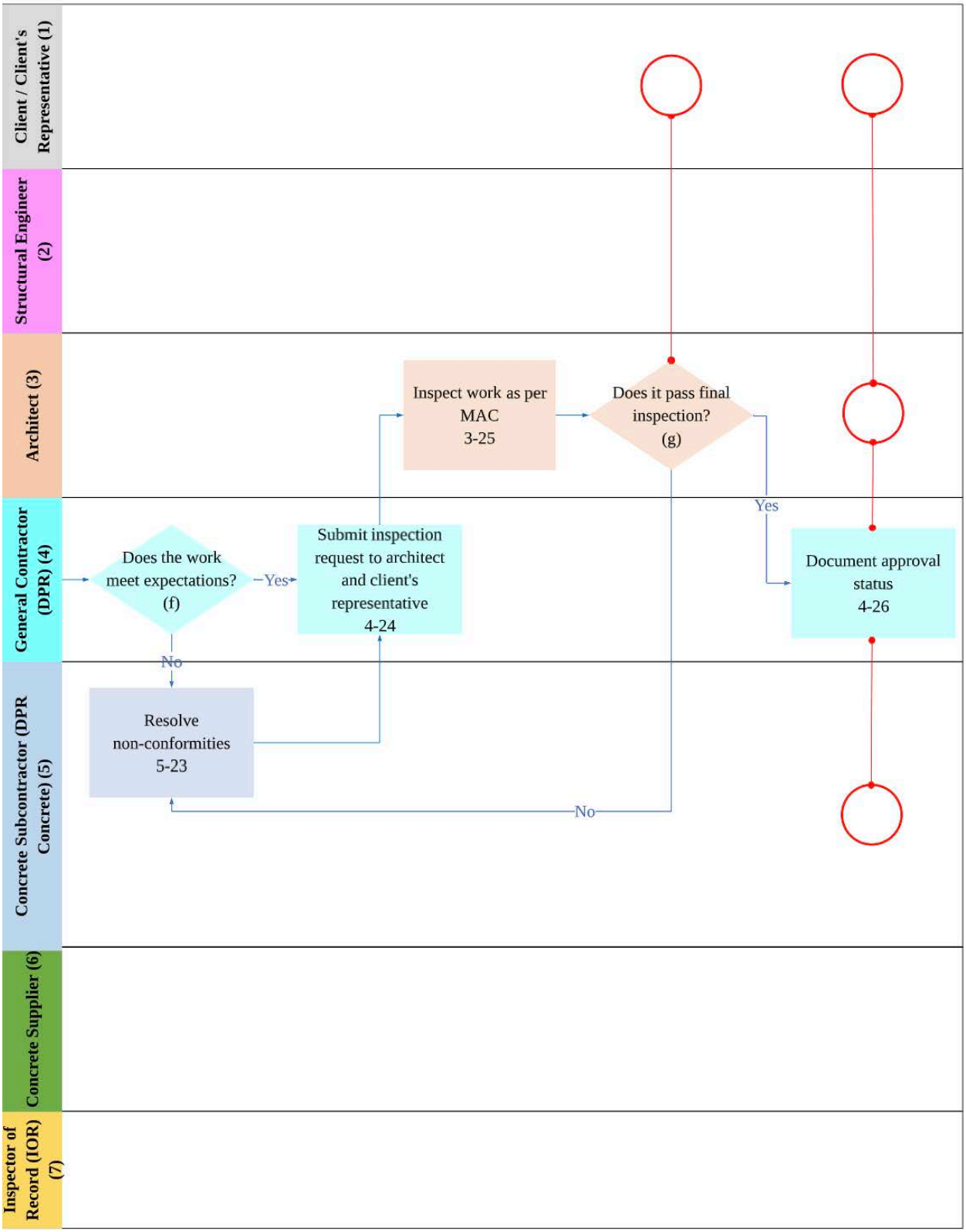


Figure 5.11: BBQ Process for Architectural Concrete Shear Walls (5/5)

I highlight key parts of the quality process used for this scope in the following subsections.

5.4.2.1 Using Mockups and First-in-Place (FIP) Installation to Inform DFOW/MAC Conversations

The GC started the DFOW/MAC conversations to clarify quality requirements by asking what is distinguishing about the scope and what standards specify about it. For the case of architectural concrete shear walls, for example, questions included (1) how wall corners and joints were expected to look, (2) how clean and neat the finished surface would end up looking after removing the concrete forms, (3) would the surface require an extra pass to clean them, (4) in what conditions must the forms be to leave the surface as expected. When planning for mockups or FIP installations (Figure 5.12), all requirements were considered in the conversations to set MAC, not only DFOWs.

Figure 5.12: First-in-Place Installation of Architectural Concrete Shear Walls (Photo: © Sulyn Gomez, 2019-08-19)

As part of the mockup and FIP installation, SPW concrete tested and refined a set of operations that craftworkers were to perform to install work as expected.

5.4.2.2 Including Last Planners in Quality Conversations

The team included builders (last planners) in quality planning to (1) share constructability suggestions, (2) design operations to perform work as expected (e.g., Figure 5.13), (3) offer alternatives, e.g., for wall finishes, and explain the implications on cost, schedule, and safety, and (4) highlight what is not achievable and the constraints they anticipate to have during construction.

"I think [BBQ] impacted the field a lot more in a better way. They started instituting the same formwork in quality for the architectural walls, and then the non-architectural walls. All of our walls and columns are very good which is a good thing, you're taking the time and effort for something that is very good and you're applying it to everything you do. [SPW concrete] is kind of perfecting the craft when they do that." – PE

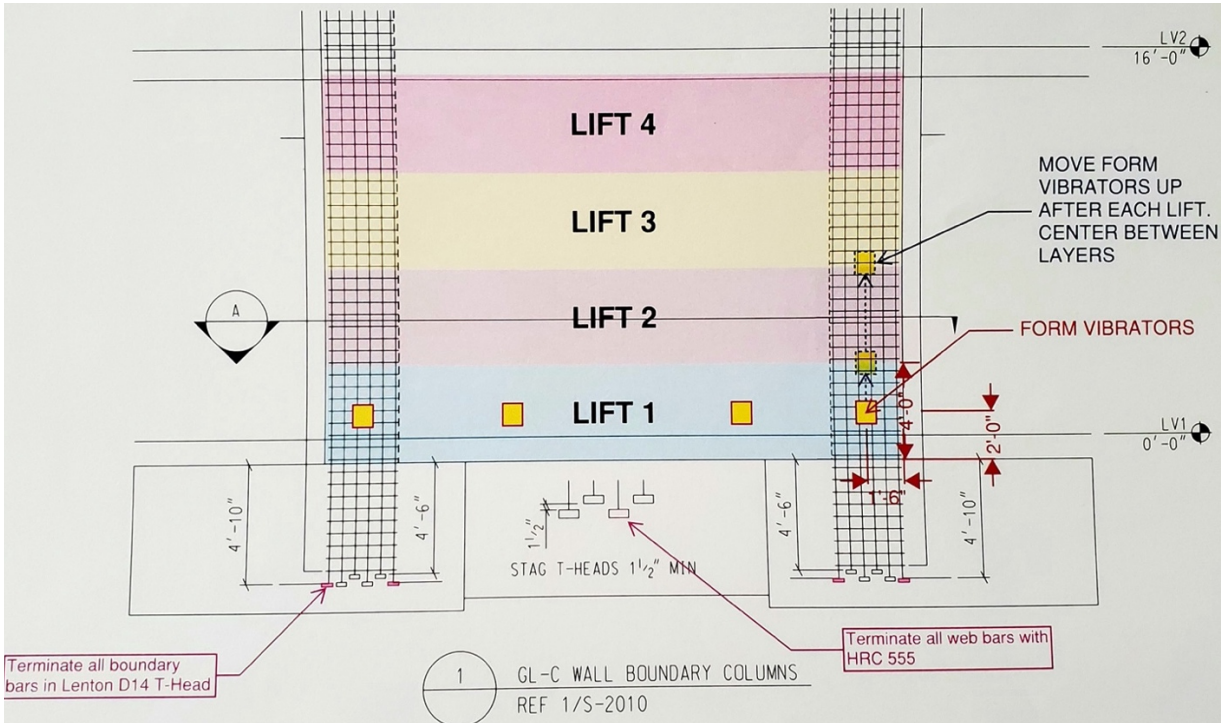


Figure 5.13: Excerpt of Operations Designed to Build Architectural Concrete Shear Walls (Photo: © Sulyn Gomez, 2019-04-24)

5.4.2.3 Documenting Agreements and Communicating Them to the Field

While the DFOW meetings provided that space to understand project participants' expectations and seek alignment before building, documenting the agreements made is just as important for meeting quality requirements.

"There was one bulletin [document with changes from the architect] that happened when we were on level 2 that basically stopped the job for like three weeks. The change was that we added stud rail materials around 13 columns while we were replacing the reinforcing [but such change wasn't reflected in the drawings]. We actually had to move material that was already in place for half of the job. It was a real disaster in document control." – PE

The example above resulted from a change agreed upon during a DFOW meeting but not incorporated in the design documents. The team took corrective actions to prevent the experiences they had from happening again:

"There is now a formal process that we've mapped out that takes into account that we know the change is coming because now we have a weekly meeting to discuss upcoming design changes. There is a review period where we are allowed to review and make comments, and we have the DFOWs documented." – PE

This team documented the agreements they made in terms of quality and posted them in the office (Figure 5.14) and field (Figure 5.15) to show all those involved what the MAC was for the scope and thrive for a consistent execution during construction.

> *"In the office, we now have a packet that we can basically tell other Pes or tell other owners how we've done this work." – PE*

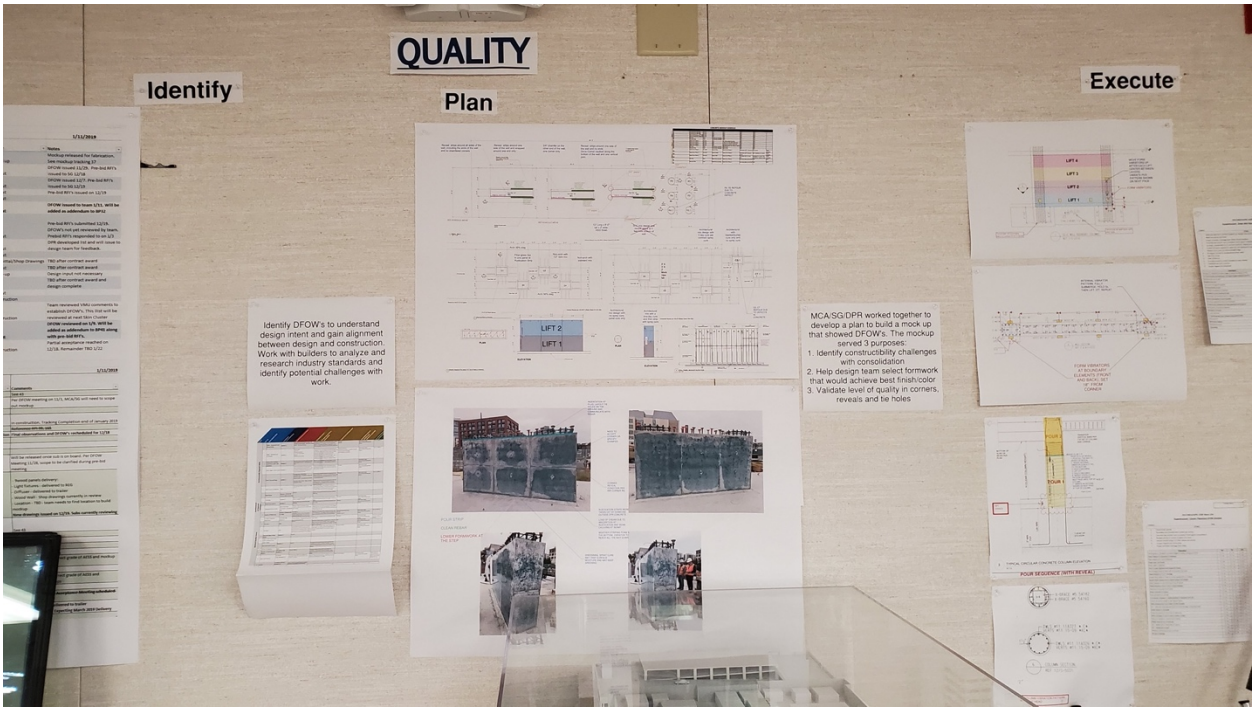


Figure 5.14: Wall Displaying MAC for Architectural Concrete Shear Walls and Overview of Operations to Follow during Construction (Photo: © Sulyn Gomez, 2020-02-24)

The team placed packets of information needed for construction in strategic locations across the project to ease the access for craft:

> *"Those [packets of information placed in the field] are excellent. We're making something that is usually regarded as just workmanship and it's always in someone's head, and now we're making basically a cookbook recipe of it [Figure 5.15]." – PE*

Figure 5.15: Handout Content List Used in the Field (Photo: © Sulyn Gomez, 2020-02-21)

The consistency with which the team documented the quality requirements agreed upon and the process to achieve them helped the team not only to have good outcomes in this project but develop standards for future use:

> *"I think it [BBQ] definitely makes our SPW groups a lot better. Now concrete has a regimen of what to do for architectural concrete. I think they've always got the ability to do it, but now they have it as a recipe of what they could do [to achieve the outcomes we got here]. Now, we have something that the guys in the field can teach other people, teach whole groups at a time and even host sessions on what they can accomplish. It's like a recipe for laying out a formwork using this slab and erecting it this way, check these 5 things before, and it's a checklist, it's very easy to do, then you apply the concrete, and you apply it at this rate, check this rate, you put in the vibrator, you leave it in there for this many seconds and you raise it, and you count. That literally is a recipe that we have in the field. Then wait X days, remove this one A, B, C and we get this product." – PE*

In the next section, I discuss some opportunities for improving the team and explore what else could be done to keep improving.

5.5 Discussion

Training project participants on BBQ:

I observed that some project participants implementing BBQ struggled to understand how to apply it at the project level. Even though every person might have individually been trained on various aspects of quality, it does not necessarily mean that the project participants are ready and aligned on managing quality as a team. Training can support those trying to implement a quality approach and keep the team aligned.

In early 2019, I collaborated with one of the GC's national leaders to develop the company's first BBQ training pilot (Chapter 6). The training introduces key behaviors for quality and illustrates how some teams implemented BBQ at various levels to understand and align expectations, agree to certain quality requirements, and deliver as per agreed requirements. Although the team I studied

for this case did not have the chance to participate in the training when the project was in construction, over 700 employees had taken the training by February 2023.

Engaging all project participants needed in DFOW/MAC conversations, but only those needed:

While BBQ is a collaborative approach and it requires input from various project participants, the project participants in this study understood early on that having more people than needed could cause the process to be longer and more frustrating for those involved as decisions were delayed with input from a large number of people:

> *"There were like 20 people in the same [lab casework] mockup [review], they were pointing out things, writing sticky notes, and making comments here and there and it got almost overwhelming at a point. There was a very strategic way that we could have planned. We wanted [only the architect] to have their initial review because they're responsible for the design, they can comment on things and lead the users' group to see certain things that they're responsible for [and not others]. Once a user comes in, they can go and say, 'why isn't it [casework] black?' And we chose it [the color] 18 months ago, you cannot go back to this, that's the reason why you have the architect go over it first. The architect says, 'Ok I like everything, [now you user] look at these things, e.g., check the drawer, that's your job, don't change color or material, we've already decided that.'... That got out of control for a period of time... I get frustrated when that happens. I think everyone was engaged. It's just when you have that many people engaged, sometimes it can be detrimental to the mockup [or inspecting any work]."*

Over time, the Pes leading each scope better identified who they needed to include in the quality conversations and when. This showed respect for those who participated in the conversations and helped the team manage such conversations where quality expectations were discussed and aligned more efficiently.

5.6 Conclusions

In this chapter, I explored the implementation of BBQ by one project team. BBQ helped project participants manage subjective, vague, and conflicting requirements related to the scope studied. Participants in the BBQ exploratory study felt that BBQ required more work upfront. However, they recognized that it was worth implementing to avoid problems (mistakes, defects, rework) later when the scope is built and does not satisfy expectations. BBQ's basic steps for agreeing to requirements (i.e., expectations to meet) in this project include understanding and aligning on DFOWs and MAC. Project participants did a number of things to achieve this understanding and alignment, from visiting other projects to help establish MAC, to getting input from the craftworkers on work methods, etc.

6. BUILDING QUALITY BUILDERS (BQB) TRAINING

This chapter presents the findings of a study I conducted to refine the BBQS Prototype 1. After conducting the exploratory studies, I collaborated in designing training for one of the general contractors (GC) in the fundamentals of this GC's Behavior-Based Quality (BBQ) approach. This training is called "Building Quality Builders (BQB)." I analyzed some of the data gathered in BQB to refine my prototype.

The chapter is organized as follows. Section 6.1 describes the BQB background. Section 6.2 presents an overview of the data gathered in BQB. Section 6.3 presents my methodology to analyze the data collected. Section 6.4 presents my findings. Section 6.5 discusses my findings. Last, Section 6.6 concludes this chapter.

6.1 BQB Background

Participants in this training are practitioners who have either led the GC's BBQ process or have been involved in the implementation of parts of the quality process (e.g., during preconstruction, in subcontractor coordination meetings). As of 2021, 26 groups with a total of 259 participants have completed BQB. Participants' roles include, for example, project managers (PM), project engineers (PE), estimators, MEP coordinators, foremen, assistant superintendents.

In the BQB training, participants received a variety of materials, including:

1. Videos where leaders of the company describe the BBQ purpose
2. Videos of projects that implemented parts of the GC's BBQ
3. Examples of DFOWs and MAC developed for various scopes in past projects.

6.2 BQB Data

All participants in the training were asked 20 questions (Tables 6.1-6.2) about different parts of the GC's quality process. I co-designed these questions with a member of the GC's quality corporate team. Each participant in the training answered these questions in writing, and then their responses were used to guide live group discussions. I used the responses to 6 of these questions (shown in italics in Tables 6.1-6.2) to develop my prototype 2.

Table 6.1: Questions Asked in the BQB Training and Questions Selected for Refining the BBQS Prototype 1 (1/2)

Question ID	Question Statement	How Question Adds to BBQS Refinement
1	Can you give an example of when you had a misalignment of expectations?	---
2	How does quality apply to [GC] values?	---
3	What are the benefits of implementing [GC]'s quality process?	---
4	What did you hear from George and Rodney?	---
5	*What behaviors do you see when teams implement [GC]'s quality approach (DFOWs and MAC)?*	Identify behaviors desired for the BBQS.
6	*How would you start the conversations about quality, DFOWs and MAC?*	Identify ways to start conversations around quality.
7	Please provide your best definition of DFOW.	---
8	What are potential barriers to implementing a DFOW approach? What strategies would you use to overcome them?	---
9	Why is it important to have a shared quality language at [GC]?	---
10	Why is it important to understand the owner's expectations before starting the work, even in pursuit?	---
11	*How do you communicate quality expectations to trade partners?*	Identify ways to communicate expectations.
12	How do you build a culture of quality in your team and your project?	---
13	*How do you communicate quality expectations to designers and owners?*	Identify ways to communicate expectations.
14	*How do you manage the DFOW/MAC process for your project?*	Identify steps that could support the BBQS processes.
15	*What tool do you use to communicate DFOWs and MA)?*	Identify tools to communicate expectations.
16	How can you make sure DFOW conversations are happening at the right time?	---
17	How could teams benefit from doing cause mapping for quality misses?	---

Table 6.2: Questions Asked in the BQB Training and Questions Selected for Refining the BBQS Prototype 1 (2/2)

Question ID	Question Statement	How Question Adds to BBQS Refinement
18	How do the quality and DFOW approach apply to every work you do in any phase of the project lifecycle? (construction work, mockups, site logistics)	---
19	Report on your DFOW conversation. Did you agree on MAC?	---
20	What actions will you take to show quality leadership from your role, and how will you measure success?	---

6.3 Data Analysis Methodology

For each of the 6 questions selected, I took the following steps:

1. Compile data in a single source: Responses of BQB were recorded in various formats (e.g., Excel spreadsheets, OneNote, Menti, [GC]'s learning center) as the training itself has been in continuous development and the tools used to record the responses have been shifting accordingly. I created a single database with all the BQB responses and one PDF for each of the 6 questions in italics (e.g., an excerpt of compiled responses for question 5 is shown in Figure 6.1).
2. Define questions to explore from the data:

   Q1) what are the behaviors that project participants have observed as fundamentals for quality?

   Q2) how do project participants manage quality when using the GC's BQB approach?

   Q3) how can GCs start quality conversations to get the BBQS rolling?

   Q4) what methods and tools do project participants use or think are best practices for managing quality?

   Q5) how do project participants communicate quality expectations both to the owner and architect and to subcontractors and craftworkers?

Respondent	ID	Questions 5: What behaviors do you see when teams implement DPR's quality approach (DFOWs and MAC)?
Personal information hidden on purpose	23	The trends in behaviors when teams implement DFOW process are as follows: Start early, Don't be afraid to ask questions if you don't know, Clear definitions of expectations ando relayed to all participants leads to success, Reduction in rework
	24	
	25	Have everyone connected to building process with good communication,(do mock ups, evaluate submittals, share information with sub contractors) in an early manner
	26	Trends in behavior.... This should be a very early-on meeting, asking the right questions, and involving the owner. This should be an item that is visually shown and communicated to the field, and it should be continuously followed up on. Like on a subcontractor or OAC meeting. Visual aspects.
	27	Follow up on the MAC
	28	
	29	Be proactive, Communication and transparency within that communication. Find out what is important to the owner. Hash out all the focus points/distinguishing features early-plan for them, write them down, and present them to let everyone know what they are. Which ties back to uniqueness and when we plan for these focus points the work should be enjoyable.

Figure 6.1: Excerpt of Responses for BQB Question 5

3. Identify patterns in the responses: After reading through all the responses for each of the questions, I noted the different themes or topics that became more repetitive and manually color-coded these themes (Figure 6.2). I took a deductive coding approach and created a list of pre-defined codes that I deemed applicable to the topic based on my literature review.

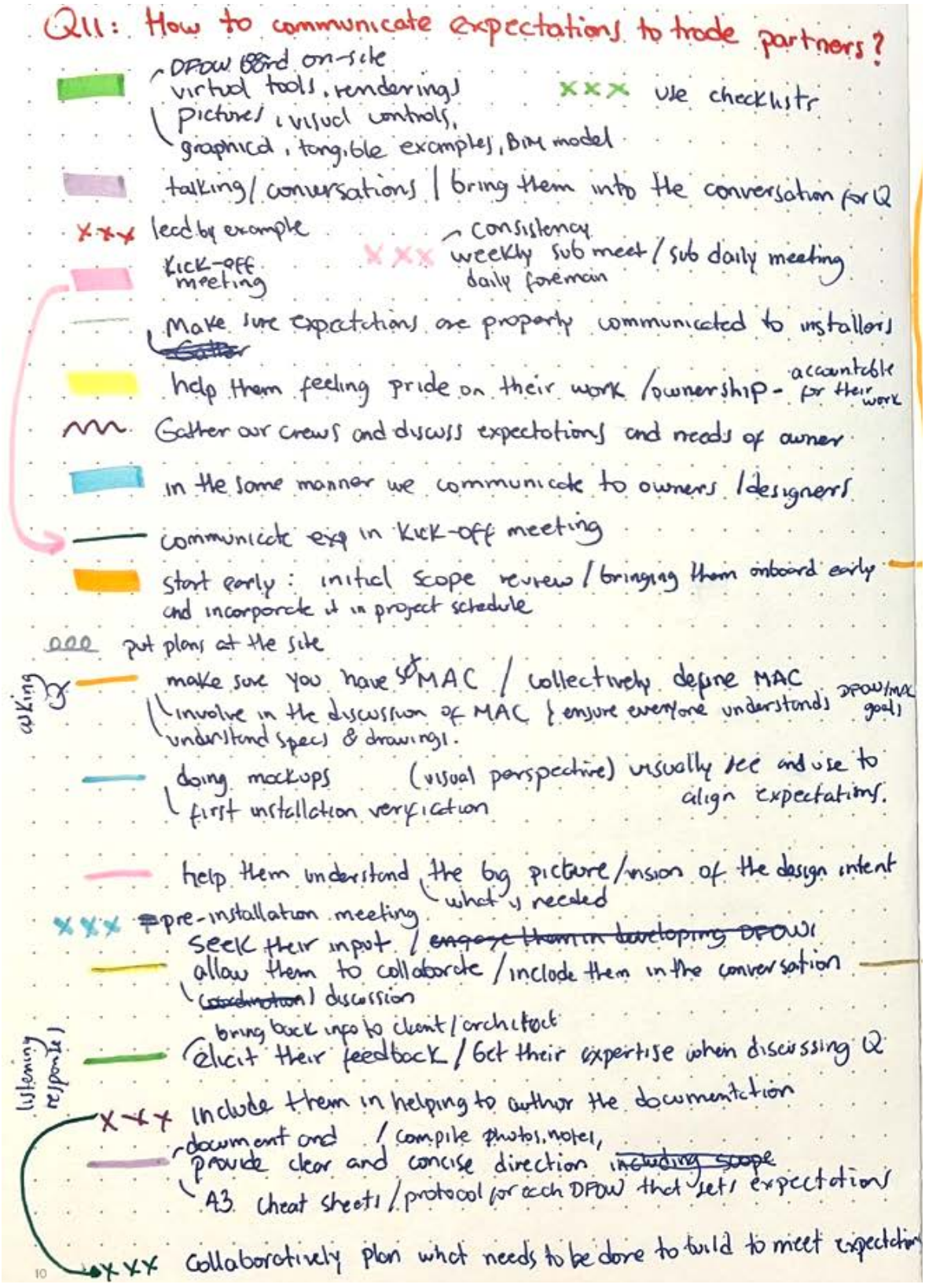
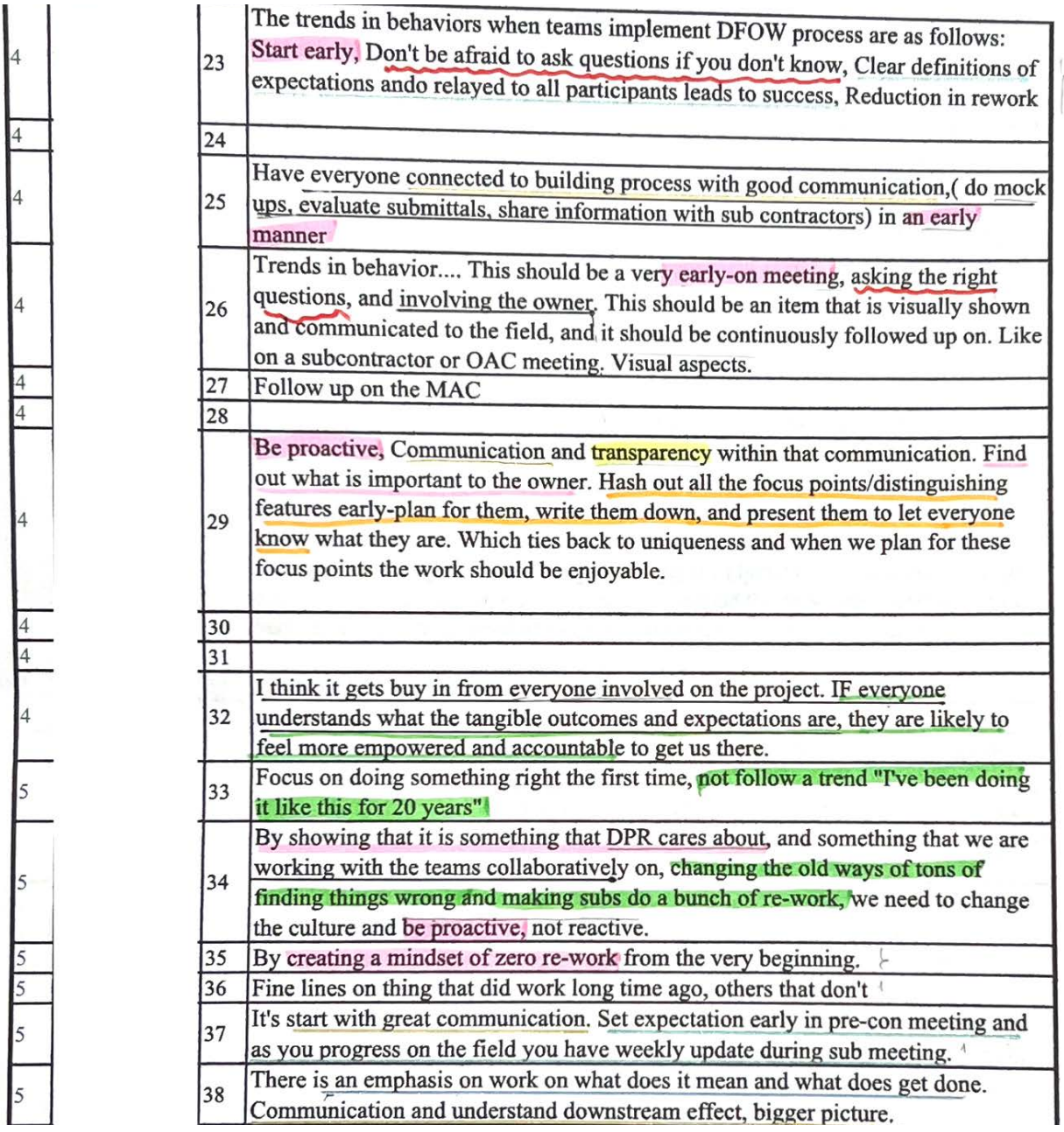


Figure 6.2: Excerpt of Color-Coded Categories for BQB Question 11

4. Manually color-code responses: I conducted my first round of coding (Figure 6.3) using the color-codes initially developed. In addition to the deductive approach from the previous step, I used an inductive coding approach and read all the responses in detail to add new codes representing themes that were not identified previously. Using this approach, new codes emerged from the raw data itself.



4	23	The trends in behaviors when teams implement DFOW process are as follows: Start early, Don't be afraid to ask questions if you don't know, Clear definitions of expectations ando relayed to all participants leads to success, Reduction in rework
4	24	
4	25	Have everyone connected to building process with good communication,(do mock ups, evaluate submittals, share information with sub contractors) in an early manner
4	26	Trends in behavior.... This should be a very early-on meeting, asking the right questions, and involving the owner. This should be an item that is visually shown and communicated to the field, and it should be continuously followed up on. Like on a subcontractor or OAC meeting. Visual aspects.
4	27	Follow up on the MAC
4	28	
4	29	Be proactive, Communication and transparency within that communication. Find out what is important to the owner. Hash out all the focus points/distinguishing features early-plan for them, write them down, and present them to let everyone know what they are. Which ties back to uniqueness and when we plan for these focus points the work should be enjoyable.
4	30	
4	31	
4	32	I think it gets buy in from everyone involved on the project. IF everyone understands what the tangible outcomes and expectations are, they are likely to feel more empowered and accountable to get us there.
5	33	Focus on doing something right the first time, not follow a trend "I've been doing it like this for 20 years"
5	34	By showing that it is something that DPR cares about, and something that we are working with the teams collaboratively on, changing the old ways of tons of finding things wrong and making subs do a bunch of re-work, we need to change the culture and be proactive, not reactive.
5	35	By creating a mindset of zero re-work from the very beginning.
5	36	Fine lines on thing that did work long time ago, others that don't
5	37	It's start with great communication. Set expectation early in pre-con meeting and as you progress on the field you have weekly update during sub meeting.
5	38	There is an emphasis on work on what does it mean and what does get done. Communication and understand downstream effect, bigger picture.

Figure 6.3: Excerpt of Color-Coded Responses for BQB Questions 4-5

5. Categorize nodes: After my first-round pass at coding the responses using a combination of deductive and inductive approaches, I grouped them into categories (Figure 6.4). I grouped codes that were similar or pertained to the same topic to respond to the questions I created for refining BBQS.

Q14
How do you manage the DFOW/MAC process for your project?

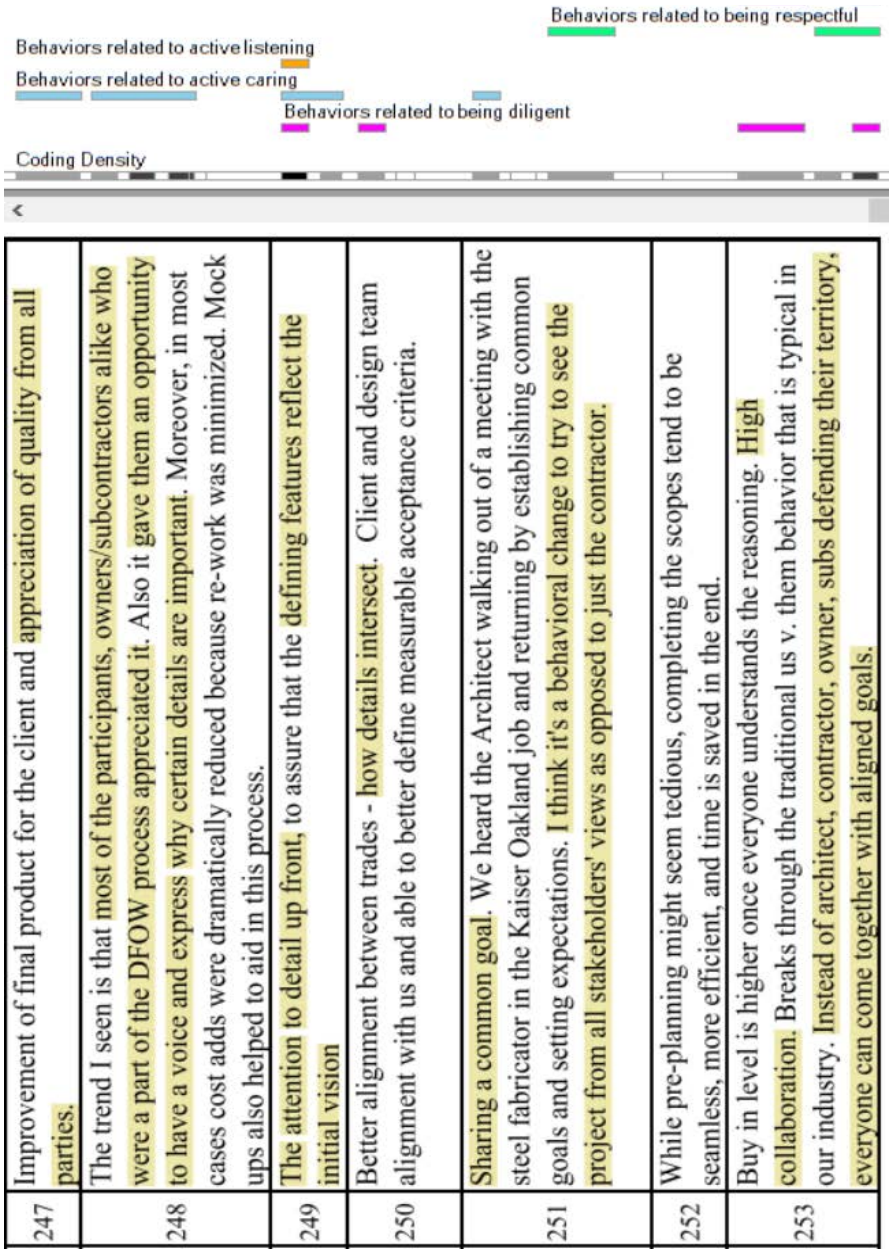
Get process ready to start	Get people ready to start	Roll out process planning	Maintain process
Agree on a process to follow (e.g., frequence of meetings, responsibility matrix)	Learn from owners, architects, AHJ, and trade partners	Involve all needed participants and ensure everyone has a space to share	Consistenly guide conversations to allow sufficient understanding of expectations and alignment
Do prework: study drawings and specs, create visual rendering if needed, set a list of questions (inconsistencies, RFIs needed), collaborate with preconstruction team, run preflight meetings, and create an initial list of DFOW/MAC	Educate and train participants: Help building process capability	Schedule quality conversations with an adequate time to act	Consult participants needed for input to shape expectations (trained foreman, MEP coordinators e.g., constructability feedback, shop drawings needed)
Use organization resources (pump primers, vConstruct, quality plan)	Get process buy-in (set the table and tone)	Organize quality kick-off meeting	Keep meeting minutes and send them out to all after meetings

Figure 6.4: Excerpt of Categorized Themes for BQB Question 14

6. Refine coding: I imported each of the PDFs with responses compiled to NVivo 12[6] to do a further round of coding data (Figure 6.5) and re-examine the codes I created by hand. In this round, I went through all the responses and reassigned codes using the categorized themes created in the previous step. Through this additional round of coding, I identified trends such as common tools used to communicate quality expectations and the behaviors in practice. All my final node categories are shown in Appendix 7.

I used the outcomes of this analysis to improve BBQS prototype 1 and develop prototype 2, e.g., by expanding the BBQS processes with steps that practitioners suggested taking to deliver quality.

[6] NVivo 12 is a qualitative data analysis software for coding and analysis (QSR International 2021).



247	Improvement of final product for the client and appreciation of quality from all parties.
248	The trend I seen is that most of the participants, owners/subcontractors alike who were a part of the DFOW process appreciated it. Also it gave them an opportunity to have a voice and express why certain details are important. Moreover, in most cases cost adds were dramatically reduced because re-work was minimized. Mock ups also helped to aid in this process.
249	The attention to detail up front, to assure that the defining features reflect the initial vision
250	Better alignment between trades - how details intersect. Client and design team alignment with us and able to better define measurable acceptance criteria.
251	Sharing a common goal. We heard the Architect walking out of a meeting with the steel fabricator in the Kaiser Oakland job and returning by establishing common goals and setting expectations. I think it's a behavioral change to try to see the project from all stakeholders' views as opposed to just the contractor.
252	While pre-planning might seem tedious, completing the scopes tend to be seamless, more efficient, and time is saved in the end.
253	Buy in level is higher once everyone understands the reasoning. High collaboration. Breaks through the traditional us v. them behavior that is typical in our industry. Instead of architect, contractor, owner, subs defending their territory, everyone can come together with aligned goals.

Figure 6.5: Excerpt of Coding in NVivo for BQB Question 5

6.4 Findings

6.4.1 Understanding Behaviors Desired for Quality in Practice

Tables 6.3-6.4 illustrate how the behaviors desired for the BBQS are observed by practitioners involved in the quality delivery process.

Table 6.3: Behaviors in Practice Described by Project Participants (1/2)

Behavior in Place		**Count**[7]
Being respectful		***46***
	Engaging needed stakeholders	20
	Being open, honest, and candid when having conversations	8
	Understanding stakeholders see things from different perspectives	6
	Being respectful with each other	5
	Transferring easy and clear information to the ones building	4
	Helping everyone have a better understanding of the work	3
Active caring		***125***
	Creating clear visions of goals to meet	28
	Understanding what is important to stakeholders and why before moving forward	27
	Feeling proud and excited about the work done	25
	Fostering high team morale and a positive team atmosphere	17
	Seeing quality as paramount	17
	Fostering ownership	6
	Checking-in regularly	2
Making reliable promises		***31***
	Holding stakeholders accountable, making commitments	22
	Being consistent	4
	Building as per agreed expectations	3
	Inspecting as per agreed expectations	1
	Providing alternatives	1
Speaking up		***46***
	Building trust, integrity, transparency	21
	Asking questions as needed; no asking the -right- questions	11
	Speaking up and having the courage to discuss the uncomfortable	9
	Increasing familiarity	3
	Providing and soliciting feedback	2

[7] The "Count" in this table refers to the number of times the listed behavior was counted in the responses analyzed. The number of times a behavior was mentioned in this table does not reflect the importance of such behavior; the count is only the quantification of the number of times participants recall observing the behavior in practice while managing quality.

Table 6.4: Behaviors in Practice Described by Project Participants (2/2)

Behavior in Place		Count
Being diligent		***143***
	Collaborating and willing to participate	54
	Making sure there is alignment about the expectations to meet, so everyone is on the same page	26
	Paying attention to details	14
	Developing plans to execute as per agreements made	13
	Being focused	11
	Documenting agreed expectations	9
	Understanding how to do things before proceeding	6
	Accepting that drawings and specs might not tell the whole story nor the best method	5
	Being curious, inquisitive	3
	Keeping track of performance	2
Active listening		***77***
	Communicating assertions, no assessments	39
	Anticipating, having conversations early and routinely before work takes place	33
	Paying attention to what others say	5
Active learning		***7***
	Learning from experiments and breakdown	5
	Focusing on problem-solving	1
	Sharing knowledge	1

When implementing the BBQS, the above are examples that can be shared with practitioners to illustrate how others have seen each of the BBQS behaviors look in practice.

6.4.2 Starting and Continuing Quality Conversations

BQB participants suggested the following strategies when starting the quality process:

1. Get participants' buy-in and maintain them engaged
2. Show participants that they are contributing to quality and get their commitment
3. Have conversations about quality expectations and define requirements to meet. For DFOWs/MAC, the GC can start with a preliminary list to guide the discussions with other project participants who have a stake in the scope
4. Make quality part of existing conversations, e.g., meetings with clients and architects, coordination meetings
5. Train participants on the way quality is managed in their projects

6. Put the behaviors described in the previous section in practice, e.g., be respectful of others' expectations, try to understand others' vision and reasoning behind why they care about something, and include them in the decision-making process to define quality expectations.

6.4.3 Strategizing Communications about Quality

Table 6.5 summarizes the strategies the BQB participants highlighted to communicate quality expectations and requirements between the GC, owners, architects, and subcontractors.

Table 6.5: Strategies in Communicating Quality Expectations

Strategy	Description
Starting quality conversations early	Communicate quality process to project participants in the bidding phases so they buy considering the expectation of their involvement in quality conversations throughout the project delivery.
Including quality conversations in all relevant instances to the extent possible	Include quality conversations during the bidding process, orientation, kick-off meetings, preconstruction meetings, mockups, first-in-place installations.
Engaging and leading participants by example	Build a united front for quality, share and celebrate quality stories, and treat all in the same respectful way.
Co-developing plans for the field	Build plans for what needs to be done in the field to meet quality requirements, make sure craftworkers participate and are bought into the plan, and put plans accessible in the field.
Co-developing design documents to show requirements that convey agreed expectations	Involve all those who have a stake in a scope to participate in the review and update of project documents (drawings and specifications) to provide input in the quality conversations and make sure any changes are documented.

As project participants have conversations to understand their expectations and start aligning what requirements are to be met, they need to design what tools to use to communicate such requirements. Appendix 8 describes various tools practitioners use to communicate requirements, from the design drawings to A3s consolidating DFOW/MAC conversations.

6.4.4 Summarizing the Quality Process

BQB participants described various parts of the quality process that can be grouped as follows:

1. Get people and process ready to start: Get familiar with those involved in the process, share examples of past projects to illustrate various parts of the process, and agree on a project-specific process to follow
2. Roll out process planning: Schedule quality conversations with enough time to act and put quality into the agenda

3. Get ready for building: Foster accountability and reliable promises; keep craftworkers informed of the requirements to meet and use visuals aids and checklists to communicate requirements in the field
4. Maintain process: Be consistent in documenting quality conversation agreements; make sure agreements are included in project documents
5. Follow-up and learn: Control quality against the agreed requirements, track metrics for improvement, and develop plans for continuous improvement.

6.5 Discussion

Planning to deal with some expected but not desired behaviors

In addition to the behaviors described above, which are desired for quality, BQB participants also described some challenging behaviors that teams might encounter when managing quality. These include some participants not seeing the value of the DFOW/MAC process, being apprehensive and showing negative stigma, thinking of quality as aesthetics only, and relegating the quality responsibility to one person (quality champion) only.

6.6 Conclusions

In this chapter, I explored practitioners' input on various parts of the quality process from the perspective of a GC. I learned and summarized how the behaviors desired in the BBQS were observed by these practitioners. In addition, I highlighted some of the strategies and tools they use when communicating quality expectations.

7. BBQS REFINEMENT CASE 1

This chapter presents the findings of a retrospective study I conducted to refine BBQS Prototype 2. Project Case 1 was chosen based on the General Contractor (GC)'s quality corporate team, Bay Area Quality Support, and the GC's self-performed work (SPW) drywall leadership's advice. They suggested Case 1 being among their best Bay Area projects. I used Case 1 data to analyze the relationship of my model variables (team psychological safety, behaviors for quality, and team performance), and document what the team did to let them successfully deliver quality.

The chapter is organized as follows. Section 7.1 introduces the project background. Section 7.2 describes the methods used to analyze the study data. Section 7.3 analyzes the model variables. Sections 7.4 and 7.5 illustrate the project's processes, methods, and tools that supported the team in delivering quality. Section 7.6 presents the project's DFOWs applicable to the scope of the study. Section 7.7 presents a discussion of the findings. Last, Section 7.8 concludes this chapter.

7.1 Project Background

7.1.1 Project Overview

Case 1 is a Tenant Improvement (TI) project. The building area is 154,000 square feet and includes labs, a vivarium, and office spaces. DPR had various SPW scopes on this project, including drywall, concrete, doors-frames-hardware (DFH), acoustical ceiling tile (ACT), and thermal and moisture protection. I focused this research on drywall scopes.

7.1.2 Project Delivery Method and Project Team

Case 1 was delivered under a Design-Build (DB) contract. Due to the collaborative nature of DB projects, some stakeholders were onboarded early during design, including the designers, the GC, and MEPF trades. All SPW scopes had a lump sum contract agreement with the GC. This project started in the first quarter of 2021, around the time UCSF Block 23A was reaching completion. Most of the GC's admin team transitioned from the Block 23A project to Case 1.

7.2 Methods

I studied Case 1 using a combination of methods to analyze the variables in my model and identify best practices the team used to deliver quality. My primary contact at Case 1 was a project manager (PM) who led quality onsite and collaborated closely with me to facilitate data collection.

The study involved two phases of data collection. First, using qualitative methods, I visited the site and conducted in-depth interviews (Appendix 9) to describe the team's quality process. Second, using a quantitative method, I designed and administered one survey to measure the three variables in my model, including psychological safety, behaviors for quality, and team performance.

7.2.1 Site Visits and Interviews

I visited Case 1, while in construction, in September 2021, May 2022, and July 2022. In the following sections, I use site visit photos to illustrate various instances of the quality delivery process. In addition, between August and September 2022, I interviewed 10 project participants. As described in Section 3.3, I used a purposive sampling technique and interviewed at least one participant of each role involved in the quality delivery process for the scopes studied.

In interviews, I asked team members to describe their quality process, from defining requirements to inspecting delivered work and managing lessons learned. I transcribed the interview recordings for analysis to answer the following questions:

1. What are the distinguishing features of work (DFOW) for the scopes studied?
2. What was the project team quality process? (i.e., what steps were followed, and who participated in these steps?)
3. What methods and tools were used in the quality delivery process?
4. What learning strategies were adopted when the measurable acceptance criteria (MAC) were not met?
5. What evidence do participants provide for their assessment of the study variables?

After transcribing and reading through the interview responses, I used a combination of deductive and inductive coding to analyze the transcripts. I used a deductive coding approach based on BBQS Prototype 2 elements to document Case 1's quality process specifics. Then I used an inductive coding approach to identify details from reading through the data and provide evidence of the study variables to assess the consistency of the survey outcomes.

7.2.2 Survey

All project participants who were part of planning or building the scopes were invited to participate in the surveys (Appendix 10). Most participants completed the surveys and returned them to me in sealed envelopes. In a few cases, they completed the survey online. The sample consisted of 25 participants, including 7 staff and 18 craftworkers. I received 22 responses, an 88% response rate, including 5 staff and 17 craftworkers.

I used a few reverse questions in the survey to keep respondents from answering carelessly. Later, I learned that while staff members interpreted the reverse questions correctly, many craftworkers reported having difficulty understanding or responding to them. The following subsections describe the analysis I conducted to assess the adequacy of the survey instrument.

7.2.2.1 Survey Reliability

I used Cronbach's alpha to measure the internal consistency of my instrument and determine its reliability. This survey measures the three variables of my study using multiple questions on a 1-7 Likert scale. Each variable is subdivided into sub-variables. Psychological safety variable is divided into 2 sub-variables. Behaviors desired for quality variable is divided into 7 sub-variables. Similarly, team performance variable is divided into 2 sub-variables. Table 7.1 shows each sub-variable's alpha value.

Table 7.1: Cronbach's Alpha and Statistics for Study Variables and Sub-Variables

Variable	Sub-variable	# of Items	α	Mean	SD
Psychological safety (PS)		**20**		**5.893**	**0.846**
	In relation to team leader	10	0.923	5.714	1.185
	In relation to other members of the team	10	0.872	6.073	0.730
Behaviors desired for quality (BQ)		**52**		**5.851**	**0.721**
	Being respectful	7	0.907	5.935	0.916
	Actively caring	9	0.807	5.965	0.720
	Making reliable promises	7	0.734	5.474	0.852
	Speaking up	8	0.840	5.994	0.732
	Being diligent	7	0.776	5.968	0.676
	Actively listening	7	0.907	5.656	0.985
	Learning	7	0.818	5.916	0.697
Team performance (TP)		**10**		**6.327**	**0.494**
	Project outcomes	9	0.764	6.298	0.540
	Comparison with past projects	1	N/A	6.591	0.503

Most researchers desire a minimum Cronbach's alpha value of 0.70 for reliability (Schmitt 1996). Based on Case 1 survey responses, some alpha were close to 0.70 for a few sub-variables. To improve the reliability of the way each sub-variable was measured and simplify the data collection instrument, I examined the factor loadings for each sub-variable in the following section.

7.2.2.2 Factor Analysis

Factor analysis is a technique especially suitable for analyzing relationships between survey questions. I examined each sub-variable to determine the extent to which each question was related to the sub-variable. Because I prepared the set of questions for each sub-variable based on previous studies that measured a similar psychometric variable, I loaded all the questions per sub-variable into a single factor. Through the factor analysis, I assessed which questions explained most of the variance within a sub-variable (higher factor loads explain the larger variance). I observed that some factor loadings were low (below 0.7) in Figure 7.1. I identified to which questions these belonged and randomly interviewed some survey participants. In these interviews, craftworkers pointed out the questions that were hard to understand, including all the reverse questions and a few of direct ones. For the next round of surveys, I either removed or reworded these questions for clarity, depending on their factor loads and whether the answer to the question could be inferred by other question(s) in the same group.

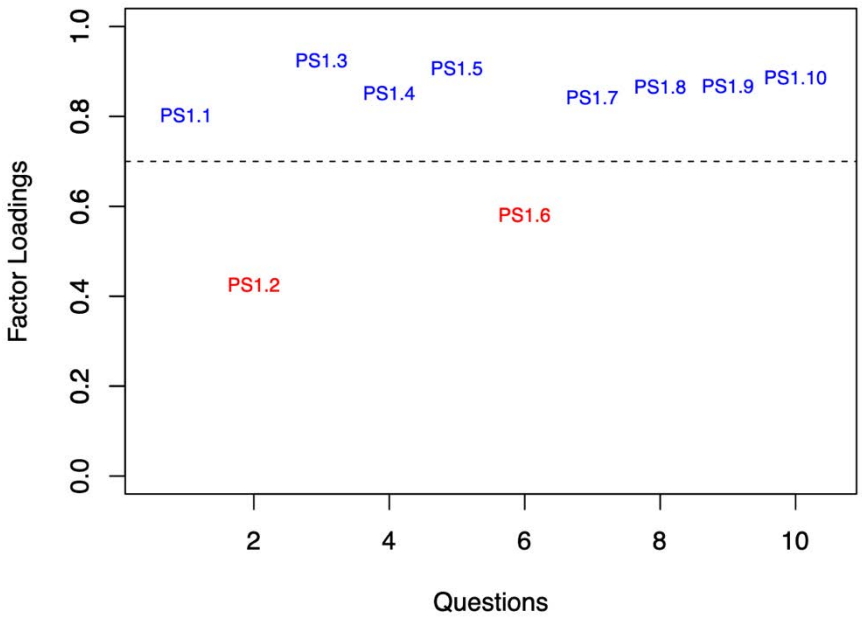


Figure 7.1: Factor Loadings for Psychological Safety in Relation to Supervisor Sub-Variable

For the psychological safety in relation to supervisor sub-variable, 2 questions had a factor loading below 0.70. Workers reported that question PS1.2 ("It is difficult to ask the leader of this team for help") was confusing to understand. In addition, the response to this question can be inferred from the response to questions PS1.1 and PS1.8, so I removed PS1.2 for the next round. For PS1.6 ("If I see a colleague making a mistake, I feel safe speaking up to my team leader"), workers reported that typically, when they see a colleague making a mistake, they approach the person and talk to them, but it did not mean they felt psychologically unsafe to speak up to their team leader. I removed question PS1.6 for the next round. I analyzed each of the sub-variables in the same way. Appendix 11 describes the results of the factor analysis I conducted for the remaining sub-variables. Appendix 12 shows my refined survey instrument used in Case 2.

7.3 Team Psychological Safety – Behaviors for Quality – Performance

7.3.1 Team Psychological Safety

Case 1 team's psychological safety score was 5.893, on a 1-7 scale where 1 and 7 represented a low and high psychological safety environment, respectively. The team score, on the medium-high spectrum, was evidenced through the interviews:

> *"It was really easy to converse with anyone If I needed something. I had to use 14-20 different drawings [to input information to Dusty robot], and they had different people on the team dealing with those. I was very comfortable to go and ask to understand the drawings." – Virtual design and construction (VDC) Engineer*

> *"[on this team] We can rely on one another. We can admit our mistakes and our shortcomings." – Architect*

> *"I believe that we make it safe for everybody to discuss." – SPW Drywall PM*

"I'm not shy reporting any mistakes that I make, and no one here is... Everyone can speak up here." – GC Assistant Superintendent

I measured psychological safety from two perspectives; how psychologically safe participants felt when it came to interacting with their team leaders (PS1 = 5.714) versus their peers/other members of their project team (PS2 = 6.073). From the exploratory studies at Block 23A and Block 33, I found that strengthening relationships with supervisors positively influences psychological safety. In those studies, I also found that psychological safety may be influenced by the time team members worked together on the same project, the time they have been working for their companies, and the company they work for (e.g., GC, subcontractors, designers). Due to the limited number of data samples collected in Case 1, I analyzed the results using one category only, the membership of the participant, whether the participant was a staff or craft member. Table 7.2 shows the results of both subgroups.

Table 7.2: Perception of Team Psychological Safety from Staff and Craft

Psychological Safety	**Craft Perception**		**Staff Perception**	
	M	*SD*	*M*	*SD*
In relation to team leader (PS1)	5.418	1.18	6.720	0.26
In relation to other members of the team (PS2)	5.947	0.77	6.500	0.33

Even though all study participants were part of the same project team, craftworkers reported lower psychological safety than the staff did. At the onset of the project, all the staff who were onboarded on the project at that time participated in team-building exercises provided by an external consultant to help them function as a high-performing team. As part of these exercises, the consultant assessed team members' personalities and used that information as an icebreaker to help them know each other better. Throughout the project execution, the team held some happy hours and team lunch-and-learn sessions.

"Team lunches are great; you can just sit and talk to people and hear about what they do on the weekends… It helps to build interpersonal skills." – Architect

From Table 7.2, I found psychological safety in the craft group as an opportunity for the team to foster psychological safety further. The team leaders, from the project managers to the trades' superintendents and foremen, play a key role in improving psychological safety within craft; for instance, by exhibiting examples of behaviors that they would like craft to display to help them feel psychologically safer:

"I've learned this over the years… when I make a mistake, I try to be like, hey look, I did this, this is how we're going to deal with it [solve it], I made a mistake. I try to do that so that it's okay when other people make a mistake, they can say something, and then we can work through that. Hiding it can be bad." – SPW Drywall PM

In the next sections, I analyze the team behaviors, present evidence of how they took place onsite, and what opportunities Case 1 team could have explored to improve further.

7.3.2 Team Behaviors for Quality

As reported in Table 7.1, all behavior sub-variables were scored at 5.4 or above on average. I analyzed the distribution of responses per sub-variable. Figure 7.2 shows the count distribution for each sub-variable using the mean rounded down per participant.

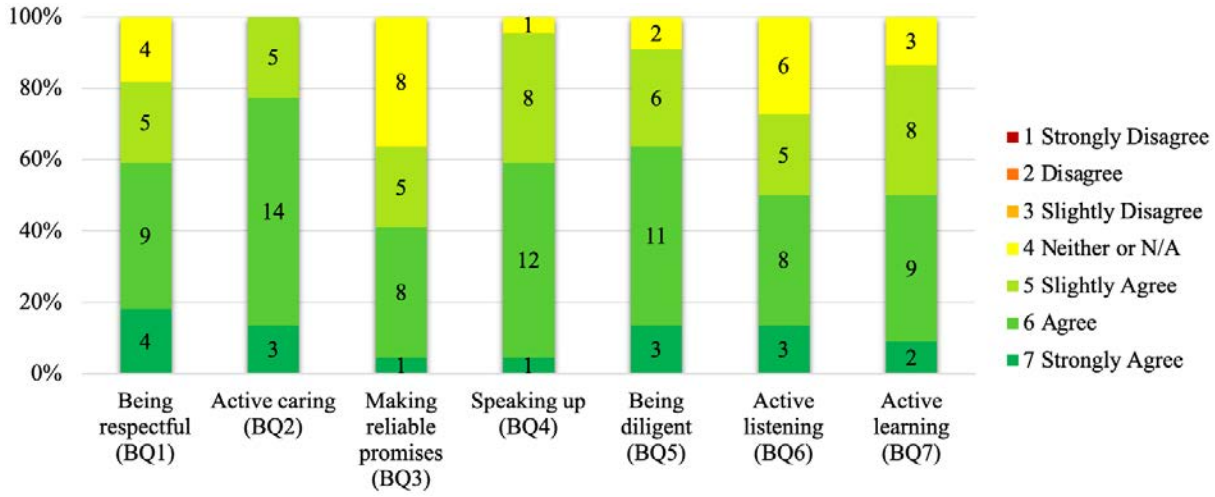


Figure 7.2: Case 1 Reporting Count of Behaviors Desired for Quality (n = 22)

Figure 7.3 shows the mean for each sub-variable and the standard error divided by staff and craft members (active learning $M_{Staff} = 6.34$, $SD = 0.46$; $M_{Craft} = 5.79$, $SD = 0.71$; active listening $M_{Staff} = 6.31$, $SD = 0.44$; $M_{Craft} = 5.46$, $SD = 1.02$; being diligent $M_{Staff} = 6.43$, $SD = 0.41$; $M_{Craft} = 5.83$, $SD = 0.68$; speaking up $M_{Staff} = 6.50$, $SD = 0.29$; $M_{Craft} = 5.84$, $SD = 0.76$; making reliable promises $M_{Staff} = 6.37$, $SD = 0.50$; $M_{Craft} = 5.21$, $SD = 0.75$; active caring $M_{Staff} = 6.49$, $SD = 0.33$; $M_{Craft} = 5.81$, $SD = 0.73$; being respectful $M_{Staff} = 6.68$, $SD = 0.32$; $M_{Craft} = 5.71$, $SD = 0.92$).

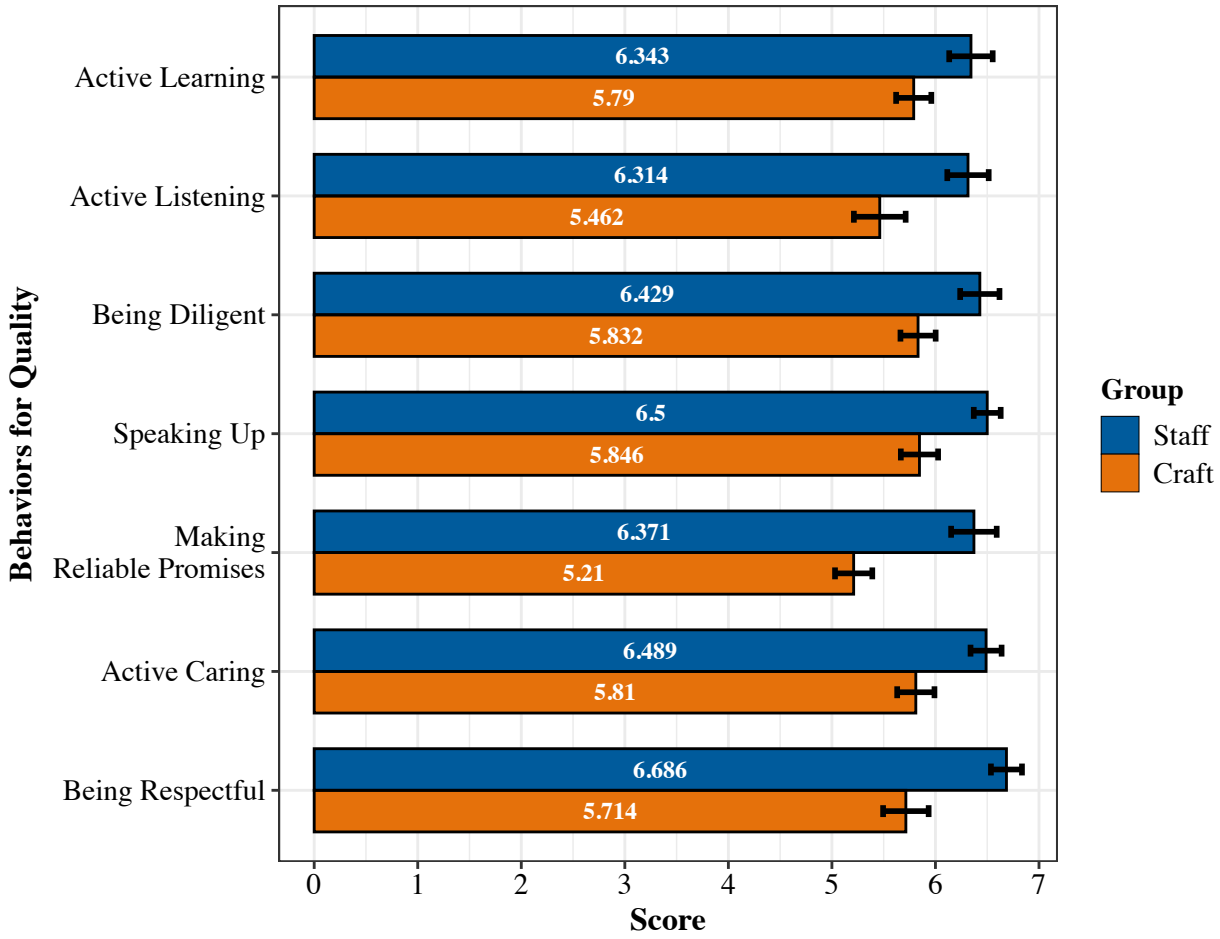


Figure 7.3: Case 1 Scores for the Behaviors Desired for Quality Sub-Variables

I used the interviews to better understand what prompted the survey scores. The following sections present interview excerpts to illustrate each sub-variable (BQ1-BQ7).

7.3.2.1 Being Respectful

Participants reported being treated with respect and having received opportunities to develop their capabilities. The Lean principle of respect for people is reflected in the team's effort to appreciate diversity and learn about other team members' perspectives, while helping them continue expanding their knowledge. This effort was oriented toward both, staff and craftworkers. For staff, for example, the BIM coordinator, GC's preconstruction executive, and SPW superintendent took the GC's training on quality (Building Quality Builders). For craft, who already have 4 years of union training, the GC held training sessions on several topics, for example, best practices in firestopping. Similarly, SPW drywall trained a couple of their workers on the use of the layout robot so they could operate it themselves.

> *"From the questions that we answered and the profiles that he [the consultant] generated, he was able to say, 'you are this kind of person, you'll actively go out, and you will actually say hi to everyone, and you'll do this, and you'll do that.' And I think that really helped us all to understand people a bit better at those early stages in the project." – Architect*

"All the ideas were always heard, whether you were an engineer or a manager, everyone was heard equally, and I'd say that as a great sign of respect… [when using Dusty onsite, the GC asked Dusty users] did you feel it was useful onsite? Was it confusing to you? What else do you think we should layout onsite with Dusty?... there was definitely a lot of feedback after each area [was completed], and we kept iterating the [layout] process to make it better and more useful [GC's engineer leading Dusty operation was willing to admit the limits of her knowledge and felt safe to ask for help]." – VDC Engineer

Although the participants interviewed reported that team members generally got along well and intentionally planned activities to become a high-performing team (e.g., personalities assessment), the GC could have explored the following initiatives to foster more consistency. First, considering that new companies and employees get onboarded at separate times on the project, the team could have used a quality implementation plan (QIP) describing at a high level the expectations for how this team managed quality. In this way, newcomers can get up to speed faster. Second, the project could have developed some craft-focused team-building sessions to help this group feel appreciated and appreciate others, and show it through respectful behaviors. Because of the survey results and the relationship between respect for people and psychological safety described in the literature, the team could have further fostered both simultaneously.

7.3.2.2 Active Caring

Participants described many actions the team took showing active caring, e.g., by preventing or minimizing trade damage to the extent possible, engaging team members in quality conversations, and providing craft the information they needed to build.

"It was refreshing having a young, energetic team that was out there to do a great job." – Architect

"We print all the spool sheets and have them ready for our guys... [In addition, the GC superintendent] was awesome. She had it all detailed out. She knew exactly what was going to happen." – SPW Drywall Superintendent

"This is the first job in which I found it easy to find the information we needed... The GC superintendent helped us a lot in that aspect; all walls had the QR codes with relevant information… whenever we had a question, or something didn't seem right, they [GC, architects] clarified things for us." – Drywall Foreman

"Every person I talked to on the project every time was always very passionate about their part on the project, always trying to follow up and do the best they can." – VDC Engineer

"When we walk the site [to look at trade damage] with two foremen and identified a damage, one said, 'hey, you took care of this for me the other day, don't worry about it; I'm going to go and fix this now'." – GC PM

The team hosted DFOW conversations for various scopes of work; drywall was not one of them, but still, they planned the scope well, heavily relying on the experience of the SPW drywall team.

"Drywall doesn't really have DFOWs." – GC PM

Even though drywall may seem a straightforward scope, it is important that the team engages in DFOW conversations to get aligned on the key features of the work. As I describe in later sections, the team and I created a list of drywall DFOWs applicable to Case 1.

7.3.2.3 Making Reliable Promises

Participants reported doing well in making and keeping commitments as a team, e.g., agreeing to apply level 5 finish to a drywall wall, considering the resources available of manpower and time required to complete the work per the acceptance criteria. When commitments were not achievable, participants provided counterproposals or said "no" with explanation of why it either should not or could not be done as requested:

> *"On this project, requests were talked as a group; sometimes [GC] would say this area has to be done tonight, then we would talk about it, [and make a counterproposal], and we would agree to finish half of it that day and the rest the following day." – SPW Drywall Superintendent*

> *"We are good about saying when something is not achievable. They [other team members] might not agree with this, but there it is." – SPW Drywall PM*

> *"When we cannot commit, we explain why. They [GC] are very reasonable." – SPW Drywall Foreman*

Constant check-in and talking about the upcoming work helped the team make work ready and be prepared for upcoming work:

> *"We sit down regularly in the big room and say, what's coming up? What information do I need? What information do you need? Can you get this done by Friday, or is this something that's going to take longer?" – Architect*

> *"[for the QC walks] we distribute an agenda to the architect saying, 'this is what we're going to walk today' [to set clear expectations on what we committed to delivering for inspection by that date]." – GC Assistant Superintendent*

While it is good that many people reported being able to make reliable promises for the project's success, it is important that everyone in the project understand what alternatives they have when they receive a request. As discussed in earlier sections, craft psychological safety was lower than staff. A requirement for reliable promising is the ability to say "no." If craft don't feel psychologically safe, they may commit to things they are not confident of achieving.

7.3.2.4 Speaking Up

Participants reported being confident when expressing their thoughts, concerns, questions, etc.

> *"I like to ask; I prefer to ask or be asked rather than do the thing again." – SPW Drywall Foreman*

> *"Experimentation was always communicated; we'd say I'm really confident about this, but I know these are the things that might or might not work." – VDC Engineer*

> *"Most people have felt empowered to say, 'I think I've got an issue here; can I just talk to you about it?', even if it's just as simple as: 'am I being crazy?', can you just take a look at this real quick one?" – Architect*

As shown in Table 7.2, Case 1 had some room for improvement in fostering a psychologically safe work environment, which is closely related to speaking up. While many people in the team

reported feeling safe to speak up, it is important that they do not over-rely on others' confidence to speak up, especially among craftworkers.

> *"If I have a problem, I talk about it, and it's a lesson learned. If my foremen make a mistake, they come to me and tell me, so we figure out how to fix it… I have no problem speaking up, and neither have my guys; they have no problem." – SPW Drywall Superintendent*

7.3.2.5 Being Diligent

Participants described the detailed process they followed in planning and building for quality. For instance, typically checking the information to ensure it is complete, accurate, etc. In the field, similarly, checking expiration dates, materials, etc.

> *"As we [SPW drywall] get a new set of drawings and a new set of specs, we review and make comments on it internally, then these [comments from the drywall team] will go over to the job team [guided by the GC] review sessions." – SPW Drywall PM*

> *"I dedicate myself to doing QC and making sure we don't miss things." – Drywall Foreman*

> *"For the first area that we did [use Dusty robot], we were definitely a little concerned on how things will go, whether we'll have everything entered out for the site on that day. In terms of accuracy, we talked openly that we were going to double-check Dusty layout to verify it is in the right place." – VDC Engineer*

> *"We did two weekly office hours… we sat down and went through any open questions; like there is a window here, and you can get daylight on this wall, so we're going to see any imperfection [due to light conditions on the wall]." – Architect*

Diligence requires being constant; even when things were going well, it was important for the team to keep checking and not become complacent:

> *"You have to constantly walk the details because guys will become complacent [stop checking details after a certain point if they believe the work is just repetitive]." – SPW Drywall Superintendent*

7.3.2.6 Active Listening

Participants highlighted that in-person communication worked well; they felt heard and paid attention when others spoke.

> *"Our team does a really good job with this… we've got experienced people, but they don't let their ego or pride get in the way, and they are willing to listen." – SPW Drywall PM*

> *"If you have an idea to share, everyone [at Case 1] listens and pays attention. If you have a problem, you'll get an ear to listen to you." – GC Assistant Superintendent*

> *"I needed to interact with a lot of people, whenever I asked them information about a certain scope, they were very eager to tell me everything that goes into it." – VDC Engineer*

Remote work, though, presented some challenges for active listening:

> *"[during remote work] everyone is looking at a computer screen all day long, and they're trying to multitask, calendars are full of meetings. You're listening, but are you*

understanding? Are you taking in that information? For a lot of it, you have probably missed half of what's been said." – Architect

7.3.2.7 Active Learning

Participants described various strategies they took to learn, from the experimentation with the layout robot to the documentation of quality issues on PlanGrid.

"Everything was very open to trying new processes, or innovate, and make something better… For the layout robot, we had a lot of iterations on what was good, what was not useful, and what was actually not good at all and confusing to people." – VDC Engineer

"We do a risk assessment when a job is just starting. We look at all the risks that the job potentially has. That's where a lot of our lessons learned showed up. I'll put the issues that we had on a similar job into the risk assessment tool." – SPW Drywall PM

"[referring to a newly hired engineer] He knew the technical stuff from the books, but didn't know much about the field, so he asked questions and was interested in the work." – SPW Drywall Foreman

"When we find a mistake on a floor, we try to avoid it on the upper floors… Still, we've had repeating mistakes that occurred. It wasn't a lot, but some stuff that slipped our minds… During the daily rush that we have on the field, it's impossible to follow [remember] all the lessons learned." – GC Assistant Superintendent

The team could have adopted a more disciplined approach for documenting lessons learned as they occurred by using strategies to analyze root causes, such as 5 whys or cause mapping, to avoid having the issue occur again.

"I don't think there's any lessons learned document, or anything like that that really captures it. It ends up being just like a knowledge thing that exists in people's heads." – Architect

"When we're framing, all the mistakes are pretty much caught by us [but not documented], because we're literally putting it in place." – Drywall Superintendent

In the learning process, making sure that issues are treated as learning opportunities is a shared responsibility. It starts with the person who encounters the issue, who has the responsibility to report it and begin to think about the possible causes. Then those planning the work have the responsibility to be receptive of issues being reported and welcome those reporting, as well as plan preventive actions.

7.3.3 Team Performance

I measured the sub-variable team performance in two ways. First, by inquiring about the participant's perception of their project outcomes. Second, by asking participants to compare the outcomes of their project against the average past experiences they had.

Table 7.3: Perception of Team Performance from Staff and Craft

Team Performance (TP)	Craft Perception		Staff Perception	
	M	*SD*	*M*	*SD*
Project-specific performance on quality (TP1) (1 = low performance; 7 = high performance)	6.170	0.53	6.733	0.28
Performance on quality as compared to past projects (TP2) (1 = we could do much better; 7 = we did very well)	6.588	0.50	6.600	0.54

As shown in Table 7.3, all participants from the craft and staff reported Case 1 to have good performance. In addition, their performance, when compared to previous experiences, was above their perceived performance in past projects.

7.3.3.1 Quality Issues Identification Time

One of the metrics I defined to assess team performance on quality is when quality issues are identified and fixed. For this analysis, I only used three tiers of identification (from Figure 3.4), mistakes identified in (1) Tier 1 by the person who installed the work or their direct supervisor (by field), (2) Tier 2 by the GC PE, quality champion, or superintendent, and (3) tier 3 by the architect. I selected these tiers because of the field, GC, and architect's involvement during quality control throughout construction. During the interviews, I asked the participants to assess *when quality issues were identified using these tiers based on 100% of the issues identified on the project during construction for the scope studied*. Figure 7.4 shows the participants' responses. Their perceptions substantially varied. For example, the GC's quality champion thought that 60% of the quality issues were caught in the field, 30% by the GC, and 10% by the architect. In contrast, the architect thought that 30% of the quality issues were caught in the field, 50% by the GC, and 20% by the architect. Although the goal for quality is to deliver things right the first time, when issues occur, detecting them as early as possible minimizes their impact. In Case 1, on average, the issues identified and fixed by the field personnel accounted for almost 50% of the total, by the GC around 35%, and by the architect around 15%.

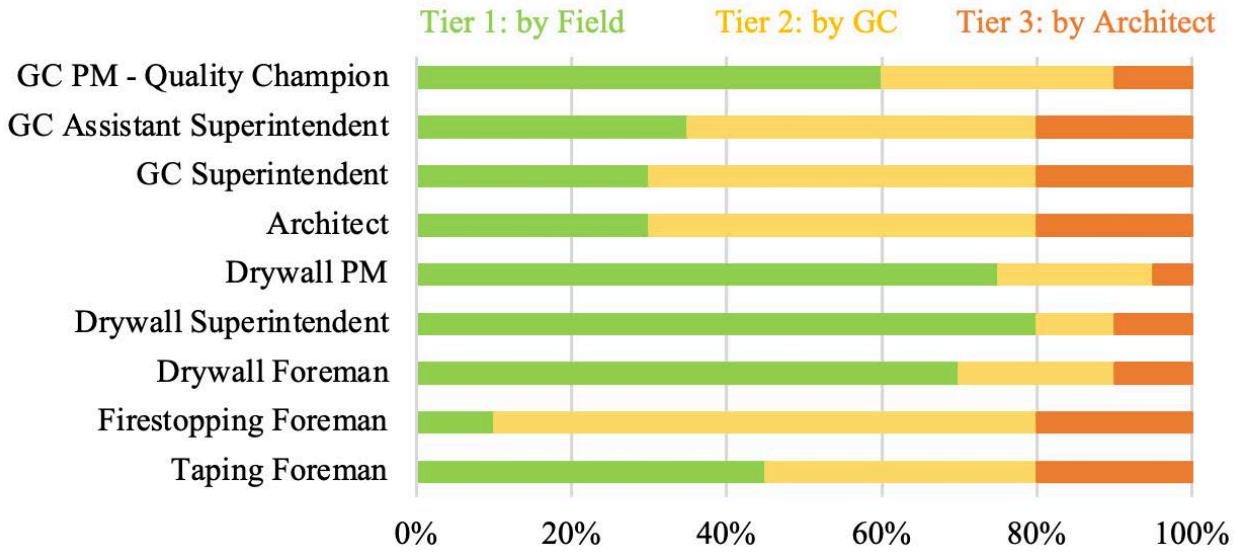


Figure 7.4: Participants' Perception of Time when Quality Issues were Identified at Case 1

7.3.3.2 Documentation of Quality Issues

From my interviews, I expanded the tiers I used from 3 to 5 to describe how the quality issues identified were managed, including how they were identified and documented:

1. **Tier 1 – By field, including SPW drywall installers, foremen, and superintendent:** No formal documentation process was defined. Issues identified by field personnel were verbally communicated among them on a need-to-know basis and fixed as they occurred. The mean score for learning behavior from the craft was 5.78, reflecting the need to establish a more systematic way to track quality issues and learn from them. Installers were encouraged to check the work they completed in one area before moving to the next. Then, their foremen conducted site walks a few times a day, overseeing the work and highlighting quality issues. Then the superintendent walked the site on an as-needed basis and brought up issues that the foremen missed. Lessons learned at this level were stored as experiences in people's heads.
2. **Tier 2 – By GC, including PE, quality champion, and superintendent:** Documentation of quality issues was managed through PlanGrid. Some, at the discretion of the person identifying the mistake, particularly for what they considered to be minor issues, were just verbally communicated to the field instead. The GC documented quality issues through a rolling completion list (RCL) and punchlist PlanGrid workspaces.
3. **Tier 3 – By Architect:** Documentation of quality issues was managed through PlanGrid. The architect conducted 1 or 2 site walks per week and documented quality issues. These issues were sent to the GC as an architectural observation site report, who then coordinated with the trades for correction.
4. **Tier 4 – By Authority Having Jurisdiction (AHJ):** No formal documentation process was defined. The AHJ inspection was focused on the structural and fire conformity of requirements and was limited to inspecting (1) shot pins that fasten the bottom track to the concrete floor, (2) fire taping for fire-rated walls, and (3) screw spacing. Issues identified were verbally communicated to the GC, who then verbally communicated them to the

appropriate trades for correction. If any issue was identified during the AHJ inspection, the GC rescheduled the inspection for a later day once the issue was resolved.

5. **Tier 5 – By contractor receiving work:** No formal documentation process was defined. The painter subcontractor receiving drywall work walked the site and inspected whether the wall finish met their expectations. The GC added a clause in their contract saying that they were responsible for accepting the work they received from the predecessor subcontractor. The painter was held accountable for checking that the drywall wall finishes were at the level they needed considering the painting assigned to each wall. For example, glossy paint, as shown in Figure 7.5, often requires a Level 5 finish wall. When issues were identified, the directive was that the painter subcontractor had to communicate the issue to the drywall subcontractor for correction. The GC reported that there were only a few instances where the painter mentioned quality issues from drywall, mostly due to cracks on sections of walls.

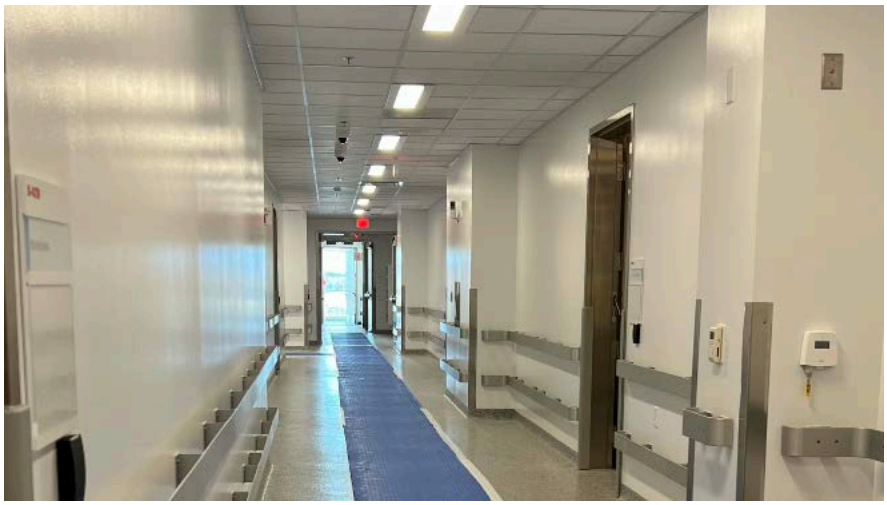


Figure 7.5: Walls with Glossy Paint Finish (Photo: © Sulyn Gomez, 2022-07-19)

The total number of quality issues documented in PlanGrid for Case 1 was 6,106. Around 3.6% of the issues documented were assigned to SPW drywall, a total of 218 quality issues. Around 23% of those (50 items in PlanGrid) were related to wall finishes, including issues with taping, sanding or mudding on specific wall sections, cleaning up caulking around penetrations, fixing popped screws, etc. The high percentage attributed to finishes resonated with what participants described during interviews.

> *"Regarding drywall, my biggest concern is that we had some screw heads that are popping because of the movement of the building. Also, some of the drywall joints were pretty visible [joints can be better concealed in walls with high level of finishes such as level 4 or 5 finish wall, and this discussion needs to be part of the DFOW conversation for the scope]." – GC Assistant Superintendent.*

Another 15% of those issues (33 items) were related to missing backing (Figure 7.6). Some backing parts were missed because they were initially missed on the backing map prepared based on subcontractors' shop drawings, and others were missed during installation. Backing is a key piece installed during framing for all walls with loads attached. Installing backing to the expected quality, although not a complicated operation by itself, highly depends on the accuracy and

completeness of the information provided by the owner, for owner equipment, and any contractor who needs to hang something on the wall.

> *"I wouldn't say it [backing] is a complex operation in the field, but it's more work upfront. We [GC] need information from the subcontractors and architects, like where to install backing, what height, and what type of backing. The weight [of what is hung on the wall] determines what type of backing to install, and the height is usually defined in the [subcontractor] shop drawings. We [GC] did an exercise after we had all the submittals, like casework and Division 10, to capture all the required backing. It was mainly the PE looking at the drawings and submittals, and populating everything on a plan [called backing map that contained all the information on a single map]." – GC PM*

Figure 7.6: Missing Backing for Handrail (Photo: © Sulyn Gomez, 2022-05-12)

Another 10% of the issues assigned to SPW drywall (22 items) were related to patching holes, including holes for penetrations or openings that were deemed unnecessary later on (potentially due to a design change or better alternate routing). Another 10% was related to trade damage, including holes caused by hits on the wall, damaged studs that need to be replaced (Figure 7.7), or backing sections that were removed by other subcontractors and needed to be reinstalled. The remaining 42% of issues (92 items) had various causes, from cracks on the wall, studs or backing installed in the wrong location, and issues with descriptions not specified.

Figure 7.7: Trade Damage to Wall Frame (Photo: © Sulyn Gomez, 2022-05-12)

Table 7.4 shows the number of quality issues documented in PlanGrid at tiers 2 and 3. As described above, issues in tiers 1, 4, and 5 were not documented, so more issues than the ones reported in the table likely occurred.

Table 7.4: Number of Quality Issues Documented by Tier

Quality Issue Identification Level	# of Issues Documented for All Scopes	# of Issues Documented Assigned to SPW Drywall
Tier 2: By GC	2,466 (40%)	141 (65%)
Tier 3: By architect	3,640 (60%)	77 (35%)
Total	6,106	218

The status of issues resolution was sent weekly to the assigned participants.

7.3.4 Relationship Psychological Safety – Behaviors for Quality – Performance

Table 7.5 shows the correlations I found between my model variables. As shown, psychological safety is highly correlated to behaviors for quality ($r = 0.866$), and this, in turn, is highly correlated to team performance ($r = 0.808$). This supports my hypotheses 1 and 2 (Section 1.5) that suggest that psychological safety is positively associated with behaviors for quality, and behaviors for quality is positively associated with team performance, respectively. The small sample size, however, does not support strong conclusions.

Table 7.5: Model Variables Correlations

n = 22	Psychological Safety (PS)	Behaviors for Quality (BQ)	Team Performance (TP)
Psychological Safety (PS)	1.000	0.866	0.623
Behaviors for Quality (BQ)		1.000	0.808
Team Performance (TP)			1.000
All correlations shown in this table are significant at $p < 0.01$			

7.4 Processes to Support Quality Delivery

Figures 7.8-7.13 describe the process steps Case 1 followed to build drywall walls, including the design development, layout, and framing and taping work. As a convention, I numbered each activity describing who performed the step and what activity it was. Circle marks show the involvement of project participant(s) from a stakeholder group in an activity led by another. I explain these activities in Appendix 13 and highlight key activities in the following subsections.

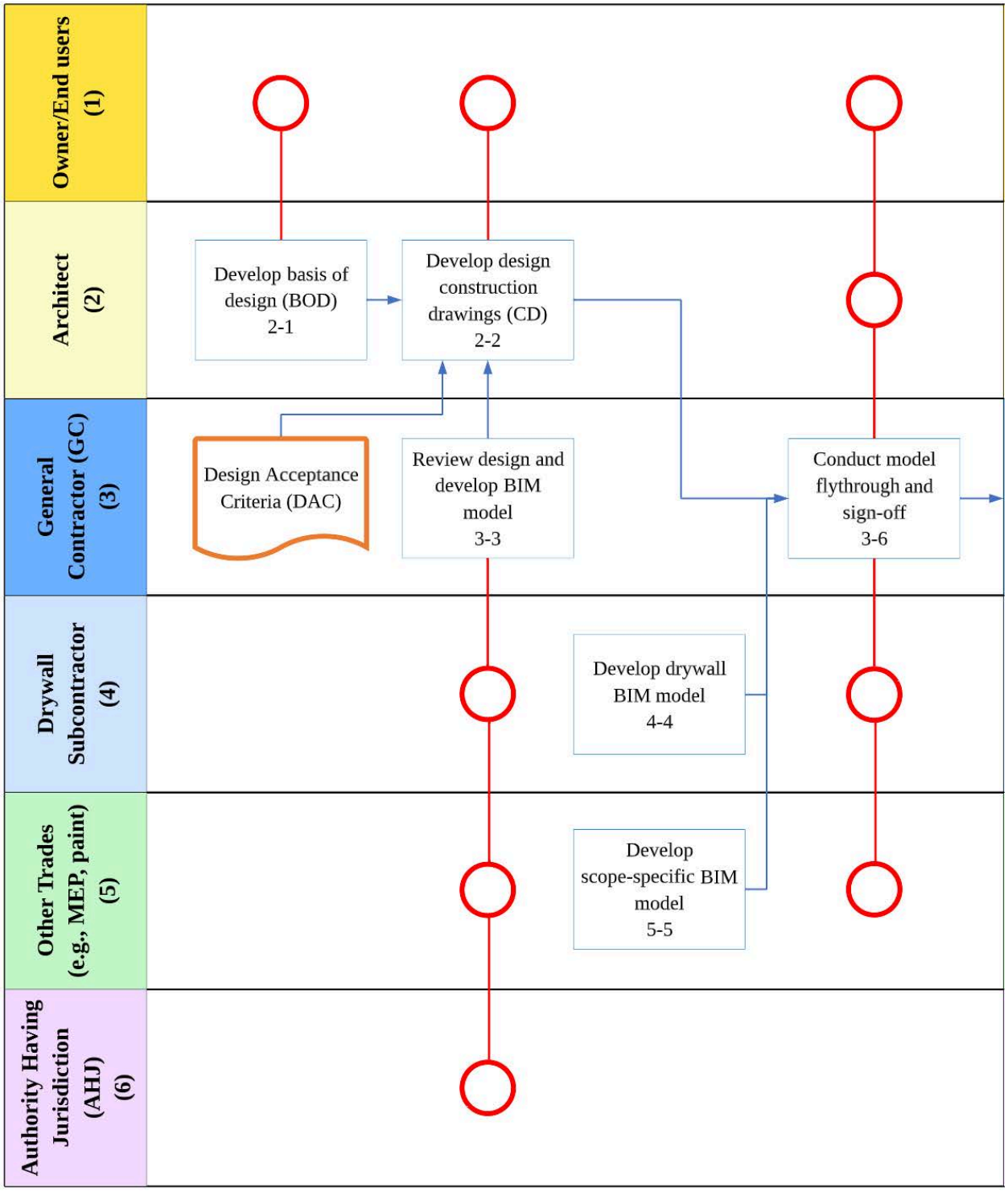


Figure 7.8: Case 1 Quality Management Process Map for Drywall Scope Studied (1/6)

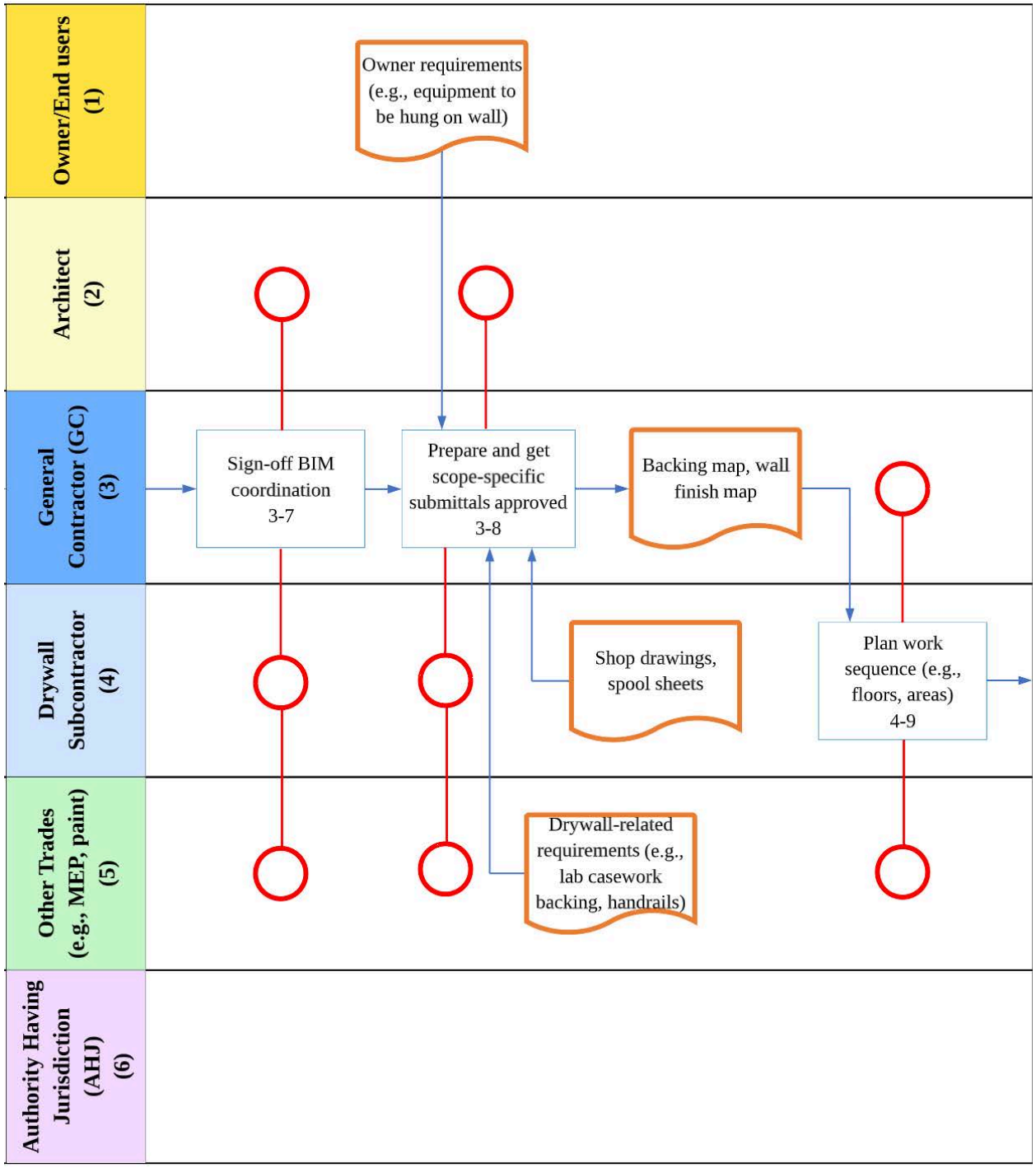


Figure 7.9: Case 1 Quality Management Process Map for Drywall Scope Studied (2/6)

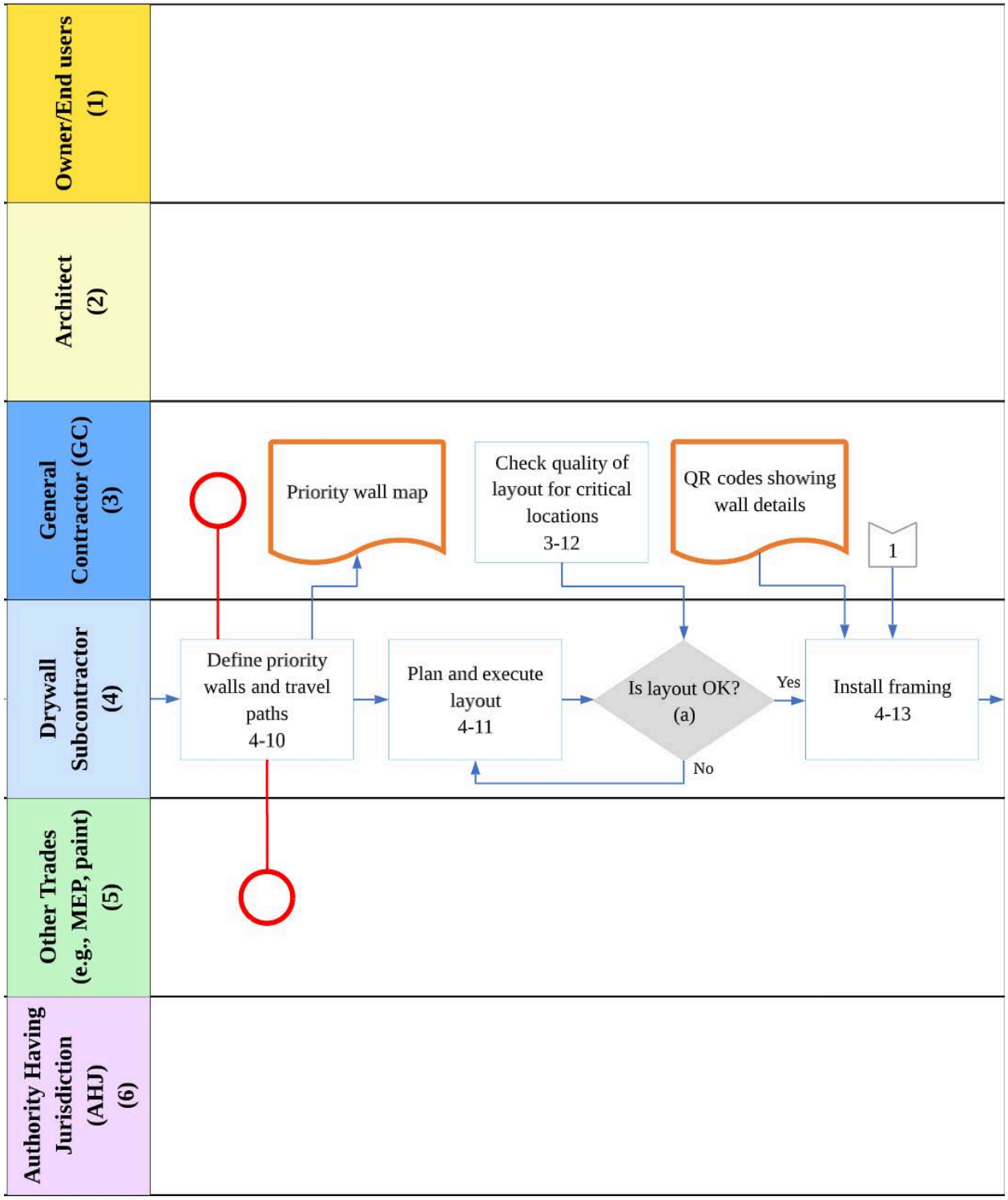


Figure 7.10: Case 1 Quality Management Process Map for Drywall Scope Studied (3/6)

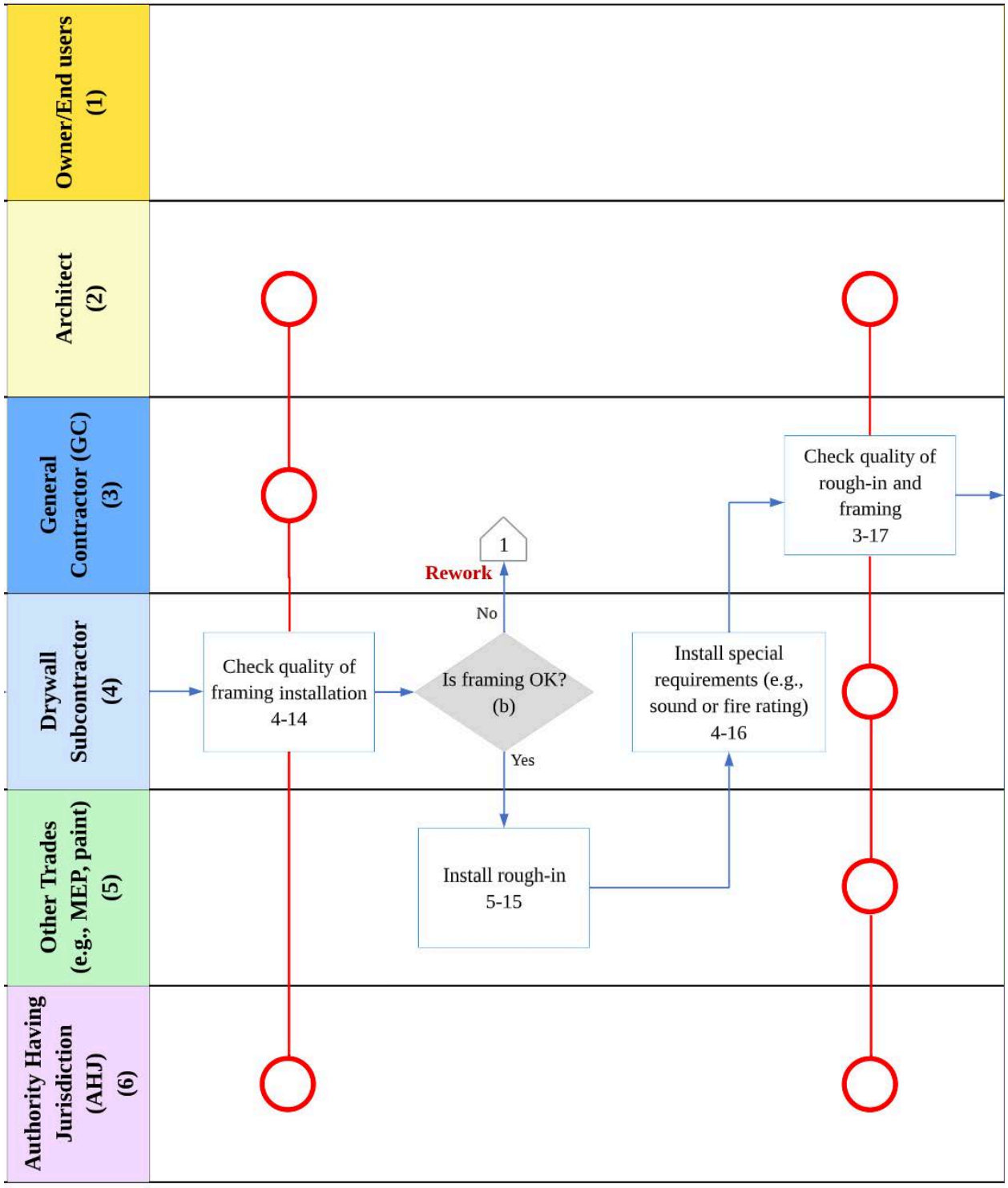


Figure 7.11: Case 1 Quality Management Process Map for Drywall Scope Studied (4/6)

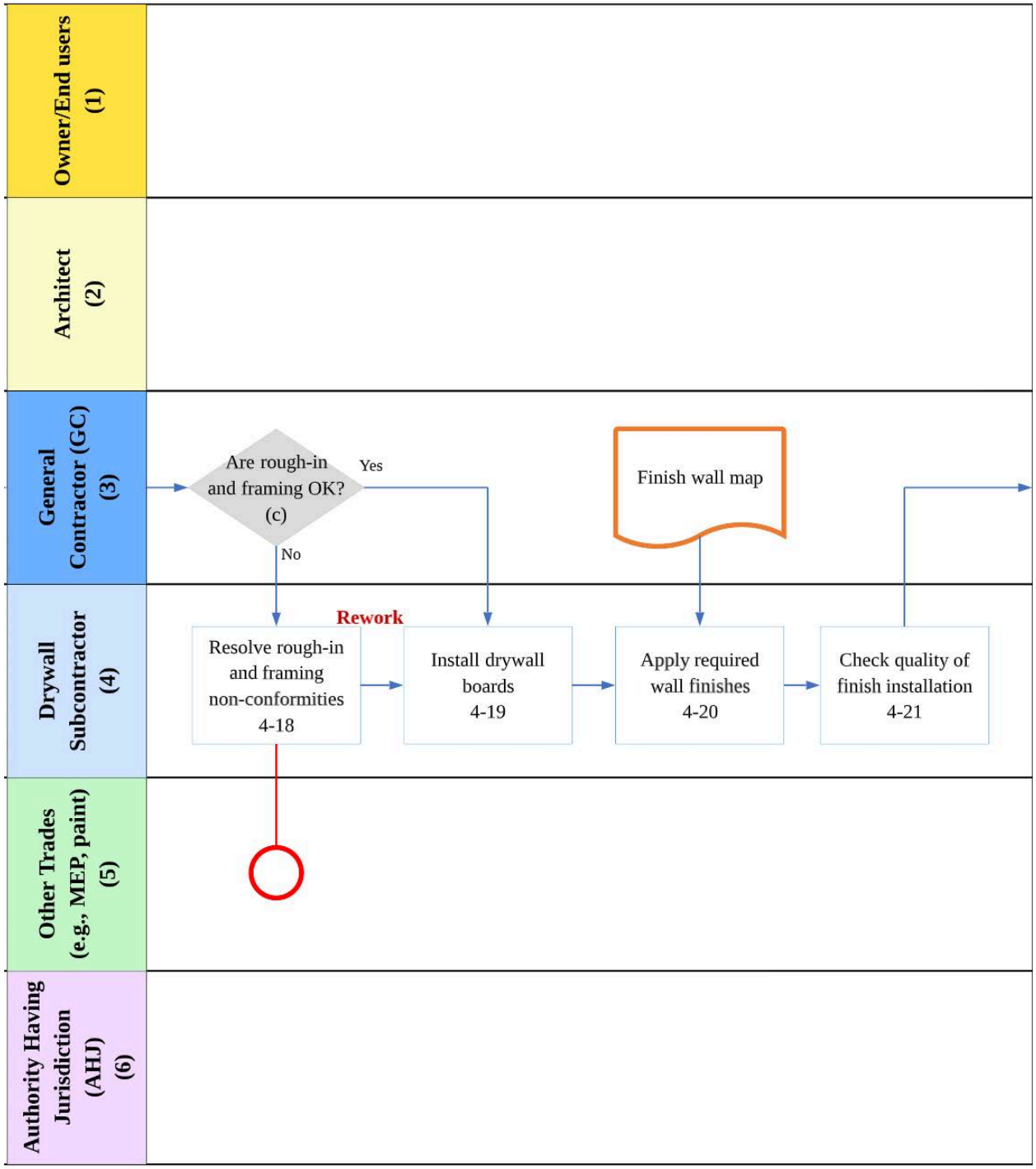


Figure 7.12: Case 1 Quality Management Process Map for Drywall Scope Studied (5/6)

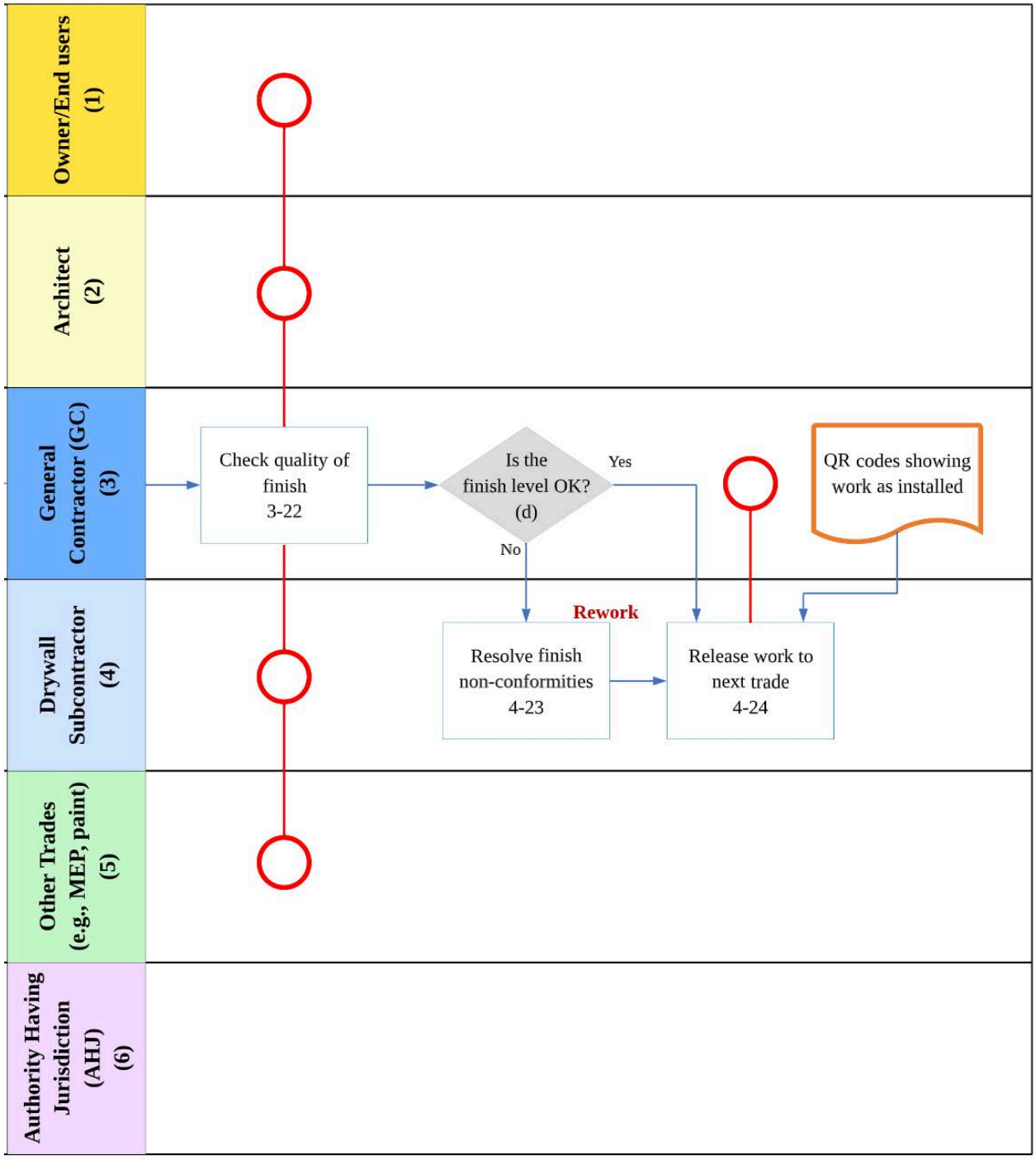


Figure 7.13: Quality Management Process Map for Drywall Scope Studied (6/6)

In the following subsections, I highlight key parts of the quality process and describe the methods and tools that supported these.

7.4.1 User Flythrough Sessions

The Case 1 team expanded the scope of what is typically done in BIM coordination by holding user flythrough sessions (activity 3-6) where the end users were included in model review. These sessions helped prevent misalignment of requirements by aligning expectations and making sure the information used for construction was (1) free of clashes, (2) consistent among disciplines, and (3) end-users understand what these requirements are for areas of relevance to them. Case 1 had four different user groups (1) environmental health and safety, focused on constructability and safety, (2) biology lab users, focused on lab usability, including, for example, applicable requirements for their equipment, such as framing needed to install the stainless steel overhead exhausts in chemistry rooms or the size of the class II A2 biosafety cabinets thimble connect in the cell culture rooms, (3) vivarium lab users, also focused on lab usability, and (4) general facility management, focused on accessibility and maintenance.

Figure 7.14 shows the workflow that Case 1 team developed to describe their design development process. This process used the GC's DAC as a guide to assess design completeness for the design packages (e.g., for 60% construction drawings). DAC is a checklist the GC uses to review project drawings at a high level and may contain DFOW information. While the DAC is a GC's standard checklist applicable to any of their projects, DFOWs are project specific.

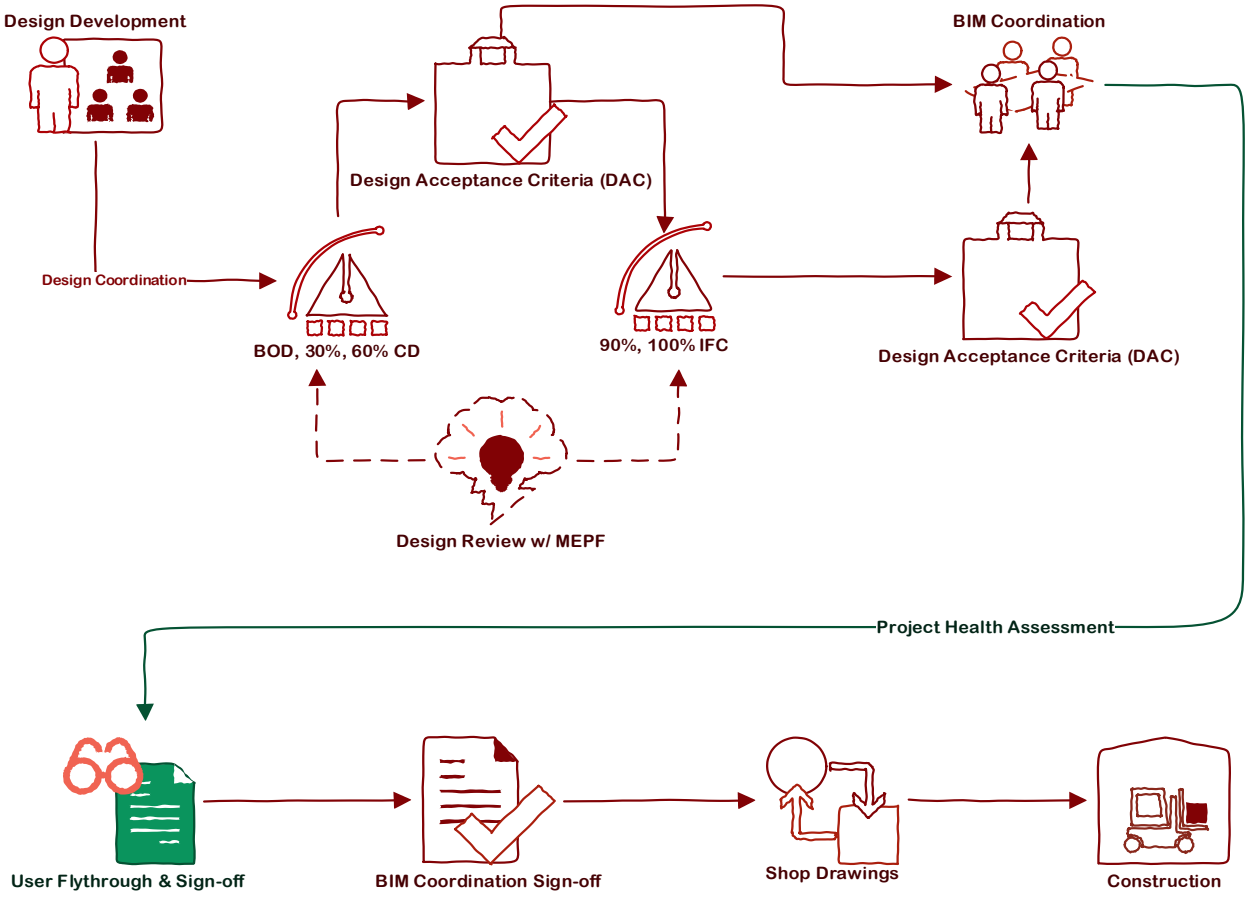


Figure 7.14: Model Flythrough Workflow (Courtesy of Case 1 Architect)

In the design development process, in addition to coordinating the BIM model, Case 1 hosted user flythrough sessions with the intent to understand the user group requirements of the space and scope from their perspective. For example, if a wall is meant to be used as a feature wall where a company logo will be applied, it may have specific requirements from finishes to lighting conditions that need to be reflected in the project documents that will be used for construction. Access panels may also have specific requirements from the perspective of the facility managers who need adequate access to the building equipment or valves, etc. to maintain the facility.

The flythrough sessions were a requirement for model sign-off, and therefore were conducted before production started. According to the Case 1 VDC Engineer, more than half of the issues resolved during BIM coordination were identified during the user flythrough sessions, and addressed prior to model sign-off.

> *"There was less rework during construction because we managed to resolve so many clashes that usually result in rework in the field; like a wall that is going to clash with a duct that runs along it… all that kind of stuff was coordinated through team effort during design." – Architect*

The Lean pursuit of elimination of waste is reflected in the user flythrough sessions. These sessions helped prevent waste that otherwise could have occurred if quality issues from the users' perspective were not detected prior to construction. Most of the project team worked co-located in the big room. Having the right people involved in the discussions allowed the team to exchange concerns and solutions to potential issues concurrently.

7.4.2 Distinguishing Features of Work Process

The team held DFOW conversations for various scopes of work that the GC or architects considered key features of the project. Most of these conversations occurred during the design development phase (activities 2-2 to 3-8). No specific DFOW conversations were planned for drywall work. However, the project team held conversations about various aspects of the drywall scope during construction.

> *"[we talked about] what's coming up that they need our input on; for example, we're going to be building this feature wall next week; what do you want to see? When do you want to come and take a look at it? What kind of things are you concerned about here? Are there any details or junctions that we [SPW drywall] need to pay attention to?" – Architect*

Although some of these conversations came as construction progressed, planning what discussions need to be held for the drywall scope studied is key for aligning expectations of delivered work. For instance, DFOW conversations could have allowed the team to anticipate scenarios of potential misalignments, such as the joints between the drywall board and the windows:

> *"We could see an ugly gap between the window frame and the sheetrock, another between the soffit and the trim for the curtain. We had plenty of these cases. We ended up caulking these to make them look nicer… Although it's not something that we can prevent, we can plan better." – GC Assistant Superintendent*

Section 7.6 describes the project's drywall potential DFOW conversations.

7.4.3 Architect Site Walks

The architect, who was co-located and worked from the big room, walked the site at least once a week and documented observations of non-conformities in a field observation report. For the scope studied, the architect's participation in quality control through his site walks is highlighted in activities 3-17 and 3-22. These walks, described in Figure 7.15, occurred throughout the construction phase, allowing the architect to be actively involved in quality control and help identify non-conformities.

> *"We did regular walks through the job site once or twice a week with GC superintendents and produced weekly architectural field observation reports. Those walks and the field observation reports were used for corrective action with the trade partners… The time we spent in person walking the job site became the most valuable time [for the identification and correction of non-conformities]." – Architect*

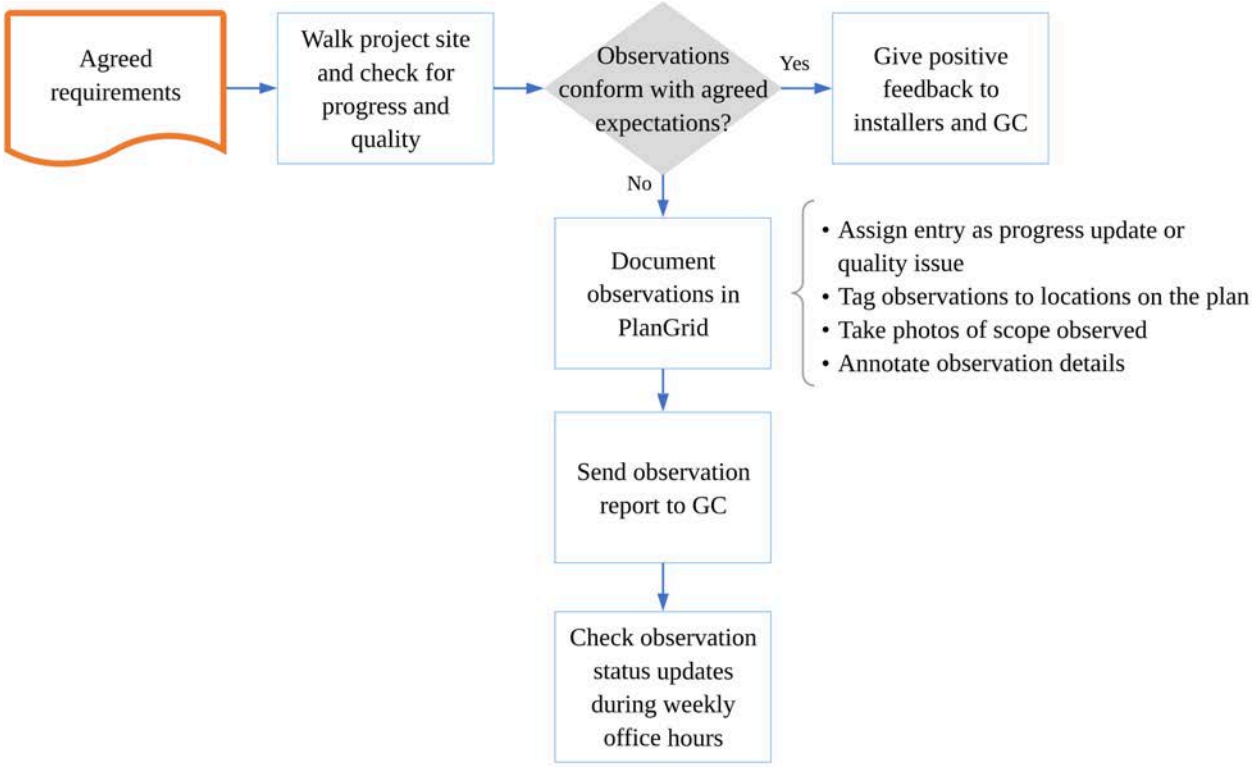


Figure 7.15: Case 1 Architect Site Walk Process

7.4.4 Trade Damage Process

Trade damage is a tough topic of conversation between subcontractors. Typically, it is assessed and allocated to subcontractors towards the end of the project when the GC is closing out contracts.

> *"Trade damage has always been this subject that no one wants to deal with." – GC PM*

GCs carry high risk when their SPW groups have scopes of work that are waiting to be compensated for trade damage-related costs. If trade damage is not managed appropriately (tracked and documented), it increases uncertainty for the GC and SPW groups involved.

In the traditional approach of waiting toward the end of the project to allocate trade damage responsibility, implicit assumptions are made: (1) the liable stakeholder responsible for causing the damage can be identified easily, and (2) stakeholders are able to reliably identify who was working in the area where the damage occurred. Instead, Case 1 approach to trade damage was to systematically manage damage to better allocate responsibilities for repair. For instance, when drywall started closing walls, the GC's plan was to:

1. Start tracking damage in drywall work, including framing and wall closeup; a considerable amount of trade damage occurs in this stage.
2. Schedule recurring walks to document trade damage. The GC's PM scheduled monthly walks, for almost a year, with all subcontractors working on the project during that time.
3. Include all relevant stakeholders in tracking walks. The GC's PM walked the site with the subcontractor's foremen or subcontractor's PMs and documented damage identified. The drywall, MEPF, and ceiling subcontractors were part of almost all the trade damage walks.
4. Foster transparency using a common platform. Case 1 used a common workspace in PlanGrid showing relevant information (e.g., location, date) about the damage identified.
5. Estimate the financial and time impact of damage close to its occurrence. After each walk, the GC sent a request for quotation to the subcontractors whose work needed repair.
6. Allocate costs to the responsible subcontractor. The GC reviewed daily reports to identify who was working in a specific area when the damage was identified and what activity they were doing in such area. They also looked at manpower per trade. Then, they divided the cost according to who was onsite and with what manpower in the month when the damage occurred. In this way, subcontractors knew the trade damage cost monthly. The effort provided more real-time input for the subcontractor's cash flow and a more accurate projection of their costs.

"Subcontractors really like how transparent this process was. They were able to see trade damage charges along the way rather than being left in the dark until the end." – GC PM

7. Foster desired behaviors: The GC encouraged collaboration among subcontractors and ownership of the damage they caused to the extent possible.

"We saw a lot of handshakes [for people committing to fix damage] happening in real-time. That's one of the reasons we wanted the foremen to be part of the process. When we identified damage, many times the foreman already knew about the damage and worked out a deal amongst themselves. This helped reduce the administrative work of calculating and distributing costs for repair." – GC PM

Figure 7.16 describes the process Case 1 followed to document and manage the repair of trade damage. This process was based on two Lean tools. First, Gemba, to walk the site, identify trade damage, and assess the damage where it occurred. Second, standardization to set a process that project participants, who joined the project at different times, adopted consistently. In doing this, all participants were aligned on how to manage trade damage. This process could have been leveraged by investigating causes and countermeasures to avoid reoccurrence. By identifying the potential causes of damage in a zone, the team could design prevention plans to implement in the next zones.

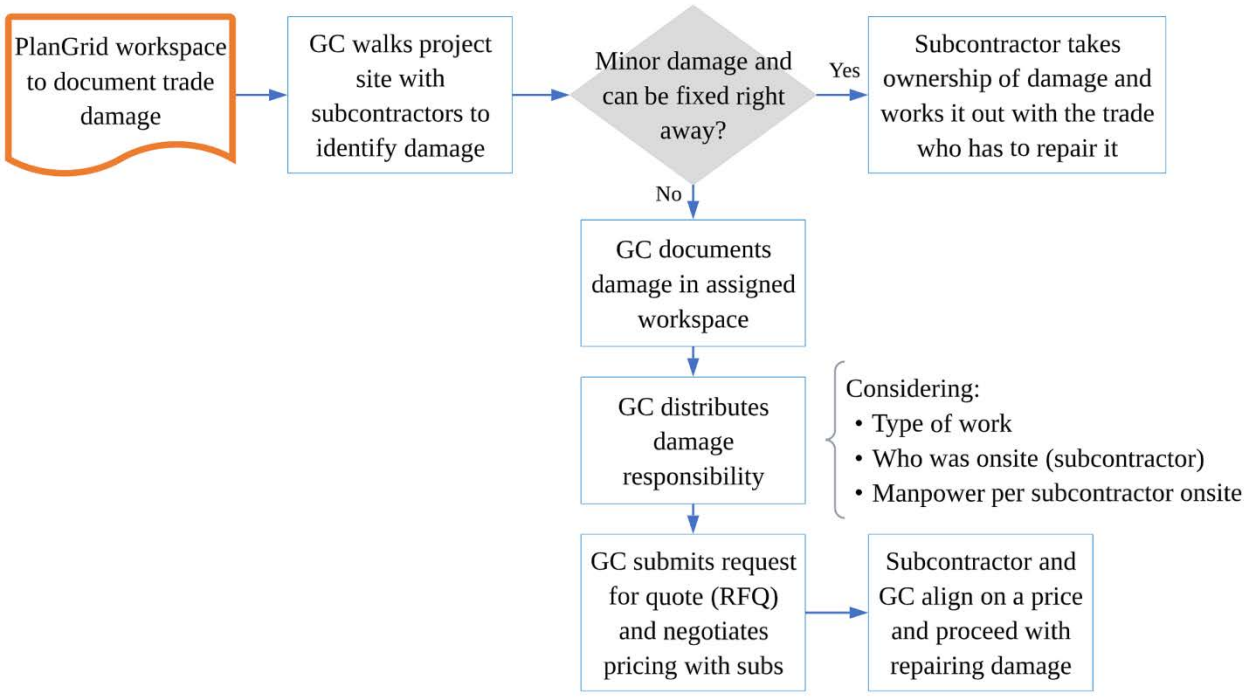


Figure 7.16: Case 1 Quality Control: Trade Damage Management Process

This process resulted in a better distribution of responsibilities:

> *"We have the biggest crew on the jobs, so we have the most manpower. In past projects, trade damage costs would be divided based on how many men you had on the job, so we would have the highest trade damage cost. Here [in Case 1], we didn't do that. The GC took the daily reports to figure out who was in the area [assigning the damage to those who caused it]." – SPW Drywall PM*

The next section describes methods and tools used in Case 1 for drywall work.

7.5 Methods and Tools to Support Quality Delivery

This section describes the methods and tools used to deliver the scopes studied.

7.5.1 Automating Wall Layout: Dusty Robot

Dusty is a robot patented by DPR Construction, designed and built as an automated solution to perform layout in the field. Case 1 was the first project where Dusty was used on a large scale. Dusty uses a 2D CAD file as input and prints what the file contains, from lines to symbols, depending on the contractor's needs. Figure 7.17 shows Dusty with its operator in action.

Figure 7.17: Dusty Robot Laying Out Walls (Photo: © Sulyn Gomez, 2022-11-03)

Typically, when doing manual layout, only certain grid points and the double line of the walls are laid out. Dusty ended up being faster and more accurate. Dusty produced 3 times the points a human crew would layout and drew straight lines with 1/16'' (1 mm) accuracy, and it has the capability to provide additional details as needed:

> *"We printed the studs and the sheetrock. We had four lines for each wall [Figure 7.18]. So, if a pipe has to go exactly in the center of a wall, you'll have laid out one layer of sheetrock or two layers of sheetrock [to see whether the pipe fits in the center of the wall as expected]." – VDC Engineer*

The use of Dusty was primarily meant for drywall layout. However, due to the benefits subcontractors saw of its use, Case 1 team expanded its scope beyond drywall, and included the layout of some overhead MEP systems such as lights, sprinkler heads, ceiling tiles, etc. Its use gave value to the whole team and became part of SPW drywall standard work.

> *"Drywall SPW has taken it on themselves [the use of Dusty], and they use the robot for every project they're working on, so it has become a part of all the SPW layout." – VDC Engineer*

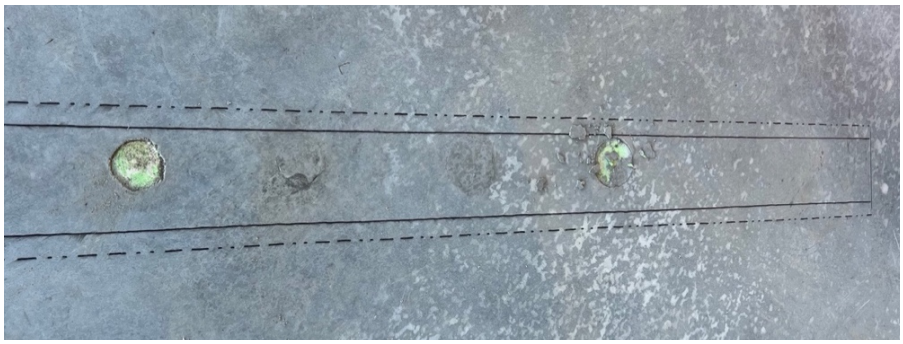


Figure 7.18: Wall Layout with Dusty (Photo: © Sulyn Gomez, 2022-11-03)

The GC went through a learning curve with Dusty. The team conducted small experiments as they progressed and got feedback from the users (subcontractors using Dusty for layout) to improve their operations. Strategies adopted through experimentation for the use of Dusty include:

1. Use different colors for each subcontractor and different symbols for specific purposes, so installers do not get confused
2. Engage subcontractors and get their buy-in to maximize the value of using Dusty
3. Spray a coat on ink to make it more durable, especially in areas where heavy loads will be moved as the ink might wear off
4. Plan what ink to use according to the flooring finish requirements.

Lean methods and tools involved in the adoption of Dusty include, for example, (1) Mistakeproofing devices such as the different colors and symbols used for different purposes, so drywallers and electricians can differentiate what layout belongs to each by the appropriate line color or symbol, (2) Visual management showing information such as the width of each side of the wall (Figure 7.18), which made it clear where pipes can penetrate the floor without conflicting with the drywall board location, (3) PDCA and (4) collaborative design of operations allowing the team to learn and improve from experimenting and getting feedback from users.

7.5.2 Facilitating Communication in the Field: QR Codes

Typically, a person trying to see what is installed in certain areas has to check many drawings from multiple specialties such as electrical, mechanical, plumbing, etc. The Case 1 team created screenshots from various drawings and BIM models, and put them together into a single PDF package per room or area. Everyone in the project had access to the package through dynamic QR codes that were posted as small stickers on the walls (Figure 7.19). Dynamic QR codes allowed them to replace the information in the PDF package, without replacing the actual physical QR code posted. Figure 7.20 shows an excerpt of such a PDF package.

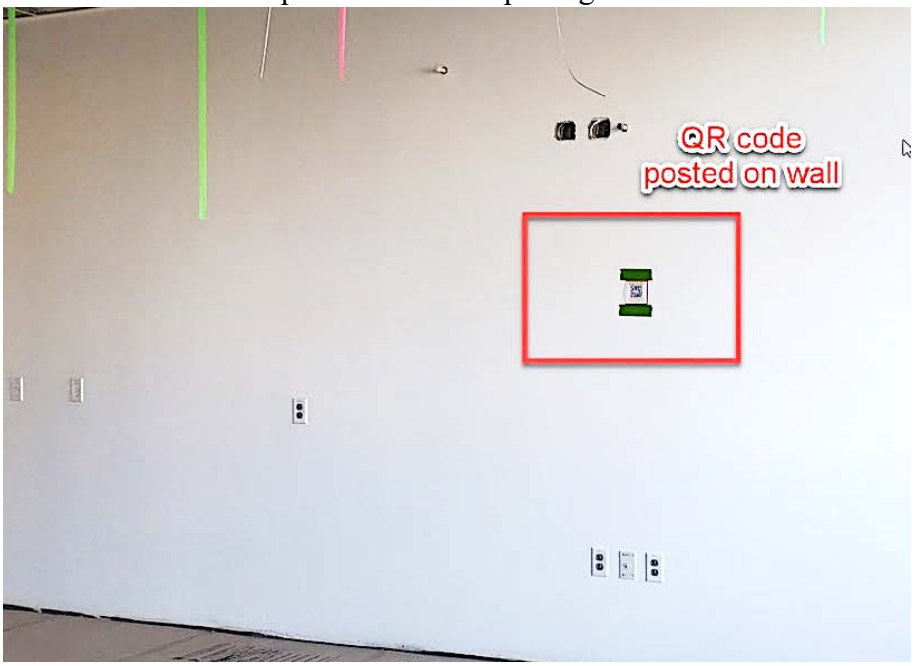


Figure 7.19: QR Code Posted on Wall (Photo: © Sulyn Gomez, 2021-09-29)

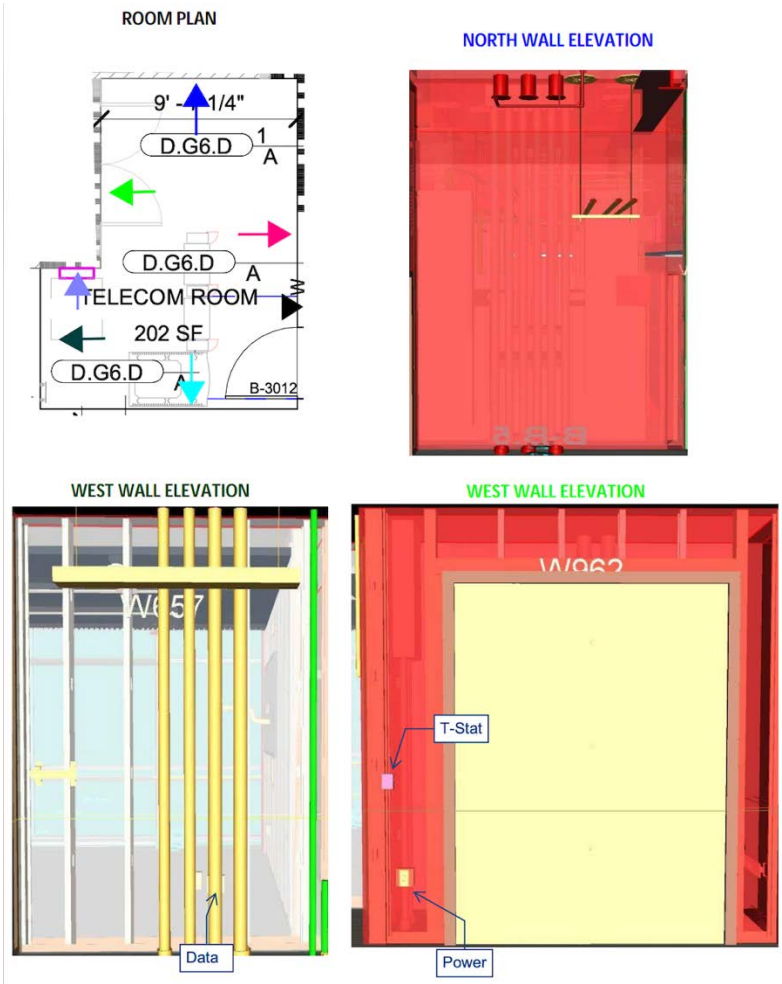


Figure 7.20: Excerpt of PDF Package in QR Code Part I (Courtesy of DPR)

Case 1 used the QR codes for two purposes:

1. QR Codes for in-wall quality control: These QR codes contained all the information needed for wall closeup and helped the team avoid rework for missing things inside the wall, for example, access panel box frames or backing sections. The team had all the information needed to verify whether what was installed matched the requirements without looking at 15-20 different drawings. These QR codes were accessible anytime during and after framing work and facilitated quality control for all project participants involved.

"The superintendent used it [QR code] a lot because every time she walked, she could say, 'hey you can't close this wall because something is missing here.' Once you close the wall, there is a lot of rework. Compared to her previous jobs, where she had to open the wall for changes, here [in Case 1], we had very few cases where we had to open something for a change. We are both working on a common project right now, and we're doing the same thing here [using QR codes for in-wall quality control]." – VDC Engineer

"[The PDF package] have the architectural plan, the layout of the room, trade plans like electrical power plan, lighting plan, plumbing plan, mechanical plan, snapshots from the 3D model, wall elevations showing all the boxes, ceiling plans and overhead views from the model, etc." – GC Assistant Superintendent

2. QR Codes for damage prevention to in-wall utilities after wall closeup: Before closing the walls, the team took photos showing what was inside the wall and added these photos to the PDF package. For instance, carpenters may hit pipes when screwing something onto the wall if they do not know the pipe's location inside the wall.

"[for example] There's plumbing in a wall, so, we put a tape measure showing that this plumbing is 6 ft from the doorframe [or any other reference point like Figure 7.21] and took a picture of its location. [Using these photos] We put the QR code [for damage prevention] on the wall, then when carpenters [and other trades] go and hang their stuff, they just scan the QR codes, go to that photo, and know where to avoid [putting their screws]." – GC Assistant Superintendent

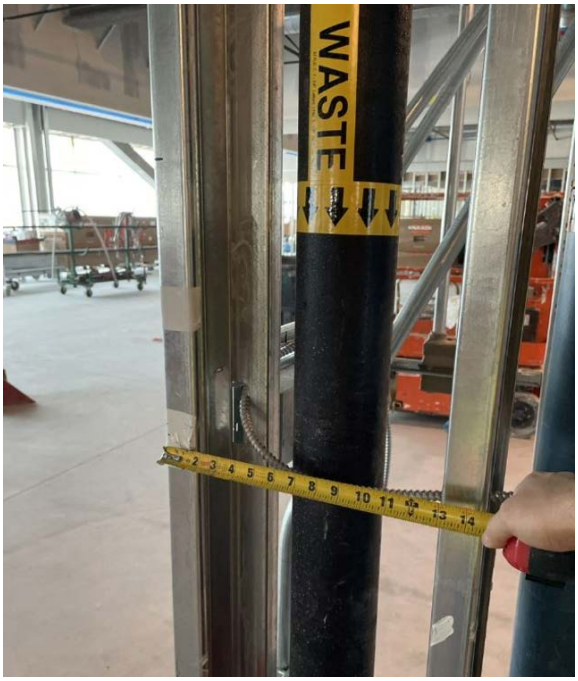


Figure 7.21: Photo Included in PDF Package in QR Code Part II to Show Pipe Location with Respect to Wall Corner (Courtesy of DPR)

The use of QR codes to communicate information to the field involved the use of (1) visual devices, including the QR codes themselves and the PDF packages with all relevant information needed for building and QC, and (2) standardization for creating PDF packages with model views, spool sheets, etc., so that the packages would include all needed information.

7.5.3 Using Visuals to Communicate Expectations and Outcomes

The GC adopted visual management during their QC, so subcontractors knew what walls were ready to closeout or which ones had quality issues that needed to be addressed before continuing work. Figure 7.22 shows a framing section sprayed with purple color after passing quality control. Other colors were used to alert quality issues, such as missing backing pieces.

"We painted the spots where we can sheetrock. Instead of giving installers a plan or a list saying do this wall or don't do this one, we used spray paint. It was a really productive way to coordinate the installation. Basically, if you see the color purple, it means the wall

is ready for sheetrock; you don't even have to think about it, just install the sheetrock." – GC Assistant Superintendent

Figure 7.22: Wall Framing with Purple Spray after GC Quality Control (Courtesy of DPR)

SPW drywall also adopted visual management to prepare for city inspections. Once the framing was ready for inspection, drywall craftworkers painted the shot pins (Figure 7.23).

"The [city] inspector asked me to paint all the pin heads so that the inspector didn't have to spend time looking where the pins are; he just wanted to walk and quickly see where they were installed. Sometimes [when we skipped a pin], he would walk and tell me 'this head is not painted,' and we'd go and paint it to pass the inspection." – Drywall Foreman

Figure 7.23: Shot Pin Heads Painted for Inspection (Photo: © Sulyn Gomez, 2021-09-29)

The adoption of this method involved (1) going to Gemba and verifying work conforms with the agreed MAC, (2) speaking up when non-conformities are identified so these can be addressed as close to their occurrence as possible, and (3) using visual management to mark the areas that passed QC and those that require rework, so the craft can see where they need to go back.

7.6 DFOWs Applicable to Drywall and Framing Scope in Case 1

The DFOWs I described in Table 7.6 were developed through a series of conversations with various project participants who were part of planning and executing the drywall scope studied, from the drywall superintendent, to the architect, to the GC PM leading the scope, to the foremen, etc. The table grew as I interviewed more participants and gathered their perspectives about what they considered a DFOW for the scope studied. I refined the table with feedback from Case 1 quality champion and the Bay Area quality leader, who closely collaborated with me throughout the study.

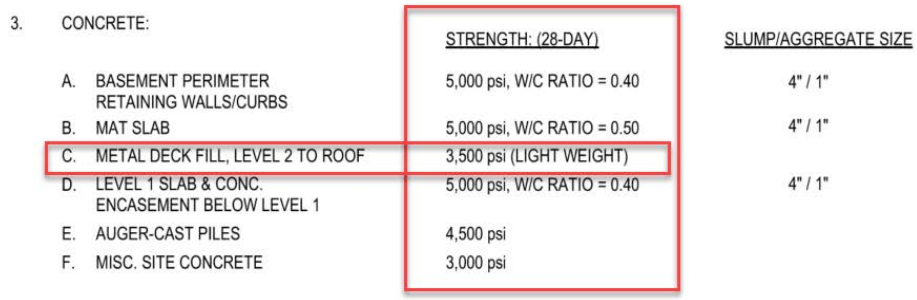
Table 7.6: Case 1 DFOWs for Drywall Scope Studied

DFOW Conversation	Topics to Include in Conversations
Priority walls and travel path openings	- Ensure MEPF and drywall expectations are aligned. - Ensure travel paths have been coordinated with the GC and owner for the installation of large equipment.
Backing; backing map	- Include all the scopes that need backing; e.g., casework, Division 10, owner equipment. - Define all backing types, locations, and heights.
Finishes; from level 0-5 wall finish	- Intended use of the wall; e.g., Is it a wall where end-users will spend all day working? Is it at a prominent area in the building? - Lighting exposure; e.g., Are there large windows in the area that will project good natural light on the walls? Is the area in a long corridor with not much natural light? Are long light fixtures attached to the wall or hanging off the ceiling? - Viewing position; e.g., angle and distance for inspection.
Control joints; besides the control joints that are defined by code every 30 ft.	- Is SPW drywall suggesting additional control joints to avoid/minimize cracking in a particular zone (e.g., where they have observed cracking occur on past projects such as frames in high transit doors)? If so, is the architect/owner OK with the proposed locations? - Can the joint be placed in a location that best creates symmetry in the wall or where the joint can be better hidden rather than at the 30 ft mark?
Joints between drywall board and openings	- Intersection with window and door openings. - Soffits.
Framing details	- Include framing details that installers are familiar with and understand in the drawings. - Align on information to be included in spool sheets.
QR codes with in-wall information	- Make information (e.g., spool sheets showing every stud and backing required and the devices and conduits projected for the wall) easily accessible to everyone. - Ensure that any changes in design are incorporated.
Model coordination	- Coordinate with (1) MEPF trades for interior partition walls, and (2) exterior skin trade or metal panel supplier for exterior metal stud framing. - Coordinate openings; e.g., for light switches, access panels.

Holding DFOW conversations allows the project participants to align on the items in Table 7.6 and provides a space to answer scope-related questions.

"On the first floor, the shot pins [standard to attach the bottom track to concrete slabs] wouldn't go down, and it happens on a lot of projects. We [installers] can't get the pins fully shot down. It's whatever is put into that concrete that will not let regular pins go into it. So, to fix this, we have to use the black pins, but those are hard to get right now; they are almost 6-8 months out. Do they [concrete subcontractor] just put too much hardener in the mix? They always say it's the same mix, but why can we get our pins on all other floors but the first one?" – SPW Drywall Superintendent

Conversations about concerns like this could help the drywall team understand that concrete floor strengths may indeed vary (Figure 7.24), anticipate this on the next project, and discuss with the GC how to manage this problem.



3. CONCRETE:	STRENGTH: (28-DAY)	SLUMP/AGGREGATE SIZE
A. BASEMENT PERIMETER RETAINING WALLS/CURBS	5,000 psi, W/C RATIO = 0.40	4" / 1"
B. MAT SLAB	5,000 psi, W/C RATIO = 0.50	4" / 1"
C. METAL DECK FILL, LEVEL 2 TO ROOF	3,500 psi (LIGHT WEIGHT)	
D. LEVEL 1 SLAB & CONC. ENCASEMENT BELOW LEVEL 1	5,000 psi, W/C RATIO = 0.40	4" / 1"
E. AUGER-CAST PILES	4,500 psi	
F. MISC. SITE CONCRETE	3,000 psi	

Figure 7.24: Excerpt of Drawing Notes with Concrete Slabs Weight Information (Courtesy of DPR)

7.7 Discussion

Planning for quality, a consistent effort to foster desired behaviors:

Early on in the project, some Case 1 project participants were part of a kickoff meeting where the GC introduced the DFOW process. The GC explained why it was important to discuss and get alignment on the DFOWs and then led scope-specific DFOW conversations. The architects actively participated in many of these sessions.

"We needed to make sure that when we went through the details [of the DFOWs] with all the different trades, we knew what we were expecting to see there, and paid close attention to those key aspects of the project." – Architect

While the kickoff meeting helped increase awareness about the process and helped start some DFOW discussions, this was limited to only the group of staff from the companies who were onboarded on the project at that time. Strategies that can help address this challenge are:

1. Have a written project-specific QIP:

   When interviewed, participants reported that they either did not believe the project had a QIP or were unaware of its existence. Not having a QIP does not mean that the project is not doing quality work, team members may either have some experience and know how to execute the operations for their scope and the applicable standards, or just happen to figure things out on the way with some rework involved. However, having a QIP can help plan and execute for quality consistently across disciplines and can be used to onboard project

participants as they join the project. Appendix 14 shows the QIP template I developed. When writing a QIP, have the team contribute and commit to it.

2. Foster a common language:

   While some of the participants I interviewed were familiar with the DFOW language, others had not heard the related wording (DFOW, MAC) before. Coincidently, those familiar with it were staff members, and those unfamiliar with it were craftworkers, including foremen. It is important that those who build know key aspects of the work, the DFOWs applicable, and how the delivered work will be inspected. Showing that the staff cares about craft includes making sure they understand expectations, including DFOWs, if applicable, and their respective MAC, so they know how delivered work will be inspected.

Planning for existing condition's constraints when building a TI:

Case 1 core and shell were built by a predecessor contractor. SPW drywall faced some challenges when using Dusty due to the misalignment between some of the existing wall locations built by the predecessor contractor and what the drawings showed.

> *"There's always going to be some level of discrepancy between what you design as an architect and what actually gets built out there. [On this site] we had 5 inches less width in one of our rooms, which then meant that the door maneuvering clearance didn't meet code. So, we then had to pull that wall further south to make sure the room met the minimum code requirements for door maneuvering clearances in there… to an extent, it's part of what you expect working in an existing building." – Architect*

Inconsistencies in real location and drawings caused issues, for example, aligning wall layout to elevator shafts (existing structure). Dusty drew lines as shown in the drawings, but those were not aligning correctly with the existing walls, so the subcontractor had to do this portion of the layout again manually. Once the team identified the areas of conflict, they excluded those sections from Dusty layout on the following floors, and did a manual layout instead.

Planning for mockups or first-in-place to help align expectations:

Although no drywall mockups were built in Case 1, the drywall superintendent highlighted that other projects he worked on used drywall level 4 and 5 finish mockups, ceiling mockups, and access panel mockups.

> *"We didn't build a temporary mockup. The architect viewed our work [once installed onsite] to determine our quality. I'm sure they went out there and viewed it and said it was Okay. I don't remember there being a conversation about a first-in-place. The problem occurs if we aren't aligned then [during inspection]; everyone can look at and inspect wall finishes in a different way." – SPW Drywall PM*

The use of drywall mockups or FIP installations can help align expectations on finishes while allowing craftworkers to understand the steps needed to install work and meet the agreed MAC.

Adopting visual management for quality planning and control:

The use of QR codes requires some work upfront. The PDF package creation was a time-demanding activity, and the assistant superintendent who launched the idea and created the first few PDF packages still had a project to run. After piloting it on the project, the team saw value in doing the packages and sharing them with the field using QR codes, and outsourced the packages'

mass production to one of their subsidiaries that provides VDC, project controls, accounting, and software development solutions.

The QR code creation investment could benefit projects with complex systems and dense MEPF work, such as life science projects, rather than low MEPF systems like residential buildings.

Expanding learning opportunities:

Quality issues documented were identified in Tiers 2 and 3. However, documenting quality issues in Tier 1 seems especially important due to the number of issues caught and fixed by participants in this tier.

> *"When we're building, all the mistakes are pretty much caught by us because we're literally putting it in place, and if something doesn't look right, we stopped and figured things out and fixed it." – SPW Drywall Superintendent*

> *"I don't write them [lessons learned], but I have a good memory, so I remember it." – Drywall Foreman*

While the documentation of issues in Tiers 2 and 3 helped track them, tools such as cause mapping and 5 whys could have been used to understand what could have caused the issues in the first place. Once the team understands the potential causes, they can strategize ways to avoid having such issues again. The GC and SPW groups had a lessons learned session at the end of the project; by then, however, many of the issues could have been forgotten, or in some cases, the participants who knew the most about such issues may not be available. Being deliberate in documenting lessons learned as they occur could help the team in their learning journey. Case 1 approach to documenting lessons learned from using Dusty can be expanded to the quality issues they encountered.

In addition to understanding the potential root causes for quality issues, notifying earlier tiers about what they missed can help them be more aware of the issues the next time they inspect the work before releasing it to the next tier for inspection.

Setting expectations upfront for BIM model:

Case 1 used the coordinated model for various purposes, from adding model views to the PDF packages linked to QR codes, to providing information to framing and drywall installers about wall openings. The level of modeling expected needs to be defined upfront during the bidding process, so teams consider those expectations when forecasting their staffing and pricing. For instance, subcontractors could plan to have their foremen or installers participate in the model coordination or user flythrough sessions to get feedback on constructability and potential safety risks associated with executing the work as designed.

7.8 Conclusions

In this chapter, I explored the relationship between my research variables, psychological safety, behaviors desired for quality, and team performance. I found that psychological safety is positively associated with behaviors desired for quality, which are positively associated with team performance. In addition, I documented the processes, methods, and tools that Case 1 team used to support the delivery of quality for the scope of my research. Also, I described the DFOWs applicable to this scope.

8. BBQS REFINEMENT CASE 2

This chapter presents the findings of a study I conducted to test and refine BBQS Prototype 3. I chose Case 2 project based on the GC leadership's advice. The GC, at the time of the study, had been awarded a number of projects with the same client. I used Case 2 to analyze the relationship of my model variables, identify opportunities for improvement along the study participants, and implement the BBQS to support the delivery of quality on the project.

The chapter is organized as follows. Section 8.1 introduces the project background. Section 8.2 describes the methods used to analyze the study data. Section 8.3 analyzes the study variables, team psychological, behaviors for quality, and team performance pre- and post-BBQS implementation. Sections 8.4 and 8.5 illustrate the project's processes, tools, and methods that supported them in delivering quality, including the ones the team had in place pre-BBQS and those that the team improved or started using when implementing BBQS. Section 8.6 presents the project's DFOWs applicable to the scope of the study. Section 8.7 discusses my findings and possible limitations. Last, Section 8.8 concludes this chapter.

8.1 Project Background

8.1.1 Project Overview

Case 2 is the third building built by the same GC in a data center campus. Each of the buildings was awarded in phases. At the time of the study, Case 2 project's core and shell phase had been completed, the white space phase (space ready for IT equipment, e.g., drywall partitions for rooms and large MEP equipment such as power distribution units) was under construction, and the built-up phase (i.e., space ready for tenant occupancy, e.g., installing the hot aisle containment systems and server racks) had just been awarded. The building area includes data halls (space for data center modules), office space, mechanical, electrical and telecommunications rooms, and an equipment yard. The GC had various SPW scopes on this project. For the white space phase, the SPW groups included drywall, DFH, ACT, and thermal and moisture protection work.

8.1.2 Project Delivery Method and Project Team

Case 2 was delivered under a Design-Build (DB) contract. The GC, architect, and MEP contractors (called PRIMES) have a direct contract with the owner. The price agreed with the client considered some SPW scopes in the proposal on a lump sum basis, including SPW drywall. The GC and PRIMES were involved during the design and collaborated with the architects providing feedback from the contractor's perspective. Case 2 started construction in the first quarter of 2021; however, many project participants have known each other since the construction of the campus's first building in 2018.

8.2 Methods

I studied Case 2 using a combination of quantitative and qualitative methods to analyze the variables in my model pre- and post-BBQS and identify opportunities for improvement to deliver quality. My primary contacts at Case 2 were the project manager (PM) overseeing the construction of other projects with the same client, the field engineer (FE) leading quality from the GC's end, and the SPW Drywall foreman leading quality from the field's end. They all collaborated closely with me to facilitate data collection.

The study involved five phases of data collection. First, using qualitative methods, I visited the site and conducted in-depth interviews to describe the team's quality process pre-BBQS. Second, using a quantitative method, I administered one survey to measure the three variables in my model, including psychological safety, behaviors for quality, and team performance, all pre-BBQS. Third, I collected performance metrics pre-BBQS. Once I completed the third phase, I tested BBQS in collaboration with the project team. Fourth, I re-administered the survey to measure the variables in my model post-BBQS. Fifth and last, I collected performance metrics post-BBQS.

8.2.1 Site Visits and Interviews

I studied Case 2 from October 2022 to February 2023. I interviewed 10 project participants between October and November using in-depth semi-structured interviews (Appendix 9). I used a purposive sample, as in Case 1, and analyzed their responses to answer the following questions:

1. What are the distinguishing features of work (DFOW) for the scope studied? What DFOWs identified in Case 1 apply to Case 2?
2. What was the project team quality process? (i.e., what steps were followed, and who participated in these steps?) How can this process be improved?
3. What methods and tools were used in the quality delivery process? What additional methods and tools would Case 2 participants like to use to deliver quality?
4. What learning strategies were adopted when the measurable acceptance criteria (MAC) were not met? How can the management of lessons learned be improved?
5. What evidence do participants provide for their assessment of the study variables?

8.2.2 Survey

I invited all project participants who were part of planning or building the scope studied to participate in the surveys. Some participants completed the surveys and returned them to me in sealed envelopes; others completed the survey online. Table 8.1 describes the participants' sample.

Table 8.1: Case 2 Survey Participants

Description	Pre-BBQS	Post-BBQS
Total number of people invited to participate	24 (9 staff, 15 craft)	30 (12 staff, 18 craft)
Total number of participants	23 (8 staff, 15 craft)	26 (8 staff, 18 craft)
Participation rate	96%	87%

Turnover in construction projects was a challenge in this research, where I intended to compare Pre- and Post-BBQS implementation. The turnover may be caused due to the changes in scope or amount of work that typically occur in construction projects every few weeks or months. While some participants continued to work on the project for the span of time of the implementation and participated in both surveys Pre- and Post-BBQS, others participated in only one or the other. For my analysis, I used the data I collected from all participants regardless of when they joined the study.

For Case 2, I refined the survey instruments used in Case 1. The following subsections describe the analysis I conducted to assess the adequacy of the refined survey instrument (Appendix 12).

8.2.2.1 Survey Reliability

As in Case 1, I used Cronbach's alpha (Table 8.2) to measure the internal consistency of my instrument and determine its reliability.

Table 8.2: Cronbach's Alpha and Statistics for Study Variables and Sub-Variables

Variable	Sub-variable	# of Items	α	Pre-BBQS		Post-BBQS	
				Mean	SD	Mean	SD
Psychological safety (PS)		**16**		**6.334**	**0.815**	**6.519**	**0.533**
	In relation to team leader (PS1)	8	0.965	6.418	0.733	6.682	0.440
	In relation to other members of the team (PS2)	8	0.983	6.250	0.958	6.355	0.771
Behaviors desired for quality (BQ)		**35**		**5.991**	**0.754**	**6.280**	**0.758**
	Being respectful (BQ1)	6	0.956	5.862	1.137	6.275	0.783
	Actively caring (BQ2)	6	0.927	6.065	0.940	6.326	0.965
	Making reliable promises (BQ3)	3	0.893	5.971	0.864	6.217	0.974
	Speaking up (BQ4)	4	0.930	5.902	0.970	6.211	0.960
	Being diligent (BQ5)	4	0.921	5.989	0.748	6.326	0.796
	Actively listening (BQ6)	6	0.891	6.036	0.594	6.167	0.841
	Actively learning (BQ7)	6	0.923	6.072	0.733	6.397	0.702
Team performance (TP)		**8**		**6.299**	**0.499**	**6.528**	**0.607**
	Project-specific (TP1)	7	0.903	6.298	0.517	6.532	0.595
	Compared to past projects (TP2)	1	N/A	6.304	0.635	6.500	0.905

All Cronbach's alpha values were above the minimum value desired for reliability (0.70), indicating that the survey has a good-high level of reliability. To further examine the questions of this survey, I examined the factor loadings for each sub-variable in the following section.

8.2.2.2 Factor Analysis

As in Case 1, I loaded all questions per sub-variable into a single factor. Most questions loads were above 0.7, except for a few that I reworded for clarity for the final round of surveys. Appendix 15 describes the factor analysis results I conducted for each sub-variable.

In the next section, I present my analysis of the site visits, interviews, and survey responses.

8.3 Team Psychological Safety – Behaviors for Quality – Performance

I summarize my findings Pre- and Post-BBQS implementation in the following subsections.

8.3.1 Team Psychological Safety

As shown in Table 8.2, Case 2 team's psychological safety score Pre-BBQS was 6.334, on a 1-7 scale where 1 and 7 represented a low and high psychologically safe environment, respectively. The team score, on the high spectrum, was evidenced in the interviews:

> *"Admin side, we're very good at asking questions and acknowledging when we make a mistake. I'm a big proponent of the only way you really learn is by doing something, and if you do it wrong, learning from it and how to fix it." – Field Engineer*

> *"Here, the [craft] guys let me know when they see a mistake, no matter who caused it. We all make mistakes, even me being the foreman." – Drywall Foreman*

Unlike Case 1, psychological safety with respect to their team leaders (PS1 = 6.418) was rated slightly higher than with respect to their peers (PS2 = 6.250). Especially for the craft, the drywall foreman has been recognized for his collaborative behavior, not only within the drywall craft but with workers from other contractors and the city inspector:

> *"His [foreman's] collaboration with the other contractors on the project is top-notch. Even in tough conversations, he is able to keep his cool, negotiate, and ultimately leave the situation with a positive outlook from all involved." – Field Office Coordinator (FCO)*

As in Case 1, the participants from the staff group reported feeling psychologically safer than those from the craft Pre-BBQS, but this gap decreased Post-BBQS (in relation to peers $M_{Craft\text{-}Pre} = 5.97$, $SD = 1.06$; $M_{Staff\text{-}Pre} = 6.76$, $SD = 0.36$; $M_{Craft\text{-}Post} = 6.21$, $SD = 0.87$; $M_{Staff\text{-}Post} = 6.67$, $SD = 0.34$; in relation to team leader $M_{Craft\text{-}Pre} = 6.22$, $SD = 0.82$; $M_{Staff\text{-}Pre} = 6.78$, $SD = 0.33$; $M_{Craft\text{-}Post} = 6.64$, $SD = 0.49$; $M_{Staff\text{-}Post} = 6.76$, $SD = 0.31$). Figure 8.1 shows the results of both subgroups with their standard errors.

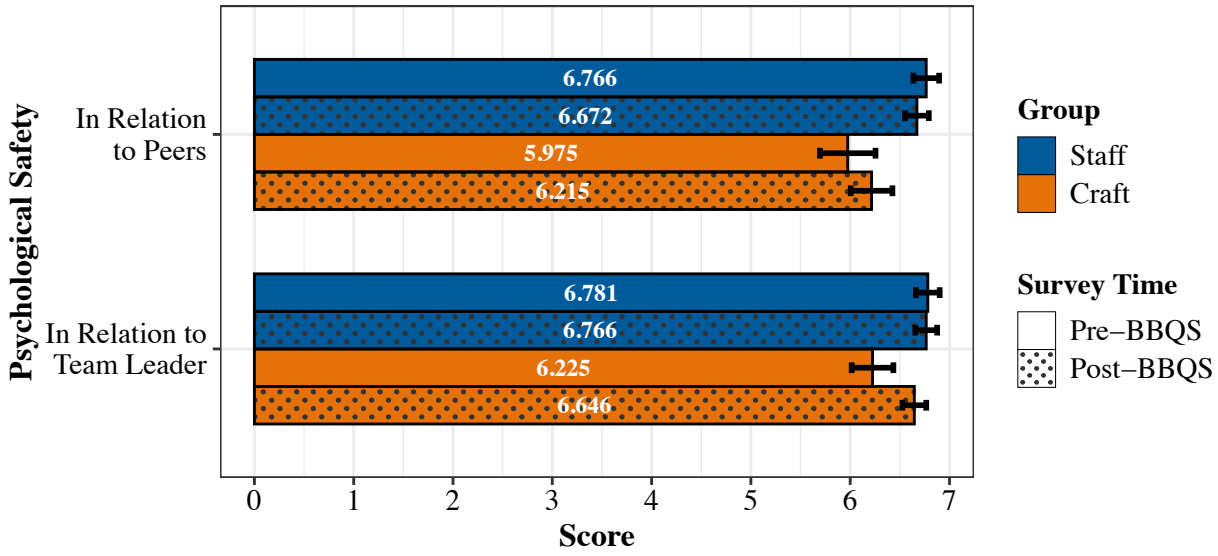


Figure 8.1: Team Psychological Safety Pre- and Post-BBQS for Staff and Craft Groups

I observed that some participants had a hidden expectation that craft would speak up when something is not clear:

> *"I'm the one leading [the field]. I have to make sure that I'm telling them [craft] exactly what the drawings say. The most important part is that they understand what I'm saying. If they have a question, they need to let me know." – Drywall Foreman*

However, from the survey and interviews, I identified craft psychological safety as an area for improvement for the project team:

> *"In a 1 [low PS]-7[high PS] scale, I'd say they [craft] are at a 3 or 4. In that [PS] aspect, I think it's something we can work on a lot… The relationship I have with the craft allows them to have more trustworthiness and communication with me. Something that I have seen in this job that is different from the previous jobs is that in my previous jobs we had this kind of more united front to this kind of things [PS]. The attitude [on my previous projects] was that we were all a big team, and if someone screwed up, we all helped, and no one was afraid." – Field Engineer*

The GC project leadership, being aware that craft psychological safety was not as high as they expected, started focusing on ways to foster it:

> *"One thing we're working on is identifying different avenues for people to feel safe and speak up… I think it would be reformatting some discussions to be more craft-led." – PM*

Knowing the need to focus on craft psychological safety, I started the first BBQS implementation session with a conversation with the craft about psychological safety. One of the things I asked them was to share, putting a check on a post-it, if they felt that they wanted to speak up or say something that could benefit the team, but instead remained silent due to fear or embarrassment while working in Case 2. Figure 8.2 shows that 26 out of 28 participants (highlighted in red squares over the sticky notes) reported remaining silent on at least one occasion.

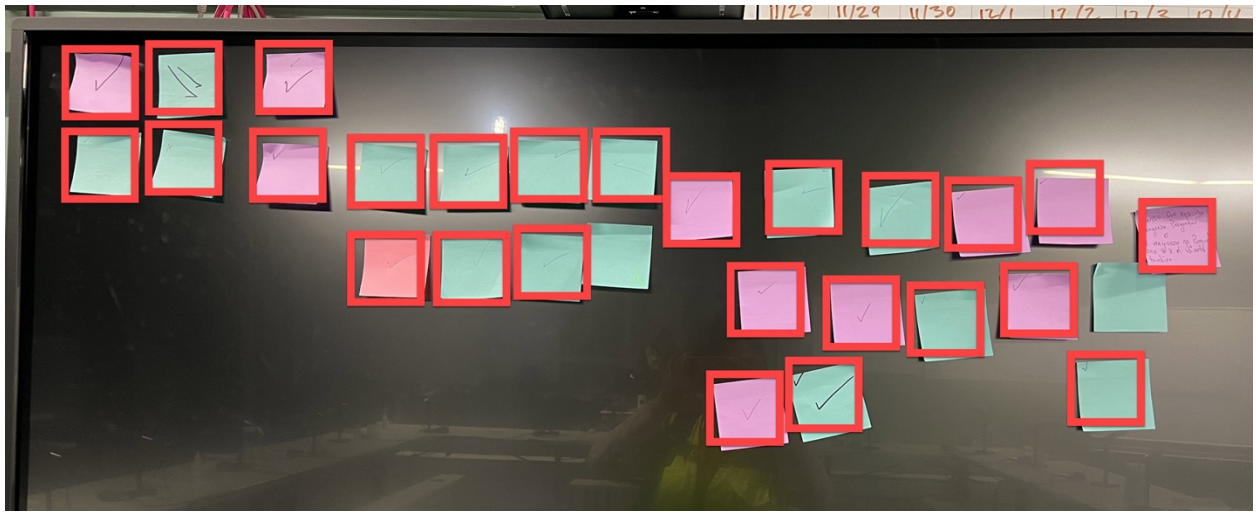


Figure 8.2: Post-its Participants Used to Report Keeping Silent at least Once in Case 2 (Photo: © Sulyn Gomez, 2022-12-14)

I highlighted the importance of psychological safety in quality in all the working sessions I hosted with the craft group. I summarize these sessions in Section 8.5.5.

In the next sections, I analyze the team behaviors, present evidence of how they took place onsite, and what opportunities for improvement I explored with the team.

8.3.2 Team Behaviors for Quality

As reported in Table 8.2, all behavior sub-variables were scored at 5.8 or above Pre-BBQS and 6.1 or above Post-BBQS. I analyzed the distribution of responses per sub-variable Pre- and Post-BBQS. Figures 8.3-8.4 show participants' average scores per sub-variable Pre- and Post-BBQS, respectively. All sub-variables Post-BBQS received higher scores.

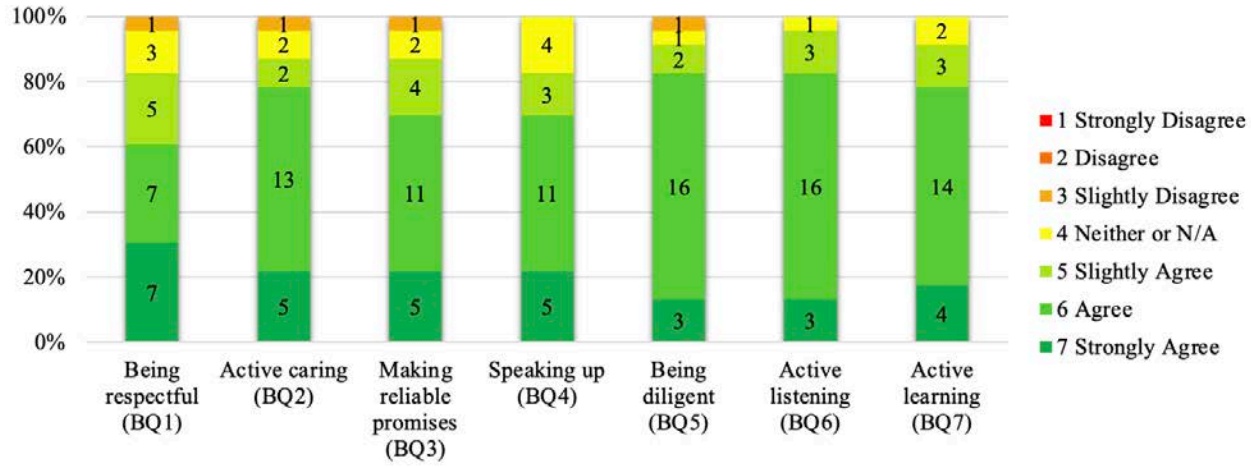


Figure 8.3: Case 2 Reporting Count of Behaviors Desired for Quality Pre-BBQS (n = 23)

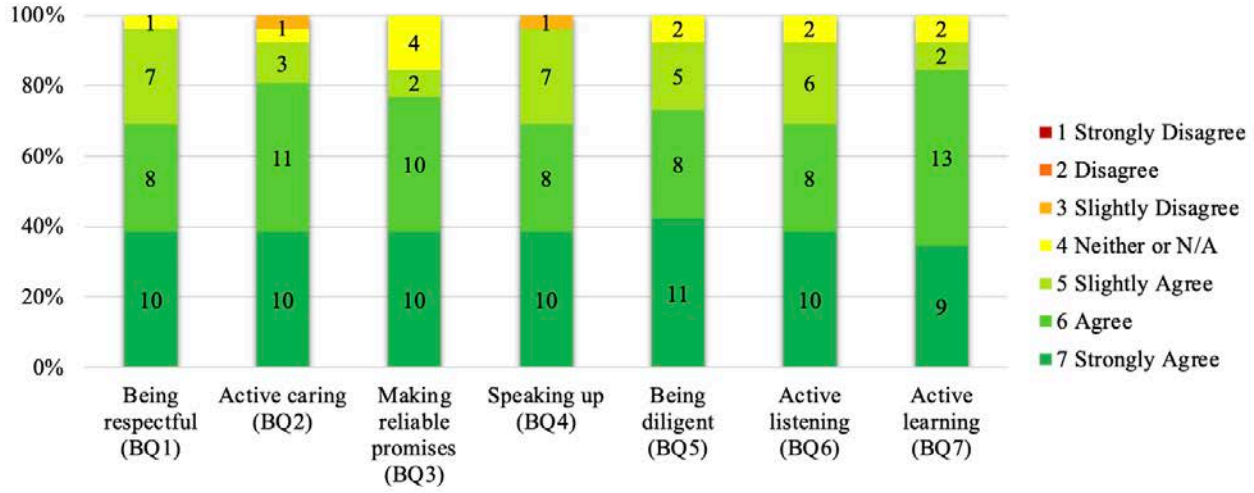


Figure 8.4: Case 2 Reporting Count of Behaviors Desired for Quality Post-BBQS (n = 26)

Figure 8.5 shows the score for each behavior sub-variable and the standard error divided among staff and craft participants, Pre- and Post-BBQS (active learning $M_{Craft\text{-}Pre}$ = 5.92, SD = 0.79; $M_{Staff\text{-}Pre}$ = 6.35, SD = 0.53; $M_{Craft\text{-}Post}$ = 6.42, SD = 0.80; $M_{Staff\text{-}Post}$ = 6.33, SD = 0.44; active listening $M_{Craft\text{-}Pre}$ = 5.87, SD = 0.60; $M_{Staff\text{-}Pre}$ = 6.33, SD = 0.47; $M_{Craft\text{-}Post}$ = 6.18, SD = 0.85; $M_{Staff\text{-}Post}$ = 6.12, SD = 0.85; being diligent $M_{Craft\text{-}Pre}$ = 5.85, SD = 0.80; $M_{Staff\text{-}Pre}$ = 6.25, SD = 0.58; $M_{Craft\text{-}Post}$ = 6.40, SD = 0.77; $M_{Staff\text{-}Post}$ = 6.15, SD = 0.86; speaking up $M_{Craft\text{-}Pre}$ = 5.63, SD = 1.04; $M_{Staff\text{-}Pre}$ = 6.40, SD = 0.56; $M_{Craft\text{-}Post}$ = 6.18, SD = 1.11; $M_{Staff\text{-}Post}$ = 6.28, SD = 0.50; making reliable promises $M_{Craft\text{-}Pre}$ = 5.80, SD = 0.91; $M_{Staff\text{-}Pre}$ = 6.29, SD = 0.70; $M_{Craft\text{-}Post}$ = 6.35, SD = 0.93; $M_{Staff\text{-}Post}$ = 5.91, SD = 1.05; active caring $M_{Craft\text{-}Pre}$ = 5.85, SD = 1.01; $M_{Staff\text{-}Pre}$ = 6.45, SD = 0.68; $M_{Craft\text{-}Post}$ = 6.22, SD = 1.11; $M_{Staff\text{-}Post}$ = 6.56, SD = 0.48; being respectful $M_{Craft\text{-}Pre}$ = 5.32, SD = 1.04; $M_{Staff\text{-}Pre}$ = 6.87, SD = 0.24; $M_{Craft\text{-}Post}$ = 6.15, SD = 0.84; $M_{Staff\text{-}Post}$ = 6.54, SD = 0.58).

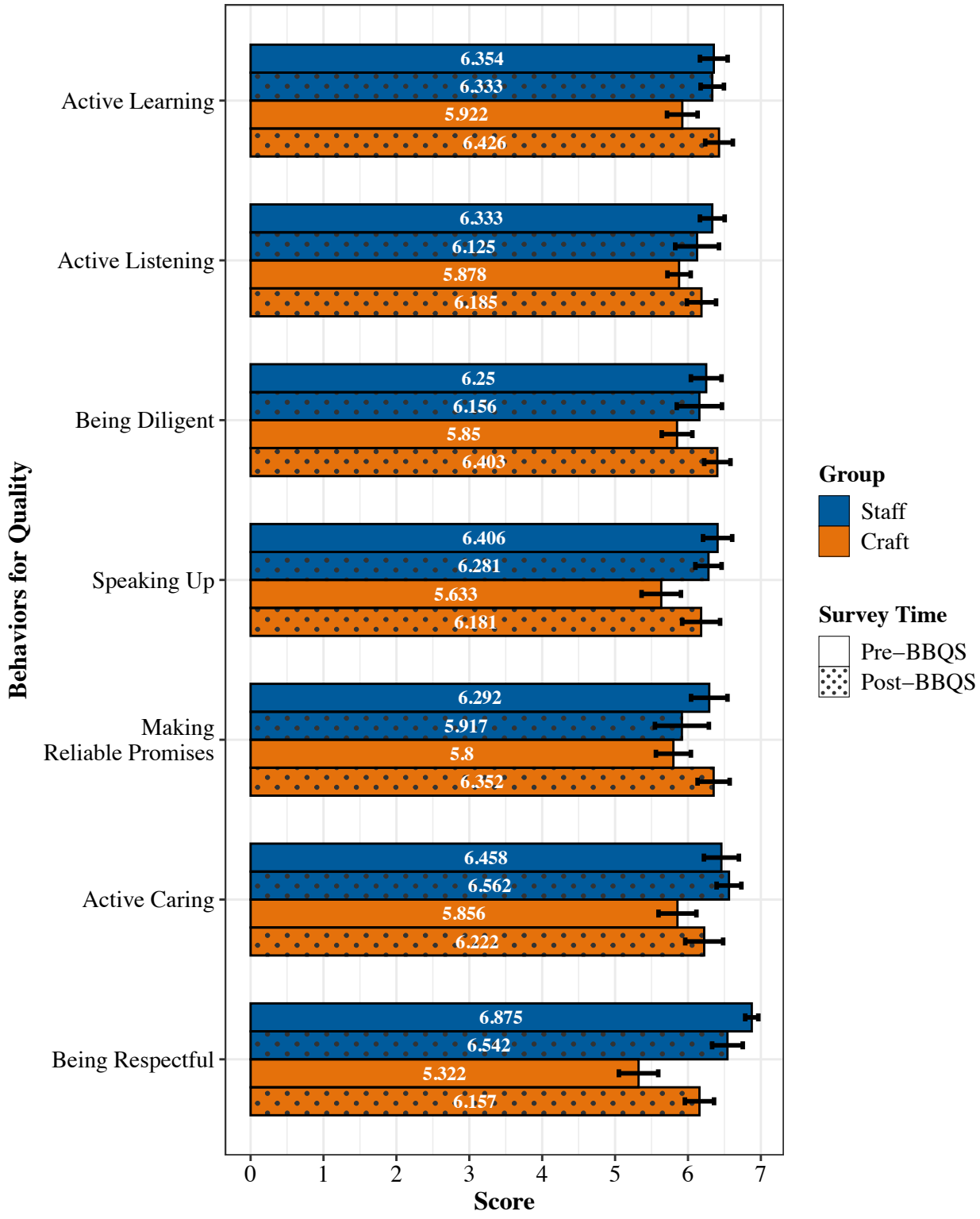


Figure 8.5: Behaviors Desired for Quality Scores for Case 2 Pre- and Post-BBQS Including All Participants

As shown in Figure 8.5, while the craft group scores increased Post-BBQS, the staff group either maintained or slightly increased or decreased their scores per sub-variable. I worked closely with the craft group to implement BBQS in the field, so I expected to see an increase in the results. I also analyzed whether I could observe a similar trend when analyzing the responses of those who participated in both Pre- and Post-BBQS surveys. I found a similar trend in this smaller sample (Figure 8.6), but the increase in craft behaviors for quality was even more significant for those participants who were part of the study from beginning to end (active learning $M_{Craft\text{-}Pre} = 5.40$, $SD = 1.10$; $M_{Staff\text{-}Pre} = 6.44$, $SD = 0.51$; $M_{Craft\text{-}Post} = 6.30$, $SD = 1.09$; $M_{Staff\text{-}Post} = 6.33$, $SD = 0.57$; active listening $M_{Craft\text{-}Pre} = 5.46$, $SD = 0.76$; $M_{Staff\text{-}Pre} = 6.50$, $SD = 0.44$; $M_{Craft\text{-}Post} = 6.06$, $SD = 1.09$; $M_{Staff\text{-}Post} = 6.44$, $SD = 0.96$; being diligent $M_{Craft\text{-}Pre} = 5.25$, $SD = 1.11$; $M_{Staff\text{-}Pre} = 6.41$, $SD = 0.52$; $M_{Craft\text{-}Post} = 6.40$, $SD = 0.84$; $M_{Staff\text{-}Post} = 5.67$, $SD = 1.18$; speaking up $M_{Craft\text{-}Pre} = 5.35$, $SD = 1.19$; $M_{Staff\text{-}Pre} = 6.75$, $SD = 0.43$; $M_{Craft\text{-}Post} = 5.95$, $SD = 1.84$; $M_{Staff\text{-}Post} = 6.33$, $SD = 0.57$; making reliable promises $M_{Craft\text{-}Pre} = 5.00$, $SD = 1.13$; $M_{Staff\text{-}Pre} = 6.22$, $SD = 0.69$; $M_{Craft\text{-}Post} = 6.20$, $SD = 1.30$; $M_{Staff\text{-}Post} = 5.78$, $SD = 1.17$; active caring $M_{Craft\text{-}Pre} = 5.00$, $SD = 1.30$; $M_{Staff\text{-}Pre} = 6.66$, $SD = 0.44$; $M_{Craft\text{-}Post} = 5.97$, $SD = 1.70$; $M_{Staff\text{-}Post} = 6.28$, $SD = 0.63$; being respectful $M_{Craft\text{-}Pre} = 4.96$, $SD = 1.18$; $M_{Staff\text{-}Pre} = 6.88$, $SD = 0.19$; $M_{Craft\text{-}Post} = 5.90$, $SD = 1.14$; $M_{Staff\text{-}Post} = 6.67$, $SD = 0.57$).

While I collaborated with the staff group on the BBQS implementation, I found what may have influenced the results. First, in the Post-BBQS survey, some participants were part of the craft sessions, and they learned things from the craft perspective that they were not aware of before the study, such as the fact that craft didn't feel as psychologically safe as some staff members thought they would. Second, shortly after the study started and the participants completed the Pre-BBQS survey, the team faced a big quality issue with wall finishes. This issue helped them realize that they were not doing as well as they initially thought in planning quality and fostering behaviors desired for quality. I describe this issue in more detail in the DFOW section (8.6.1).

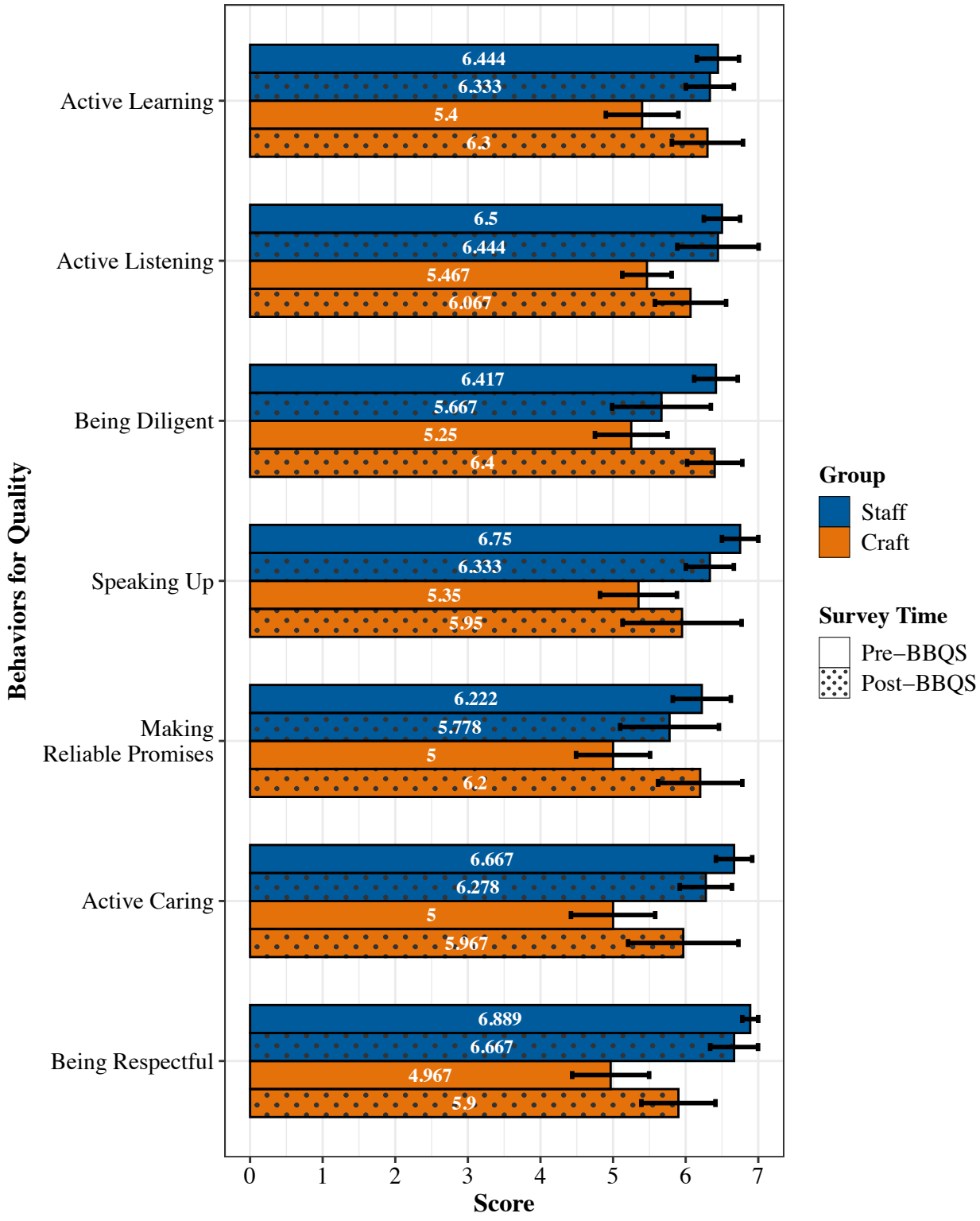


Figure 8.6: Behaviors Desired for Quality Scores for Case 2 Including Only Participants who Took Both Pre- and Post-BBQS Surveys

I used the interviews to better understand what prompted the survey scores. The following sections present excerpts from the interviews to illustrate evidence of each sub-variable (BQ1-BQ7), and the opportunities for improvement that Case 2 participants suggested exploring through the study.

8.3.2.1 Being Respectful

Participants described the way they treated each other, which started with strong leadership who was convinced that an environment with respect could help the team members thrive:

> *"We toast each other, talk to people, not screaming or yelling. For me coming on this job was a huge goal to make a positive atmosphere, and that made a huge difference. I've been on other jobs where it's hostile; you can feel the tension. The work there is not as good, and people are not happy. All that is stressful and sucks. There's no reason for it; it doesn't have to be that way. You can make that better." – GC Superintendent*

Team members reported that respect was visible between the drywall foreman and the city inspector, too, because the good work being delivered increased the trust among them:

> *"Our drywall team knows exactly what the [city] inspector is looking for. The relationship we have with him is so good. When he comes, it's a very simple walk. It's good to see the trust that the inspector has in our drywall team. He respects and trusts the guy in the field that he's doing it right." – Field Engineer*

Although the participants reported that team members generally respected each other, they also identified room for improvement. Some of the actions suggested to keep fostering respect include, for example, being more aware of how team members express their points of view and doing so in a respectful way:

> *"Definitely some room for improvement in being respectful. Sometimes egos come in that probably need to be reduced. I'm not saying we're bad by any means, I think you [GC] still do a good job, but I think we could be a little bit more respectful for teams." – Client*

Another opportunity for improvement that team members brought up is recognizing good work as a way to positively reinforce it:

> *"Some people get a lot of really good recognition on this job site, but I think in the broad sense there're more people that deserve a little bit more respect and recognition." – PM*

> *"We should recognize when someone is doing something well, even if it's part of what they should be doing. We prevent some people from thinking that they are working so hard without any recognition. I think that it is something that craft would love." – Field Engineer*

8.3.2.2 Active Caring

Participants described actions that show active caring, such as the consistency from the GC in planning and checking the work installed.

> *"We're constantly doing walks [to check work installed]. Our Pes and foremen try to do a prewalk of most spaces ahead of the walks with the client." – PM*

One example of how the GC engaged in the field was through the daily huddles where the superintendents and field engineer discussed the work with the craft:

"We have daily huddles where we talk to everyone [from the field] about what we'll be doing. We're good in relaying the [design] information to the field." – Field Engineer

Another example of active caring was shown by GC, who highlighted the connection between trade damage and safety to encourage workers to minimize trade damage and keep people away from hazardous situations:

"One concept that we always talk about here is trade damage as a danger to other people." – PM

Because of the years that the team had been working together, participants brought up some suggestions to keep the "active caring" behavior active:

"To a certain extent, there has been some complacency of people realizing in some aspects how the client maybe doesn't care as much about aesthetics and understands the driving track of this project is the schedule. You can see a bit of a get-it-done mentality sometimes from this." – PM

This includes encouraging more involvement from the drywall leadership in the field:

"[My supervisors] tell me, 'why would I go if there are no issues?'. Well, if they come when we have issues, then it's already too late. They have to be here engaged before issues ever occur." – Drywall Foreman

And also, being more consistent with the DFOW process, which would help the team understand what the client really cared about (e.g., keeping their equipment free of dust) even more than what they did:

"There's definitely a lot of room for improvement [in active caring], to be honest with you. When a piece of equipment comes, our team makes a lot of comments on that from a cleanliness standpoint. We need to do better about that; it also comes back to the guy cutting the piece of drywall saying, 'maybe I shouldn't cut the piece of drywall right here [next to the equipment], or is there a better way of doing this?'. So, trying to get that process better [to minimize dust in our equipment]." – Client

8.3.2.3 Making Reliable Promises

Participants reported doing good in making reliable promises among the staff.

"With the staff, I think there is confidence in saying 'no' knowing that nothing [bad] is going to happen, contrary to what a craftworker may think. They think that if they say 'no', it'll negatively affect them. The best way to help them is by giving an example. If something happens, it's important for them to see that a certain person spoke and nothing happened to them. They'll see if it happened to this person, they can do it too." – Field Engineer

More owner involvement would benefit the cycle of reliable promises to make sure that the team is aligned on what is really wanted:

"We could probably use continually more owner involvement from the clients, and especially from their operations department on the front end of developing these quality plans." – PM

On the GC's end, reliable promises could be improved by prioritizing the requests made:

"[Describing opportunities for improvement] We could do better identifying the priorities because we've been shifting priorities onsite as things come up, then being able to communicate the timeline for review or even generating a report… Does it take you an hour or 4 days? So, understanding what's really needed and what's possible." – Client

On the architect's end, reliable promises can be improved by being more diligent in the drawings updating process:

"Our architect is off-site, and they're not as involved in the day-to-day decisions in this project. Sometimes it's like they're the last to know… The issue we typically find is that we make a decision on one phase of the project, but the drawings don't get updated. [e.g.,] We sent an RFI to modify the column size in the data module rooms, but they didn't update the drawings and it caused issues with the tenant server installation down the road." – PM

8.3.2.4 Speaking Up

Participants reported that the staff group seemed strong in speaking up, but they pointed out some room for improvement in the craft group:

"When I screw something up, I'm very vocal about it. I see it differently with our craft, honestly." – Field Engineer

"We have a leadership team that is very good at speaking up. I think there is some development of speaking up from the journeyman and even young foremen's perspective that definitely needs some work out here. We need everyone to understand that if they raise their hand and say, 'there's an issue out here', they're actually helping the project. We don't want raising issues to be a negatively reinforcing topic. We want to positively reinforce people being open and honest about what they're seeing out there." – PM

This shows that leadership understood the need to work with the craft group to help them speak up more comfortably.

"Everyone seems to be pretty open, but from what I can see, I'd say craft is probably a little bit less [prone to speak up]." – Client

Something that can help craft in speaking up is by having a foreman who shows it by example and speaks up and communicates what he needs to do the work as expected:

"If I need something, I'd ask. [e.g.,] If I need more people because the job is extending more, then I ask for more people." – Drywall Foreman

This recommendation can be generalized to all relationships of superior and subordinate, e.g., journeyman to apprentice, foreman to journeyman and apprentice, general foreman to foreman, superintendent to general foreman, PM to superintendent, etc.

8.3.2.5 Being Diligent

Participants showed diligence starting in the design development by providing input in the design documents to make them clearer:

"There were things that were not clear in the drawings when we started the project. It did take a decent amount of work to really get a full understanding of what goes where." – PM

"We could see that there were details that were well thought out. A lot of review and care went into all the details; every drawing set we got went through a certain review with us, with the owner, and the other contractors." – Field Engineer

This diligence could also be seen in the field where the foreman took ownership of the work installed and posed questions when needed to understand what he needed to do before doing it:

"If there's a mistake, it's because I didn't explain it well enough. Something I've learned is that if I'm not sure about what I'll do, it's better not to do it." – Drywall Foreman

One of the areas of improvement I observed, and participants reported is the quality plan development and its use by the team. While some participants said that the quality plan was getting updated as needed, some pointed out that they had not even looked at it or knew where it was:

"Our quality plan is a living document." – PM

"Do we use the quality plan here? Probably, I don't even know. Do we talk about quality all the time? Yes, 100%." – GC Superintendent

As said above, not having or reviewing the quality plan does not mean the team does not care about quality or somehow plans for it. However, thinking through the quality process and writing it can give a team more consistency in the way they manage quality for the various scopes of work. One example of what can be better defined in a quality plan is the scope of the quality walks:

"[Weekly walk client-contractors] needs to be more defined because it's not organized now. It's more like, 'do you want to walk today'? or 'what do you want to walk today' or 'what issues do we need to talk?'. It's more like coordination, but I don't think we've ever actually had an in-depth let's-look-at-quality walk… What we don't do is differentiate between what is a coordination walk and what is a punch walk. Now it's both together, and it's not ideal." – Client

Another opportunity for improvement for this team was making sure all people needed were included in the conversations and making sure information in drawings was up to date before building:

"[Describing opportunities for improvement] If you [GC] are engaging portions of our team [client], you gotta have the right person in the room. If you don't have the right person in the room, you got to do the whole meeting over again. So, ensuring that people show up and are actively engaged is huge." – Client

"Sometimes changes are reported too late, or we don't get to invite all the people who have to be present in the discussions." – Field Engineer

8.3.2.6 Active Listening

Participants highlighted active listening among the staff as something working well, and the office structure as a factor that helped sustain this behavior:

"Our desk layout is there for a reason, and it's just so that we're all involved. When someone has a question, we're all listening, and we'll dive in and have a quick huddle of what the discussion is, even though it didn't pertain to us first, we still get involved because we're a team." – GC Assistant Superintendent

Something else they highlighted as an important factor for active listening among staff-craft was the use of the craft's native language to the extent possible:

> *"We're lucky to have one of our superintendents speak Spanish [besides me], so I get to communicate with [craft] on a different level than everyone else here." – Field Engineer*

To strengthen active listening, with the number of virtual meetings still going on in the project, the client suggested:

> *"[Describing opportunities for improvement] We have quite a bit of virtual meetings, so getting to the point where we start turning the cameras on. It helps ensure that people are engaged instead of multitasking, kind of listening to you and not doing something I shouldn't be doing." – Client*

In addition, although verbal communication is great, with the use of Procore for document control, the team highlighted the need to reinforce discipline and consistency in the notifications sent through that platform to communicate quality issues:

> *"A lot of our communication to remedy the RCL [rolling completion] items is through email or phone calls because people get a little numb from Procore notifications over time. [e.g.,] when we need them to patch a section of drywall, they [SPW drywall] tend to ignore [Procore] requests after some time, so it's a lot more effective that we just pick up the phone and talk." – PM*

8.3.2.7 Active Learning

Participants from the GC's staff were eager to learn, and a few months before the study started, they took the GC's training in quality (Chapter 6).

> *"We train each other on what we need to learn. Like if you ask me to make an RFI, I'll tell you I don't know, but if I wanted to learn how to make one, I'll just go to one of my Pes and ask them to show me, and I'll learn. If they don't know how to make the schedule, I'll show them. It's part of our career growth. I know I don't know everything; they're my resource. They know they don't know everything; I'm their resource." – GC Assistant Superintendent*

> *"We took the Building Quality Builder training together. Everyone knows we still have a lot to learn and help each other constantly." – PM*

Although the team had a good understanding of the client quality expectations because of past experience with them, quality issues still occurred:

> *"[the owner] already knows what they are looking for [during punch walks] because we had done projects with them before… Also, we know what we messed up on too and how to fix it… But you know, new things always arise, even if you're technically doing the same thing over and over. When the doors were installed, they were painted in a different color [than the existing ones], so the owner immediately came and said, 'the doors' color have to match those in the hallways', and I didn't know that because I hadn't been in the other buildings." – Field Engineer*

Participants reported that although the quality issues they had were minor, these were repetitive issues that they needed to address for continuous improvement:

"Our biggest headache out here is just making the same mistake over and over." – PM

"Some mistakes are continually brought up. Sometimes we have [client] team members who call them out as 'lessons not learned'." – Client

"A lot of our items [in quality planning] are slightly reactionary, meaning they have come up from issues we had with this client in the past. Moving forward, being more proactive rather than reactive would be the improvement to the quality plan." – PM

As these issues are addressed, it is important to document the lessons learned:

"We could work more on documenting our lessons learned." – Field Engineer

"Tons of knowledge is forgotten, and all you remember is the last 30 days of [bad things] you went through." – GC Superintendent

8.3.3 Team Performance

Figure 8.7 shows the team performance scores and standard errors (compared to past projects $M_{Craft\text{-}Pre}$ = 6.13, SD = 0.63; $M_{Staff\text{-}Pre}$ = 6.62, SD = 0.51; $M_{Craft\text{-}Post}$ = 6.61, SD = 0.77; $M_{Staff\text{-}Post}$ = 6.25, SD = 1.16; project specific $M_{Craft\text{-}Pre}$ = 6.30, SD = 0.57; $M_{Staff\text{-}Pre}$ = 6.28, SD = 0.41; $M_{Craft\text{-}Post}$ = 6.57, SD = 0.54; $M_{Staff\text{-}Post}$ = 6.42, SD = 0.72).

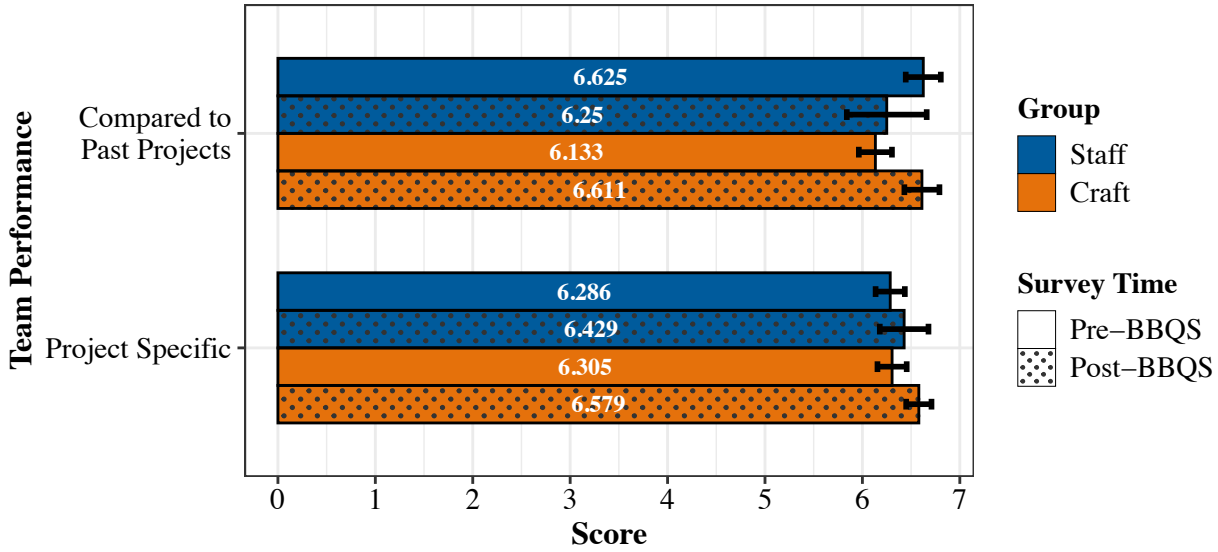


Figure 8.7: Team Performance Pre- and Post-BBQS Considering All Participants' Perception

When analyzing the results of those who were part of both the Pre- and Post-BBQS assessment and participated in identifying and resolving the issue with the previously mentioned wall finish, Figure 8.8 shows a slightly different trend (compared to past projects $M_{Craft\text{-}Pre}$ = 6.20, SD = 0.44; $M_{Staff\text{-}Pre}$ = 6.66, SD = 0.57; $M_{Craft\text{-}Post}$ = 6.20, SD = 1.30; $M_{Staff\text{-}Post}$ = 5.33, SD = 1.52; project specific $M_{Craft\text{-}Pre}$ = 6.11, SD = 0.73; $M_{Staff\text{-}Pre}$ = 6.47, SD = 0.50; $M_{Craft\text{-}Post}$ = 6.48, SD = 0.71; $M_{Staff\text{-}Post}$ = 5.91, SD = 1.01). The staff participants' responses indeed reflected what occurred onsite. For the craft, however, although they had to fix the issue with the wall finish, they thought they were doing well overall.

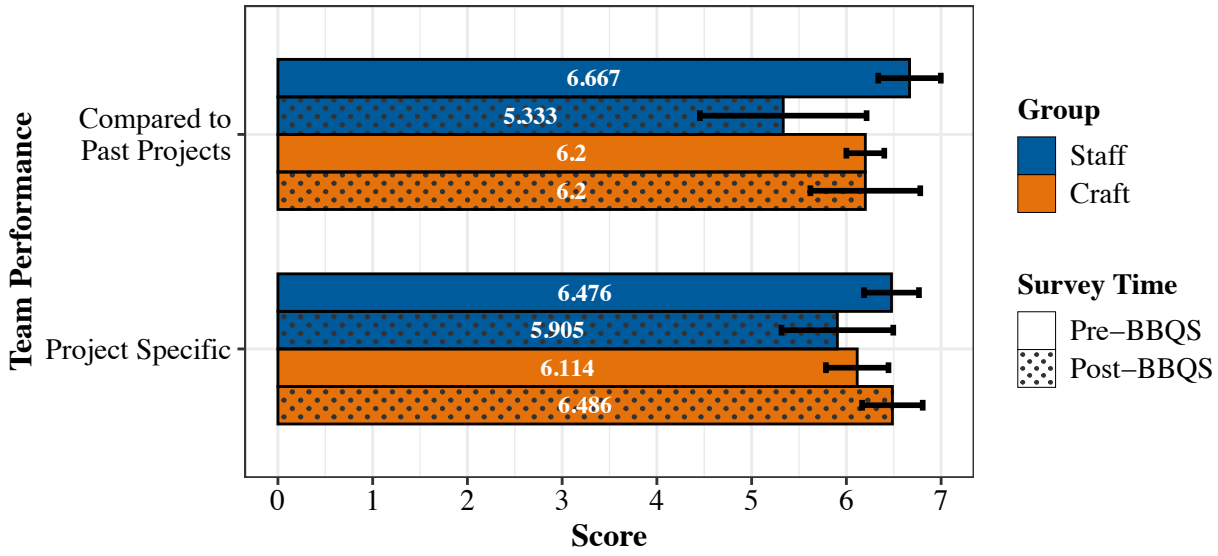


Figure 8.8: Team Performance Pre- and Post-BBQS Including Only Participants who Took Both Pre- and Post-BBQS Surveys

Both craft and staff participants reported the project to have good performance. In addition, their performance, when compared to previous experiences, was above their perceived performance in past projects. The survey results were supported through the interviews:

> *"It's truly amazing how we almost don't have rework here, coming from projects that unfortunately had a bunch; this one is going smooth." – Field Engineer*

> *"The overall quality of the job is extremely successful. Although we haven't been able to fully correct a few issues." – PM*

8.3.3.1 Quality Issues Identification Time

As in Case 1, I asked the study participants to assess when quality issues were identified using three tiers, shown in Figure 8.9, where all or almost all quality issues are solved. I selected these tiers because of the field, GC, and owner's involvement during quality control throughout construction. Figure 8.9 shows the participants' responses. Their perceptions substantially varied. For example, the GC's PM thought that 40% of the quality issues were caught in the field, 40% by the GC, and 20% by the owner. In contrast, the drywall foreman thought that 99% of the quality issues were caught in the field and the remaining 1% by the GC. On average, the issues identified and fixed by the field personnel accounted for 52% of the total, the GC 28%, and the owner's representative 20%.

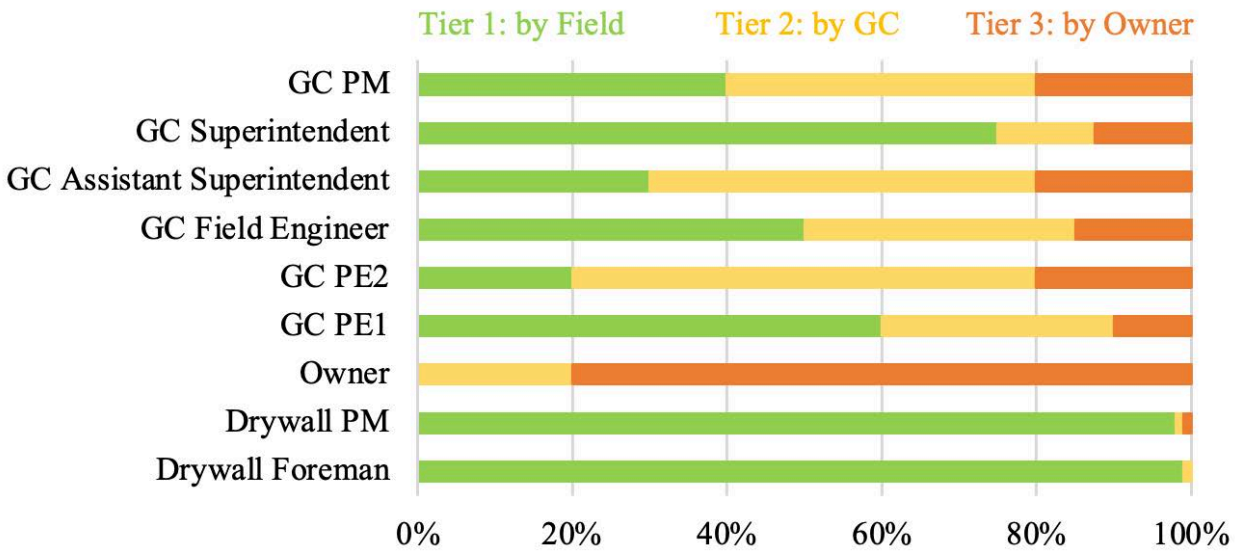


Figure 8.9: Time when Quality Issues were Identified in Case 2

Unlike Case 1, the owner participates in the identification of quality issues in Case 2.

> *"The most rigorous inspection process is with our client. We've had weekly quality inspection walks from the start of the project with the owner to develop our RCL. Those weekly inspections are where most of our items [documented issues] are identified." – PM*

Like Case 1, a large percentage of the quality issues identified in Case 2 was identified in the field.

> *"The GC scheduled the inspections, and I make sure everything is ready before he [inspector] comes. We have to build everything as in the drawings… I'm the one who identifies almost all mistakes." – Drywall Foreman*

Reportedly, almost all issues are identified and fixed in the field. However, "*almost all mistakes*" described above does not reflect the 52% resulting from the participant's perception. From my observations, this might have occurred because the issues fixed in Tier 1 are often not reported, and Tiers 2 and 3 participants might not know some of these issues ever occurred.

8.3.3.2 Documentation of Quality Issues

Table 8.3 summarizes how issues were managed in each tier applicable to Case 2.

Table 8.3: Case 2 Quality Issues Documentation Strategy Description

Quality Issue Identification Level	Description
Tier 1: By field, including SPW drywall installers and foreman	No formal documentation process was defined. As in other SPW jobs, installers checked the work, then their foreman checked it. As in Case 1, issues identified by field personnel were verbally communicated among them on a need-to-know basis and fixed as they occurred, and lessons learned at this level were stored as experiences in people's heads.
Tier 2: By GC, including PE, quality champion, and superintendent	Documentation of quality issues was typically managed through Procore. However, at the discretion of the person identifying the mistake, some issues were just verbally communicated to the field instead of documented on Procore. Issues not documented were typically considered minor or identified during pre-punch walks (i.e., informal walks with the owner to inspect completed work areas before formal punch walks).
Tier 3: By owner representative	Documentation of quality issues was typically managed through Procore. However, some issues were just verbally communicated to the GC for correction, especially those identified during pre-punch walks.

Unlike Case 1, the architects in Case 2 project were not as involved during field quality control, except during commissioning. The architect visited the site every 3-4 months, but they proactively collaborated to deliver quality on the front end by being invested in providing a solid design. Once the three tiers of inspections were completed, the AHJ inspected structural and fire requirements for code compliance. Although the team described they did not have issues passed to the AHJ, if they occurred, these would be documented as markups on the printed drawings in the field office.

Table 8.4 shows the number of quality issues documented on Procore. The number of quality issues documented in Case 2 seemed lower than those in Case 1. Many factors may have influenced this difference. E.g., the phase of the project when the study took place. In Case 1, the study was done at the end of the project, by when all the punch walks were conducted, and the report provided the total number of issues documented across all phases. In Case 2, the issues documented represent only what was documented at specific snapshots of time during the white space phase of construction, and final punch walks had not been conducted by the time I completed the study. In addition, in Case 2, many quality issues seem to have been caught and solved in Tier 1, or verbally communicated among the field for correction.

> *"For quality, if they [craft] see something doesn't look right, they're not going to call me and say, 'this doesn't look right'. They're just going to fix it." – GC Assis. Superintendent*

> *"Because of the previous phases, they know exactly what the inspector is looking for. Our drywall foreman is really good at catching things, very rarely, things slip up his checks. [In addition] The field admin team, the superintendents, and the other engineers are very active on the field, so it's easier to see when something's off… If I'm walking and something doesn't look right, I'll call the foremen." – Field Engineer*

Table 8.4: Number of Quality Issues Documented in Procore

Stage	Pre-BBQS implementation (week = 0)	During BBQS implementation (week = 6)	Post-BBQS implementation (week = 12)
Total number of issues documented (between Tiers 2 and 3)	59	133	133
Number of issues assigned to SPW drywall	12 (20%)	33 (25%)	33 (25%)
Average response time	24.3 days	23.4 days	24.5 days

I did not divide the percentage of issues identified in tiers 2 and 3 because of the team's RCL walks. In such walks, the FE or PE leading the scope walked with the owner's rep and took pictures of the issues brought up during the walk. While the GC identified some of the issues documented, others were brought up by the owner, and I did not have a way to discern which ones were identified by each from Procore. In addition, some of the issues identified were not documented but communicated to the subcontractors for correction via text or verbal communication.

I also explored the type of issues that the Case 2 team was documenting (Table 8.5).

Table 8.5: Quality Issues Documented Distributed by Category

Type of Quality Issue Documented	Pre-BBQS (week =0, #issues = 12)	During BBQS (week = 6, #issues = 33)	Post-BBQS (week = 12, #issues = 33)
Trade damage	42%	48%	48%
Framing cleanliness	25%	9%	9%
Joints between mesh and drywall	17%	6%	6%
Patch holes	8%	15%	15%
Others (finishes, sizing, caulking penetrations)	8%	22%	22%

Unlike Case 1, in Case 2, I did not see instances where missing backing pieces or popped screws were documented, but rather a significant increase in trade damage instances was documented. This does not mean there were no missing pieces of backing from time to time, but instead that this was not an issue typically documented in the project. The documented trade damage was primarily caused due to bumps into the drywall walls. Figure 8.10 illustrates wall damage identified by the owner during an RCL walk. During the walk, the owner put green tape on the wall to indicate that such damaged section needed to be repaired.

Figure 8.10: Trade Damage to Drywall Wall in Case 2 (Photo: © Sulyn Gomez, 2022-12-21)

8.3.4 Relationship Psychological Safety – Behaviors for Quality – Performance

Tables 8.6-8.7 show the correlations I found between my model variables. As shown, psychological safety is highly correlated to behaviors for quality (r = 0.729; r = 0.698), and this, in turn, is highly correlated to team performance (r = 0.602; r = 0.758). As in Case 1, this supports my hypotheses 1 and 2 (Section 1.5) that suggest that psychological safety is positively associated with behaviors for quality, and behaviors for quality is positively associated with team performance, respectively. However, the small sample size does not support strong conclusions.

Table 8.6: Model Variables Correlations Pre-BBQS

n = 23	**Psychological Safety (PS)**	**Behaviors for Quality (BQ)**	**Team Performance (TP)**
Psychological Safety (PS)	1.000	0.729	0.747
Behaviors for Quality (BQ)		1.000	0.602
Team Performance (TP)			1.000
All correlations shown in this table are significant at $p < 0.01$			

Table 8.7: Model Variables Correlations Post-BBQS

n = 26	**Psychological Safety (PS)**	**Behaviors for Quality (BQ)**	**Team Performance (TP)**
Psychological Safety (PS)	1.000	0.698	0.483
Behaviors for Quality (BQ)		1.000	0.758
Team Performance (TP)			1.000
All correlations shown in this table are significant at $p < 0.01$			

8.4 Processes to Support Quality Delivery

Case 2 processes to deliver the drywall scope studied has various similarities to Case 1. I highlight the key sub-processes in the following subsections and include the process diagram in Appendix 16 with a description of each step in Appendix 17.

8.4.1 Quality Implementation Plan (QIP) Process

Unlike Case 1, Case 2 did have a QIP. However, after reviewing it, I realized that the team's QIP was a generic template developed by the GC's quality team. When consulted about scope-specific QIPs, study participants either were unaware of the existing QIP or referred me back to the generic QIP.

> *"I haven't looked at the quality plan [QIP]. I can't really speak about where the document even is. [The Case 2] project has been well established by now, so I didn't really get the whole backside behind it [having joined the project 10 months ago]." – Field Engineer*

I shared my QIP template (Appendix 14) with the team and some examples of visuals they could use to show good and bad installation examples. I improved such a template with the lessons learned from this project.

8.4.2 Distinguishing Features of Work Process

The Case 2 team planned and held some DFOW conversations for the core and shell phase. However, these conversations did not continue for the following phase, white space.

> *"We attempted to go through the DFOW process during the core and shell and defined what's truly required. [However] we have not updated the DFOWs [since then]. We have not followed the DFOW conversations that we went through in the beginning." – Client*

Even though the GC understood the owner's expectations relatively well for most of the scopes due to their experience working with them, the team had new scopes even for a similar building:

> *"We had a sound wall on this building that we haven't done in the previous buildings. It was a whole new system for our team, so we decided to do a mockup." – Field Engineer*

Nailing down the DFOWs and MAC could help clarify quality expectations:

> *"Let's think how I assess it [quality of walls]… We didn't say, 'Hey, you guys stay five feet away from it'. We didn't go through that level of detail, but that would be a good point just defining how am I inspecting a panel that's eight feet in the air?." – Client*

Section 8.6 describes the project's potential DFOW conversations for the drywall scope studied.

8.4.3 Craft Involvement in Quality Planning and Execution

Craftworkers are typically not as involved as they should be in the quality process:

> *"Are all people needed part of the quality conversations? No, and I'd say that's a no for almost every job because 99% of those conversations are happening over tons and tons of meetings, and one of the people that need to be part of these conversations at a minimum*

is one of the guys that's actually going to be in the field when it's happening. A lot of times, we don't have that." – GC Superintendent

One of the spaces where the GC team had conversations about quality was the daily huddles with the craft:

"The daily huddles help a lot to make sure we're in agreement on what needs to be done." – GC Assistant Superintendent

Involving the craft in quality planning benefits the work and the team. For instance, the craft can provide input about safety and constructability. Figure 8.11 illustrates an example of a scope with relatively risky building steps where craft input was used in designing the building process.

"I didn't have any experience [installing mesh]. It wasn't difficult, but we got to be very careful with the safety of those installing them. Materials are heavy, and the edges are very sharp. We needed three people to do the job. One cuts the mesh, and two hold it until the first person puts on the fasteners. If you try doing it with fewer people, it may fall and cut your hand or fingers. It's a hazardous material." – Drywall Foremen

Figure 8.11: Wall with Mesh Installed Full Height (Photo: © Sulyn Gomez, 2022-10-24)

Although as part of the GC's quality control process, their superintendents, FE, and Pes walked the site and checked the work installed, the GC relied on the drywall worker to check the quality of the work once installed.

> *"Specific items we go and double check, specific openings we go double check. But sometimes we don't have time to check everything. So, the key is to have each worker make sure that they know what they have to do." – GC Superintendent*

8.5 Methods and Tools to Support Quality Delivery

This section describes the methods and tools used in Case 2 to deliver the scope studied.

8.5.1 Using Mockups or First-in-Place (FIP) Installations to Understand Quality Expectations

Because the buildings that the GC built before were literally next to each other on the same campus, the team walked to the other buildings when needed to see examples of work installed:

> *"If we go back to the first building we built on this campus, we had mockups of prefabricated exterior walls and multiple mockups of the screen wall condition. Now [on this building], we've already done our mockups, it's right next door [on the buildings we built before]." – PM*

The owner changed some scopes from past projects to Case 2. For instance, while they had some combination of mesh-drywall walls in the previous buildings, they decided to design a whole room of full mesh walls this time:

> *"[In the Case 2] our PDU [Power Distribution Unit] galleries are all mesh walls. This was the first time that we've had that on a building like this. So, when we built it the first time, we had the owner and the architect walk the site, and we showed them what we were going to be doing [how the mesh wall would look like when completed]." – Field Engineer*

In addition to variations in the scopes they built before, the team also had a new scope for which they did a FIP for fitup (Figure 8.12). In the FIP, they discussed the methods to be used and took pictures to add to the transmittal used to document agreements.

Figure 8.12: Case 2 Team Inspecting a Section of the Hot Aisle Containment FIP (Photo: © Sulyn Gomez, 2023-01-23)

8.5.2 Automating Walls Layout: Dusty Robot

As in Case 1, Case 2 also used Dusty robot for various scopes layout in the project. As the robot operation was still evolving, Case 2 tested multiple alternatives to find what suited their needs best:

> *"We did a whole bunch of experiments with the ink and tested cleaning it off. We need to make sure it [layout] stays on long enough to actually use it. Our strategy now is to tape over the marks (Figure 8.13)." – GC Superintendent*

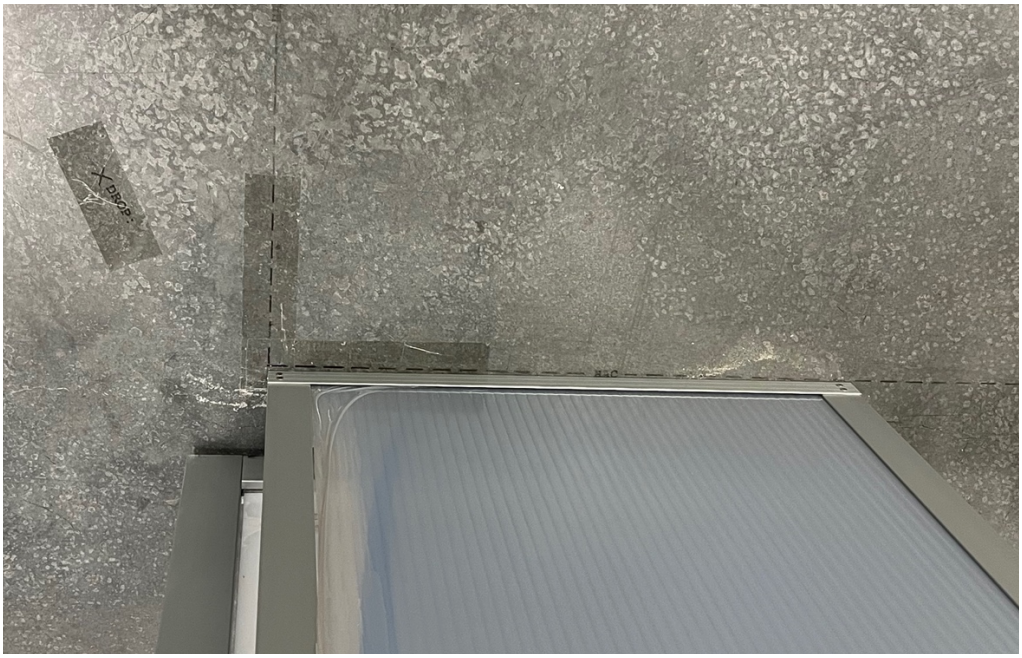


Figure 8.13: Dusty Layout for Hot Aisle Containment FIP (Photo: © Sulyn Gomez, 2023-01-23)

The users reported benefits from using it, both in production and quality of layout:

> *"[Dusty] makes the job way easier, and it's a lot faster and more accurate [than traditional manual layout]." – GC Assistant Superintendent*

8.5.3 Using Visuals to Communicate Expectations and Outcomes

The GC adopted visual management to communicate quality expectations in the field by using a board with images describing good and bad installation examples (Figure 8.14).

> *"Some of those pictures [in the board] will change because of the environment of what we're building change. We'll have new expectations to share. We're trying to populate it now with pictures from our electrical Prime because that's the majority of the work happening now." – GC Assis. Superintendent*

While using the board was great for visually communicating what was good and what was not, it required maintenance to ensure the information posted there was up-to-date and relevant for the scope being built.

Figure 8.14: Quality Benchmark Board in Case 2 (Photo: © Sulyn Gomez, 2022-09-26)

In addition to the Quality Benchmark board, Case 2 drywall team used a similar strategy to the one in Case 1 and colored the pins in the framing bottom track (Figure 8.15) for the inspector:

> *"We color our pins; in that way, it's easier for the inspector to see where the pins are located." – GC Assistant Superintendent*

Figure 8.15: Shot Pin Heads Painted for Inspection (Photo: © Sulyn Gomez, 2021-09-30)

8.5.4 Preventing Trade Damage

A considerable amount of trade damage to drywall work is caused by bumping into walls. As described in Table 8.5, almost half of the quality issues documented for drywall scope were assigned as trade damage in this project. The team installed protection throughout the corridors (Figure 8.16) to lessen such damage to the walls.

"We manage rework by protecting what we can. And what we don't protect, we will fix it until the end of the project." – GC Assistant Superintendent

Figure 8.16: Wall Protected to Avoid Damage (Photo: © Sulyn Gomez, 2022-09-26)

8.5.5 Developing Capabilities

Both staff and craft groups supported each other in developing their capabilities.

"First aid training opportunity was sent to some of the people in the office, and I was like that should be offered to everyone. So, I asked all the foremen and craft and had all my people go to that training. It's one of the things we do to make sure everyone's learning, not just the admin." – GC Assistant Superintendent

In addition to being supportive, people in leadership positions took the responsibility to teach others:

"I assign some [craftworkers] who are good and know what they're doing with others who don't know as much, so they are trained. That's my plan so those who know help others… Also, I'm open to learning. Not because I'm the foreman I know the most. If they have a better way to do the job, we'll do it." – Drywall Foreman

"If they [anyone in the project] don't know, they ask me. If I don't know, I'll ask the question and escalate it, but not just leave it there. I'll ask someone else. I'll take that responsibility." – GC Assistant Superintendent

As part of this study, I received strong requests to work with the craft group in the BBQS implementation. I started hosting working sessions with the craft group (Figure 8.17) to increase awareness about concepts from psychological safety to reliable promises. We applied all the concepts to the scope they built; for example, when discussing reliable promising, we examined the drywall finish MAC guide (Appendix 18) I developed by consulting applicable standards.

Figure 8.17: Participants in Working Session to Dive into Quality from the BBQS Perspective (Photo: © Sulyn Gomez, 2022-11-11)

"[Planning to work with craft] is awesome. [Doing it in Spanish] is exactly what's needed. I mean, if English is not your first language, let's break it down to the easiest way to communicate [quality expectations] to them." – Client

I held these working sessions in both Spanish and English simultaneously. Participants spoke mostly Spanish, but a few of them spoke English, and I wanted to have all of them engaged in the conversations. Some feedback participants provided at the end of the BBQS implementation were:

> *"Very impressed with this kind of program. We learned how important it is to respect individuals and the importance of helping others. Great job Sulyn!." – Craft*
>
> *"This is a good program to educate people on how to perform on the job site." – Craft*
>
> *"I like that craft got learning from this experience. I can see that they understand what is trying to be done, and they seem more united as a team because of it." – Field Engineer*

I was able to connect with the participants and foster PS:

> *"I hadn't actually thought that there were people who didn't feel safe to speak up, and this helped me to feel more confident to speak up." – Craft*
>
> *"I learned I ask questions when I'm not sure about the plan before starting work." – Craft*

Participants also shared how they would apply what we discussed to their job:

> *"I learned to make sure everyone on the team is on the same page prior to starting work in order to deliver quality work on time." – Craft*
>
> *"I learned that respect for each other goes a long way to creating a great work environment. Communicating a clear picture of needs and progress can go a long way to getting the job done right. If communication isn't good, then you end up with both sides having a different picture of what to do." – Craft*

Figure 8.18 shows our last session attendees. While almost all participants in this session were craft because it was oriented toward that group, we had participants from the staff joining the sessions to learn, back me up, and show support from the project leadership.

Figure 8.18: Case 2 Craft and Staff Participants (Photo: © Sulyn Gomez, 2023-02-03)

I also had weekly meetings with the staff group to check the study's status and separate cluster meetings to work on the BBQS implementation. We discussed the individual actions they'd take to foster psychological safety from the staff end, for example, by participating closely with the craft throughout the study, and some methods to analyze quality issues' root causes.

> *"I will lead by example now. This continuous training [sessions on BBQS] is appreciated. I will show curiosity and ask questions, accept different opinions, and offer help to those who need it." – PE*

In addition to the sessions hosted onsite, the GC team organized training sessions (Figure 8.19) to teach the basics of data center construction to other Pes and PMs within their company.

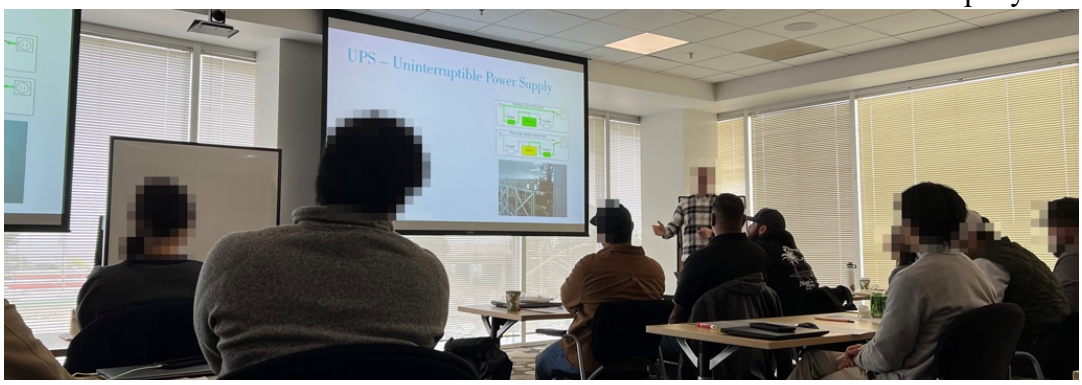


Figure 8.19: Case 2 GC Leadership Team Teaching other Pes and PMs (Photo: © Sulyn Gomez, 2022-12-08)

8.6 DFOWs Applicable to Drywall and Framing Scope in Case 2

I describe each applicable DFOW for the drywall scope studied in the following subsections.

8.6.1 Wall Finish

Even though the focus for the client was on mechanical and electrical systems, for the drywall scope, the wall finish level was a DFOW for the areas designed to be occupied by the tenant.

> *"We've had a lot of conversations as to what rooms get what finishes. We had up to level zero finish in some places, which means just pure metal studs. The general principle here is, if it's a customer-facing space, which means the tenant is going to go into this space, then it gets a higher level, like a level 4 finish wall; and if it's not, they want a minimum wall finish to meet the functional requirements for the mechanical systems." – PM*

As identified in Case 1, relevant discussions for drywall finish include the wall's intended use. Input from builders could enrich the DFOW discussions by providing input on things that can provide better value to the client:

> *"[Describing requirements that didn't seem right] Not painting the electrical rooms, it's literally just unfinished drywall (Figure 8.20), which is insane to me. It's now open to any kind of moisture. A layer of primer protects the drywall and the taping finish, and it's not very expensive to prime things. If it were me in a conversation, I'd say let's just be practical and try to push that [to prime walls]." – GC Superintendent*

Figure 8.20: Wall Finish in Electrical Room (Photo: © Sulyn Gomez, 2021-09-30)

Another quality-related discussion for drywall finish is how the inspections will be conducted, including lighting conditions and viewing position. In this case, the inspection criteria per level of finish were not that clear at first, not even for the installer:

> *"When I went to talk to our drywall [taping] foreman, I was like, 'dude, how do you not know this? That's all you do'. He should be able to say blah blah blah, this is how this is done, and here are the documents [standards to backup criteria]." – GC Superintendent*

For the corridors, the wall light came from the fixtures attached to the wall:

> *"The inspection will happen in natural light, which is nothing because there are no windows. But we do have lights on the wall, and they shine right down the wall." – GC Superintendent*

When defining the MAC, the team must understand the client's expectations and ensure all participants are aligned on how the work will be inspected.

> *"We don't have that person that goes and stands two feet away from the wall looking at the whole building trying to put green tape [to point out quality issues] on everything and find the little things." – PM*

When the study started, I learned that MAC was not well defined before installation started, and the installer did not have clarity at first of what he was required to do, so the team faced some issues:

> *"We have a wall finish issue right now on this job (Figure 8.21)… Now, on a job like this, we're not going to do a mockup for wall [because the priority is the mechanical and electrical systems]. On other jobs where interiors are the focus, totally, we'll do a mockup. But this one is a different animal; it's a different environment [priority]. To me, it goes back to the definitions of the levels of finishes. How is that defined? I need to go back and research now… One thing you [I] can do here is making a simple template describing what the five levels of drywall finish are; that's huge. We have to think about the inspection criteria as well." – GC Superintendent*

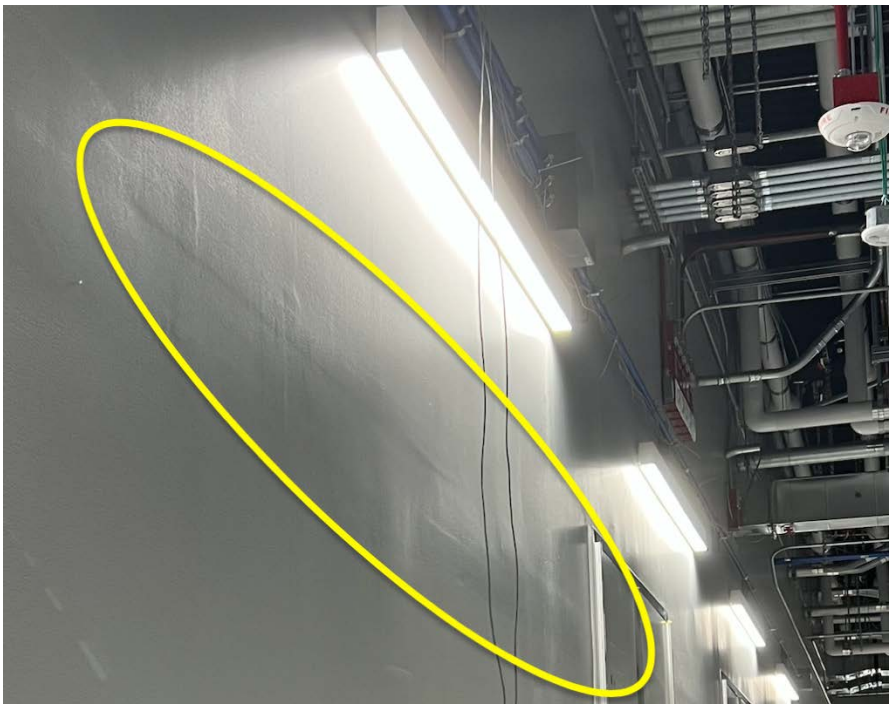


Figure 8.21: Quality Issue with Wall Finish (Photo: © Sulyn Gomez, 2022-10-24)

As the team and I explored the relevant standards to understand the various finish levels and what it takes to build each level, the drywall team redid the sections of the wall that needed to be reworked (Figure 8.22) to conform with the quality requirements for that level of finish.

Figure 8.22: Rework for Wall Finish Quality Issue (Photo: © Sulyn Gomez, 2022-11-28)

8.6.2 Cleanliness

One of the critical quality DFOWs for drywall for this client is cleanliness. I assigned this DFOW to drywall because a high quantity of dust is generated from cutting drywall boards.

> *"We have a cleaning sign-off here. So, we have to clean 100% of the galleries before we turn on the equipment. The [client's] employee who is in charge of this site will come, and he'll sit on the floor, he'll swipe his hand everywhere. He'll go through the drywall track and run his finger to make sure that's 100% clean." – GC Assistant Superintendent*

I participated in RCL walks, where the client representative expressed some concerns about the cleanliness of the site. Figure 8.23 shows a portion of framing where the client, in one of the RCL walks, put his fingers on and showed the dust he collected, highlighting that it was not what he expected to find. He also explained during the walk that dust may damage their equipment, therefore his concern. He opened one of the pieces of equipment in the mechanical room and put his finger inside (Figure 8.24) to show the participants in the walk the dust accumulated there too.

When planning operations, because of the importance cleanliness have to this client, the team could add a more rigorous dust mitigation plan to minimize the impact of cutting inside the jobsite.

Figure 8.23: Dust in Framing Bottom Track (Photo: © Sulyn Gomez, 2022-12-21)

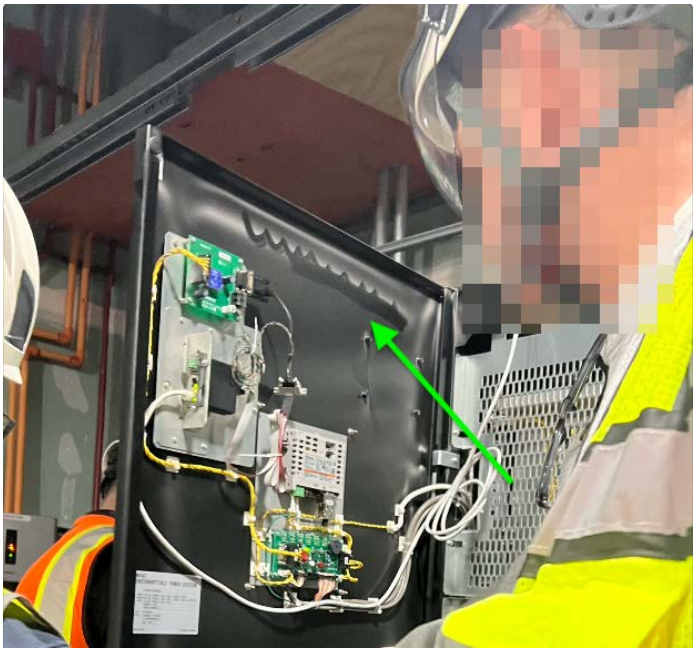


Figure 8.24: Dust inside Owner Equipment (Photo: © Sulyn Gomez, 2022-12-21)

8.6.3 Security Mesh

In previous sections, I described the use of the mesh as something unique in this type of project. As such, the security mesh is a DFOW for the drywall scope. Understanding the purpose of this DFOW helped plan the scope with more care.

"I learned the purpose of the whole mesh system that we have in the DM [data module] spaces. In those walls, a third of the wall is drywall, and the second third is a metal mesh. It was designed like that for air flowing." – Field Engineer

Part of the MAC for the mesh sections referred to the penetrations (Figure 8.25) tolerances:

"[the mesh] cannot have a hole larger than ¾" and they [client] will go around with a ruler and inspect that [opening size]." – PM

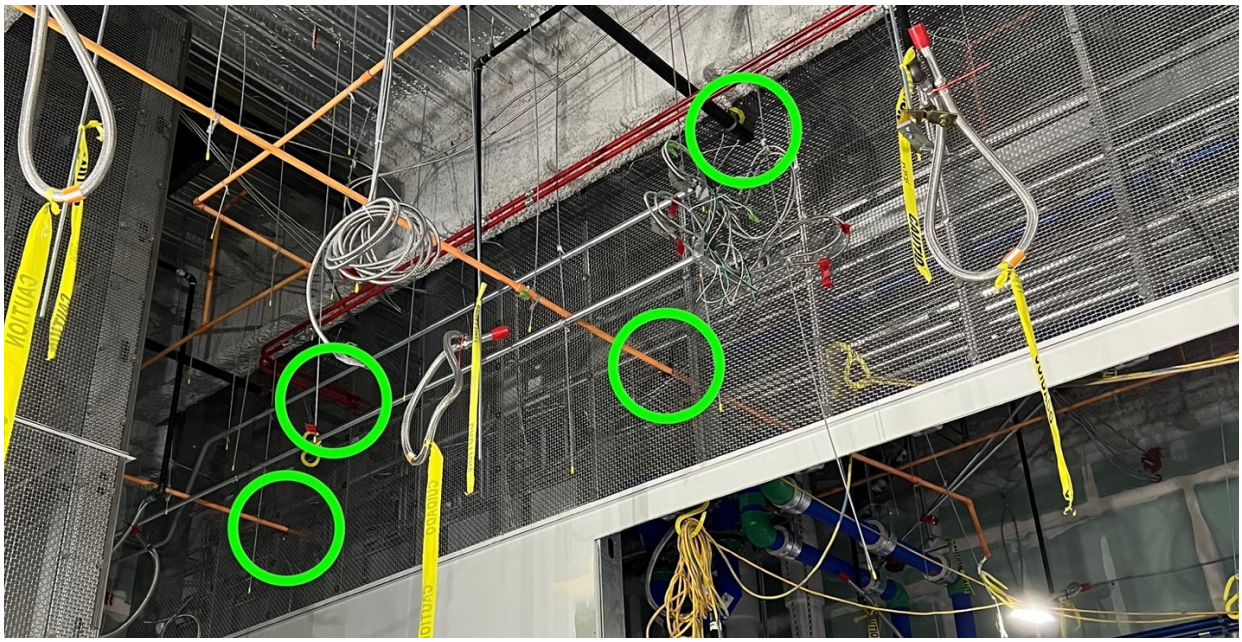


Figure 8.25: Penetrations in Mesh Wall (Photo: © Sulyn Gomez, 2022-10-24)

8.6.4 Priority Walls, Penetrations, and Backing

As in Case 1, priority walls were identified as a DFOW for Case 2. This DFOW requires heavy coordination with MEPF trades because of the installations inside and on top of the walls and the openings for access and moving equipment.

"We sat down in weekly coordination meetings with the other main trades. We talked about where all the equipment needed to go, and we created a priority wall map as well as a demo map. We talked about shafts that need to be reopened for every phase of construction we have out here. We got the Prime contractors to sign off on those maps." – PM

Although defining backing belongs heavily to design, GCs need to pay attention to this using common sense; e.g., if a wall is supposed to hold mounted heavy equipment, it might need more reinforcement than average walls. In addition to backing, which was highlighted as a DFOW for drywall in Case 1, in Case 2 the team highlighted penetrations as another DFOW.

"We have lots of framed-out openings within our walls where large bundles of mechanical, electrical, and plumbing equipment will pass through the walls. That is driven by our coordinated model and requires our Primes to provide our drywall team with the proper layout in order to get the penetrations in the right place." – PM

8.6.5 Coordination with Prefabricated Panel Supplier

Exterior panels and their framing are another DFOW for this project. The team needs to define first what walls are to be prefabricated and ensure all trades with related scope (e.g., embedded MEP installation) are bought into the prefabricated scope. In one of the exploratory studies conducted, an architect described that they did not plan for interior partition walls to be prefabricated, but the GC had, and the project ended up using some prefabricated partition walls, which restricted the design flexibility in those areas.

When prefabricating, the team must coordinate various scopes, such as drywall, MEPF, and waterproofing. Penetrations (Figure 8.26) and openings (Figure 8.27) need to be defined in coordination with all these scopes.

> *"Prefab is not perfect, especially when it comes to multiple-phase delivery of projects on a DB job where things constantly change. [SPW drywall] has done all our field-installed rework and penetrations for the exterior prefab panels. So, if we need a new opening cut, the [panel supplier] is not involved in it except by RFIs of what we can or can't do. [SPW drywall] reframes and puts the sheets back, and then hand that off to the waterproofing contractor" – PM*

Figure 8.26: Interior Detail of Prefabricated Exterior Panel (Photo: © Sulyn Gomez, 2023-02-03)

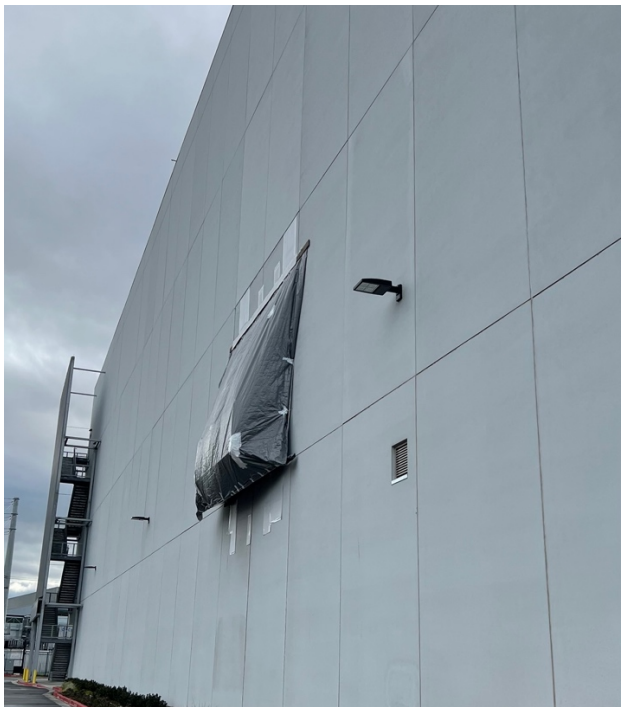


Figure 8.27: Prefabricated Exterior Panel (Photo: © Sulyn Gomez, 2023-02-03)

8.6.6 Model Coordination

As in Case 1, the BIM model is a DFOW for this project with dense MEPF installations. The team used the model for planning site work.

> *"Definitely, the coordinated model is a distinguishing feature [for drywall walls construction], especially for a very MEP-heavy project like ours." – Field Engineer*

In the beginning, the field team was not as involved in the BIM coordination process, missing some key details:

> *"We modeled a bunch of openings that apparently aren't what they are supposed to be [in size]. We also did a model lock but never verified that the openings would not perfectly suit the electricians who wanted a bunch of openings to be even bigger." – GC Superintendent*

Learning from that experience, the superintendents started participating consistently in BIM coordination meetings and providing input from the builder's perspective:

> *"We actively use our BIM model onsite. We [superintendents] have been helping the BIM team; they're not builders. Now we've been more involved in model review providing constructability input… What we're going to do now for level 2 is to look at the spool sheets and make sure that all are happy with what we have as far as openings and frameouts… so we don't have to go back and open walls." – GC Assistant Superintendent*

8.7 Discussion

Transcending beyond an improvement in quality

Although I designed the BBQS to improve the delivery of quality, because of its behavioral focus, its implementation can influence how team members interact and the outcomes they achieve:

> *"The architects are very willing to adjust or change the drawings to help out the field. And because they're so willing to help, the field is more inclined to be understanding when a change can't be made; they probably have a good reason for it." – Field Engineer*

> *"I learned to respect and value the work of every person on the job site. I will use every single lesson I learned in these sessions to improve production and quality." – Craft*

It also encourages the team to support each other and find solutions together when problems arise:

> *"[The client and GC staff] don't come to see if we're making mistakes; they come to see how the project is going and if we need something." – Drywall Foreman*

> *"[Psychological safety] is a pretty strong characteristic of the group here. Everyone's empowered to share challenges and make it known to the team so that everyone can work together to provide a solution." – Client*

Documenting lessons learned consistently

One of the opportunities for improvement that the participants from the GC and client highlighted is the documentation of lessons learned. Although the team used Procore as the official mechanism to document quality issues, the participants interviewed reported more than one criterion they used to decide what gets documented. Some pointed out the impact on other trades as a reason to document the issue identified, some said it depended on the severity of the issue, and others whether the issue wasn't solved fast enough when communicated verbally.

> *"For me, the biggest factor to add something to RCL is whether it affects a lot of other trades and requires coordination." – Field Engineer*

While I realized from Case 1 to Case 2 that documenting every single quality issue may not be the best way to go with the limited resources a project team has:

> *"Our life is filled with documents, and it depends on the level of mistake. If we do something that's $100 to fix, then, it's not getting documented. If the level 4 production of walls is not going well, we document it. If we're just going to write everything, we're going to spend a whole bunch of time adding additional paper to the millions of documentation [we already have]." – GC Superintendent*

Being aware of this, the team can define certain criteria to better determine what gets documented and what does not. In this way, the subjectivity of whether something needs to be documented is eliminated.

In addition, to leverage lessons learned, each contractor in the project can be more disciplined in documenting the quality issues within their own crews and have them take the lead in reducing their frequency.

Strengthening staff-craft support

While Case 2 participants identified working with craft as a priority in this study, the craft participants pointed out that staff support was key in successfully implementing BBQS.

> *"We learned many things [in the BBQS implementation] that we'll put in practice. We need support from the management, so all we were taught work successfully. These [BBQS] sessions benefit us a lot." – Craft*

In one of the last staff meetings I attended in the project, the superintendent asked all the Pes to get more involved in the field for quality control by walking the site at least once a week and talking to the craft, asking questions to better understand how the work is installed, and constantly checking whether work installed meets MAC.

Planning to break down the language barrier to engage craft in quality planning and execution

A common challenge I identified across studies is how team members engage craftworkers who do not speak English to gain their input in planning what requirements are to be met and how to meet them. To the extent possible, teams can use their resources available to bridge this gap:

> *"We're lucky that one of our superintendents also speaks Spanish. We get to communicate with our craft on a different level than everyone else here. They've formed that bond of being comfortable coming to me, sharing the issues they have." – Field Engineer*

When human resources are unavailable, visuals (e.g., posters, pictures, diagrams) in both languages provide another means for communication to receive input from craft.

8.8 Conclusions

In this chapter, I explored the relationship between my research variables, psychological safety, behaviors desired for quality, and team performance Pre- and Post-BBQS. As in Case 1, I found that psychological safety is positively associated with behaviors desired for quality, which are positively associated with team performance. BBQS implementation resulted in favorable outcomes in all my study variables. In addition, I documented the BBQS implementation outcomes and participants' feedback, which I used to refine my BBQS prototype 3. Also, I described the DFOWs applicable to the scope studied; while some were similar to the ones I identified in Case 1; Case 2 had some others that applied to this specific project.

9. CONTROL CASE, CROSS-CASE ANALYSIS, AND MEDIATION ANALYSIS

This chapter presents the findings of a control case study, where BBQS was not implemented, and a cross-case study analysis, where I compared Cases 1, 2, and the Control case. I limited my analysis in the control case to measuring my study variables using only the survey instrument used in the previous cases. This chapter also presents the mediation analysis I conducted to explore the indirect effect of psychological safety on team performance via the behaviors desired for quality.

The chapter is organized as follows. Section 9.1 presents my control case results. Section 9.2 compares those results against Case 1 and 2 results. Section 9.3 presents the mediation analysis between my study variables. Section 9.4 discusses my findings and possible limitations. Last, Section 9.5 concludes this chapter.

9.1 Control Case

9.1.1 Project Background

The Control case was built by the same GC who built Cases 1 and 2. As in the previous cases, the GC used SPW groups for various scopes, including drywall.

9.1.2 Survey

I invited all the project participants who were part of planning or building the scope studied to participate in the surveys. Table 9.1 describes the participants' sample for the control case.

Table 9.1: Control Case Survey Participants

Description	Study Begins	Study Ends
Total of people invited to participate	11 (2 staff, 9 craft)	5 (1 staff, 4 craft)
Total number of participants	9 (0 staff, 9 craft)	4 (0 staff, 4 craft)
Participation rate	82%	80%

9.1.3 Team Psychological Safety – Behaviors for Quality – Performance

I measured my study variables twice, in parallel to my measures in Case 2.

9.1.3.1 Team Psychological Safety

Figure 9.1 shows the results of the team's psychological safety scores and standard errors (in relation to peers M_{Pre} = 5.62, SD = 0.74; M_{Post} = 6.15, SD = 0.54; in relation to team leader M_{Pre} = 6.12, SD = 0.61; M_{Post} = 6.40, SD = 0.45). Although the results show an increase in psychological safety, upon examining the individual's responses, I found that the increase in the overall results was caused because those with low psychological safety scores at the beginning of the study were

not part of the project anymore when the study ended. Around 33% of participants who reported lower psychological safety in the initial survey had either moved to other projects or stopped working. Another 33% who reported average psychological safety in the group had either moved to other projects or stopped working. The remaining 33% who continued working on the project were coincidentally the ones who reported high psychological safety, which made the bars shift right.

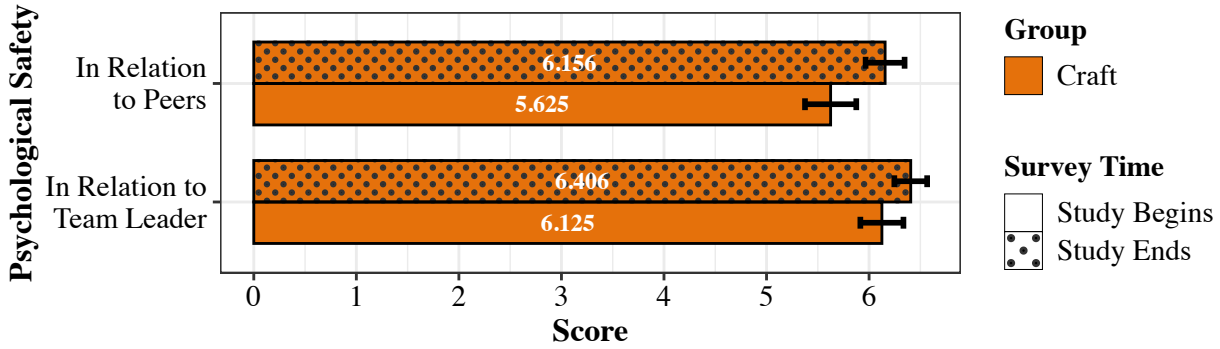


Figure 9.1: Team Psychological Safety at the Beginning and End of the Study for Control Case

9.1.3.2 Team Behaviors for Quality

Figure 9.2 shows the behaviors scores and standard errors. On average, the scores did not move considerably (active learning M_{Pre} = 6.18, SD = 0.53; M_{Post} = 6.08, SD = 0.26; active listening M_{Pre} = 6.01, SD = 0.25; M_{Post} = 6.00, SD = 0.37; being diligent M_{Pre} = 6.13, SD = 0.30; M_{Post} = 6.12, SD = 0.40; speaking up M_{Pre} = 5.72, SD = 0.77; M_{Post} = 5.93, SD = 0.29; making reliable promises M_{Pre} = 6.18, SD = 0.47; M_{Post} = 6.41, SD = 0.46; active caring M_{Pre} = 5.98, SD = 0.64; M_{Post} = 6.25, SD = 0.36; being respectful M_{Pre} = 5.83, SD = 0.48; M_{Post} = 6.04, SD = 0.31). For the ones that moved slightly, I observed something similar to what happened with the psychological safety score. The participants who scored the behavior sub-variables lower were not in the project at the end of the study.

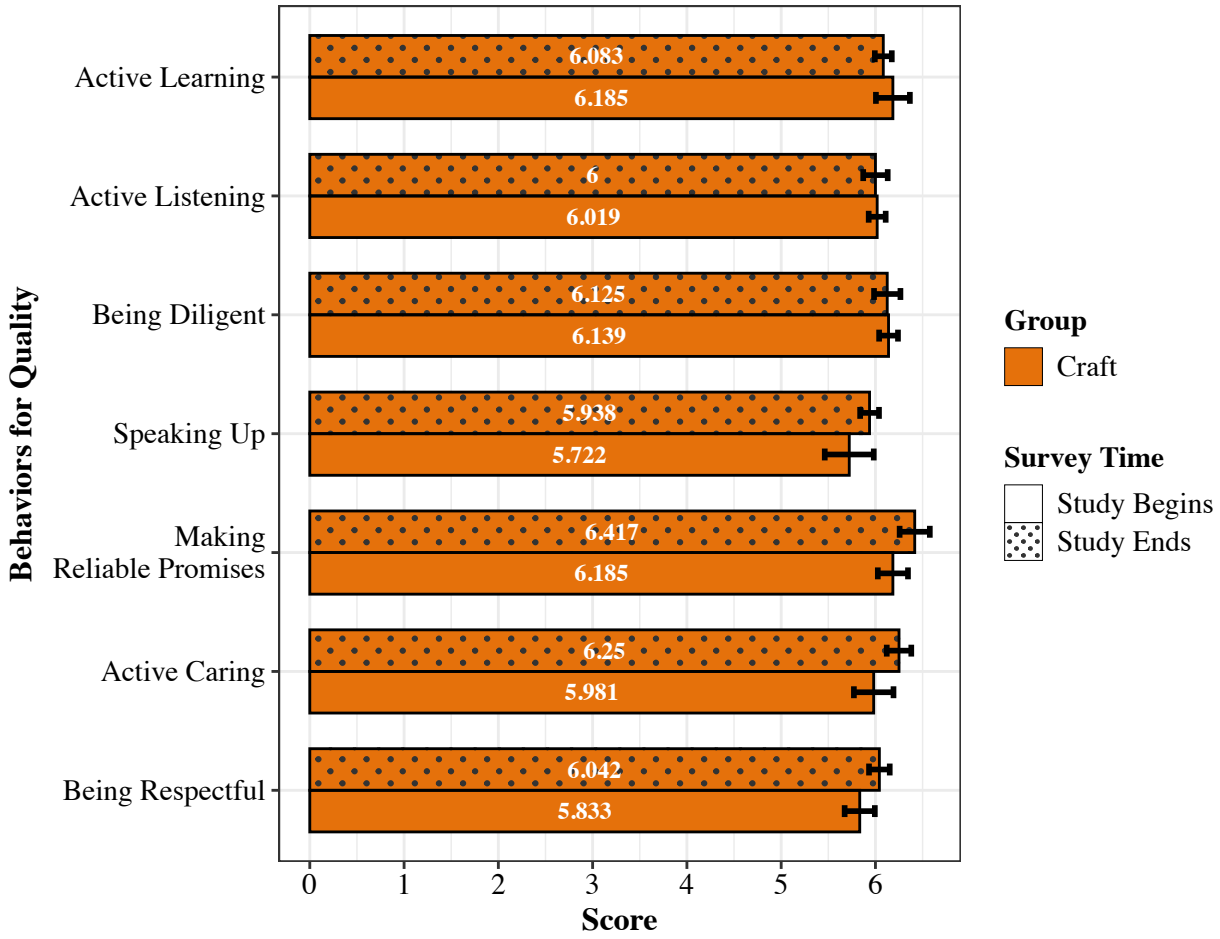


Figure 9.2: Behaviors Desired for Quality Scores for Control Case

9.1.3.3 Team Performance

Figure 9.3 shows the team performance scores and standard errors. I observed a similar trend to the one reported for psychological safety and behaviors for quality. The variations in the participants' sample can explain the slight increase (compared to past projects M_{Pre} = 6.55, SD = 0.52; M_{Post} = 6.75, SD = 0.46; project specific M_{Pre} = 6.11, SD = 0.38; M_{Post} = 6.21, SD = 0.39). When considering the responses of only the participants who took both surveys, the scores were similar at the beginning and end of the study.

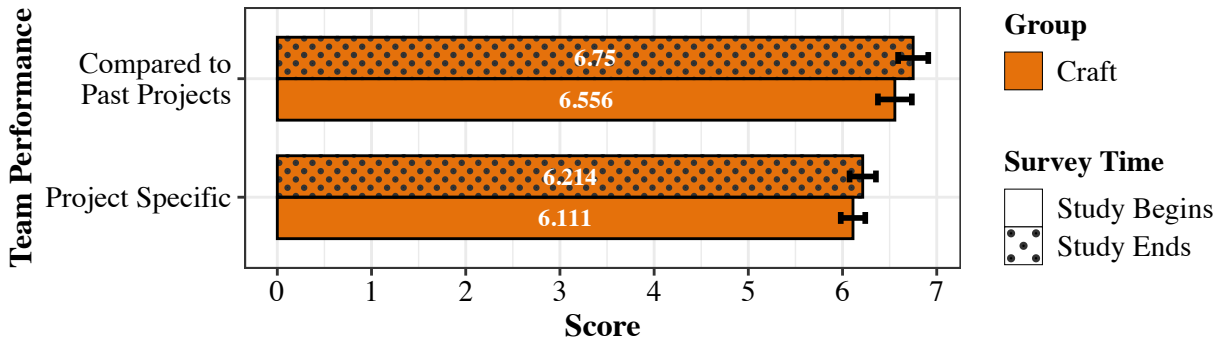


Figure 9.3: Team Performance Reported in Control Case

9.1.3.4 Relationship Team Psychological Safety – Behaviors for Quality – Performance

Table 9.2 shows the correlations I found between my model variables. As shown, PS is highly correlated to BQ (r = 0.729; r = 0.698), and this, in turn, is highly correlated to TP (r = 0.602; r = 0.758). As in Case 1, this supports my hypotheses 1 and 2 (Section 1.5) that suggest that PS is positively associated with BQ, and BQ is positively associated with TP, respectively. However, the small sample size does not support strong conclusions.

Table 9.2: Model Variables Correlations when Study Started

n = 9	Psychological Safety (PS)	Behaviors for Quality (BQ)	Team Performance (TP)
Psychological Safety (PS)	1.000	0.691	0.786
Behaviors for Quality (BQ)		1.000	(0.567)
Team Performance (TP)			1.000
Correlations in parentheses are not significant at $p < 0.05$			

Table 9.3: Model Variables Correlations when Study Ended

n = 4	Psychological Safety (PS)	Behaviors for Quality (BQ)	Team Performance (TP)
Psychological Safety (PS)	1.000	0.793	(0.127)
Behaviors for Quality (BQ)		1.000	0.700
Team Performance (TP)			1.000
Correlations in parentheses are not significant at $p < 0.05$			

9.2 Comparing Control Case and Case Study 1 and 2

9.2.1 Comparing Study Variables

I measured a longitudinal change (before-after BBQS) only in Case 2 and the Control case. Some of the comparisons I present in this section focus on the change in these projects only. Other

comparisons are focused on changes among groups of different memberships because of the difference between the craft and staff groups in my study variable scores. Regarding the analysis per membership, staff participants are only from Cases 1 and 2; staff members from the Control case were invited but did not participate.

9.2.1.1 Team Psychological Safety

Pre- and Post-BBQS

Unlike Case 2, where psychological safety scores after BBQS implementation are higher, in the Control case, no major changes are observed within the original sample of respondents. Although the BBQS is meant to improve the delivery of quality more, an indirect impact can be observed in psychological safety among those implementing it.

Staff-Craft Groups

The staff in both Cases 1 and 2 reported high levels of psychological safety with respect to their team leaders and peers. In addition, the psychological safety score for each of their team leaders and peers are close, with a gap as small as 0.015 and as large as 0.22 on a 7-point scale.

Craft members from all the projects participated in the study. Cases 1 and 2 craft psychological safety results were lower than those from the staff. The gap staff-craft in psychological safety was lower in Case 2 Post-BBQS. Among the three cases, the group with the higher psychological safety score was Case 2. Case 1 and the Control case project scores were very similar. Across the three groups, some differences can be observed between craft psychological safety concerning the team leader and their peers.

9.2.1.2 Team Behaviors for Quality

Pre- and Post-BBQS

The behaviors in Case 2 improved considerably (up to 1.2 points higher) with respect to the Control case, especially for those participants who were part of the BBQS implementation from start to end.

Staff-Craft Groups

The staff in Cases 1 and 2 scored higher values for the behaviors for quality when compared to the craft group. After implementing the BBQS, the staff-craft gaps decreased significantly; for some of the behaviors, craft reported even higher scores than craft.

Case 2 before BBQS reported behavior scores slightly lower than Case 1. After BBQS, however, the scores of all the behaviors in Case 2 were much higher (up to 1.142 points higher) than Case 1.

9.2.1.3 Team Performance

Pre- and Post-BBQS

The project-specific performance reported in Case 2 was slightly higher than the one in the Control case. In addition, after the BBQS, the performance slightly increased. The performance reported seems to be related to the behaviors for quality and psychological safety. Results showed an increase in psychological safety, behaviors for quality, and team performance.

Staff and Craft Groups

The staff and craft perception of project performance was similar, with a gap ranging from 0.012 to 0.563. Cases 1 and 2 reported slightly higher project-specific performance than the Control case.

9.2.2 Statistical Significance Analysis

I ran a Welch two sample t-test to determine the statistical significance of the increase observed in my study variables after implementing BBQS in Case 2.

Table 9.4: Welch Two Sample t-test Results

Case 2	Mean Pre-BBQS	Mean Post-BBQS	Difference in Mean	p-value
Behaviors for Quality	5.748	6.267	0.519	<0.05
Psychological Safety	6.100	6.430	0.330	0.117
Team Performance	6.283	6.583	0.300	0.064

Table 9.4 shows that the increase in the behaviors for quality variable is statistically significant Post-BBQS, supporting my hypothesis 4, which claims that BBQS develops behaviors desired for quality management. Although there is an increase in the other two study variables, psychological safety and team performance, and the means are higher Post-BBQS, the p-values do not provide statistical significance for such an increase. Hypotheses 5 and 6 that claim that BBQS improves team psychological safety and team performance in quality, respectively, cannot be demonstrated with statistical significance as the p-values are higher than 0.05. A larger sample could strength this analysis and better determine hypotheses 4-6.

9.2.3 Comparing Metrics

Timing for issue identification

Table 9.5 shows the time when quality issues were caught in Cases 1 and 2. As shown, more than half of the issues were identified and fixed by field personnel. Case 1 team, which had a more discipline quality control process (i.e., with the QR codes), reported a higher percentage of issues identified by the GC.

Table 9.5: Cross-Case Quality Issues Identified by Tier

Project	Tier 1: By field	Tier 2: by the GC	Tier 3: by 3er party (architect or owner)
Case 1	50%	35%	15%
Case 2	52%	28%	20%

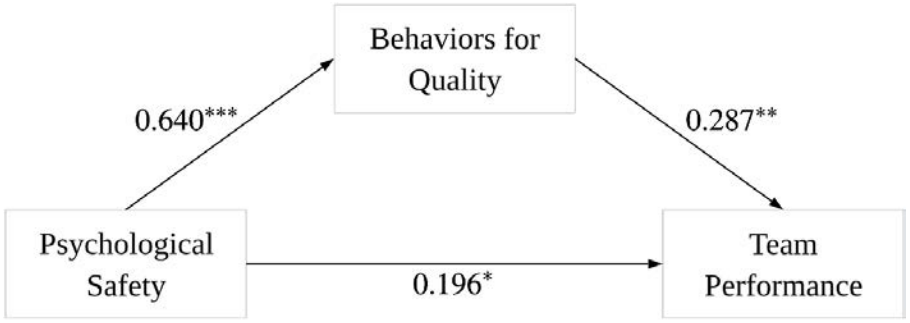
While the best-case scenario is not to have quality issues, when these occur, the second-best-case scenario is to identify the issue as early as they occur (in Tier 1 by field personnel).

Percentage of quality issues assigned to drywall

In Case 1, less than 4% of the documented issues were assigned to drywall. In Case 2, this number was between 20%-25%. This difference, however, could have been caused by the procurement method in Case 2, in which the Prime contractors were responsible for the quality of their work, and they managed their issues separately, and almost all the issues documented by the GC were limited to the work of their SPW scopes. I cannot use this metric in order to support my claim regarding team performance in its current version, but it may be a valid metric for comparison should the way the teams documented the quality issues were more similar.

9.3 Mediation Analysis

The hypothesis I tested is that there is an indirect effect of the team psychological safety on their performance managing quality via the behaviors desired for quality (hypothesis 4 in Section 1.5). Figure 9.4 shows my mediation model and the regression coefficients. I used data from all three cases, including Case 1, Case 2 Pre-BBQS, and Control case, with a total of 62 responses.



$^{*}p < .05; ^{**}p < .01; ^{***}p < .001$

Figure 9.4: Mediation Model with Regression Coefficients

I conducted a three-step analysis (Baron and Kenny 1986) to test whether the conditions to demonstrate mediation were satisfied: (1) the independent variable significantly influences the dependent variable, (2) the independent variable is significantly related to the presumed mediator, and (3) the contribution of the independent variable drops substantially for partial mediation and becomes insignificant for full mediation when simultaneously testing the independent variable's and the mediator's effect on the dependent variable. In this model (Figure 9.4), psychological safety is the independent variable, behaviors desired for quality is the mediator, and team performance is the dependent variable.

Step 1: The coefficient shown in Figure 9.5 is known as "total effect" in mediation analysis. Total effect describes the effect that the independent variable has on the dependent variable. As shown in this figure, psychological safety is significantly positively associated with team performance, supporting the first of the four conditions.

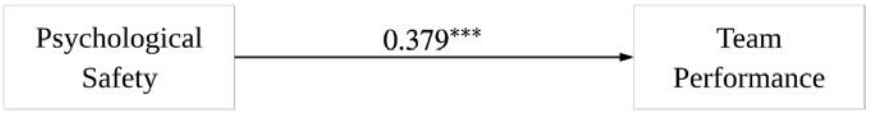


Figure 9.5: Independent Variable Effect on Dependent Variable

Step 2: I run a simple regression of the independent variable onto the mediator. As shown in Figure 9.6, psychological safety is significantly positively associated with team performance, supporting the second of the four conditions.

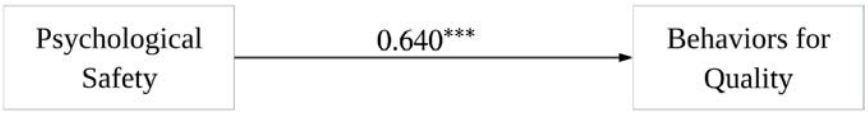


Figure 9.6: Independent Variable Effect on Mediator

Step 3: When simultaneously assessing the independent variable's and the mediator's effect on the dependent variable (Figure 9.7), the contribution of the independent variable drops substantially (from 0.379, $p < 0.001$ to 0.196, $p < 0.05$).

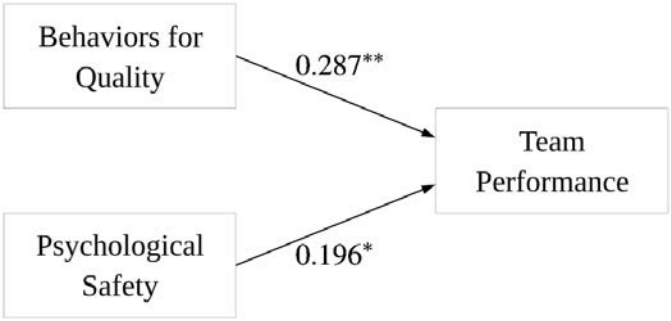


Figure 9.7: Independent Variable's and Mediator's Effect on Dependent Variable

I used Bootstrapping (Preacher and Hayes 2004) to estimate the confidence intervals (CI) with 1,000 simulations to see if this mediation effect is statistically significant. Table 9.6 shows the bootstrap results with their respective CI and statistical significance value. The total effect of the independent variable onto the dependent variable in the table (0.379) is the coefficient in Step 1. The average direct effect (ADE, 0.196) is the direct effect of the independent variable on the dependent variable when considering the mediator, as in Step 3. Finally, the ACME or average causation effect represents the indirect effect of the independent variable on the dependent variable via the mediator, which equals the total effect minus the direct effect.

$$ACME = 0.640\ x\ 0.287 = 0.379 - 0.196 = 0.183$$

In this case, the p-value for the indirect effect, ACME, represents a statistically significant mediation.

Table 9.6: Causal Mediation Analysis Results with Bootstrapping

	Estimate	95% CI Lower	95% CI Upper	p-value
ACME	0.183	0.029	0.470	< 0.05
ADE	0.196	-0.106	0.400	0.228
Total Effect	0.379	0.258	0.500	< 0.001
Proportion Mediated	0.483	0.082	1.290	< 0.05

All four conditions were satisfied, confirming my hypothesis that behaviors for quality are a mediator between team psychological safety and team performance.

9.4 Discussion

Focusing efforts where needed

This study helped each of the projects identify specific areas for improvement. For example, the type of quality issues that projects have varied from project to project; therefore, it is important to understand what each team needs to focus on. For instance, in Case 1, around 50% of the issues documented were related to issues with wall finishes, missing pieces of backing, and patching holes, and only 10% was related to trade damage. In Case 2, however, almost 50% of the issues documented related to trade damage, and another close to 10% was related to frame cleanliness.

Similarly, one of the lessons learned that came up as a result of the BBQS implementation in Case 2 was to foster a higher involvement of staff in the field to participate in quality control from the GC perspective. For instance, in addition to documenting changes on drawings or models in the planning stage, PEs and PMs could go to the field and follow up, make sure that craft workers understand how to read the information from planning for construction and know what the measurable acceptance criteria (MAC) is (i.e., what to look for and how to look for it). Also, having the staff getting to know the craft workers during field walks allows for bridging the staff-craft gap identified in this study. In this way, when any piece of information is incorrect or not clear to the craft workers installing the work, they could bring it up and get the help they need.

Conducting longitudinal studies when the sample changes

In construction projects, it is nearly impossible to have a consistent sample of participants for longitudinal studies because of the rotation in scopes and team members on a project. In addition to analyzing the data I collected at the beginning and end of my study in Case 2 and the Control case as a whole, to better understand the responses, I had to analyze also what changes occurred for those who were involved throughout the study.

Foreseeing changes due to conducting the study

I anticipated that the scores at the end of the study might increase just by having taken the survey. The survey questions provided an indication of what is expected at the leadership level. However, changing behaviors is not as easy as telling people what to do. Results supported the latter. In the control case, results at the end of the study did not show much of a change, while the case studies Post-BBQS showed an improvement in all the study variables, with statistically significant improvement in the behaviors for quality variable. For the Post-BBQS assessment, all study

participants participated in rethinking what their role was in managing quality and how their behaviors impacted the delivery of quality.

9.5 Conclusions

In this chapter, I reported my findings from a Control case study and compared them with the previous Cases 1 and 2. Results supported my hypotheses that implementing the BBQS increases the behaviors for quality, and that behaviors for quality mediate between psychological safety and team performance.

10. BEHAVIOR-BASED QUALITY SYSTEM

This chapter presents the Behavior-Based Quality System (BBQS) developed in this research. In developing the BBQS, I adopted a similar approach to the one used for the Last Planner® System (LPS) in Ballard and Tommelein (2021). They describe the system based on the functions it entails, the presuppositions about the world where these functions are performed, the principles that guide behaviors desired to perform these functions, the processes to perform them, and the methods and tools used to support these processes.

By the time a General Contractor (GC) is engaged in a construction project, typically, the management of expectations has already been done to some extent by the owner and architect with the negotiation of permits, agreements concerning issues such as increased traffic load, and other such matters involving external stakeholders. I developed the BBQS from the perspective of GCs managing quality once they are engaged in a project.

The chapter is organized as follows. Section 10.1 formulates the functions the BBQS tries to accomplish. Section 10.2 explains the presuppositions the system is built on. Section 10.3 presents the foundational principles and behaviors for the system implementation. Section 10.4 outlines the processes involved in implementing the system. Last, Section 10.5 illustrates the methods and tools that can facilitate the system implementation.

10.1 BBQS Functions

The BBQS functions are defined as the job needed to be done in the service of delivering quality products. The GCs' role in managing quality starts with a readiness check of the quality requirements already developed and continues with making sure that stakeholders' expectations are aligned before installing work. The GC's readiness check (1) allows the GC to understand what decisions have been made (i.e., the requirements defined prior to the GC's engagement in the project), if they have been made properly (adequately adapted to constraints such as money, time, supplier capabilities), and taken into account compatibility with one another, and (2) verifies that stakeholders are aligned on the requirements to meet (i.e., have the same understanding of decisions made).

Function: Getting people and process ready to get started

1. Learning from project participants (e.g., owners, architects, authorities having jurisdiction, trade partners) to the extent possible to understand their intent, identify potential challenges, and define a mitigation plan.
2. Getting project participants' buy-in, e.g., by describing successful examples of past projects, explaining potential benefits, including overview description in onboarding material.
3. Engaging all project participants needed and building a psychologically safe space where everyone has a space to share, e.g., speak up about expectations or constraints.
4. Agreeing on the quality process to follow and training project participants on the overall quality system, so they know what is expected from them and are committed to participating in the process fully.

5. Scheduling quality conversations with adequate time to act.

Function: Determining requirements to meet

1. Understanding expectations (e.g., specifying properties of the scopes to be built, drawing packages completion) of all project participants needed.
2. Defining constraints that may limit the specified expectations.
3. Deciding the expectations' feasibility considering the project constraints and being transparent about infeasible expectations.
4. Aligning expectations to be met (adjusting them to be clear and compatible, i.e., ensuring all can be achieved within project constraints).
5. Assessing readiness for clarity, gaps, and conflicts for work to be performed.
6. Using lessons learned from previous projects where similar work was done.
7. Aligning expectations to be met (i.e., establishing what needs to be met to achieve expectations) and documenting agreements as requirements.

Function: Agreeing on methods for assessment

1. Specifying how the product will be assessed once delivered (i.e., assessing the presence or absence of agreed properties).
2. Checking the understanding of project participants about the agreed method of assessment.

Function: Designing operations to be capable

1. "Specifying what work should be done when and by whom to achieve objectives" (Ballard and Tommelein 2021).
2. Planning to conform – preparing to build per the agreed expectations and executing the plan as intended.
3. Building capability needed to conform with agreed work.
4. "Making release of work between specialists reliable" (Ballard and Tommelein 2021).
5. Experimenting with the operations design and providing feedback to adjust agreed requirements as needed.
6. Involving installers in designing and testing operations design to determine feasibility to meet quality, safety, and cost requirements.
7. Asking craftworkers to make sure they understand the requirements.

Function: Supporting consistent execution in the field

8. Communicating information in a way that craftworkers putting work in place understand the requirements, e.g., posted instruction for standard operations, access to a virtual model.
9. Empowering craftworkers to speak up when things are unclear or mistakes occur.
10. Giving feedback to craftworkers as they build and helping them incorporate the feedback.

Function: Inspecting work as per agreed requirements and learning

1. Assessing delivered work as it is installed and specifying whether it conforms with agreed expectations following reliable promising.
2. Learning from failures and improving how work gets done.

3. Learning from success and documenting best practices for future use.

10.2 BBQS Presuppositions

The following presuppositions are assumed to be true about quality management:

1. Construction projects are "one-of-a-kind" deliverables (Koskela 2000).
2. Information may be ambiguous, inconsistent, conflicting, or have gaps (Porteous 1992, Stasiowski and Burstein 1993, Assaf et al. 1995, Juran and Godfrey 1999, Lowe 2001).
3. Human beings are constantly making assumptions. When it comes to quality, making assumptions is not the problem. However, acting on those assumptions without ensuring they have been tested (i.e., expectations that are assumed to be true are also verified before executing the work) is a problem.
4. Project participants might have different expectations, and the "I've been doing this for 20 years" thinking needs to change.
5. Alignment of expectations is necessary for delivering quality products.
6. A "one-size-fits-all" approach is not an adequate solution when it comes to quality. This approach ignores contextual factors that are important for understanding project participants' intent and limitations to shape project expectations to meet.
7. Drawings and specifications might not tell the whole story or the best method.
8. "A prerequisite for reliable promising is that performers can say 'no' to a request" (Ballard and Tommelein 2021). When saying "no," suppliers should provide a reason or counteroffer.
9. Attention to people's behaviors is a necessary but not sufficient condition for the successful delivery of quality products.
10. Psychological safety promotes learning behaviors, and learning behaviors promote team performance (Edmondson 1999).
11. Project participants might make a hidden (and likely wrong) assumption that everyone on the project feels psychologically safe.
12. Enhancing engagement (e.g., of those who will supervise and perform the work) results in better plans and improves the delivery of quality products.
13. Lessons learned relying on memory only will likely be forgotten; documenting them helps the project participants have them available for later consultation when needed.

10.3 BBQS Principles and Behaviors

The BBQS principles are the following:

1. Foster psychological safety:

   Drive out fear (Deming 1982, Edmondson 1999). Even though it can be argued that this advice seems to be addressed to people in leadership roles, project participants in any role can do their part to follow this advice, e.g., a craftworker reporting a mistake made while putting the work in place. "Build a culture of stopping to fix problems, to get quality right the first time" (Liker 2004).

2. Train participants and build discipline:

   Help participants prepare to fully engage in the implementation of the system, from the expected behaviors to the processes to deliver quality. Because of the diverse background that those building a construction project bring to the team, it is necessary that participants are aligned on the way quality is managed on a project.

3. Build with care and be mindful:

   When making assumptions, test them and document their resolution. Emphasize prevention and cease dependence on inspection (Deming 1982, Juran and Gryna 1993). Listen to others' expectations, and pay attention to conflicting or vague information and gaps in current plans.

4. Identify what is distinguishing and focus on it:

   Seek to understand what other participants care about, and once aligned on what is distinguishing about the scope, strive to achieve that intended outcome.

5. Involve all project participants needed:

   Engage all people needed and produce plans collaboratively; "man is fallible, but maybe men are less so" (Gawande 2010). Make sure they have the information, skills, and knowledge needed to meet agreed requirements before starting installation.

6. Practice integrity – Do as you say you are going to do:

   "Make and secure reliable promises and speak up should you anticipate any change" (Ballard and Tommelein 2021). Changes in quality, for example, can be encountered when agreements are made by looking at a mockup that was built using specific materials, but then a certain material is not available in the amount needed when building the project. When checking the delivered work, do so as per the agreed requirements, not individual expectations.

7. Foster caring and avoid trade damage:

   Seek to foster a sense of ownership and pride from craftworkers in their work and those of others in the project. Help participants understand that the quality of the project depends on the quality of each scope delivered.

8. Leverage knowledge and lessons learned:

   Learn from experimentation and breakdowns (Shewhart 1939, Deming 1986, Juran 1986, Ballard and Tommelein 2014) and collaborate with subject matter experts for guidance when planning quality for a scope.

These principles are the basis for the behaviors desired to sustain the BBQS. Principles are intertwined, and more than one principle can be reflected in one behavior and vice versa. Behaviors that I consider to be fundamental for managing quality are:

1. Being respectful:

   The act of treating others with dignity and courtesy and helping them to develop capabilities for the work (e.g., teaching them how to see and solve problems as part of daily work by conducting Gemba walks).

2. Active caring:

   The act of constantly looking out for the quality of the project and the safety and welfare of other project participants who are to install the work right the first time.

3. Making reliable promises:

   The act of committing to something that is achievable under certain constraints. In the context of quality, making a reliable promise can go from agreeing that something will be built as per the agreed DFOWs and MAC to committing to building it in X number of days.

4. Speaking up:

   The act of sharing ideas and expressing freely any question, concern, suggestion, etc., relevant to the work of concern.

5. Being diligent:

   The act of being careful, probing, just not accepting what is given, as is, without making sure it is right (i.e., complete, accurate).

6. Active listening:

   The act of making a conscious effort to hear not only the words that are said but the message being communicated with all senses (i.e., paying full attention to the speaker and what this person does or does not say).

7. Active learning:

   The act of purposely applying the PDCA cycle of continuous improvement. Learning can be understood as a process by which people acquire new knowledge or skills; in this case, active learning would involve project participants engaging in activities that allow learning from experiments and breakdowns.

Figure 10.1 describes my research model and study variables (in white boxes), showing their relationships.

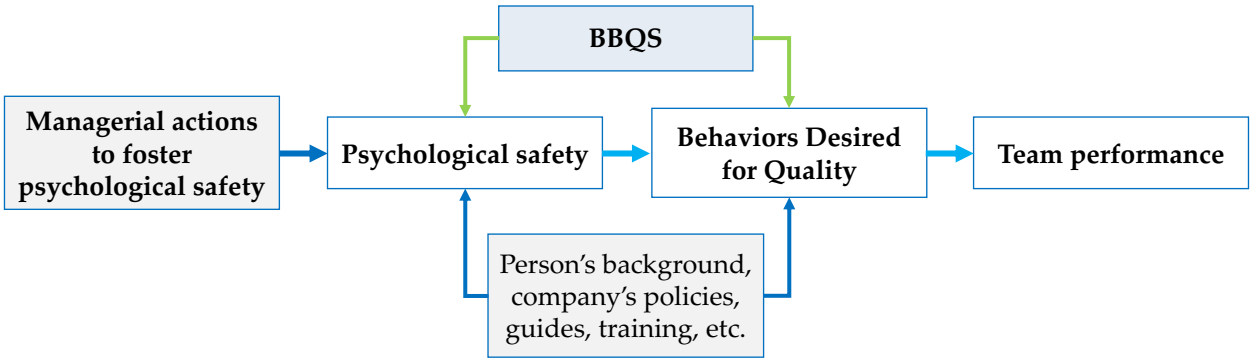
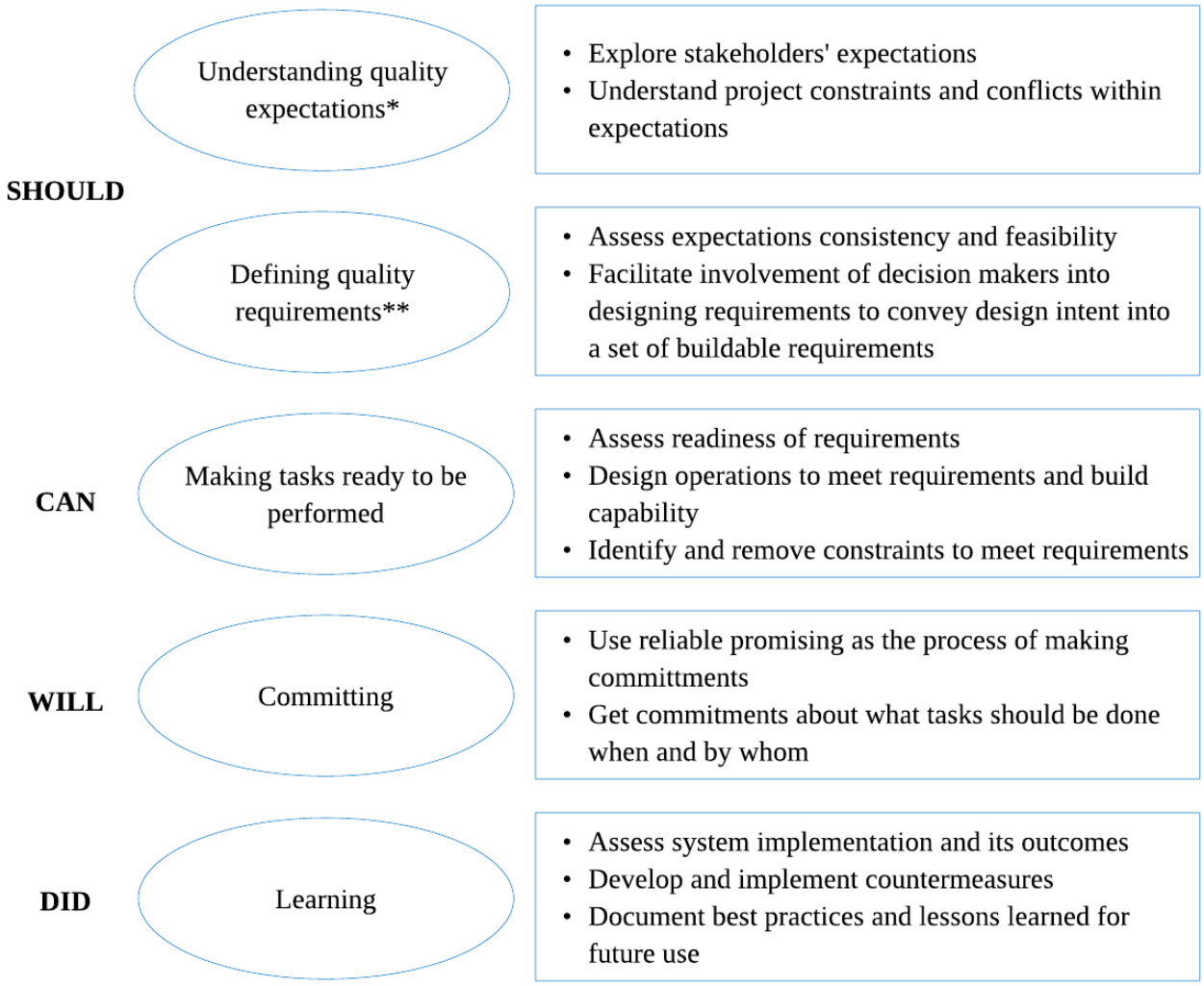


Figure 10.1: Relationships Between Team's Psychological Safety, BBQS Behaviors, and Team Performance

In the previous chapters, I studied the above relationships and calculated correlations between my study variables in two project teams. Such relationships need to be analyzed in a larger data set to provide a more representative value.

10.4 BBQS Processes

The SHOULD-CAN-WILL-DID distinction for planning and control in the LPS is described in Ballard and Tommelein (2021). They described "SHOULD" as setting milestones and planning handoffs; "CAN" as making sure that scheduled tasks are ready to occur; "WILL" as committing to perform scheduled tasks; and "DID" as learning from the outcomes comparing what happened with what was supposed to happen. This distinction, in the world of planning and control, intersects with quality management as it does with safety management, etc. I described the BBQS using Figure 10.2 to show the intersection between LPS and quality management. As shown in such figure, the BBQS works at different levels to perform its functions.



** Expectations are mental models that exist in people's minds*

*** Requirements are the agreed upon expectations defined by stakeholders*

Figure 10.2: Levels of Action of the BBQS

I adopted the same terminology as in Ballard and Tommelein (2021), which describes a process as a "series of events and steps that produce an outcome." The BBQS functions can be achieved through a series of steps described in Figures 10.3-10.7.

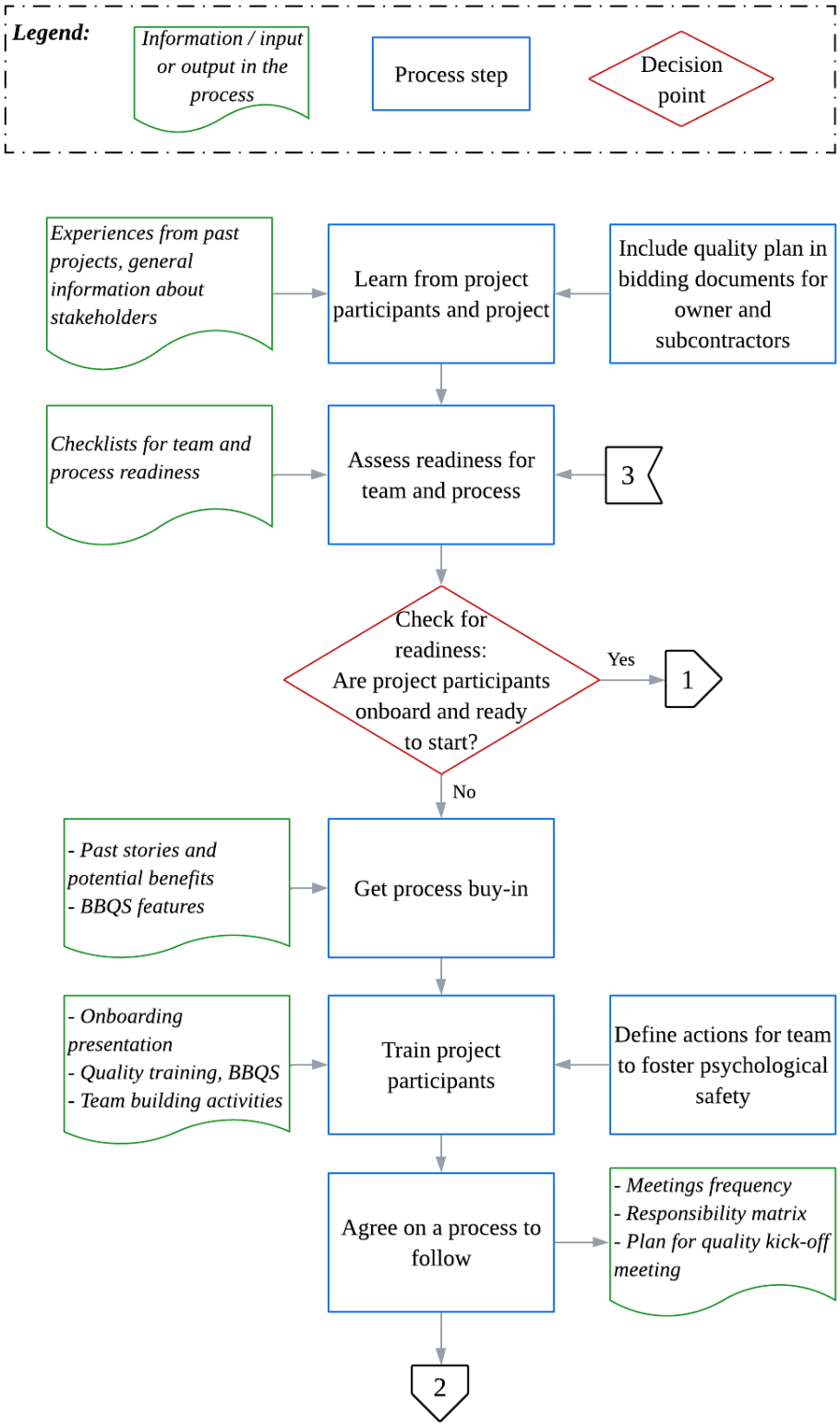


Figure 10.3: BBQS Quality Process (1/5)

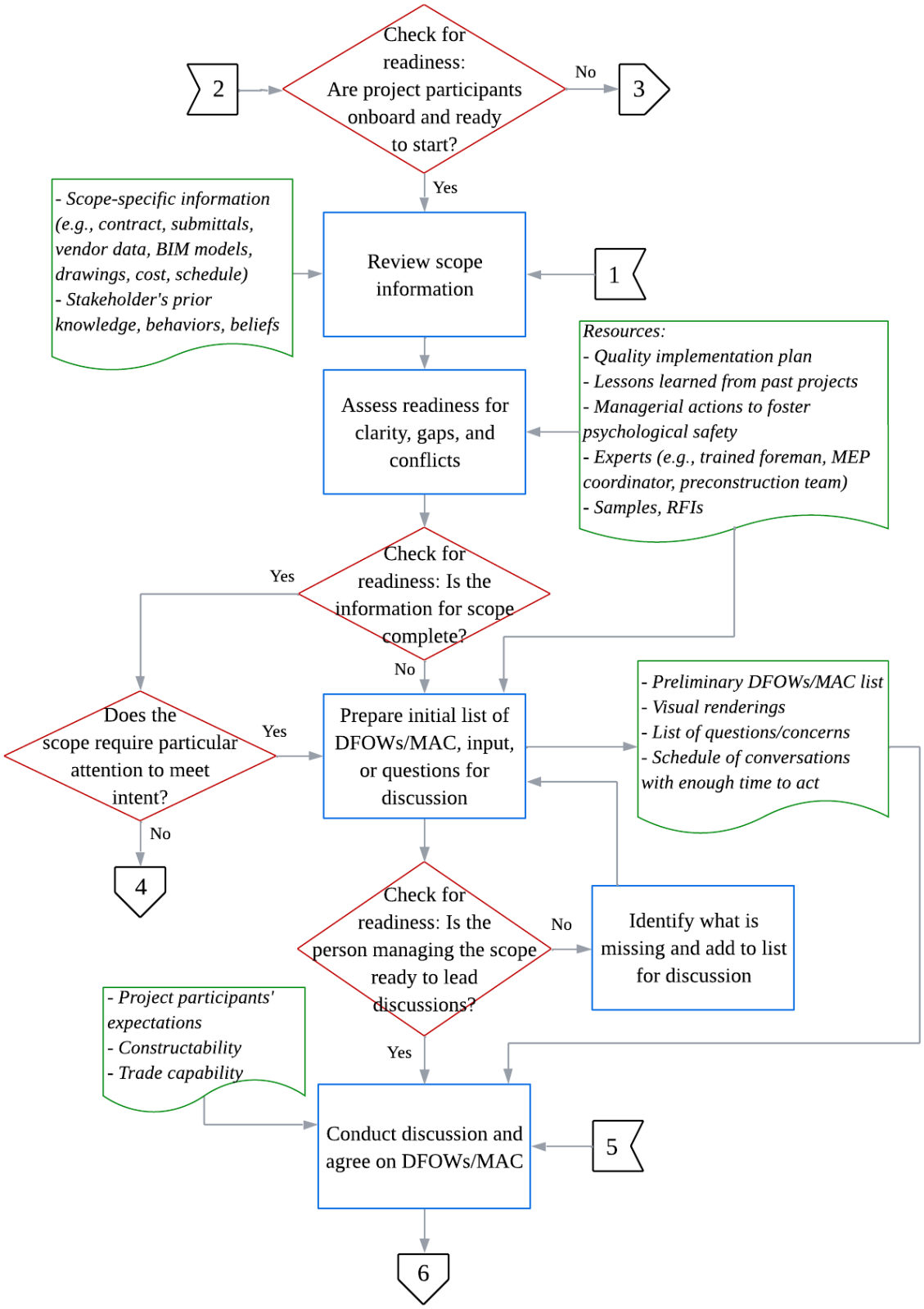


Figure 10.4: BBQS Quality Process (2/5)

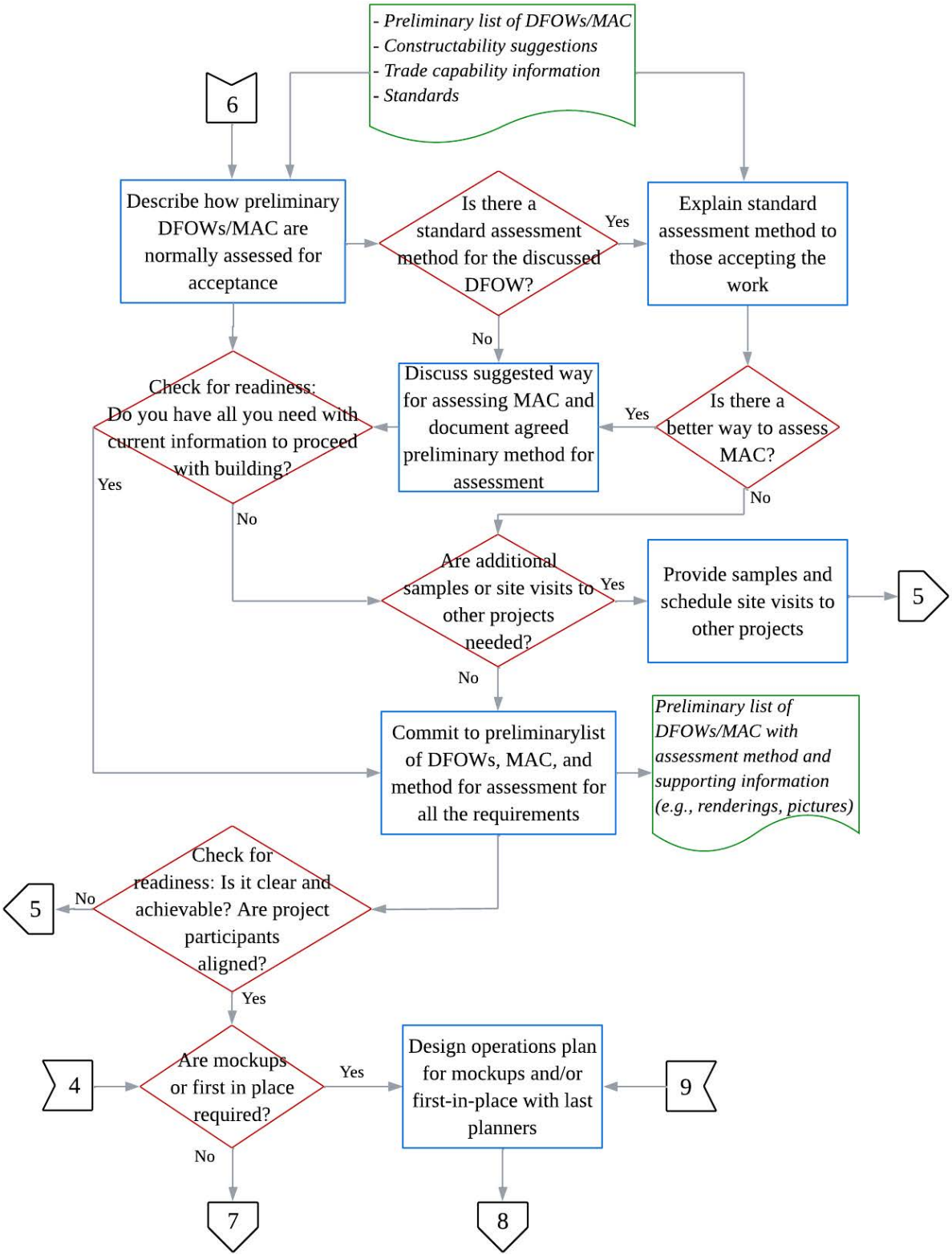


Figure 10.5: BBQS Quality Process (3/5)

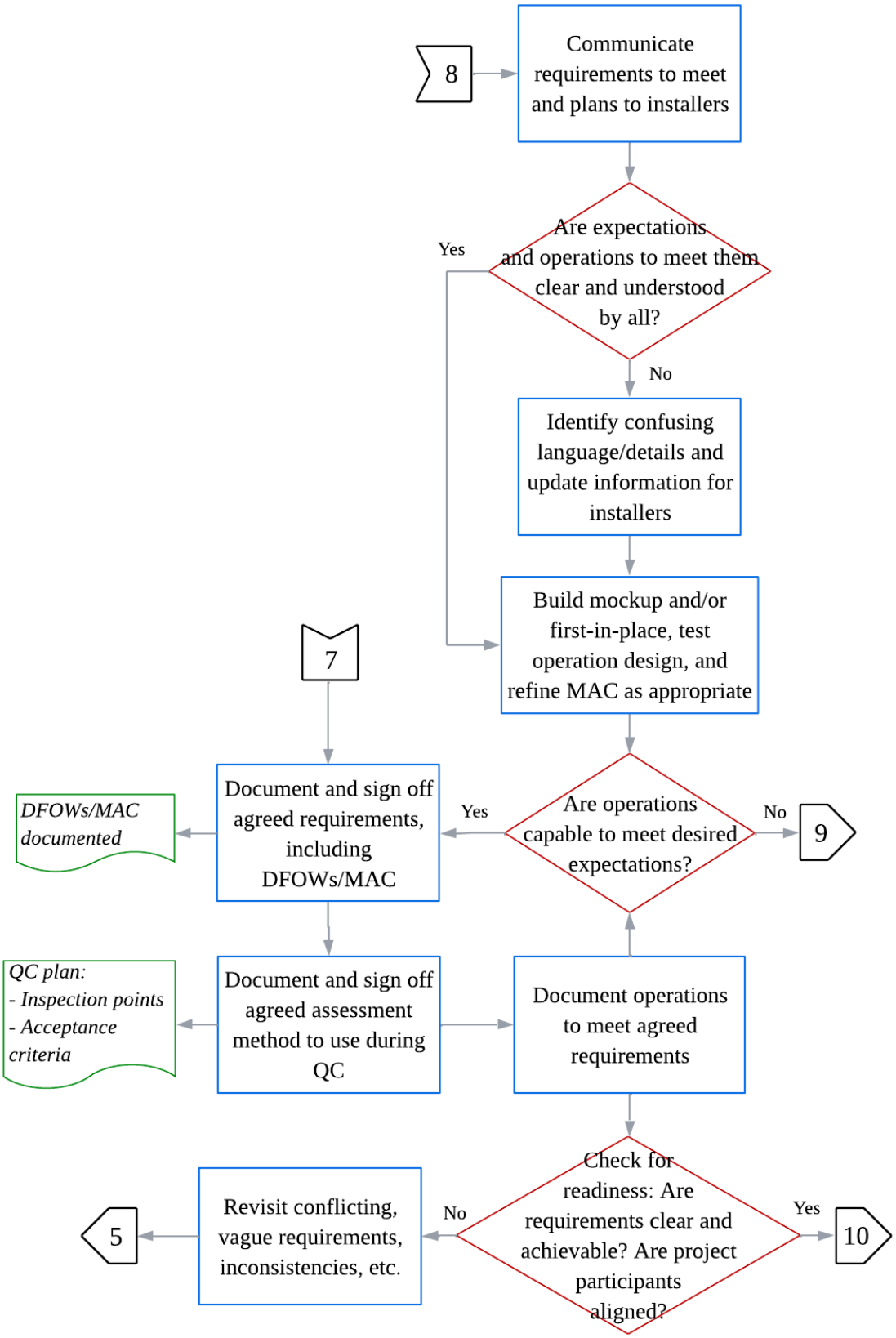


Figure 10.6: BBQS Quality Process (4/5)

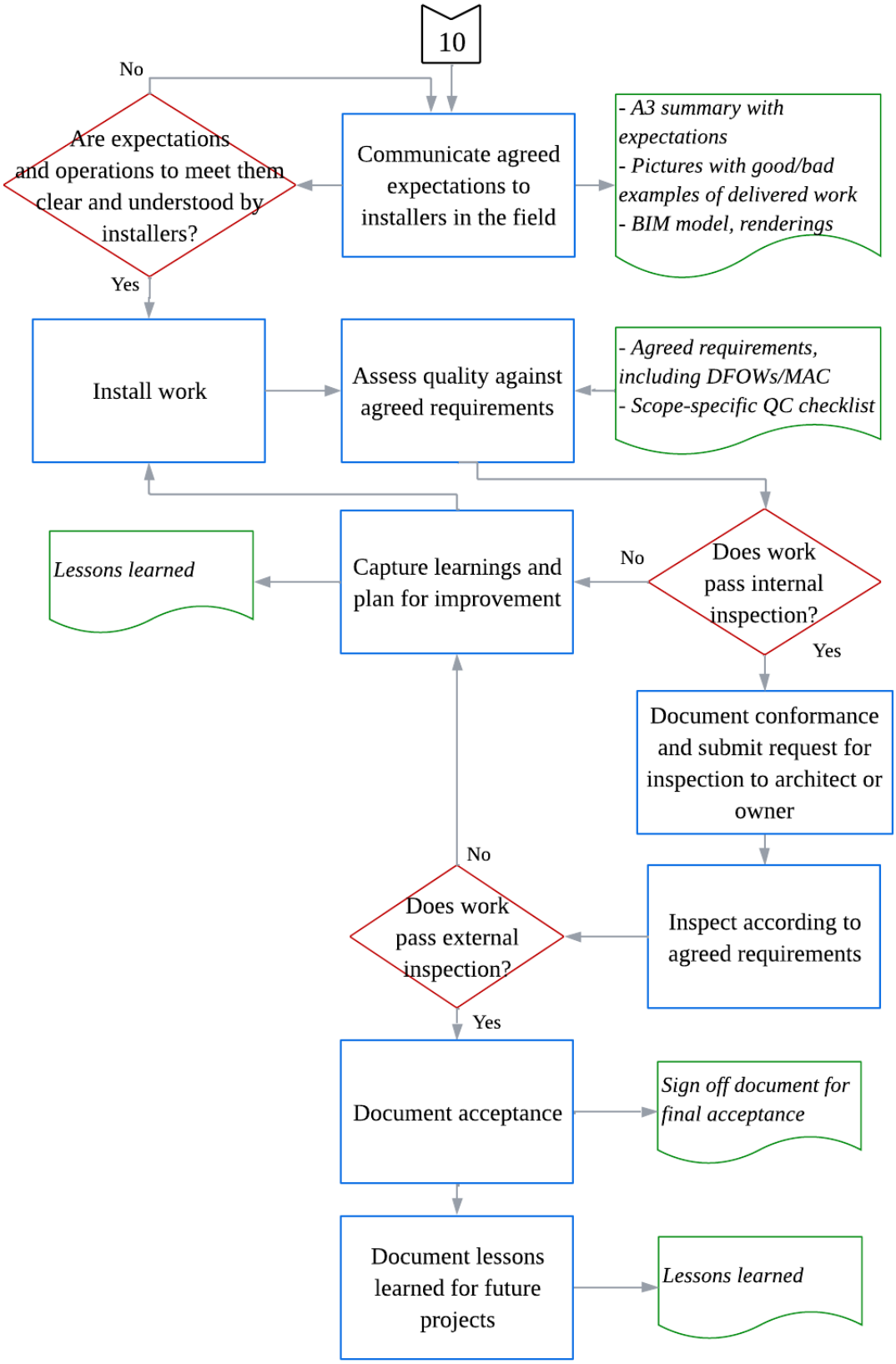


Figure 10.7: BBQS Quality Process (5/5)

10.5 BBQS Methods and Tools

In addition to the methods and tools for quality management that I highlighted in the literature review (Section 2.3), in the following subsections I describe some others I developed when implementing the BBQS.

10.5.1 Performing Readiness Assessment

This method consists of assessing, at different instances of the delivery process for any deliverable, that the work in that instance is done correctly and the performer is ready to proceed to the next step. The readiness assessment is a systematic way to:

1. Assure that a process or a task can be undertaken as planned (Karandikar et al. 1993)
2. Identify potential issues and plan strategies to overcome such issues (Plested et al. 2009)
3. Foster conversations needed (Williams 2014) for the quality delivery process.

This assessment is conducted by the performer forecasting the different things (e.g., resources, activities) needed to maintain flow in the delivery process. The GC can conduct this assessment, for example, as a way to assess the project information received, e.g., from the client and designers to the GC, or from the GC's staff to craftworkers building a scope of work.

Although GCs typically get involved in the delivery of the project once the owner and designers have developed the project design and handed off a set of drawings and specifications to them, planning for quality should start further upstream in the supply chain. If the GC does not participate in the design phase, GC is still held responsible for assessing what has been done earlier to understand expectations and determine requirements. For example, the performer (PE or foremen) needs to verify that information to be handed over to craftworkers for construction (e.g., drawings, specifications, BIM model) is certain, complete, free of conflicts and ambiguities, and that the appropriate project participants were engaged in producing such information.

The readiness assessment at different instances of the construction process can be done to prevent (1) conflicts and clashes on the field, (2) misunderstandings and filling out gaps with wrong assumptions, and (3) ambiguities, etc.

Table 10.1 shows a checklist to assess the team readiness to perform the quality process. This tool includes best practices for launching the quality process.

Table 10.1: Readiness Assessment Checklist – Get Quality Conversations Ready to Start

	To Do Activities
Get Team Ready	
1	Identify the stakeholders needed for discussing and analyzing the expectations for the scope of work
2	Design team building activities, create familiarity, and have a plan in place to foster psychological safety among your team
3	Make people feel they can contribute to quality and get their commitment
4	Get buy-in: share successful examples, describe potential benefits of implementing the process
Get Process Ready	
5	Introduce quality during onboarding
6	Introduce the topic in already existing project meetings such as OAC, BIM coordination
7	Schedule meeting times specifically assigned to quality discussions
8	Describe the overall quality process and refine it with the project participants involved
Get Ready to Facilitate Discussions	
9	Have a quality champion for each scope (project engineer or manager leading the scope of work) and for the project overall (i.e., superintendents) to lead the process
10	Seek and study documents that reflect the expectations for the scope
11	Draft an initial list of DFOWs/MAC and specify why these require particular attention
12	Pose questions to guide conversations
13	Look to understand their vision and why they care about something in particular

Table 10.2 shows a checklist to assess the team readiness prior to building. Some items in the list apply to all scopes, while others are scope specific.

Table 10.2: Readiness Assessment Checklist Prior to Building

Checklist of items applicable to any scope	
1	We understand the design intent of the project and specific scope
2	The information is conflict-free with itself and other discipline's scopes
3	The information is clear (i.e., no ambiguities)
4	The information is complete (i.e., no gaps)
5	We are aware of other project participants' expectations about this scope
6	We have strived to confirm assumptions made regarding quality expectations
7	We have documented input resulting from conversations with other project participants and have the project documents updated to match agreements made
Checklist for scope-specific	
8	We know who the project participants are needed that should participate in defining quality for this scope
9	Project participants needed (those who are responsible, accountable, or have certain authority) are engaged in the conversations to define quality
10	We know where issues in the past have occurred for this scope
11	Operation design clearly specifies steps to perform, and the resources needed
12	Processes designed to build scope are capable of delivering as per expectations
13	We understand and agree with how the assessment of conformity to requirements will be performed
14	All resources needed are ready for execution, including the schedule and budget

10.5.2 Talking to People Using Empathic Listening

This method highlights the importance of talking and listening (i.e., maintaining conversation) and focuses on communicating and seeking to understand quality requirements (e.g., understanding how the presence or absence of the desired quality will be assessed; a GC understanding the design intent of a specific scope). Conversations are "our main way of expressing our ideas, opinions, goals, and feelings to those we come into contact with" (Gabor 2011). Quality conversations help move project participants' expectations into a set of buildable requirements. When applying this method, all relevant project participants for a deliverable need to be identified and involved in quality conversations. Identifying and including the decision-makers in the process is important to make these conversations effective. For instance, when questions or concerns arise about the work to be done, asking the right people can help get the right answer.

When having conversations, it is important to practice empathic listening, which consists of understanding others' positions (e.g., the architect's design intent) but confronting and supporting when needed (Covey 1990). The cycle of conversations for clarification and negotiation to a request made is the first step toward reliable promising (Section 2.3.4). When a request is made, the person receiving the request should say back what his understanding is to check and make sure that the two have the same understanding of the request.

Due to the nature of construction projects, participants may have never met before, so it is even more important to maintain open channels of communication and open minds and senses (Lowndes 2003, Gabor 2011). For instance, concrete subcontractors may remove their concrete hats and try to understand the designers' intent when asking them to make "mirror-like" concrete walls.

Various strategies can be adopted when having conversations (Table 10.3). In practice, this method may include, for example, conversations and brainstorming sessions to identify constraints (e.g., a drywall subcontractor whose workers are experienced in building level 4 finished walls might be limited if requirements change to level 5 finishes).

Table 10.3: Strategies to Adopt when Talking to People

	Strategy
Talking Consistently	
1	Consistently guide conversations to allow sufficient understanding of expectations and alignment
2	Consult project participants for input needed to shape expectations (e.g., constructability feedback, shop drawings needed)
3	Schedule consistent and constant check-ins, continual communication
Using Empathic Listening	
4	Listen and pay attention to others' expectations (e.g., architect's intent) and ideas (e.g., craft suggestions for operations design)
Documenting Conversations and Sharing Agreements	
5	Keep meeting minutes and send them out to all after meetings
6	Make sure changes agreed upon have been implemented in existing project documents
7	Keep project participants updated on any change in current plans

10.5.3 Creating Designated Spaces for Conversations and Feedback

This method consists of having designated spaces for giving and receiving feedback. Broekstra (1998) suggested that organizations are a network of conversations. Such conversations have the power to define people's perception of the world (Winograd and Flores 1986) and are critical for learning (Baker et al. 2002). To optimize the way these conversations are conducted, it is important to consider:

1. Different elements of a conversation (e.g., request, negotiation) (Flores 2013).
2. How to navigate conversations when feedback is offered (e.g., close with a commitment) (Stone and Heen 2014).
3. Commonly used rules (e.g., agree to disagree, do not take things personally, challenge by choice, respect, and no attacks) to have conversations that allow learning (Arao and Clemens 2013).

Table 10.4 illustrates some of the settings where conversations about quality can take place. These spaces are to be designed based on the project's needs, e.g., quality coordination meetings that are scheduled times to discuss quality-related topics for specific scopes, or all-hands meetings where

quality can be a 5–10-minute talk as part of the 1 hour-long meeting. Some of these spaces can be designed to foster psychological safety while addressing quality-related topics, e.g., craft appreciation lunches to collect feedback from craftworkers to improve current conditions.

Table 10.4: Opportunities for Engaging in Quality Conversations

Instances for Quality Conversations	
Throughout Quality Process	
	Quality coordination meetings, aka. quality office hours
	Kick-off meetings
	Pre-installation meetings
	Constructability reviews
	Page turn reviews for newly issued design documents
	Onsite walks
	Brainstorming and open sketch design meetings
During Planning	
	Conversations tightening quality to the project schedule
	Pre-task plans
	Daily huddles
	All-hands meetings
In the Context of Celebratory Events	
	Worker's appreciation lunch
	A celebration day for quality, similar to what companies host for safety

10.5.4 Designing Operations Collaboratively Using Servant Leadership

Operations design can be done through virtual prototyping, physical prototyping (mockups), and First Run Studies (FRS) (Ballard and Tommelein 2021). Howell and Ballard (1999) provided a holistic checklist for designing operations, including (1) requirements (what has to be done), (2) what is needed to execute the operation (skills, tools, equipment, materials, permits), (3) sequence (how the work will proceed), and (4) detail of operation (who will do what, when, and how). All these would greatly benefit from the participation of foremen and craftworkers involved in performing the operations.

By adopting a servant leadership style, participants in the BBQS are:

1. Focusing on understanding others to create a common ground for conversations and gain a shared understanding of requirements to meet.
2. Modeling desired behaviors and building habits so that people display such behaviors naturally, almost unconsciously.
3. Accepting the person's own fallibility and vulnerability so team members can ask questions in the presence of doubts or concerns about the work to be done in a psychologically safe environment.

Outcomes of using this method may include:

1. Clear description of requirements to meet and inspection criteria; if possible, add examples of good work and bag work (e.g., two pictures describing good and bad installation outcomes of sink countertops detailing join color, size).
2. Steps to perform (from preparing the work to cleaning the work area and eliminating debris) and performers in each step (e.g., for installing prefabricated slabs, things to describe are the lifting process to place them in their right location, inspection points).
3. Handoffs from and to other trades (coordination).
4. Materials, tools, and equipment needed (e.g., adding to the previous example, the outcome will include the response to the following questions: will a crane be needed to lift prefab slabs? Is the crane capacity enough to lift a piece of a slab to the needed location? Are slabs sent in the order they will be used (slab pieces would normally be shipped in a truck, and each piece of the slab is designed to fit a specific area; if they are shipped in a random order, this may create rework due to moving slabs to a temporary location before they need to be installed in the work sequence defined for the floor)?
5. Estimated schedule/plan and work sequence.
6. Safety for craftworkers putting the work in place and the work area to protect others working in the surroundings.
7. A plan for specifying how mistakes and rework will be reported, and how will actions be taken for improvement.

Operations design can benefit from visual tools (Table 10.5) to facilitate the understanding of requirements and the way these are to be achieved. In addition to visuals, operations designs should include, to the extent possible, descriptions simply written (putting words to the required look, feel, and functionality of requirements) to support what the visuals try to convey.

10.5.5 Using Visuals to Communicate Expectations and How to Meet Them

This method consists of using visuals to convey quality-related information in a clear and easy-to-see format, and to facilitate and simplify information management (Galsworth 2017). Graphs, charts, and diagrams can be used to share quality-related information. For instance, flow diagrams can effectively show the various steps in a process. This can help identify critical control points, who performs what, when, and the handoffs throughout the process.

Table 10.5 shows a list of visual tools that practitioners suggested as being good practices for communicating quality expectations from the owner to the contractors and from the contractors to trade partners.

Table 10.5: Visuals Tools for Communicating Quality Expectations

	Visuals Tools
1	Mockups and first-in-place where details can be seen up close, touched, and measured
2	Diagrams to help each person understand the part they play in achieving quality
3	Samples of similar or same elements to convey good and bad examples, e.g., pictures, materials, and previous projects
4	Renderings, models, and sketches showing DFOWs/MAC in detail
5	A3 with consolidated relevant information
6	Site visits to comparable work
7	Displays showing what is acceptable; e.g., good/bad examples next to where work is put in place
8	Visual controls/cues in the area of work
9	Displays showing performance, e.g., Kaizen boards onsite
10	Color-coded plans and drawings
11	Short videos for how to do things/next steps
12	Job walks
13	Quick Response (QR) codes onsite that provide access to all relevant info on the iPad or cellphone
14	Reminders like safety signage, e.g., checklists or posts with “have you done this?”
15	Floor plans highlighting DFOWs/MAC locations

10.5.6 Adopting Strategies to Prevent Language-Related Issues

This method consists of planning actions that teams can take to prevent language problems that people who are not native speakers encounter working in a team. Section 4.6.4 illustrates one action taken by one of the cases studied to overcome such problems. Understanding what is said when communicating quality requirements and the methods to meet them is key to meeting them. Teams may implement one or more of the following strategies to build communication channels for quality:

1. Have one of the leaders fluent in the language explain the work (Abas et al. 2020) and engage them in operations design as needed.
2. Use visual aids (Brady et al. 2012, Laine et al. 2014, Demirkesen and Arditi 2015, Galsworth 2017) to communicate expectations, operations to meet these, and control points, etc.
3. Train workers using their primary language (OSHA 2015, Demirkesen and Arditi 2015) and in a manner (considering workers’ education level and literacy) that they can understand (OSHA 2015).
4. Provide guidelines in the worker’s primary language (Demirkesen and Arditi 2015) or have a bilingual foreman who acts as a bridge for communication.

10.5.7 Recognizing Desired Behaviors and Sustaining Participants Engagement in Quality Management

Powell (2019) said, "appreciation and recognition are fundamental human needs." This method consists of creating structured ways to recognize and reward workers when they behave as desired for the delivery of quality (Section 10.3), e.g., report mistakes so everyone can learn from them and try to avoid their reoccurrence.

Recognizing people helps:

1. Improving employees' morale and performance (Allen and Helms 2002, Amoatemaa and Kyeremeh 2016).
2. Improving communication (Nelson 2012).
3. Showing appreciation for employees who are displaying desired behavior and reinforcing such behaviors to build and sustain desired habits (Luthans 2000, Danish and Usman 2010, Duhigg 2014).
4. Building the desired culture (Juran and Gryna 1993 p. 173).

Sections 4.6 and 8.5.5 describe some of the ways participants in this research were recognized for their contributions to quality. Recognition can be expressed in various ways, from postcards with messages such as "Thanks for delivering quality right the first time!" to invitations for lunch with peers or supervisors, to publicly sharing the names of rewarded people on a board, to spontaneously congratulating a worker for his performance (Brun and Dugas 2008, Nelson 2012).

11. CONCLUSIONS

This chapter is organized as follows. Section 11.1 summarizes the research findings and answers the research questions and hypotheses tested. Section 11.2 highlights the contributions to knowledge. Section 11.3 discusses generalizability and possible limitations. Section 11.4 introduces future research areas to explore in quality management. Section 11.5 concludes this research with final remarks.

11.1 Research Findings

11.1.1 Summary of Findings

Delivering quality is meeting the agreed expectations of those involved in the building process. Such expectations, once agreed upon, become the requirements that are to be met to assess the successful delivery of quality. When general contractors (GCs) join a project, the project requirements may be developed to some extent. During construction, GCs typically use requests for information (RFIs) and submittals as means to clarify requirements. In more integrated projects, GCs also provide constructability feedback on requirements during design development. However, quality-related issues still persist, resulting in rework or acceptance of poor work. Studies on quality management have heavily focused on statistical process control, tolerance management, and standards development. Such focus has been expanding to incorporate the role people play in the management of quality. BBQ proposes improving the delivery of quality by focusing on people's behaviors to foster alignment and minimize quality issues. Evidence in this research shows people understand BBQ's proposition but struggle to understand how to adopt it. The system I present in this dissertation, Behavior-Based Quality System (BBQS), provides a systemic view of BBQ.

I designed the BBQS on two foundational concepts, psychological safety and Lean. Inspired by the Last Planner® System (LPS) benchmark, I designed five features for the BBQS: (1) functions needed to deliver quality, (2) presuppositions about the world where these functions are performed, (3) the behaviors needed to perform the functions and the principles on which they are based, (4) the processes used to perform the system functions, and (5) methods and tools that facilitate executing the processes. Inspired by studies that explore the construct of psychological safety, I incorporated this construct across the BBQS features, for example, one of the BBQS principles suggests fostering psychological safety so any team member having questions or concerns about quality requirements can speak up without fear of retaliation or being embarrassed. By developing the BBQS, I aim to assist those who want to deliver quality requirements but struggle with the how-to:

> *"A little bit of me was like, 'I'd like some type of guidance.' It's easy to say go out there and do it [manage quality]. People keep on telling me 'you got to go out there and do it [implement a behavioral approach to manage quality], you're the one closest to the work on the field, you know how to implement it.' Honestly, no, I don't, I really don't." – PE*

I used design science research and developed the BBQS in four iterations. First, I conducted exploratory studies where I analyzed the construct of psychological safety in two construction

project teams and the use of BBQ to manage quality in one of them. Second, I analyzed responses collected from practitioners who had applied BBQ to some extent and shared their perspectives of what worked well for them and the behaviors they observed within their teams. Third, I conducted a retrospective case study to learn what a team did to deliver quality on a project known by the GC participating in the research as one of their best-in-class projects. Fourth and last, I conducted longitudinal studies on two projects in parallel; I used one as a control case and implemented BBQS on the other and then compared their outcomes.

When implementing the BBQS and comparing the results against a control case, I found that psychological safety, behaviors for quality, and team performance were better in the project that used the BBQS. In that project, I found a statistically significant increase in the behaviors for quality Post-BBQS. Across my case studies, I also found that psychological safety is positively associated with behaviors desired for quality, and these, in turn, are positively associated with team performance. In addition, I determined that the behaviors for quality have a mediating role between psychological safety and team performance. An improvement in team performance can be achieved in a psychologically safe work environment via the behaviors desired for quality.

Furthermore, I analyzed psychological safety and the behaviors for quality by staff and craft members and found a gap that needs to be closed. Staff members reported higher levels of psychological safety and higher scores for the desired behaviors than craft members. Because of this, the focus in the last case study was working with the craft and guiding them to understand the BBQS, their role in delivering quality, and putting what they learned into practice. All participants reported better outcomes after the study:

> *"I like that for the first time there's a program like this [supporting craftworkers implement BBQS] to train the craftworkers, and also where people from the office are involved… I learned to talk about mistakes without fear, and when I don't know something, I'm not afraid to ask for help." – Craft*

> *"The [BBQS working] sessions taught us not to be afraid to ask questions. It also helped us know that communication is key to help prevent misunderstandings of expectations and keep everyone in the loop with what's going on in the field." – Craft*

Asking questions before installing work when in doubt helps minimize rework. Similarly, talking openly about mistakes leads to learning and continuous improvement. Having the craft really understand the quality requirements that will be used to assess their work is key to meeting such requirements. For instance, at the beginning of the study, I identified that the cleanliness in the data server rooms was a DFOW for the client, and I communicated this to the staff and craftworkers. The number of quality issues reported related to cleanliness decreased from 25% of the total number of issues Pre-BBQS to 9% Post-BBQS (Table 8.5).

This research contributes to knowledge by augmenting the literature on quality management and psychological safety, proposing a psychometric tool to assess construction teams' psychological safety and the behaviors desired for quality, closing the gap between staff and craft psychological safety and their behaviors for quality, and presenting a system that highlights the human factor in the delivery of quality and guides teams implementing a behavioral approach to quality.

11.1.2 Research Questions and Answers

This section summarizes the answers to the research questions introduced in Section 1.5:

1. **What are the features of the BBQS?**

   The BBQS is composed of the following features: functions, presuppositions, principles and behaviors, processes, and methods and tools. The features I proposed do not constitute the only possible features of the system, and can be further refined through practice. The features of the BBQS are described in Chapter 10.

2. **What managerial actions can be taken to foster the behaviors desired for the successful realization of the BBQS?**

   In the exploratory studies, we designed and tested some actions to foster psychological safety in collaboration with the project teams. Such actions were as simple as hosting craft lunch-and-learn sessions where craftworkers had a space to provide feedback, or as elaborated as organizing onsite committee meetings where participants from the craft and staff worked together to answer pre-defined questions. The actions we implemented in this research are further described in Section 4.6.

3. **How to assess the BBQS effectiveness?**

   The BBQS effectiveness can be measured in terms of the outcomes of its implementation (outcome metrics), and the implementation itself (process metrics). For the outcome metrics, I found an improvement in all my study variables, including psychological safety, behaviors for quality, and team performance in the project where I implemented the BBQS. Similarly, for the process metrics, I found, for example, better participants' engagement during planning and more involvement in quality control during installation.

4. **What relationships exist, if any, between psychological safety, behaviors for quality, and team performance?**

   I found strong positive correlations between psychological safety and the behaviors desired for quality, and these, in turn, with team performance. In addition, I found that the behaviors for quality mediate between team psychological safety and their performance managing quality (Section 9.3).

11.1.3 Hypotheses Tested

I tested the following hypotheses:

1. Team psychological safety is positively associated with behaviors desired for quality.
2. Behaviors desired for quality are positively associated with team performance.
3. Behaviors for quality are a mediator between team psychological safety and team performance.
4. Implementing the BBQS could develop behaviors desired for quality management.
5. Implementing the BBQS could improve team psychological safety.
6. Implementing the BBQS could improve team performance in quality.

The results of the case studies and statistical analysis support hypotheses 1-4. While psychological safety and team performance were better Post-BBQS implementation, hypotheses 5 and 6 did not pass the statistical significance test. A question remains open, would a larger sample allow to observe a statistically significant increase in psychological safety and team performance when implementing the BBQS? This research is a first step in the construction industry toward

understanding the impact of the BBQS on a project team psychological safety, behaviors for quality, and performance.

11.2 Contributions to Knowledge

Table 11.1 summarizes the contributions to knowledge by chapter.

Table 11.1: Contributions to Knowledge

Chapter	Contribution
2	Synthetizes the literature on quality management with a focus on construction.
	Locates behavior-based quality (BBQ) in the building-in-quality (BiQ) approaches as opposed to inspecting-in-quality (IiQ).
	Describes links between Lean, psychological safety, and quality.
	Makes the case for focusing on behaviors to manage quality.
	Highlights methods and tools to support the delivery of quality.
3	Proposes a research methodology that uses a combination of qualitative and quantitative methods to design and test an artifact
4	Documents two case studies focused on psychological safety in construction projects.
	Extends the research on psychological safety by focusing on construction teams.
	Describes actions tested to foster psychological safety in construction teams.
5	Documents one case study focused on BBQ with an application on a scope of concrete.
6	Synthetizes the process and findings of exploring participants' responses from quality training focused on behaviors.
7 & 8	Documents two case studies where I tested and refined the BBQS, validated its utility to built-in-quality, and assessed the relationships between my study variables: psychological safety, behaviors desired for quality, and team performance.
9	Makes the case for the utility of the BBQS by comparing projects where it was implemented versus a control case study. Also presents the mediation analysis between psychological safety, behaviors for quality, and team performance.
10	Describes the BBQS features to support the delivery of quality.
	Highlights and improves the application of existing functions for quality management and proposes "getting people and process ready to start" and "agreeing methods for assessment" as additional functions needed for quality management.

11.3 Generalizability and Limitations

11.3.1 BBQS Scalability

The theoretical and philosophical foundations for the BBQS can be adapted to not only multiple scopes of work within the construction industry, but likely also in other industries. For instance, the principle of fostering a psychologically safe environment could fit any industry; psychological safety is good not only for the wellbeing of the person, but it benefits the team as a whole, having individuals speak up, share ideas, learn together, and achieve better outcomes. Similarly, the functions proposed, such as getting people ready to start, may be needed in other types of situations beyond planning for quality. Instead of assuming that individuals in a team know something or that they would ask for help should they need something, wouldn't it be better to have a team starting with an introduction to what they are supposed to know? In that way, all team members have clear expectations, for example, when identifying a mistake, the team relies on them to report it, so it becomes a learning opportunity for all and likely will help others to avoid making the same mistake.

The DFOWs presented in this dissertation focus on architectural concrete walls and drywall and framing scopes for specific projects. Teams with similar scopes in other projects still need to identify their applicable DFOWs and define their respective MAC. Because of the uniqueness that characterizes construction projects, each has a unique set of requirements, even for the same DFOW, the measurable acceptance criteria may differ; e.g., tolerances, colors, shapes. However, for teams starting their journeys implementing the BBQS, they can use the DFOWs I identified and start asking their teams whether these apply to their projects and what others they would add when planning quality for each scope.

The BBQS requires an early investment of resources for defining the quality requirements and how to meet them. Although at first sight, it may seem like more work for project teams, using the BBQS actually involves reorganizing the resources and having people plan the work well enough before building, instead of having them firefight and fix quality issues later during construction.

11.3.2 Sustainability of the Intervention

Implementing the BBQS, as an intervention to acquire some behaviors and learning a set of skills within an environment of psychological safety, requires repetition and reinforcement. As described in Section 2.7, the repetition of behaviors within a particular setting allows the formation of habits. Once a habit is formed, behaviors are ingrained in people's minds and occur almost unconsciously. As part of the intervention, participants were repeatedly exposed to BBQS features and had the opportunity to practice with actual project information, e.g., drywall finish quality requirements by level (Appendix 18). The intervention, however, is time-limited. While the team who participated in implementing the BBQS reported better results than the control team, the changes (e.g., in behavior) would require repetition and practice to be sustained within the team over time. In addition, a challenge in the construction industry is the turnover rate. Teams are typically assembled to deliver a project, but individuals within each team might change on an as-needed basis throughout the project lifecycle. When the individuals who participated in the intervention get assigned to another project, they are expected to be exposed to new team dynamics. A new team involves, for example, a new assessment of how psychologically safe their team members feel, the behaviors and habits each of them bring to the team, and skills they have developed. This

new team would need to be trained on the BBQS. Even if some participants of a newly formed team were part of the team who underwent the intervention, they would still need to be retrained along with the rest of the team as the team dynamics might change. Continuing training will be required for teams implementing the BBQS. The BBQS features are meant to continuously improve, and the training will follow (e.g., by including and training teams on better methods and tools to facilitate meeting the BBQS functions).

11.3.3 Psychological Safety and Behavioral Assessment

Even though the number of cases I analyzed is limited, through iteration with these cases, I developed and refined a survey to assess psychological safety and team performance that is valid and reliable. Although designed to study quality, this survey could be used outside the quality context for assessing team behaviors for planning. For instance, whenever individuals work in teams, they typically make requests and rely on others' commitments to complete a task; measuring the behavior of making reliable promises within their teams would allow them to identify opportunities for improvement oriented toward that specific behavior. In addition, the survey takes into account that psychological safety with respect to peers and supervisors may vary and allows one to assess both scenarios. Teams assessing psychological safety in these two categories could focus attention where they need most, either on the leadership or in peer-to-peer relationships.

Because of the number of questions in the survey, a constraint that researchers or companies trying to use this tool may encounter is some pushback from the craft workers' supervisors because of the time investment (time workers stop production to participate in the survey), especially for trades with the largest crews. For example, for 100 workers assuming a 20-min survey plus 10-min for setting up and going back to work, it adds up to 50-working hours. This constraint could be overcome by engaging supervisors in the BBQS implementation, letting them understand the potential benefits not only to the individuals participating in the implementation but to the project team as a whole in terms of work environment, personal growth, and performance.

While biases (e.g., Section 3.2.2) might be a concern when conducting this type of assessment, identifying these biases would allow researchers to plan how to mitigate them and gather more accurate results. As discussed in Section 9.4, in my case studies, one of the events I foresaw was that Post-intervention survey scores might be higher than Pre-intervention just by having participants taken the survey once already. I suspected that being informed that the study was taking place (Hawthorne effect, Parsons 1974) and seeing the Pre-intervention questions might give an indication of what is expected from participants. However, changing behaviors is not as easy as telling people what to do. For instance, McCambridge et al. (2014) suggest that more extensive research is needed to understand participants' effects when interventions are conducted. Table 3.1 describes the mitigation strategies I used. Results showed that just being informed of the study taking place did not modify people behaviors nor their responses in the Post-intervention survey. For example, when comparing my control case and the intervention, considering the sample of participants who took both the Pre- and Post-intervention surveys, I noticed a statistically significant improvement in the behaviors for quality in the project intervened, which was not the case in the control case. Mitigation strategies to conduct this assessment are planned on a case-by-case basis as each team and their work environment differ.

11.3.4 Causal Inferences

Causality investigates cause-effect relationships. Randomized control trials (RCT) are the standard for causal inference (Cartwright 2010, Hariton and Locascio 2018, Hernán and Robins 2020). While the sample I used may seem "random" because I did not intentionally choose the participants in the study, I do not consider the sample a RCT. Some of the missing conditions to be a well-designed RCT and possibly make causal inferences are:

1. Having concealed randomization of the subjects. In my research, I did not randomize the sample within the projects studied. I tried to resemble a RCT by having a control project, but one whole team was treated as a control sample while the other team participated in the intervention.
2. Controlling for confounding variables by treating the control and test groups identically except for the intervention being tested. In my research, because I studied different projects, each team was exposed to a unique set of features such as the GC's leadership, type and size of project, owner's involvement, etc. To minimize the impact of confounding variables, however, I intentionally studied project teams within the same GC that were using the same self-performed division, drywall, although with different workers.

To experimentally test causal effects, we could work with one team, controlling for confounding variables, and randomly assigning the participants who will be part of the BBQS implementation.

11.3.5 Commercial Terms

While the BBQS fosters a collaborative environment, where ideally GCs, architects, owners, subcontractors, and suppliers work together in understanding and aligning quality expectations in order to build with clarity and deliver quality, such level of collaboration among all the stakeholders needed is not always possible. The cases I studied had collaborative contractual agreements, allowing contractors to provide input during design. In cases where owners or architects are not as engaged in the construction phase or when contractors are not engaged during design, GCs can still use the BBQS to some extent while guiding their subcontractors in delivering quality. GCs can establish the expectations of the level of involvement from the subcontractors in the quality process during bidding and formalize terms in their contracts. Once subcontractors are onboarded, GCs are held accountable for keeping subcontractors actively engaged in the quality process, e.g., discussing DFOWs for their scopes of work during preconstruction meetings, holding them accountable for quality control with defined MAC, having them participate in the identification of quality issues and analysis of the potential root causes to co-develop prevention plans. Even for fast-track projects where schedule is the priority, if the teams do not have time to adequately plan the work and deliver things right the first time, how would they afford the time to fix all the rework resulting from unclear expectations?

11.3.6 Project Phases for BBQS Implementation

Chapter 2 describes different project phases based on the Lean Project Delivery System (LPDS): Project Definition, Lean Design, Lean Supply, Lean Assembly, and Use (Ballard 2000a, Whelton and Ballard 2003). The construction of scopes (i.e., product types) occurs in the Lean Assembly phase (when the project is completed and turned over to the customer), but most expectations are set in previous stages, Project Definition, and Design. GCs start looking back at Project Definition

to identify and resolve conflicts around expectations and continue through the phases of Design, Supply, and Assembly to ensure expectations are properly understood and conveyed for construction. Means for assessing conformity may also be agreed in the Design phase, and at least preliminary design of construction operations should take place in the Design phase in case changes in product design are needed. While GCs typically participate starting in the Lean Assembly phase, independent of when a GC is involved in a project, they can still apply the BBQS. However, similar to what happens with the commercial terms, the extent to which the BBQS is applied may vary if it is purely GC-led, e.g., owners may not all be as involved in conversations to understand and align expectations until the GC joins the project. In recent years though, more cutting-edge owners are pulling Lean by making it a requirement for the contractors in order to award the project. In Case 2, for instance, the owner recognizing the value that the DFOW conversations brought to the project early on, asked me, as part of the BBQS implementation, to work with the team on continuing these conversations for the upcoming scopes of work.

11.4 Future Work

While the BBQS in Chapter 10 was built in four iterations, its application on more projects can enrich its features, e.g., by expanding the methods and tools to deliver quality. In addition to refining the BBQS through its application in more projects, other subjects to explore in future research are:

Closing the staff-craft members gap

While both staff and craft members work together to deliver construction projects, evidence in this research suggests that there may be a gap between these two groups. This gap may start with the fact that many of them actually do not ever meet members of the other groups; for instance, most interactions among these groups occur typically between the craft leadership and the GC superintendent or field engineers only. Further research could explore what interventions can start closing this gap by improving and strengthening outgroup relationships and understand whether this siloed work (staff with staff members and craft with craft members) explains the difference found between these two groups in psychological safety and behaviors for quality. Schroeder and Risen (2016), for example, describe an intervention that positively affected relationships and attitudes among groups that could be considered enemies. Interventions to close the staff-craft gap would need to be designed considering the construction project settings and the different characteristics among these groups (e.g., college versus union educated).

Identifying factors that influence psychological safety in construction teams

Edmondson and Lei (2014) describe how psychological safety relates to factors such as leadership behaviors, human resource practices, organizational context, team characteristics, social interaction, etc. The factors I explored included the time that each participant was working with their respective project team, the organization they belonged to (e.g., GC, subcontractor), their position (e.g., apprentice, project manager), their membership (i.e., craft and staff members), etc. While I observed some patterns across these factors, further research with a larger sample could provide a path forward toward understanding the factors that play a more significant role in team psychological safety within construction teams. For instance, if the participants' membership has a strong connection to how psychologically safe they feel, actions can be intentionally designed to help those who feel less safe.

Investigating managerial actions to foster psychological safety in construction teams

I explored some actions to foster psychological safety within two construction project teams, but a larger-scale study to identify what actions GCs and companies within the Architecture Engineering and Construction (AEC) industry are taking to foster psychological safety could benefit the industry as a whole. Understanding what these actions are and its potential impact on psychological safety could help individual teams and companies adopt these actions. This would be a substantial contribution for those who want to foster psychologically safe work environments but do not know where to start.

Expanding the analysis of psychological safety, behaviors for quality, and performance across teams across contractual agreements

I argue that while each of my study variables, psychological safety, behaviors for quality, and performance may vary from team to team, the relationship among them would still remain positive. The teams I analyzed used collaborative contractual agreements (e.g., design-build). Further research is needed to explore these variables in teams using more traditional (adversarial) contractual agreements. Questions that remain open include, how adversarial contracts influence team psychological safety, their behaviors, and their performance? What is the relationship among these variables in those teams? Similar questions can be posed regarding the most collaborative types of agreements, e.g., IPD projects.

Designing simulations to train participants in the BBQS

The BBQS is composed of theoretical (e.g., principles, behaviors) and practical (e.g., processes, tools) foundations. Rybkowski et al. (2021) described how "serious games" helped participants understand Lean principles through simulations. Exploration of what simulations can help understand and implement the BBQS would facilitate its adoption by practitioners. In addition, designing on-line simulations can help with scalability for faster adoption.

11.5 Final Remarks

Meeting quality expectations is critical for the successful delivery of construction projects. Quality requirements are determined to some extent early in the projects, but they are refined throughout the construction phase. When GCs join the project, they start their management of quality by understanding the existing requirements, making sure they are clear, consistent, and really convey the intended expectations, and suggesting modification of expectations when needed to meet project participants' expectations. This research presents the BBQS as a guide for GCs to lead quality management in construction projects. Not only the BBQS embraces the technical side of quality by highlighting, for example, practical tools, but it expands the human side of quality by focusing on people, their presuppositions, and their guiding principles and behaviors.

This research connects a construct studied in industries such as healthcare and technology, psychological safety, with fostering behaviors desired for quality, and these, in turn, with improving team performance. I explored each of these through the case studies as my study variables. These variables and the strong correlations I found in my research can be further analyzed in a larger population to establish strong conclusions, and guide the AEC industry toward fostering both psychological safety and those behaviors desired for quality to improve the delivery of quality projects.

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12. APPENDICES

12.1 Appendix 1: Potential Quality Issues for Drywall and Framing Construction

Table 12.1: Potential Quality Issues Related to Drywall and Framing Construction (1/3)

Quality Issue	Description	Potential Cause
Section 1: Quality Issues Related to Lack of Alignment Around Quality		
Finish: level of finish required (Ferguson 2009, Parker 2021)	Appears when there is no alignment around the industry-wide rating system for finished drywall.	Project participants might not be as familiar with standards for finished drywall.
Finish: how lighting reflects on the panels (Negri 1997, Ferguson 2009)	Appears as if a wall has downlights, spotlighting, and sconces.	Bumps or recesses at seams, or slight craters or excess of compound over fasteners.
Sanding too much or too little (Negri 1997, All American Painting Plus 2021)	Appears as damage on the surface, especially at the seams, or a surface that is not smooth enough for painting.	Incorrect sanding application, either too much force or too little.
Section 2: Quality Issues Related to Other Scopes of Work		
Water damage, moisture, and mold (USG 2005, Quartz Drywall & Painting 2017, DWFC 2010, Home Painters 2020, All American Painting Plus 2021)	Appears as stains or strange coloration in spots, paper bond failure, softness in board core, or mildew growth.	Sustained high humidity, standing water, improper protection from water leakage, improper plumbing (e.g., leaking pipes).
Overcuts Perfection (Drywall 2016, Ferguson 2020)	Appears as overcuts and blowouts near boxes (e.g., electrical boxes).	Incorrect cutting in places where boxes are located.

Table 12.2: Potential Quality Issues Related to Drywall and Framing Construction (2/3)

Quality Issue	Description	Potential Cause
Section 3: Quality Issues Related to Operations (Installation)		
Visible joints Perfection (Drywall 2016, Parker 2021)	Appears as a visible joint or gap between one sheet of drywall and the next.	Incorrect spacing of drywall sheets or improper taping that causes air bubbles under the tape.
Screw/nail pops (Perfection Drywall 2016, Ferguson 2020, Home Painters 2020, Kaplan 2020, Parker 2021)	Appears as a screw head that pushes the compound coating out along with the screw.	When screws are set to a proper depth but without pulling the drywall tight to the framing.
Screws indentation (Ferguson 2020)	Appears as a slight depression on the board's surface.	Not enough compound is used over a screw indentation, or when drywall expands or shrinks after taping.
Incorrect screw spacing (National Gypsum 2008)	Appears as a noticeable variation in screw distancing, especially common for screws that attach drywall to vertical studs.	Incorrect installation, either too close or too far from each other.
Fastener imperfections (USG 2005, DWFC 2010)	Appear as darkening, localized cracking, a depression over fastener heads, pop or protrusion of the fastener, or the surface area surrounding the fastener.	Improper framing or fastener application, or wall movement.
Joint defects (e.g., sloppy joints) (Negri 1997, USG 2005, DWFC 2010, All American Painting Plus 2021)	Appear as ridges, depressions, or blisters at the joints, or darkening over the joints or in adjacent panel areas.	Incorrect framing or joint treatment, or incorrect preparation of drywall board, or climatic conditions.
Joint cracking (USG 2005, DWFC 2010, Perfection Drywall 2016, Home Painters 2020)	Appears as cracks on the board's edges or butt ends, or along the edge of taped joints. This issue occurs often when control joints are not accurately identified by architects or installed by contractor.	Structural movement or thermal expansion/ contraction, or fast drying of joint compounds.

Table 12.3: Potential Quality Issues Related to Drywall and Framing Construction (3/3)

Quality Issue	Description	Potential Cause
Section 3: Quality Issues Related to Operations (Installation)		
Field or angle cracking (USG 2005, DWFC 2010, Quality Built 2019)	Appears as diagonal cracks originating from corners or intersections (e.g., doors or windows, light fixtures), or in the apex of wall-ceiling or interior angles where partitions intersect.	Movement, improper application of joint compound in a corner, or excessive paint.
Fiber raising (Negri 1997)	Appears as a disruption in the transition from the smooth joint compound to the roughened, raised fibers of the board.	Drywall face paper improperly roughened during sanding of the joint compound.
Taping imperfections (Ferguson 2020)	Appears as poor bonding of the tape, edge cracking, and excessive shrinkage of the compound.	Improper application of bed on the tape and climatic conditions.
Bead cracking (USG 2005, DWFC 2010)	Appears along the edge of the flange.	Improper bead attachment, faulty bead, or joint compound application.
Loose panels (USG 2005, DWFC 2010)	Appear as rattles or moves when pressure is applied to the surface.	Improper installation of boards, framing out of alignment, or improper fastening.
Wavy surfaces (USG 2005, DWFC 2010)	Appears as boards with a bowed or undulating surface.	Improper board fit, misaligned framing, or thermal expansion.
Board sag (USG 2005, DWFC 2010, Parker 2021)	Appears in ceilings under high-humidity conditions.	Insufficient framing support, board too thin for span, poor job conditions, improperly installed or mislocated vapor retarder, or use of unsupported insulation.
Surface defects (USG 2005, DWFC 2010)	Appear in the form of fractured, damaged, crushed boards.	Lumber shrinkage or expansion.
Discoloration (USG 2005, DWFC 2010)	Appears as a board surface with a slight difference in color over joints, supports, or fasteners.	Improper paint finishing, uneven soiling, or darkening from aging or ultraviolet light.

12.2 Appendix 2: CBA Analysis for Selecting Drywall and Framing Scope to Study

CBA Analysis for Selecting Drywall and Framing Scope to Study (1/2)

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7
	Vertical Scopes				Horizontal Scopes		Mixed
	Structural Walls	Partition Walls	Chase Walls	Exterior Metal Stud Framing	Ceilings	Soffit Ceilings	Furred Walls / Beams
Factor 1: complexity/challenge in building the scope Criterion: Difficulty (e.g., level of finishes expected for the scope, interferences with other disciplines such as MEP). More is better.	Scope is typically exposed and mistakes are more noticeable. These might have embedded installations.	Scope is typically exposed and mistakes are more noticeable. These often have embedded installations.	Somehow hidden due to its location (e.g., to separate women/men bathrooms) and has many embedded things	Scope is typically exposed and mistakes are more noticeable. Core design coordination is critical for deliverying the scope. These might have embedded fixtures	Scope is typically exposed and mistakes are more noticeable. These often have embedded installations.	Scope is typically exposed and mistakes are more noticeable. These might have embedded installations.	These scopes are often small and serve to cover things such as exposed pipes
Attribute:							
Advantage:	More difficult to align and meet expectations 70	Much more difficult to align and meet expectations 100	More difficult to align and meet expectations 70	Much more difficult to align and meet expectations 100	More difficult to align and meet expectations 70	More difficult to align and meet expectations 70	-
Factor 2: ease to be repaired (maintainability) after project is delivered Criterion: Less is better.	Walls are easy to access, but structural pieces increase complexity when compared to partitions	Partitions are easy to access and might have embedded installation and furniture attached to the walls	These have many embedded pieces / equipment and walls are difficult to access	Access from outside is difficult without equipment due to elevation. Structural pieces increase complexity	Location of this scope is at a certain elevation and might he hard to reach without equipment	Location of this scope is at a certain elevation and might he hard to reach without equipment	Location and size are easily accessible
Attribute:							
Advantage:	Less ease to access and be repaired 50	Much less ease to access and be repaired 80	Much less ease to access and be repaired 80	Much less ease to access and be repaired 80	Less ease to access and be repaired 50	Less ease to access and be repaired 50	-
Factor 3: availability of scope on-site (frequency scope is built by GC) Criterion: Availability to observe the process. More is better.	Around 20% of projects use these. Out of 100 walls built in a project, 1 is structural wall	Around 100% of projects use these. Out of 100 walls built in a project, 90 are partitions	Around 100% of projects use these. Out of 100 walls built in a project, 9 are chase walls	Around 50% of projects use these and they are built early in a project when design might still be undergoing	Around 50% of projects use these	Around 50% of projects use these	Rarely build
Attribute:							
Advantage:	Scope can be observed in 5% of the projects 20	Scope can be observed in 100% of the projects 90	Scope can be observed in 20% of the projects 40	Scope can be observed in 50% of the projects 60	Scope can be observed in 50% of the projects 60	Scope can be observed in 50% of the projects 60	-

CBA Analysis for Selecting Drywall and Framing Scope to Study (2/2)

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6	Alternative 7
	Vertical Scopes				Horizontal Scopes		Mixed
	Structural Walls	Partition Walls	Chase Walls	Exterior Metal Stud Framing	Ceilings	Soffit Ceilings	Furred Walls / Beams
Factor 4: ease/access for researcher to observe the process Criterion: e.g., where the scope is located. More is better.	Vertical elements are easier to be observed	Vertical elements are easier to be observed	Vertical elements are easier to be observed	Vertical elements are easier to be observed	Ceilings are harder to be observed due to the location where they are installed	Ceilings are harder to be observed due to the location where they are installed	Columns are easier to observed but beams are harder
Attribute:							
Advantage:	Much more access for researcher to observe the process 30	Much more access for researcher to observe the process 30	Much more access for researcher to observe the process 30	Much more access for researcher to observe the process 30	-	-	Some elements have easier access to be observed 10
Factor 5: research interest to study the scope Criterion: Interest due to novelty. More is better.	Researcher has never worked with this scope	Researcher has never worked with this scope	Researcher has never worked with this scope	Researcher has never worked with this scope	Researcher has never worked with this scope	Researcher has never worked with this scope	Research worked with this scope before
Attribute:							
Advantage:	Much more interested to study the scope 85	Much more interested to study the scope 85	Much more interested to study the scope 85	Much more interested to study the scope 85	Much more interested to study the scope 85	Much more interested to study the scope 85	-
Factor 6: GC interest to study the scope Criterion: GC interest. More is better.	GC did not include this scope in their suggestion	GC suggested to study this scope	GC did not include this scope in their suggestion	GC suggested to study this scope	GC did not include this scope in their suggestion	GC did not include this scope in their suggestion	GC did not include this scope in their suggestion
Attribute:							
Advantage:	-	Much more interested 75	-	Much more interested 75	-	-	-
Total Importance:	255	460	305	430	265	265	10

CBA Analysis Importance of Advantages for Choosing Scope to Include in the Study

CBA for Choosing Scope to Study - Importance of Advantages

100	Much more difficult to align and meet expectations
95	
90	Scope can be observed in 100% of the projects
85	Much more interested to study the scope
80	Much less ease to access and be repaired
75	Much more interested
70	More difficult to align and meet expectations
65	
60	Scope can be observed in 50% of the projects
55	
50	Less ease to access and be repaired
45	
40	Scope can be observed in 20% of the projects
35	
30	Much more access for researcher to observe the process
25	
20	Scope can be observed in 5% of the projects
15	
10	Some elements have easier access to be observed
5	
0	

12.3 Appendix 3: Exploratory Study Survey to Assess Psychological Safety and Learning

To be completed by individual who is completing the survey:

- Circle your position: **1st year apprentice, >1st year apprentice, journeyman, foreman, general foreman, superintendent, general superintendent, PE, PM, other: …**
- What month and year did you start working on this project?

2017 **2018** **2019**

January	**February**	**March**	**April**	**May**	**June**
July	**August**	**September**	**October**	**November**	**December**

- How many years and months have you been with the company you are now working for? **…… years and …… months**
- Organization type: **general contractor, subcontractor, consultant, supplier, client**
- Select trade: **civil, carpenter, mechanical, electrical, plumbing, labor, iron worker, other:**

Este cuestionario debe ser llenado individualmente.

- Selecciona tu posición: **Primer año de aprendiz o peón, >primer año de aprendiz, "journeyman u oficial", "foreman u operario", "general foreman o capataz de cuadrilla", "superintendent o capataz general", superintendente general, PE, PM, otro: …**
- ¿En qué mes y año empezaste a trabajar en este proyecto?

2017 **2018** **2019**

Enero	**Febrero**	**Marzo**	**Abril**	**Mayo**	**Junio**
Julio	**Agosto**	**Setiembre**	**Octubre**	**Noviembre**	**Diciembre**

- ¿Cuántos años y meses llevas trabajando con tu compañía? **…… años y …… meses**
- Tipo de organización: **contratista general, subcontratista, consultor, proveedor, cliente**
- Seleccione su especialidad: **civil, carpintero, mecánico, electricista, tuberías, labor, acero, otro: …**

Question 1. I'm always learning new skills working with this crew.

- *Siempre aprendo nuevas habilidades laborales con este personal.*

7 Strongly Agree ***Muy de acuerdo***	**6 Agree** ***De acuerdo***	**5 Slightly Agree** ***Ligeramente de acuerdo***	**4 Neither or N/A** ***No aplica***	**3 Slightly Disagree** ***Ligeramente en Desacuerdo***	**2 Disagree** ***Desacuerdo***	**1 Strongly Disagree** ***Muy en Desacuerdo***

Question 2. If I make a mistake, my co-workers in the crew help me learn how to do the work correctly.

- *Si cometo un error, mi equipo de trabajo me ayuda a solucionar y aprender el proceso correcto.*

7 Strongly Agree ***Muy de acuerdo***	**6 Agree** ***De acuerdo***	**5 Slightly Agree** ***Ligeramente de acuerdo***	**4 Neither or N/A** ***No aplica***	**3 Slightly Disagree** ***Ligeramente en Desacuerdo***	**2 Disagree** ***Desacuerdo***	**1 Strongly Disagree** ***Muy en Desacuerdo***

Question 3. My co-workers in the crew are willing to listen to my ideas for improving how work is done.

- *Mi equipo de trabajo está dispuesto a escuchar mis ideas para mejorar el proceso de trabajo.*

7 Strongly Agree ***Muy de acuerdo***	**6 Agree** ***De acuerdo***	**5 Slightly Agree** ***Ligeramente de acuerdo***	**4 Neither or N/A** ***No aplica***	**3 Slightly Disagree** ***Ligeramente en desacuerdo***	**2 Disagree** ***Desacuerdo***	**1 Strongly Disagree** ***Muy en Desacuerdo***

Question 4. If I see someone on my crew doing something unsafe, I speak up.

- *Si veo a alguien dentro de mi personal haciendo algo inseguro, le hago saber.*

7 Strongly Agree ***Muy de acuerdo***	**6 Agree** ***De acuerdo***	**5 Slightly Agree** ***Ligeramente de acuerdo***	**4 Neither or N/A** ***No aplica***	**3 Slightly Disagree** ***Ligeramente en Desacuerdo***	**2 Disagree** ***Desacuerdo***	**1 Strongly Disagree** ***Muy en Desacuerdo***

Question 5. If I see someone on another crew doing something unsafe, I speak up.

- *Si veo a alguien en fuera de mi personal haciendo algo inseguro, le hago saber.*

7 Strongly Agree ***Muy de acuerdo***	**6 Agree** ***De acuerdo***	**5 Slightly Agree** ***Ligeramente de acuerdo***	**4 Neither or N/A** ***No aplica***	**3 Slightly Disagree** ***Ligeramente en Desacuerdo***	**2 Disagree** ***Desacuerdo***	**1 Strongly Disagree** ***Muy en Desacuerdo***

Question 6. My direct supervisor is willing to listen to my ideas for improving how work is done.

- *Mi supervisor inmediato está dispuesto a escuchar mis ideas para mejorar el proceso de trabajo.*

7 Strongly Agree ***Muy de acuerdo***	**6 Agree** ***De acuerdo***	**5 Slightly Agree** ***Ligeramente de acuerdo***	**4 Neither or N/A** ***No aplica***	**3 Slightly Disagree** ***Ligeramente en Desacuerdo***	**2 Disagree** ***Desacuerdo***	**1 Strongly Disagree** ***Muy en Desacuerdo***

Question 7. I feel comfortable talking to my direct supervisor about my safety concerns at work.

- *Me siento seguro de hablar con mi supervisor inmediato de métodos de seguridad en el trabajo.*

7 Strongly Agree ***Muy de acuerdo***	**6 Agree** ***De acuerdo***	**5 Slightly Agree** ***Ligeramente de acuerdo***	**4 Neither or N/A** ***No aplica***	**3 Slightly Disagree** ***Ligeramente en Desacuerdo***	**2 Disagree** ***Desacuerdo***	**1 Strongly Disagree** ***Muy en Desacuerdo***

Question 8. My direct supervisor is understanding when I make a mistake at work.

- *Mi supervisor inmediato es comprensivo cuando me equivoco en el trabajo.*

7 Strongly Agree ***Muy de acuerdo***	**6 Agree** ***De acuerdo***	**5 Slightly Agree** ***Ligeramente de acuerdo***	**4 Neither or N/A** ***No aplica***	**3 Slightly Disagree** ***Ligeramente en Desacuerdo***	**2 Disagree** ***Desacuerdo***	**1 Strongly Disagree** ***Muy en Desacuerdo***

Question 9. When I make a mistake, my direct supervisor helps me to correct it.

- *Cuando me equivoco, mi supervisor inmediato me ayuda a corregirlo.*

7 Strongly Agree ***Muy de acuerdo***	**6 Agree** ***De acuerdo***	**5 Slightly Agree** ***Ligeramente de acuerdo***	**4 Neither or N/A** ***No aplica***	**3 Slightly Disagree** ***Ligeramente en Desacuerdo***	**2 Disagree** ***Desacuerdo***	**1 Strongly Disagree** ***Muy en Desacuerdo***

Question 10. My direct supervisor is a good role model for safety.

- *Mi supervisor inmediato es un buen modelo a seguir para la implementación métodos de seguridad.*

7 Strongly Agree ***Muy de acuerdo***	**6 Agree** ***De acuerdo***	**5 Slightly Agree** ***Ligeramente de acuerdo***	**4 Neither or N/A** ***No aplica***	**3 Slightly Disagree** ***Ligeramente en Desacuerdo***	**2 Disagree** ***Desacuerdo***	**1 Strongly Disagree** ***Muy en Desacuerdo***

Question 11. If I make a mistake, my co-workers do not teach me how to avoid making that same mistake again.

- *Si me equivoco, mi equipo de trabajo no me enseña como eliminar mis errores para no volverlos a cometer.*

7 Strongly Agree ***Muy de acuerdo***	**6 Agree** ***De acuerdo***	**5 Slightly Agree** ***Ligeramente de acuerdo***	**4 Neither or N/A** ***No aplica***	**3 Slightly Disagree** ***Ligeramente en Desacuerdo***	**2 Disagree** ***Desacuerdo***	**1 Strongly Disagree** ***Muy en Desacuerdo***

Question 12. I am satisfied that there really is a commitment to a safe work environment where I am now working.

- *Me siento satisfecho del compromiso del equipo hacia los métodos de seguridad en el entorno donde trabajo.*

7 Strongly Agree ***Muy de acuerdo***	**6 Agree** ***De acuerdo***	**5 Slightly Agree** ***Ligeramente de acuerdo***	**4 Neither or N/A** ***No aplica***	**3 Slightly Disagree** ***Ligeramente en Desacuerdo***	**2 Disagree** ***Desacuerdo***	**1 Strongly Disagree** ***Muy en Desacuerdo***

Question 13. I participate in designing the operations of the activities I am going to execute on site and I feel safe about how we execute them:

- *Yo participo en el diseño de las operaciones o actividades que voy a realizar y me siento seguro en la forma en que se ejecutan:*

7 Strongly Agree ***Muy de acuerdo***	**6 Agree** ***De acuerdo***	**5 Slightly Agree** ***Ligeramente de acuerdo***	**4 Neither or N/A** ***No aplica***	**3 Slightly Disagree** ***Ligeramente en Desacuerdo***	**2 Disagree** ***Desacuerdo***	**1 Strongly Disagree** ***Muy en Desacuerdo***

Question 14. Do you know how to report near misses on this project?

- *¿Sabe cómo reportar incidentes/potenciales accidentes en este proyecto?*

1 Yes ***Si***	**2 No** ***No***

Question 15. Do you know how to report unsafe conditions on this project?

- *¿Sabe cómo reportar condiciones inseguras en este proyecto?*

1 Yes ***Si***	**2 No** ***No***

Question 16. Did you know that when the number of reported near misses increases, the number of accidents in a project decreases?

- *¿Sabías que, si el número de reportes de incidentes en un proyecto aumenta, el número de accidentes en el proyecto disminuye?*

1 Yes ***Si***	**2 No** ***No***

Question 17. Please describe any near misses you have ever seen or experienced. Specify if it happened on this project or previous projects.

- *Por favor describa un incidente o potencial accidente que haya visto o experimentado. Indique si sucedió en este proyecto o proyectos previos:*

Happened in: *Sucedió en:*	**this project** *este Proyecto*	**a previous project** *un proyecto previo*

Question 18. I feel comfortable and confident in reporting near misses on the project.

- *Me siento cómodo y seguro en reportar accidentes/incidentes en este proyecto.*

7 Strongly Agree ***Muy de acuerdo***	**6 Agree** ***De acuerdo***	**5 Slightly Agree** ***Ligeramente de acuerdo***	**4 Neither or N/A** ***No aplica***	**3 Slightly Disagree** ***Ligeramente en Desacuerdo***	**2 Disagree** ***Desacuerdo***	**1 Strongly Disagree** ***Muy en Desacuerdo***

Question 19. Please describe what makes you feel safe or unsafe on the project:

- *Por favor describa qué cosas te hacen sentir seguro e inseguro en este proyecto:*

1 What makes me feel safe ***Qué me hace sentir seguro***	**2 What makes me feel unsafe** ***Qué me hace sentir inseguro***

Question 20. What would help you feel safe to raise concerns, to make suggestions, to ask questions, and to feel confident that if you make a mistake, you will get help, not punishment

- *¿Qué te ayudaría a sentirte seguro de poder expresar tus preocupaciones, hacer recomendaciones, hacer preguntas y sentirte seguro de que si cometes algún error vas a conseguir ayuda y no un castigo?*

12.4 Appendix 4: Exploratory Study Survey Participants per Trade

Table 12.4: Psychological Safety Exploratory Study Participants

Trade	Round 1	Round 2	Round 3	Round 4
Carpenter	9		16	
Labor	9		2	
Drywall	12		7	
Roofing	6			
Fire Sprinkler	3	1		
Iron Worker	4			
Water Proofing	4			
Plumbing	9	3	6	
Electrical	6	4	22	
Glazing		1		
Mechanical			3	
Tile			6	
Telecommunication			5	
Superintendent				3
Project Engineer				3
Project Manager				5
MEP				1
Estimator				1
Administrative				1
NA: Not specified	2	2	10	3
TOTAL	**64**	**11**	**77**	**17**

12.5 Appendix 5: Interview Questionnaire for Exploratory Study to Describe BBQ Implementation

We are dealing with the implementation of a specific concept: behavior-based quality (BBQ). We are assessing (1) the influence of BBQ implemented on a construction site, and (2) the process used to implement BBQ as we want to improve and refine the process. It's good for our purpose to start asking how they understand the concept.

Note 1: In case interviewees are from the subcontractors and they might not be aware of the language used such as "behavior-based," or measurable acceptance criteria (MAC), I would replace the terms in the interviews for "[GC]'s approach to quality" and ask at the end of the interview: Have you heard the term "behavior-based quality (BBQ)?"

1. To get the participants understanding of BBQ as applied in the project: Can you tell me about how you would explain the behavior-based quality (BBQ) approach? What is your understanding of BBQ? What is the most important part of the BBQ process?
2. When the [GC] team explained the BBQ approach to quality to you, what parts were confusing? and what parts were clear?
3. How did you feel as you were engaged in the process? Can you describe what the BBQ approach looks like compared to what you have done on previous projects?
4. Can you give me an example of a time when you felt this BBQ approach had either positive or negative impacts on your work and for the project?
5. Can you remember any example in which the BBQ approach influenced the way project participants made decisions or took actions?
6. Would you consider applying this approach on other projects? What are the drivers and challenges that might help you define whether you would go through the process again on other projects?
7. Let's talk about the project participants' engagement process, can you think of some examples or things that happened in the project that help build project participants' engagement? Can you give me some examples on how we can improve project participants' engagement? How was your engagement in the process on this project?
8. Can you describe what the impact was of using visuals on site? Can you think about ways in which the engagement process can be enhanced/improved on site?
9. Do you remember any events that occur on this project, in which the use of visuals, forums, focus groups, training sessions or some other sort of dynamic was used to increase awareness about BBQ? Can you tell me how the quality management process was communicated on other projects?
10. Let's talk about rework and surprises on site, as we want to minimize these on construction projects: Can you think of a moment when project participants influenced outcomes by better understanding expectations early on, before something was built or even procured, and if so how?
11. How do you deal with different expectations of multiple project participants on previous projects (traditional construction)?
12. In what ways is the BBQ approach more or less effective to understand and align project participants' expectations? Can you provide examples in each case?
13. The BBQ approach involved project participants getting together, having conversations, being transparent about their expectations, as well as getting alignment about them. Did you expect to have such conversations early on in the project? Did the BBQ approach involve more or less work as compared with previous projects?
14. Did your expectations change over the meetings as the project team defined and aligned expectations? Can you give me some examples when you felt that BBQ helped to refine the scope of work?
15. What is your understanding of a "distinguishing feature of work" (DFOW) on the project? Can you describe me how you identified DFOW for your scope of work?
16. Can you explain me the process to define objective measurable acceptance criteria (MAC) for each DFOW you discussed on site?

17. Can you please give me examples of the advantages of the BBQ approach as compared to other approaches you may have used for quality management? What approaches have you used?
18. Can you give examples of advantages of these other approaches over BBQ?
19. What are the key limitations of the BBQ approach and how might they be overcome?
20. Can you summarize the main behaviors of around you that you observed during the process? (while launching, during the meetings, now?)

12.6 Appendix 6: Description of Activities and Decision Nodes for Exploratory Case in Quality Management

Project Participants:

1. Client/Client's representative
2. Structural engineer
3. Architect
4. General Contractor (GC)
5. Concrete subcontractor
6. Concrete supplier
7. Inspector of Record (IOR)

Process Activities Description:

1. **Develop project drawings and specifications:**

   The architecture firm creates a set of project documents (i.e., specifications and drawings) to be used for construction. This set contains a preliminary design for the walls that were to be finalized in collaboration with the construction team.

2. **Review and annotate design:**

   The GC and SPW concrete review project drawings and highlight some inconsistencies and questions to provide feedback during design development.

3. **Review annotations and update project documents:**

   The architects review contractors' annotations and clarify questions and concerns in the project set of documents.

4. **Identify a preliminary list of DFOWs:**

   The GC coordinates with SPW concrete and the architect to create a preliminary list of DFOW during the preconstruction phase. Details such as walls corner angles (e.g., 90-degree angle or round corners) and joints finish space are to be discussed and finalized considering samples, cost, time, and other parameters. The GC and SPW concrete created a list of DFOW based on:

   - Where issues occurred in the past
   - DFOWs from previous projects that might apply to the current project
   - Questions and concerns the team has to get clarity.

5. **Host site visits to see the different finishes available:**

   The GC and SPW concrete arrange site visit to other projects where the architect could see various conditions and better define what they want on the walls such as color surface, texture, strips, corner conditions, etc. These visits help the team understand the design intent and what details the architect and client are looking for in the walls.

6. **Provide constructability and cost input to inform drawings and specs:**

   SPW concrete shares input about the construction impacts (in time, cost, and complexity) for the features highlighted as DFOWs. SPW concrete collaborates with concrete supplier for input on materials mix, colors, etc.

7. **Study project requirements and provide concrete mix alternatives:**

   Concrete mix supplier receives information from SPW concrete and provides concrete mix alternatives and price-related information.

8. **Discuss and refine the preliminary DFOW list:**

   Based on the site visits and the information collected from the suppliers, the GC engages the project participants that have a stake on the scope of work to discuss and refine the preliminary DFOW list.

9. **Update drawings and specs considering constructability and DFOWs input:**

   The architects update the project drawings and specifications according to the new information gathered from preconstruction input and DFOW discussions.

10. **Provide input about structural requirements and allowance:**

    The structural designers provide input about structural requirements and allowance (e.g., concrete cover rebar) to the architect for updating drawings and specifications according to code regulations.

11. **Update project documents:**

    The architects update drawings and specs (considering structural feedback when needed).

12. **Revise updated project documents and DFOWs to support operations design:**

    The GC revised updated project documents and updated the preliminary list of DFOWs. The GC start coordinating the operations design with SPW concrete.

13. **Align on Measurable Acceptance Criteria (MAC):**

    The GC starts diving into the specific details for how the architect and client would assess that their expectations are met and therefore start defining the agreed quality requirements to meet. Input from SPW concrete, architect, and client are used to align on MAC.

14. **Review project documents and start planning how to meet expectations:**

    SPW concrete PE and PM review project documents and developed a preliminary plan of what craft would do to achieve expectations.

15. **Identify gaps in current drawings and specifications:**

    The architects modify the project drawings and specifications to reflect agreed quality requirements.

16. **Design plan to build mockup and/or first-in-place:**

    SPW concrete designs operations to build as per the agreed requirements. Conversations when planning the mockup include, for example, the iterations of mockups needed to visualize a set of concrete mix alternatives (e.g., wall color – 6 alternatives).

17. **Coordinate operation details with craft:**

    SPW concrete leadership coordinates the work with the craft to establish a common understanding of the work to be executed and the expectations. In this coordination, concrete leadership and craft get aligned on the operations to follow.

18. **Build mockup/first-in-place:**

    Craftworkers built the mockups and first-in-place on site using the operations design guide created, and improve the design when needed based on field work.

19. **Document observations and plan to prevent non-conformities:**

    The architects revise the mockup/first-in-place. The GC document non-conformities and coordinate with SPW concrete a plan to prevent them.

20. **Document acceptance and any additional remarks:**

    The GC documents acceptance on the mockup/first-in-place and any additional details to be considered during onsite installation.

21. **Build based on agreed MAC and inspect delivered work:**

    SPW concrete builds work based on MAC. Construction is overseen by the GC and SPW concrete foreman. Approval from the inspector of record (IOR) is required for the rebar structure installation of the walls.

22. **Check work as per MAC:**

    The GC checks work to verify it meets MAC and reports non-conformities to SPW concrete.

23. **Resolve non-conformities:**

    If work doesn't meet MAC, SPW concrete corrects non-conformities.

24. **Submit inspection request to architect and client's representative:**

    Once work passes inspection by SPW concrete and the GC, the GC sends request to architect/client to inspect the work.

25. **Inspect work as per MAC:**

    The architect or client's representative inspects the work and report non-conformities for correction.

26. **Document approval status:**

    Inspector documents status.

12.7 Appendix 7: BQB Responses Categorized

Question 5: Behaviors Observed During DFOWs/MAC Implementation

1) Behaviors related to being respectful	2) Behaviors related to active caring	3) Behaviors related to making reliable promises	4) Behaviors related to speaking up
Understanding stakeholders see things from different perspectives	Understanding what is important to stakeholders and why before moving forward	Holding stakeholders accountable, making commitments	Asking questions as needed; no "asking the "right" question"
Being open, honest, and candid when having conversations	Helping others to understand what DFOWs/MAC are and why these are important	Making reliable commitments	Speaking up and having the courage to discuss the uncomfortable
Helping everyone have a better understanding of the work	Fostering high team morale and positive team atmosphere	Building as per agreed expectations	Increasing familiarity
Transferring easy and clear information to the ones building	Feeling proud and excited about the work done	Inspecting as per agreed expectations	Building trust, integrity, transparency
Engaging needed stakeholders	Seeing quality as paramount	Being consistent	Providing and soliciting feedback
Being respectful with each other	Creating clear vision of goals to meet	Providing alternatives	
	Checking-in regularly		
	Fostering ownership		

5) Behaviors related to being diligent	6) Behaviors related to active listening	7) Behaviors related to active learning	Negative behaviors observed
Making sure there is alignment about the expectations to meet so everyone is on the same page	Anticipating, having conversations early and routinely before work takes place	Learning from experiments and breakdowns	Thinking that this is an unnecessary process and that drawings convey all required detail
Developing plans (e.g., control checkpoints) to execute as per agreements made	Communicating assertions no assessments	Focusing on problem-solving	Expecting people with the "right mindset" to be part of the process
Accepting that drawings and specs might not tell the whole story nor the best method	Paying attention to what others say	Sharing knowledge	Thinking that this is mostly done for aesthetic features
Understanding how to do things before proceeding			Seeing it just as another documentation to fill out
Keeping track of performance			Being apprehensive and showing negative stigma
Documenting agreed expectations			Not consistently following a quality plan
Collaborating and willing to participate			Leaving the process in hands of one person
Being curious, inquisitive			
Being focused			
Paying attention to details			

Question 6: How to start DFOWs/MAC Conversations

1) Taking actions to foster psychological safety	2) Approaching, getting people buy-in, and maintaining	3) Having conversations about expectations
Promoting continual communication	Making people feel that they are contributing	Drafting an initial list of DFOWs/MAC and specifying why these require particular attention
Creating familiarity	Using the same and consistent language	Having others describe their expectations, and expanding and refining list with all stakeholders involved
Showing that you care	Getting all people needed	Looking to understand their vision and why they care about something in particular
	Getting people commitment	Providing support to shape expectations: feasibility and other alternatives
		Documenting conversations (input of others and agreements)
		Seeking and studying documentation that reflects expectations
		Posing questions to guide conversations

4) Having scheduled meetings for quality discussions	5) Educating others on the quality approach and laying proper groundwork	6) Having consistency across the company
Introducing the topic in already existing project meetings such as OAC	Reaching out to others and describing the benefits of moving beyond compliance	Having clear and consistent guidelines and tools across projects
Setting meetings specifically assigned to quality discussions	Acknowledging that team members might all have different perspectives	Using tools available to guide conversations
	Starting the conversations with a small win to show others that this matters	Including quality during onboarding
	Describing overall quality process and refine it as needed	Having a quality champion to lead the process
	Pushing to talk about quality - bringing quality conversations up	
	Starting as early as possible	

Question 11: How to Communicate Quality Expectations to Subcontractors

1) Using different instances	2) Leading by example and planning conversations	3) Starting the process early
Routinely meetings: daily huddle, weekly coordination	Sharing the benefits and importance of doing this process	Identifying subcontractor's questions, concerns, challenges that might prevent them from meeting expectations
Bid process: Bid sent, post bid interview, contracting	Having open and recurrent conversations around quality	Scheduling conversations with clear milestones and deliverables
Onboarding presentation	Sharing and celebrating quality stories	Asking subcontractors to provide list of common quality issues they find on-site
Preconstruction meeting	Building a united front for quality	Helping subcontractors understand the design intent
Preinstallation meeting	Treating everyone respectfully	Improving quality process with subs
Jobsite walks		Sharing quality plan from bid/buy-out stage
Kick-of meetings		Bidding according to expectations
Mock-ups		Bringing subcontractors onboard early
First-in-place		Reviewing subcontractor's quality plan

4) Co-developing good design documents with detailed expectations to meet	5) Taking plans to the field
Co-setting DFOWs/MAC to ensure clarity and completeness of expectations to meet design intent, e.g., tolerances, color, manufacturer	Providing clear and concise direction for what needs to be done, e.g., through A3 summaries of expectations to meet
Making sure all people needed participate and take ownership of the quality of the scope, e.g., foreman, PE, installers, BIM coordinator, etc.	Using visuals on-site: DFOW/MAC board, renderings, pictures, BIM model, visual controls
Documenting and sharing detailed expectations and including scope supplement for specs that do not capture intent	Putting plans at the site - adequately communicating expectations to installers
Building mock-ups and first-in-place install to show contractor's understanding of expectations	Helping them have all they need to deliver work they are proud of
Co-developing internal QC process: GC+subcontractor	Gathering crews so expectations are understood
Addressing quality concerns ahead of time	Co-developing plans for field operations
Using adequate specs and industry standards	Using checklists to review completeness
Gathering all design documents to review and discuss	
Sharing current DFOWs/MAC	
Eliciting subcontractors feedback and expertise	
Conducting field trips to review similar work	

Question 13: How to Communicate Quality Expectations to Owners and Designers

1) Using different instances	2) Leading by example and getting buy-in	3) Starting the process early and planning conversations	4) Adopting tools and standard processes as needed
Preconstruction meeting, kick-of meetings, OAC meetings	Sharing stories of how the quality process has worked on other projects	Making sure all people needed participate and take ownership of the quality of the scope	Using visuals on-site: A3, renderings, pictures, BIM model, dashboards
- Bid process - Contract	Sharing the benefits and importance of doing this process	Scheduling conversations with clear milestones and deliverables	Following RFI and submittal process
Mock-ups	Having open and recurrent conversations around quality	Sharing and improving quality process with OA	Using checklists to review completeness
First-in-place	Speaking the same language	Setting intentional agenda topics for quality discussions	
Jobsite walks	Engaging OA early		

4) Getting ready for discussions	5) Co-developing good design documents with detailed expectations to meet
Setting clear expectations about design deliverables to check completeness of each drawing	Co-setting DFOWs/MAC to ensure clarity and completeness of expectations to meet design intent, e.g., tolerances, materials, performance, color, manufacturer
Gathering input from subcontractors and making sure everyone is aligned	Documenting detailed expectations and including scope supplement for specs that do not capture intent
Studying project documents and highlighting concerns, ambiguous term	Guiding OA to shape expectations based on constructability review and builders' input
Reviewing drawing readiness, clash detection	Providing comments, suggestions, feedback on the components contractors think are critical
Pointing out DFOWs/MAC and transform assessments into assertions	Building mock-ups and first in place install to show contractor's understanding of expectations
Trying to understand design intent and what is important for OA	Ensuring all necessary knowledge is available for an effective building process
Conducting field trips to review similar work	Making sure DFOWs/MAC are reflected in project budget and schedule
Using lessons learned and experiences	Provide samples to guide conversations and decision-making
	Doing jobsite walks to check we are building what was envisioned
	Asking questions throughout the project to clarify details when needed

Question 14: How to Manage DFOWs/MAC Process

1) Get process ready to start	2) Get people ready to start	3) Roll out process planning
Do prework: study drawings and specs, set a list of questions, collaborate with preconstruction team, and create an initial list of DFOW/MAC	Involve all participants needed and let everyone share	Use lessons learned from past project experiences where similar scope was built
Be aware of challenges and plan how to deal with them	Train participants, build capability	Consult participants needed for input to shape expectations
Agree on a process to follow: - Frequency of meetings - Responsibility matrix	Learn from owners, architects, AHJ, and trade partners	Include DFOW/MAC description in onboarding material
Make sure there is alignment between quality, schedule, safety, and cost	Give examples of successful installation	Put quality into the agenda, e.g., OAC, MEP coordination
Use organization resources (pump primers, vConstruct, quality plan)	Get process buy-in (set the table and tone)	Encourage using quality language
Keep in mind that DFOW/MAC process can be applicable to anything	Use team building activities	Organize quality kick-off meeting
Define content in release packages to drive permits and long lead items		Schedule quality conversations with an adequate time to act
Have a quality champion to lead the process		

4) Maintain process	5) Get ready for execution	6) Follow-up and learn
Document DFOW/MAC, including milestones, for transparency and tracking	Keep craft aware of expectations to meet and deliver information to field	Have a plan in place for what to do when participants anticipate DFOW/MAC will not be achieved
Consistently guide conversations to allow sufficient understanding of expectations and alignment	Have checklists (e.g., with acceptance criteria, hold points)	Inspect work with all people assigned against to what was agreed
Keep meeting minutes and send them out to all after meetings	Schedule visits to other sites and illustrate expectations	Schedule consistent and constant check-ins
Make sure changes agreed had been implemented in existent project documents	Foster accountability and reliable promises	Execute work as per agreed expectations
Listen and pay attention to others' expectations, ideas	Use visuals to facilitate the process	Get accepted sign-off
Getting all details needed even beyond specs diligently	Have on-site walks	Keep participants updated
		Track metrics for improvement

Question 15: What Tools to Use to Communicate Quality Expectations

1) Visual tools	2) Planning tools	3) Coordination tools	4) Tracking tools
Samples of similar or same elements to convey good and bad examples; e.g., pictures, materials	Existing project documentation, e.g., contract documents, code, standards	Diagrams to show the quality process and what each person does	Learning and improvement
Mockups and first in place where details can be seen up close, touched, and measured	Meeting minutes: documentation of conversations and agreements	Descriptions simply written, e.g., require look, feel, and functionality	DFOWs/MAC tracker for routinely check-in
Displays showing what is acceptable, e.g., good/bad installation examples	Kick-off, pre-installation, brainstorming, and open sketch design meetings	Tool to assign people to manage and close out specific tasks	DFOWs/MAC checklists
Displays showing performance, e.g., Kaizen boards on-site	Conversations tightening quality to project schedule	Signature of those involved in agreement	
Renderings, models, sketches showing DFOWs/MAC in detail	A3 with consolidated relevant information	Handoff process description between trades	
Reminders like safety, e.g., sign with "have you done this?"	Graphics with cost/visual pricing	Daily huddles, all-hands meeting	
Visual controls/cues at the area of work	Pre-task plan	QR on-site that shows all relevant info in the iPad	
Floor plans highlighting DFOWs/MAC locations	Constructability reviews	A person to contact	
Short videos for how to do things/next steps	Frequent planned check-ins		
Visits to comparable work			
Job walks			
Color-coded plans and drawings			

5) Design-related tools	6) Organization tools	7) Software	8) Execution tools
Guide with level of detail needed for each design deliverable	Quality implementation plan (language, testing and inspection plan) to get the process rolling	Track DFOWs/MAC in drawings: Bluebeam, PlanGrid, BIM360, BIMDocs	Tape measure
Shop drawings, submittals, RFIs, CDs and SDs with markups	Quality at [GC] presentation, contract quality section	Track meeting notes and project information: OneNote, Teams, BOX	Bubble level
Drawings readiness review		Track DFOWs/MAC: Excel, PowerPoint, PowerBI	Laser

12.8 Appendix 8: Tools Described in BQB as Best Practices for Communication Quality Expectations

Note:

1. The "Count #" column represents the number of times BQB respondents mentioned the tool as good for communicating quality expectations.

Table 12.5: Tools Used for Communicating Expectations (1/2)

Tools		Count #
Visual Tools		***179***
	Mockups and first in place where details can be seen up close, touched, and measured	67
	Samples of similar or same elements to convey good and bad examples; e.g., pictures, materials	52
	Renderings, models, and sketches showing DFOWs/MAC in detail	31
	Visits to comparable work	8
	Displays showing what is acceptable; e.g., good/bad examples next to where work is put in place	5
	Visual controls/cues at the area of work	6
	Displays showing performance; e.g., Kaizen boards onsite	2
	Color-coded plans and drawings	2
	Short videos for how to do things/next steps	2
	Job walks	2
	Reminders like safety signage; e.g., checklists or posts with "have you done this?"	1
	Floor plans highlighting DFOWs/MAC locations	1
Planning Tools		***140***
	Coordination meetings; e.g., kick-off, pre-installation, brainstorming, and open sketch design meetings	40
	Frequent planned check-ins	28
	Existing project documentation; e.g., contract documents, code, and standards	23
	A3 with consolidated relevant information	20
	Conversations tightening quality to project schedule	12
	Meeting minutes: documentation of conversations and agreements	8
	Pre-task plan	6
	Constructability reviews	2
	Graphics of design concept with pricing associated	1

Table 12.6: Tools Used for Communicating Expectations (2/2)

Tools		Count #
Coordination Tools		***92***
	Diagrams to help each person understand the part they play in achieving quality	57
	Descriptions simply written: putting words to the required look, feel, and functionality	13
	Signature of those involved to seal commitment/agreement	11
	Handoff process description between trades	7
	Daily huddles, all-hands meeting	1
	Quick Response (QR) codes onsite that provides access to all relevant info in the iPad or cellphone	1
	Contact of a person to reach out to when needed for questions or concerns related to work being executed	1
	Tool to assign people to manage and close out specific tasks	1
Tracking Tools		***67***
	DFOWs/MAC tracker for routinely check-in and turnover	44
	DFOWs/MAC checklists	20
	Learning and improvement; e.g., PDCA, cause mapping analysis	3
Design-Related Tools		***8***
	Shop drawings, submittals, RFIs, CDs, and SDs with markups	5
	Guide with the level of detail needed for each design deliverable	2
	Drawings readiness review	1
Organization Tools		***19***
	Quality implementation plan (language, testing, and inspection plan) to get the process rolling	12
	Pump primers	5
	Quality at [GC] presentation	1
	Project website	1
	RFP quality section	1
Support Software		***46***
	Track DFOWs/MAC: Excel, PowerPoint, PowerBI	27
	Track DFOWs/MAC in drawings: Bluebeam, PlanGrid, BIM360, BIMDocs	16
	Track meeting notes and project information: OneNote, Teams, BOX	3

12.9 Appendix 9: Interview Questionnaire for BBQS Studies in Cases 1 and 2

Notes:

1. This appendix contains the questions I will use to interview project participants to understand how quality is managed onsite and get a description of the current state.
2. The strategies I will use for interviewing and participants I expect to interview are described in 3.3.1.3.

General note: I will be reading the script in quotes orally at the beginning of each interview.

1) Consent to participate in interview:

"Hi, I am Sulyn Gomez, a graduate student at Cal, studying how we can improve the delivery of quality in construction projects. We value your participation in the process and would love to learn what we can do better. Do you agree to be interviewed?"

* If they consent:

"I want you to know that if at any time you don't want to answer a question or continue talking about something, please tell me, and we will move on. We can also stop this interview at any time if you wish."

* If they do not consent, no interview will be conducted with this person.

2) Audio recording consent:

"With your permission, I would like to record this interview so that I can make an accurate transcript of your responses. I will destroy the recording once I complete the transcription."

* If they consent to be recorded, I will record the interviews on Zoom.
* If they do not consent to be recorded, I will take notes only.

Preamble: Before the interviews start, I will request and read the project's quality plan (if any write-up is available) from the quality champion or project engineer leading the scope.

1. Are you familiar with your project's quality plan? Can you describe how you would typically perform the steps outlined in this plan for the scope of interior partition walls and metal stud framing shown in these figures? Please explain how you would do each of the following steps (I will read each of the 4 steps below) and include in your description who participates, when, and what these people do:

Steps	Who participates?	When?	What do they do?
1.1 Defining requirements that will be used for inspection of craftwork to determine its acceptance (understanding and aligning expectations and acceptance criteria; i.e., defining DFOWs/MAC)			
1.2 Agreeing methods for assessment			
1.3 Designing operations that craft will perform to build work as per the agreed requirements			
1.4 Inspecting as per agreed requirements			

2. For these scopes, what plan do you have in place to try to ensure that results will meet quality requirements (what things you will do and when, and where can we "see" this plan onsite; e.g., in your lookahead or on a board onsite)?

3. Do you do mockups or first-in-place installation to make sure operations can meet agreed requirements? How do you document this so it can be replicated consistently during construction? If you don't do any of these, how do you ensure that the building process will deliver the work as needed?

4. For these scopes, are there requirements that cause you concern or doubts -- especially regarding quality expectations and how to meet them? What do you do to address these concerns or doubts? For example, I want you to think about whether the level of finishes is achievable within project constraints, or if fastener spacing is within tolerances, or if penetrations in the bottom rack are correctly installed.

5. What is your inspection process for these scopes, both internally and with the city, inspection company, and/or owner?

6. Are we inspecting per the agreed requirements (DFOWs/MAC)? Do you have a rolling completion list (RCL) or a punch list, and who inputs items into these?

7. When acceptance criteria (MAC) are not met, will the items not approved go into the RCL or punch list? How do you manage rework in this case?

8. What do you do to try to identify mistakes early, and when these are identified, how do you fix them, and avoid having them later? Will mistakes identified be added to your RCL or punch list?

Preamble: The questions in the following section relate to the variables in our prototype model (psychological safety, behaviors for quality, and team performance). I do not expect to get extensive answers in this section, but rather concise responses with examples that illustrate evidence of each variable. I will use these responses to validate/support or contrast the survey results. "Team" refers to the assembly of project participants from various stakeholders (architect, drywall subcontractor, BIM coordinator, etc.) who participate in quality conversations for the scopes we will study.

Psychological safety:

Considering that psychological safety is the belief we have about whether or not you can, for example, report mistakes without the fear of getting into trouble or getting fired, and ask questions or raise concerns when you are not sure about how to do your work without feeling embarrassed of speaking up and asking for help:

9. How do you think your team is doing in that regard? Do you feel psychologically safe to speak up without fearing negative consequences?

Team performance:

In terms of team performance, I want you to think about whether your team is doing a good job in defining requirements and acceptance criteria, or if they meet or exceed expectations, or if critical mistakes repeatedly occur in this team, or if you have more or less rework than you would normally see when building these scopes.

10. What do you think about your team's performance in terms of quality?

Behavior: Being respectful

11. How do you think your team is doing in respecting others? Think, for example, whether team members respect others' expectations and try to understand their intent or help others develop their capabilities (skills, knowledge) to do their work.

Behavior: Active caring

12. How do you think your team is doing in active caring for quality? Think, for example, whether team members genuinely try to understand others' intent and expectations, or try to make sure there is a common understanding of requirements before building, or warn others about potential quality issues to prevent them.

Behavior: Making reliable promises

13. How do you think your team is doing in making and keeping promises? Think, for example, whether team members have conversations and make commitments to meet specific requirements, or if inspections are done against agreed acceptance criteria, or when expectations are not achievable, they say "no" or offer counterproposals.

Behavior: Speaking up

14. How do you think your team is doing in speaking up? Think, for example, whether team members express concerns and ask questions when requirements are not clear, or openly discuss problems and look for solutions together, or speak up when they think requirements are not feasible.

Behavior: Being diligent

15. How do you think your team is doing in diligence? Think, for example, whether team members make sure that all the people needed are part of quality conversations, or study all relevant information and are ready for discussions, or work to create a shared vision for acceptance criteria before building.

Behavior: Active listening

16. How do you think your team is doing in active listening? Think, for example, whether team members really listen and encourage others to share their expectations to define requirements and design operations.

Behavior: Learning

17. How do you think your team is doing in learning? Think, for example, whether team members acknowledge that it is ok not to know everything, or try to understand the source of mistakes and defects to prevent their reoccurrence.

12.10 Appendix 10: Original Survey Scale To Assess Team Psychological Safety, Behaviors For Quality, And Team Performance

Notes:

1. This appendix contains the data collection tool I will use to assess team's psychological safety, behaviors desired for quality, and team performance using participants' perception.
2. Section 3.3.1.4 describes the subject population and timing when I will use this tool.
3. This appendix includes the list of questions I will use and the references I consulted to build the tool.
4. The actual survey will be conducted mostly on Qualtrics, with paper-based when the participants prefer to use a printed version of it.

UC Research on Quality Management Consent Form

My name is Sulyn Gomez. I am working with Professor Iris Tommelein at the University of California, Berkeley. We are conducting a survey on quality. We are asking questions that can help us better understand the role that psychological safety and behaviors play in delivering quality, and their potential impact on team performance.

Our study is for academic research purposes only. Only UC Berkeley research team will have access to your responses. If you agree to participate, you are free to stop the survey at any time. You may change or erase any answer. You can also choose not to answer any question.

If you have any questions or concerns about this study, you may contact the researcher conducting the study: Sulyn Gomez at 765 775 6583 or sulyn@berkeley.edu; or her faculty adviser Iris Tommelein at tommelein@berkeley.edu.
If you have any questions or concerns about your rights and treatment as a research subject, you may contact the office of UC Berkeley's Committee for the Protection of Human Subjects, at 510-642-7461 or subjects@berkeley.edu.

The survey will take about 20 minutes. If you wish to participate in this study, please say yes. If you select no, the survey stops here.

I consent to participate

- ○ Yes
- ○ No

First and Last Name

Demographics

Time working with this team:

- ○ Less than 1 month
- ○ 1-3 months
- ○ 3-12 months
- ○ 1-2 years
- ○ 2-3 years
- ○ More than 3 years

Time working with your company:

- ○ Less than 1 year
- ○ 1-2 years
- ○ 2-3 years
- ○ 3-4 years
- ○ 4-5 years
- ○ 5-10 years
- ○ More than 10 years

Select your oganization:

- ○ General Contractor (GC)
- ○ Architect/Designer
- ○ Owner
- ○ Trade partner: Drywall subcontractor
- ○ Other (please specify):

Section 1: Team Psychological Safety[8]

Please answer the following questions in relation to your team leader[9]

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
I am able to bring up problems and tough issues to my team leader.	○	○	○	○	○	○	○
It is difficult to ask the leader of this team for help.	○	○	○	○	○	○	○
The leader of this team listens to my ideas for improving how work is done.	○	○	○	○	○	○	○
If I make a mistake while doing my work on this team, I feel safe speaking up to my team leader.	○	○	○	○	○	○	○
My unique skills and talents are valued and utilized by my team leader.	○	○	○	○	○	○	○
If I see a colleague making a mistake, I feel safe speaking up to my team leader.	○	○	○	○	○	○	○
The leader of this team is understanding when I make a mistake and does not use it against me.	○	○	○	○	○	○	○
When I make a mistake, the leader of this team helps me to correct it.	○	○	○	○	○	○	○
The team leader responds appropriately when concerns are raised.	○	○	○	○	○	○	○

[8] Questions for this section were adapted from Edmondson (1999), Nembhard and Edmondson (2006), Gomez (2019b), and O'Donovan and McAuliffe (2020).

[9] Your "team leader" can be your foreman or superintendent, or project manager or executive (the person who leads the work of your group).

Please answer the following questions in relation to your peers/the other members of your team:

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
I am able to bring up problems and tough issues to my peers.	○	○	○	○	○	○	○
It is difficult to ask my peers on this team for help.	○	○	○	○	○	○	○
My peers listen to my ideas for improving how work is done.	○	○	○	○	○	○	○
If I make a mistake while doing my work on this team, I feel safe speaking up to my peers.	○	○	○	○	○	○	○
If I see a colleague making a mistake, I feel safe speaking up to this colleague.	○	○	○	○	○	○	○
My unique skills and talents are valued and utilized by my peers.	○	○	○	○	○	○	○
My peers are understanding when I make a mistake and do not use it against me.	○	○	○	○	○	○	○
When I make a mistake, my peers help me to correct it.	○	○	○	○	○	○	○
My peers respond appropriately when concerns are raised.	○	○	○	○	○	○	○

Please answer the following questions in relation to your project team as a whole:

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
If I have a question or am unsure of something in relation to my work, it is difficult to ask other members of this team for help.	○	○	○	○	○	○	○
It is safe for me to make suggestions.	○	○	○	○	○	○	○
No one on this team would deliberately act in a way that undermines my efforts.	○	○	○	○	○	○	○

Section 2: Team Behaviors for Quality
Behavior: Being respectful (Fuligni et al. 2005, Lalljee et al. 2007).

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	**Strongly agree**
Members of my team foster a psychologically safe environment for others to speak up and learn.	○	○	○	○	○	○	○
Members of my team help others develop their capabilities.	○	○	○	○	○	○	○
Members of my team are polite when having conversations and making a request.	○	○	○	○	○	○	○
Members of my team have an open mind and are respectful of others' expectations.	○	○	○	○	○	○	○
Members of my team offer alternatives, to the extent possible, and not only orders when expressing expectations.	○	○	○	○	○	○	○
Members of my team do not encourage others to participate in expressing their expectations.	○	○	○	○	○	○	○
Members of my team are valued and their contribution to quality matters.	○	○	○	○	○	○	○

Behavior: Active caring (Roberts and Geller 1995, Randall 2013)

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	**Strongly agree**
Members of my team put in extra effort to deliver quality products.	○	○	○	○	○	○	○
Members of my team genuinely try to understand others' expectations.	○	○	○	○	○	○	○
Members of my team inquire others to make sure there is a common understanding of expectations before proceeding.	○	○	○	○	○	○	○
Members of my team practice peer-to-peer feedback and support.	○	○	○	○	○	○	○
Members of my team recognize and correct mistakes before they become defects.	○	○	○	○	○	○	○
Members of my team do all they can to assure and improve quality	○	○	○	○	○	○	○
Members of my team do not warn the team about potential quality issues	○	○	○	○	○	○	○
Members of my team are recognized when they behave in a way that support quality.	○	○	○	○	○	○	○
Members of my team stand up to the actions of others when warranted.	○	○	○	○	○	○	○

Behavior: Making reliable promises (Stoljar 1988, Roberts and Geller 1995, Macomber and Howell 2003, Flores 2012, King et al. 2012)

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	**Strongly agree**
Members of my team make sure the work is achievable before committing to do something.	○	○	○	○	○	○	○
Members of my team say "no" when requests are not achievable or feasible within the project constraints.	○	○	○	○	○	○	○
Members of my team make counteroffers when needed (i.e., when a request is not achievable).	○	○	○	○	○	○	○
Members of my team often misunderstand the acceptance criteria, resulting in rework.	○	○	○	○	○	○	○
Members of my team honor their commitments.	○	○	○	○	○	○	○
Members of my team often encounter broken promises.	○	○	○	○	○	○	○

Behavior: Speaking up (Premeaux 2001, Hilverda et al. 2018)

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	**Strongly agree**
Members of my team reach out to others to express concerns about the feasibility of requests when needed.	○	○	○	○	○	○	○
Members of my team ask questions to clarify requests or information when unclear.	○	○	○	○	○	○	○
Members of my team solicit advice when unsure, acknowledge we cannot know everything.	○	○	○	○	○	○	○
Members of my team confront a team member if witnessed undesirable behavior towards quality	○	○	○	○	○	○	○
Members of my team openly discuss problems and concerns (e.g., report mistakes or any deviation from the planned work).	○	○	○	○	○	○	○
Members of my team are comfortable to speak up without fear of negative consequences.	○	○	○	○	○	○	○
Members of my team can be counted on to say things that need to be said.	○	○	○	○	○	○	○
Members of my team speak up if they feel a plan or idea won't work.	○	○	○	○	○	○	○
Members of my team remain quiet rather than say what is on their mind in discussions of controversial issues.	○	○	○	○	○	○	○

Behavior: Being diligent (Bernard et al. 1996, King et al. 2012, Powell 2017)

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	**Strongly agree**
Members of my team make sure expectations of all needed project participants are part of our quality conversations.	○	○	○	○	○	○	○
Members of my team bring up project constraints that need to be considered for shaping and aligning expectations.	○	○	○	○	○	○	○
Members of my team assess readiness before moving ahead.	○	○	○	○	○	○	○
Members of my team do not point out potential consequences if quality fails for the work that will be built.	○	○	○	○	○	○	○
Members of my team carefully analyze project information and make sure expectations are achievable before putting work in place.	○	○	○	○	○	○	○
Members of my team work to create a shared vision of the desired end outcome.	○	○	○	○	○	○	○

Behavior: Active listening (Fassaert et al. 2007, Bodie 2011, King et al. 2012)

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	**Strongly agree**
Members of my team listen to and encourage each other's opinions and input when understanding and aligning expectations.	○	○	○	○	○	○	○
Members of my team listen to and encourage each other's opinions and input when planning how to build work to meet expectations.	○	○	○	○	○	○	○
Members of my team use exploring questions to promote discussions and better understand expectations.	○	○	○	○	○	○	○
Members of my team summarize points of agreement and disagreement when appropriate.	○	○	○	○	○	○	○
Members of my team keep track of points others make in discussions and decisions made.	○	○	○	○	○	○	○
Members of my team do not pay much attention when others speak	○	○	○	○	○	○	○

Behavior: Learning (Edmondson 1999, Druskat and Kayes 2000, De Dreu 2007, Kostopoulos et al. 2013)

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	**Strongly agree**
Members of my team give and ask others for feedback.	○	○	○	○	○	○	○
Members of my team review constantly their own progress and performance.	○	○	○	○	○	○	○
Members of my team carefully document how work should be done.	○	○	○	○	○	○	○
Members of my team offer new ideas and solutions when problems arise.	○	○	○	○	○	○	○
Members of my team do great work sharing information and knowledge.	○	○	○	○	○	○	○
Members of my team do not encourage others to keep learning	○	○	○	○	○	○	○

Section 3: Team Performance (Edmondson 1999, Tyler and Blader 2002, Gibson et al. 2009, Lu et al. 2011, De Jong and Dirks 2012)
Please answer the following questions in relation to your team as a whole.

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	**Strongly agree**
This team meets its customer's expectations.	○	○	○	○	○	○	○
This team exceeds its customer's expectations.	○	○	○	○	○	○	○
Critical quality mistakes occur frequently in this team's work.	○	○	○	○	○	○	○
This team succeeds in identifying mistakes to prevent them from becoming defects.	○	○	○	○	○	○	○
This team keeps getting better and better.	○	○	○	○	○	○	○
This team has considerably less rework than what we would normally have for this type of work.	○	○	○	○	○	○	○
This team reports any mistakes or defects as soon as possible to take actions needed to deliver quality work.	○	○	○	○	○	○	○
This team does high quality work.	○	○	○	○	○	○	○
This team has done a good job in making sure that what was built would conform to what was expected.	○	○	○	○	○	○	○
This team has made effective plans to make sure quality can be achieved.	○	○	○	○	○	○	○

	We could do much better	We did worse	We did a bit worse	Neither better/worse	We did a bit better	We did well	**We did very well**
How is the project's performance in quality compared to the performance of the average projects you had worked at?	○	○	○	○	○	○	○

12.11 Appendix 11: Factor Analysis for Survey Responses Case 1

Factor analysis for psychological safety in relation to peers sub-variable (PS2)

Following the logic, I used to analyze sub-variable PS1 in Section 7.2.2, I removed 2 questions that were reported as confusing to them from PS2. The questions I removed were, "It is difficult to ask my peers on this team for help" (PS2.2) and "If I see a colleague making a mistake, I feel safe speaking up to this colleague" (PS2.4). These questions, although important, can be inferred by others in the same sub-variable. PS2.2, for example, can be inferred from "I am able to bring up problems and tough issues to my peers" (PS2.1) and "If I have questions or concerns about my work, I feel safe reaching out to my peers" (PS2.5). In addition, from Figure 12.1, PS2.2 was loaded very poorly. Other questions with loads before 0.7 were PS2.6 and PS2.7. I decided to keep these questions as pairs with those in PS1 sub-variable in relation to their supervisors.

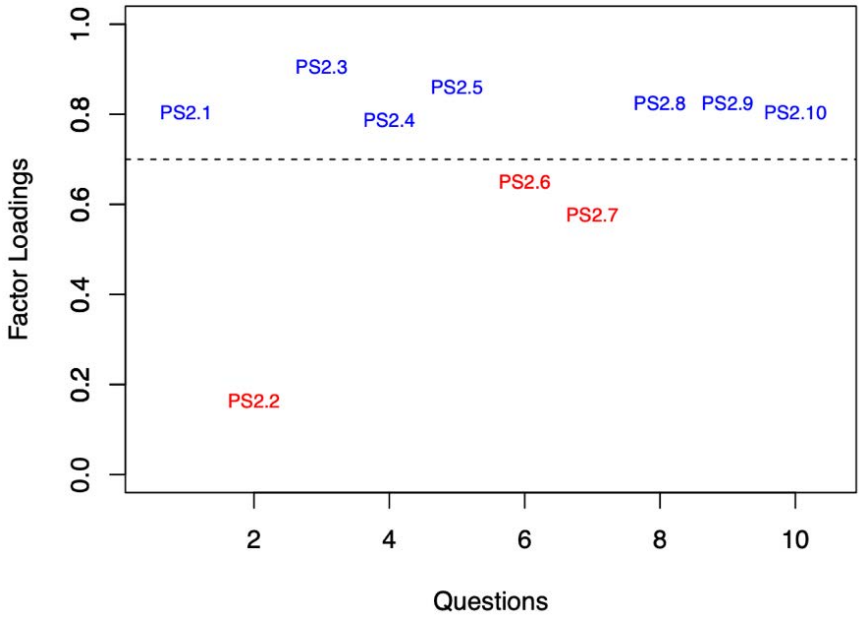

Figure 12.1: Factor Loadings for Psychological Safety in Relation to Peers Sub-Variable

Factor analysis for being respectful sub-variable (BQ1)

From Figure 12.2, for the sub-variable "Being respectful," only 1 question was loaded poorly, BQ1.6 ("Members of my team find it hard to respect people who have different points of view."). In addition, the response to this question can be inferred from the response to question BQ1.4 ("Members of my team have an open mind and are respectful of others' expectations."). I removed this question for the next round.

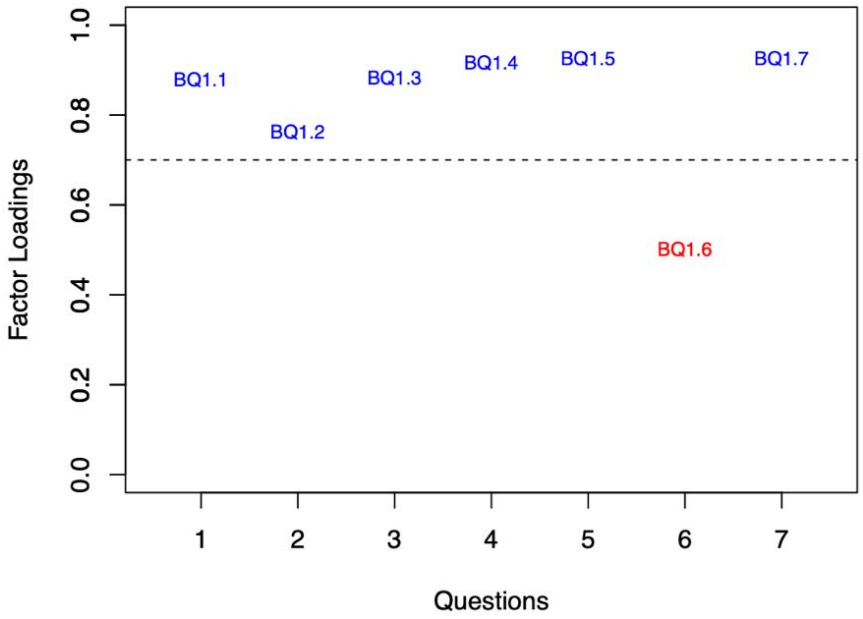

Figure 12.2: Factor Loadings for Being Respectful Sub-Variable

Factor analysis for active caring sub-variable (BQ2)

Similarly to the previous sub-variables, I removed questions that were loaded poorly (Figure 12.3), reported as confusing, or that could be inferred by other questions. Question BQ2.2, "Members of my team genuinely try to understand others' expectations" was removed due to redundancy with other questions. Questions BQ2.6 "Members of my team do not warn the team about potential quality issues," and BQ2.9 "Most of the time it doesn't pay to try hard because things never turn out right anyway" were removed because they were poorly loaded and participants reported the questions to be confusing, especially when translated to Spanish.

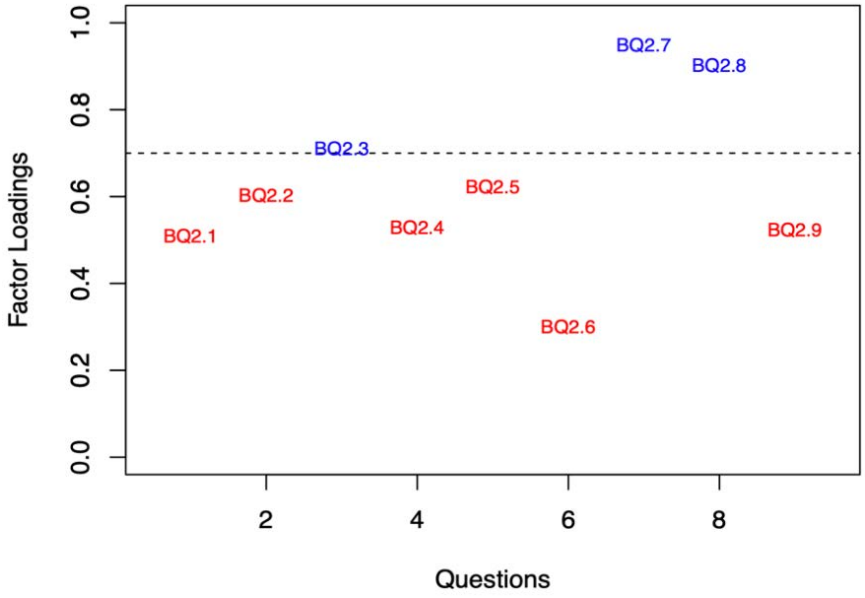

Figure 12.3: Factor Loadings for Active Caring Sub-Variable

In addition, I reworded BQ2.1 for clarity, from "Members of my team put in extra effort to deliver quality products" to "Members of my team put in extra effort to deliver quality right the first time." I reworded BQ2.5 from "Members of my team do all they can to assure and improve quality" to "Members of my team actively encourage others to participate in conversations to understand quality expectations." I kept question BQ2.4 due to the connection quality has with pride on the work for this GC.

Factor analysis for making reliable promises sub-variable (BQ3)

I removed all the questions poorly loaded from Figure 12.4, except for BQ3.1. I reworded Q3.1 from "Members of my team make sure the work is achievable before committing to do something" to "Members of my team make sure quality expectations are achievable before committing to do the work requested."

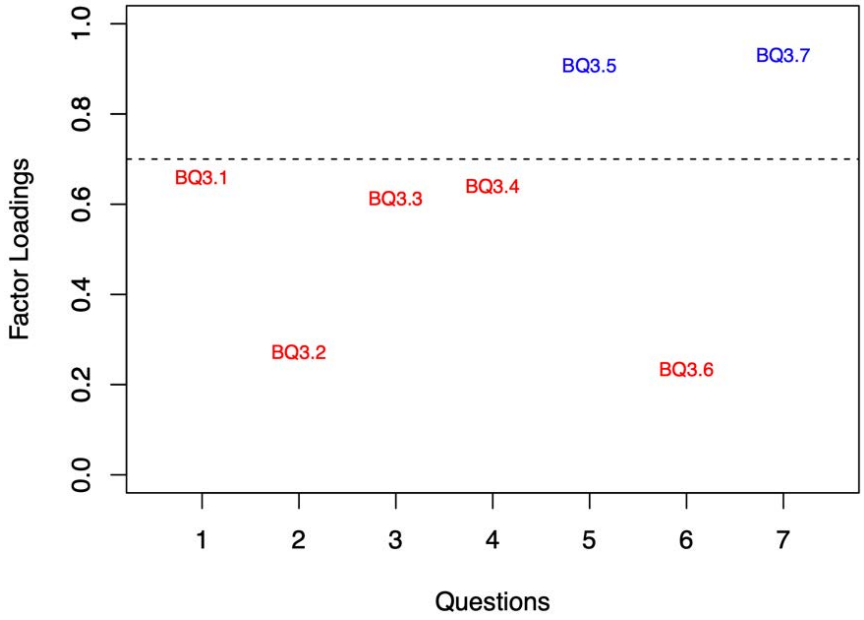

Figure 12.4: Factor Loadings for Making Reliable Promises Sub-Variable

Factor analysis for speaking up sub-variable (BQ4)

I removed all the questions loaded below 0.7 in Figure 12.4, except by BQ4.4. I reworded Q4.4 so that the translated version in Spanish can be better understood by changing the word "indeseable (Spanish of undesirable)" to "no favorable." Also, I combined BQ4.5 "Members of my team openly discuss problems and concerns (e.g., report mistakes or any deviation from the planned work)" and BQ4.6 "Members of my team can be counted on to say things that need to be said" into a single question for simplicity. The new question is, "Members of my team can be counted on to say things that need to be said and openly discuss problems (e.g., alerting of mistakes or deviations from the plan)."

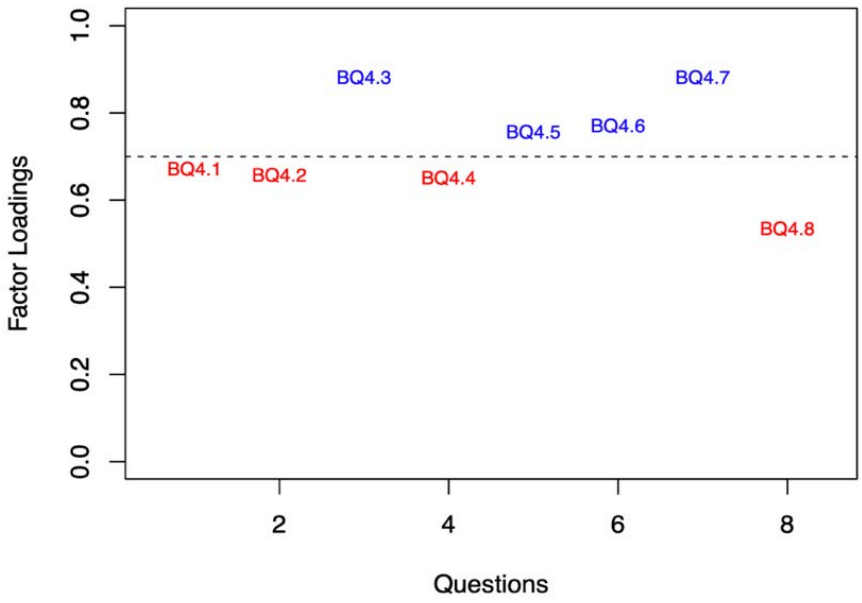

Figure 12.5: Factor Loadings for Speaking Up Sub-Variable

Factor analysis for being diligent sub-variable (BQ5)

From Figure 12.6, I removed all questions poorly loaded, including BQ5.1. In addition, I reworded question BQ5.3 from "Members of my team assess readiness (e.g., information up to date, resources available, etc.) before moving ahead" to "Members of my team assess readiness before putting work in place (e.g., by making sure information is up to date, resources are available, etc.)."

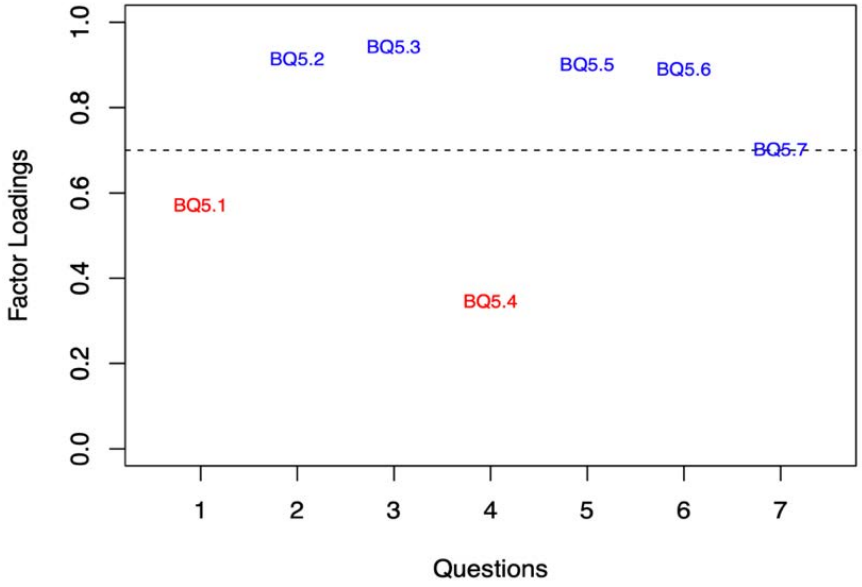

Figure 12.6: Factor Loadings for Being Diligent Sub-Variable

Factor analysis for active listening sub-variable (BQ6)

From Figure 12.7, I removed BQ6.6 as it was poorly loaded. In addition, I reworded question BQ6.1 for clarity from "Members of my team listen to and encourage each other's opinions and input when understanding and aligning expectations" to "Members of my team listen to and

encourage each other's input when understanding and aligning expectations." Similarly, I reworded question BQ6.2 from "Members of my team listen to and encourage each other's opinions and input when planning how to build work to meet expectations" to "Members of my team listen to and encourage each other's input when planning how to build work to meet expectations."

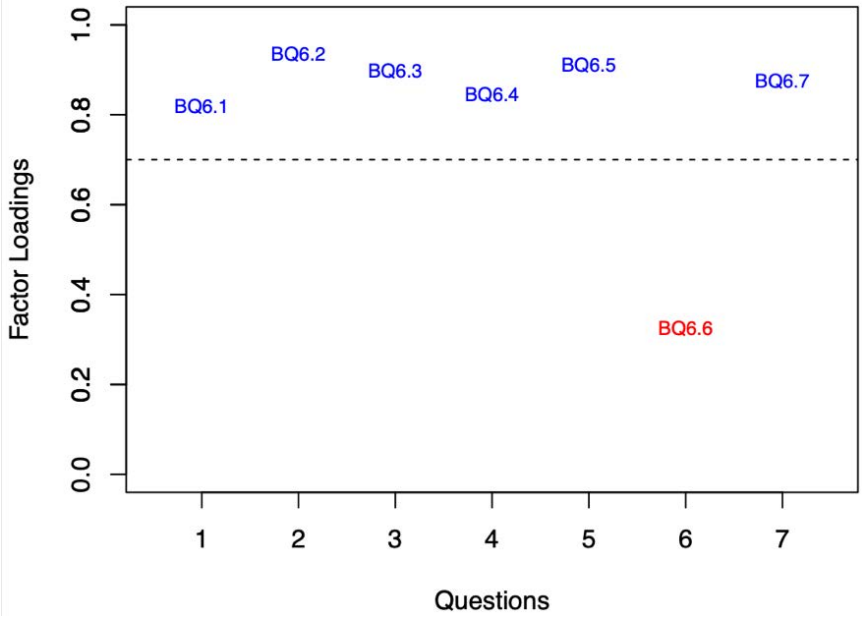

Figure 12.7: Factor Loadings for Actively Listening Sub-Variable

Factor analysis for active learning sub-variable (BQ7)

From Figure 12.8, I removed BQ7.1 as it was poorly loaded and confusing to respondents. In addition, I reworded question BQ7.3 from "Members of my team carefully document how work should be done" to "Members of my team document how work is done when building mockups or first-in-place installations to consistently build as expected later." Similarly, I reworded BQ7.4 from "Members of my team offer new ideas and solutions when problems arise" to "Members of my team offer ideas and solutions when problems arise." I also reworded BQ7.6 for clarity from "Members of my team do not encourage others to keep learning" to "Members of my team encourage others to keep learning."

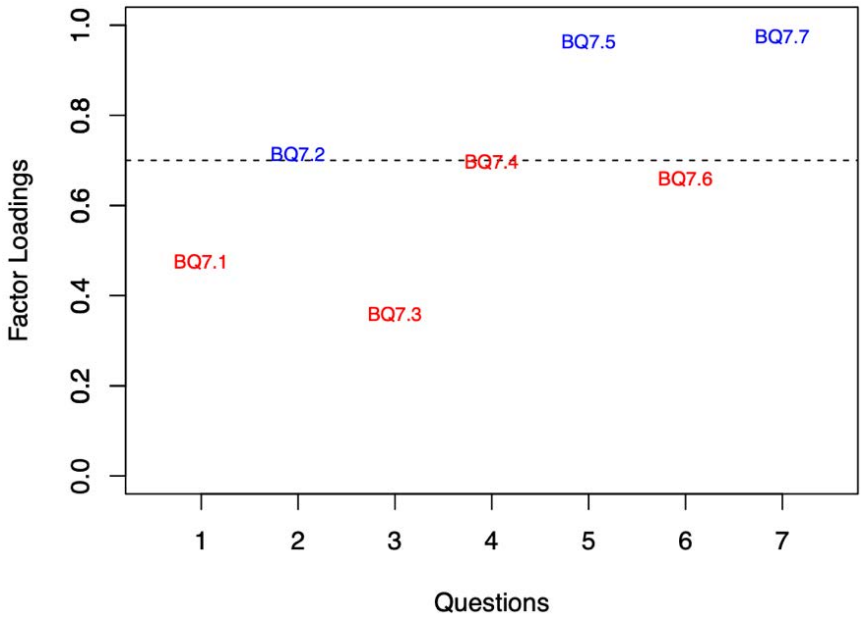

Figure 12.8: Factor Loadings for Learning Sub-Variable

Factor analysis for team performance sub-variable (TP1)

I removed all the poorly loaded questions from Figure 12.9, except for TP1.6. I reworded TP1.6 from "This team reports any mistakes or defects as soon as possible to take actions needed to deliver quality work" to "This team reports any mistake as soon as possible so it can be fixed, and deliver quality as expected."

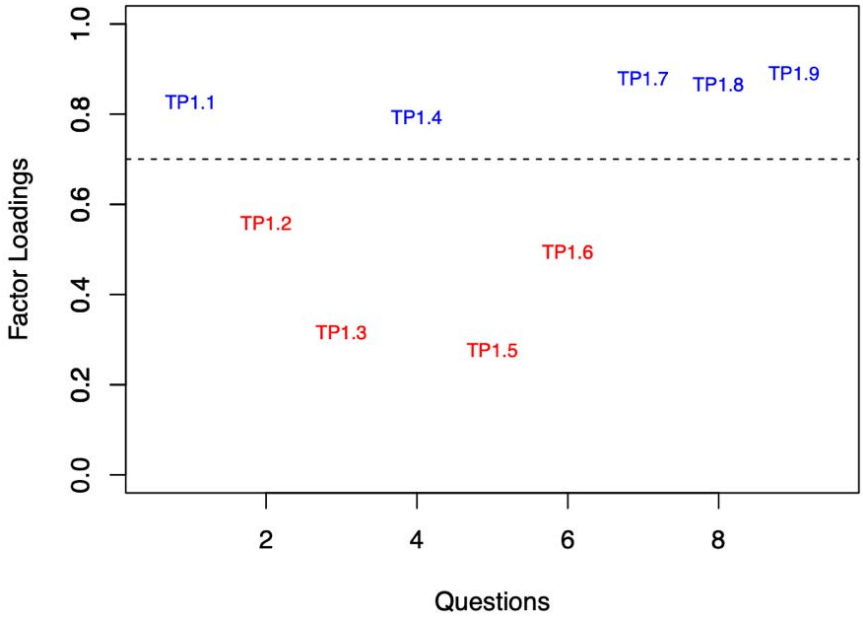

Figure 12.9: Factor Loadings for Team Performance Sub-Variable

12.12 Appendix 12: Refined Survey Scale to Assess Team Psychological Safety, Behaviors for Quality, and Team Performance

Demographics

Time working with this team, on this project:

- ○ Less than 1 month
- ○ 1-3 months
- ○ 3-12 months
- ○ 1-2 years
- ○ 2-3 years
- ○ More than 3 years

Time working with your company:

- ○ Less than 1 year
- ○ 1-2 years
- ○ 2-3 years
- ○ 3-4 years
- ○ 4-5 years
- ○ 5-10 years
- ○ More than 10 years

Select your oganization:

- ○ General Contractor (GC)
- ○ Architect/Designer
- ○ Owner
- ○ Trade partner: Drywall subcontractor
- ○ Other (please specify):

Section 1: Team Psychological Safety

Section 1.1: Please answer the following questions in relation to your team leader

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
I am able to bring up problems and tough issues to my team leader.	○	○	○	○	○	○	○
If I make a mistake while doing my work on this team, I feel safe speaking up to my team leader.	○	○	○	○	○	○	○
My unique skills and talents are valued and utilized by my team leader.	○	○	○	○	○	○	○
If I have concerns or questions about my work, I feel safe reaching out to my team leader.	○	○	○	○	○	○	○
The leader of this team is understanding when I make a mistake and does not use it against me.	○	○	○	○	○	○	○
When I make a mistake, the leader of this team helps me to correct it.	○	○	○	○	○	○	○
I feel comfortable checking with my team leader if I have questions about the right way to do something.	○	○	○	○	○	○	○
It is safe for me to make suggestions to my team leader.	○	○	○	○	○	○	○

Section 1.2: Please answer the following questions in relation to your peers/the other members of your team

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	**Strongly agree**
I am able to bring up problems and tough issues to my peers.	○	○	○	○	○	○	○
If I make a mistake while doing my work on this team, I feel safe speaking up to my peers.	○	○	○	○	○	○	○
If I have concerns or questions about my work, I feel safe reaching out to my peers.	○	○	○	○	○	○	○
My unique skills and talents are valued and utilized by my peers.	○	○	○	○	○	○	○
My peers are understanding when I make a mistake and do not use it against me.	○	○	○	○	○	○	○
When I make a mistake, my peers help me to correct it.	○	○	○	○	○	○	○
I feel comfortable checking with my peers if I have questions about the right way to do something.	○	○	○	○	○	○	○
It is safe for me to make suggestions to my peers.	○	○	○	○	○	○	○

Section 2: Team Behaviors for Quality

Section 2.1: Being Respectful

Please answer the following questions in relation to your team as a whole.

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Members of my team treat others fairly.	○	○	○	○	○	○	○
Members of my team help others develop their skills.	○	○	○	○	○	○	○
Members of my team are respectful when having conversations and making requests.	○	○	○	○	○	○	○
Members of my team have an open mind and are respectful of others' expectations.	○	○	○	○	○	○	○
Members of my team offer alternatives, to the extent possible, and not only orders when expressing expectations.	○	○	○	○	○	○	○
Members of my team are valued and their contribution to quality matters.	○	○	○	○	○	○	○

Section 2.2: Active Caring

Please answer the following questions in relation to your team as a whole.

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	**Strongly agree**
Members of my team put in extra effort to deliver the expected quality right the first time.	○	○	○	○	○	○	○
Members of my team inquire others to make sure there is a common understanding of expectations before proceeding.	○	○	○	○	○	○	○
Members of my team have much to be proud of in the quality of their job.	○	○	○	○	○	○	○
Members of my team actively encourage others to participate in conversations to understand quality expectations.	○	○	○	○	○	○	○
Members of my team are recognized when they behave in a way that support quality.	○	○	○	○	○	○	○
Members of my team stand up to the actions of others when warranted.	○	○	○	○	○	○	○

Section 2.3: Making Reliable Promises

Please answer the following questions in relation to your team as a whole.

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	**Strongly agree**
Members of my team make sure quality expectations are achievable before committing to do the work requested.	○	○	○	○	○	○	○
Members of my team honor their commitments.	○	○	○	○	○	○	○
Members of my team make sure there is clarity around acceptance criteria before proceeding.	○	○	○	○	○	○	○

Section 2.4: Speaking Up

Please answer the following questions in relation to your team as a whole.

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Members of my team solicit advice, ask questions when unsure, and embrace the fact that it is okay to not know.	○	○	○	○	○	○	○
Members of my team confront a team member if witnessed undesirable behavior towards quality.	○	○	○	○	○	○	○
Members of my team can be counted on to say things that need to be said and openly discuss problems (e.g., alerting of mistakes or deviations from the plan).	○	○	○	○	○	○	○
Members of my team speak up if they feel a plan or idea won't work.	○	○	○	○	○	○	○

Section 2.5: Being Diligent

Please answer the following questions in relation to your team as a whole.

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	**Strongly agree**
Members of my team bring up project constraints that need to be considered for shaping and aligning expectations.	○	○	○	○	○	○	○
Members of my team assess readiness before putting work in place (e.g., by making sure information up to date, resources are available, etc.).	○	○	○	○	○	○	○
Members of my team carefully analyze project information and make sure expectations are achievable before putting work in place.	○	○	○	○	○	○	○
Members of my team work to create a shared vision of the desired end outcome before putting work in place.	○	○	○	○	○	○	○

Section 2.6: Active Listening

Please answer the following questions in relation to your team as a whole.

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	**Strongly agree**
Members of my team listen to and encourage each other's input when understanding and aligning expectations.	○	○	○	○	○	○	○
Members of my team listen to and encourage each other's input when planning how to build work to meet expectations.	○	○	○	○	○	○	○
Members of my team use exploring questions to promote discussions and better understand expectations.	○	○	○	○	○	○	○
Members of my team summarize points of agreement and disagreement when appropriate.	○	○	○	○	○	○	○
Members of my team keep track of points others make in discussions and decisions made.	○	○	○	○	○	○	○
Members of my team try to understand rationales for the requests received to better set quality expectations.	○	○	○	○	○	○	○

Section 2.7: Learning

Please answer the following questions in relation to your team as a whole.

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	**Strongly agree**
Members of my team review constantly their own progress and performance.	○	○	○	○	○	○	○
Members of my team document how work is done when building mockups or first-in-place installations to consistently build as expected later.	○	○	○	○	○	○	○
Members of my team offer ideas and solutions when problems arise.	○	○	○	○	○	○	○
Members of my team do great work sharing information and knowledge.	○	○	○	○	○	○	○
Members of my team encourage others to keep learning.	○	○	○	○	○	○	○
Members of my team learn from mistakes and try to avoid making the same mistakes again.	○	○	○	○	○	○	○

Section 3: Team Performance

Section 3.1: Please answer the following questions in relation to your team as a whole

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	**Strongly agree**
This team meets its customer's expectations.	○	○	○	○	○	○	○
This team rarely, if ever, has quality mistakes.	○	○	○	○	○	○	○
This team keeps getting better and better.	○	○	○	○	○	○	○
This team reports any mistake as soon as possible so it can be fixed, and deliver quality as expected.	○	○	○	○	○	○	○
This team does high quality work.	○	○	○	○	○	○	○
This team has done a good job in making sure that what was built would conform to what was expected.	○	○	○	○	○	○	○
This team has made effective plans to make sure quality can be achieved.	○	○	○	○	○	○	○

Section 3.2: Please answer the following question in relation to quality performance

	We could do much better	We did worse	We did a bit worse	Neither better/worse	We did a bit better	We did well	**We did very well**
How is the project's performance in quality compared to the performance of the average projects you had worked at?	○	○	○	○	○	○	○

12.13 Appendix 13: Description of Activities and Decision Nodes for Case 1 Workflow

Project Participants:

1. Owner/end users
2. Architect
3. General Contractor (GC)
4. Drywall subcontractor
5. Other subcontractors (MEPF, painting, flooring)
6. Authorities having jurisdiction (AHJ)

Process Activities Description:

1. **Develop basis of design (BOD):**

   The architects document key aspects of the design intent and describe considerations taken behind major design decisions. The BOD is progressively developed before the design starts and continues being developed throughout early design. The BOD describes the thought process that guides the design; therefore, the activity includes the active participation of the owner and end users.

2. **Develop design construction drawings:**

   The architects progressively develop the design in packages and review them with input from the contractors onboard when the packages are completed. Design packages are developed for 30%, 60% completion of construction drawings (CD), and 90% and 100% completion of issued for construction drawings (IFC). For example, the GC provides input for the design packages based on the GC's Design Acceptance Criteria (DAC). DAC is a tool that establishes the expectations of drawings' completeness. Similarly, subcontractors such as MEPF and SPW drywall provide input on details (e.g., dimensions missing, potential mistakes with materials specified) that they want to have included or addressed in the CDs.

3. **Review design and develop BIM model:**

   During the design review process, the GC and subcontractors who are part of the project provide input into the design packages. In addition, architects develop the BIM architectural model and prepare to share it with subcontractors with BIM modeling included in their contracts for scope-specific models. In this activity, the drywall subcontractor provides, for example, the following input:

   - Framing details that installers are familiar with
   - Compatibility of materials in drawings and specifications (e.g., what compounds are allowed to use with specific drywall boards; no mix of compounds for the same purpose, etc.)
   - Constructability suggestions (e.g., areas where installing drywall, as usual, may either be too difficult or unsafe)

4. **Develop drywall BIM model:**

   The drywall subcontractor modelers develop their scope-specific BIM model, including framing and drywall details. This model shows, for example, the thickness of a drywall

board on each side of the wall, the spool sheets, and the openings required, such as those for windows and doors.

5. **Develop scope-specific BIM model:**

   Other trades with work related to drywall, such as mechanical, electrical, and piping subcontractors, develop their own scope-specific BIM model. They provide the necessary information to drywall, for example, the size of the openings required, the type of framing for doors and windows, etc.

6. **Conduct model flythrough and sign-off:**

   The GC hosts review sessions where relevant project participants walk through the virtual model. During these sessions, participants identify issues and solve them during the design phase, avoiding rework during construction.

7. **Sign-off BIM coordination:**

   The GC coordinates the model sign-off once the relevant project participants agree that the model is substantially coordinated. At this point, the model is shared for broader use. For example, superintendents access the model for planning and scheduling purposes, while PEs use it for developing inspection packages containing different views of the model.

8. **Prepare and get scope-specific submittals approved:**

   Construction drawings that architects prepare are meant to communicate design intent, but these drawings do not have the level of detail needed for construction. The GC and subcontractors prepare submittals for design approval that they will use for the assembly, fabrication, or installation of work onsite.

9. **Plan work sequence:**

   The drywall subcontractor, in collaboration with other subcontractors and the GC, defines the sequence that suits the site conditions and project constraints.

10. **Define priority walls and travel paths:**

    The drywall subcontractor starts planning what they would like to build as priority walls. Once their expectations are clear, they coordinate with the GC and MEPF subcontractors to understand everyone's expectations and align them. The GC provides input on where openings are needed for travel paths, for example, to move large equipment inside the building. MEPF subcontractors provide input on what systems are to be prioritized before drywall installation.

11. **Plan and execute layout:**

    The drywall subcontractor draws floor layout for walls following the sequence of work as planned. First floor layout was done manually, as typical. Dusty layout use is adopted progressively, starting on the next floor. Layout, either manual or with Dusty, is checked by the subcontractor for accuracy.

12. **Check quality of layout for critical locations:**

    The GC verifies the accuracy of critical locations such as elevators, restroom walls, corridor walls, and areas with ADA requirements. According to one of the drywall superintendents I interviewed, typically, only 5-15% of the walls layout is checked by the GC.

13. Install framing:

The drywall subcontractor installs framing, including all framing needed for both scopes studied and interior partition walls. The QR code with PDF package with information for in-wall installation is used in this step.

14. Check quality of framing installation:

The drywall subcontractor installers and foremen check the framing installed and verify whether it conforms with agreed requirements. If quality is not as expected, rework is triggered to fix non-conformities, and work is checked again.

15. Install rough-in:

Subcontractors that have embedded work install their scope in the wall. For instance, MEPF subcontractors install all their embedded systems. The QR code with PDF package with information for in-wall installation is used in this step.

16. Install special requirements:

The drywall subcontractor completes special requirements such as soundproofing, for which fiberglass or similar is installed inside the wall. The QR code with PDF package with information for in-wall installation is used in this step.

17. Check quality of rough-in and framing:

The GC and subcontractors whose work goes into the wall verify the conformity of requirements against what was built. The architect walks the site and sends his weekly site report with observation of non-conformities. The AHJ verifies whether pin installation in the bottom track conforms with requirements.

18. Resolve rough-in and framing non-conformities:

If any project participant finds non-conformities for the framing or wall rough-in, rework is triggered to fix these, and work is checked again.

19. Install drywall boards:

The drywall subcontractor installs drywall boards following agreed requirements, e.g., using fire-resistant drywall boards for fire-rated walls.

20. Apply required wall finishes:

The drywall subcontractor applies finishes as required, from taping only, to compound, to sanding, etc.

21. Check quality of finish installation:

The subcontractor verifies the conformity of wall finish delivered. This verification is limited, both in frequency and format. No specific criteria were set for this verification. From my interviews, I observed at least one instance where the installer thought the work was completed as expected, but the drywall superintendent perceived the wall not to have the quality expected and gave a directive to improve the finish before the GC inspection to avoid being called back again in that area.

22. Check quality of finish:

The GC verifies conformity of wall finish delivered against agreed requirements. The architect and owner representatives take walks to inspect the work occasionally, especially for walls with high-end finishes. Also, subsequent subcontractor verifies whether the work they received conforms with the requirements to install their scope of work.

23. **Resolve finish non-conformities:**

    If non-conformities are found for the wall finish, rework is triggered to fix these, and work is checked again.

24. **Release work to next subcontractor:**

    The drywall subcontractor, in coordination with the GC, hands over work to receiving trade; for example, painters or tile subcontractors. The QR code with PDF package with information for wall as installed is used in this step as input for the subsequent subcontractor.

Decision nodes:

a. Is layout OK?

After defined sections of layout are completed, the drywall subcontractor and GC verify the layout accuracy using critical control points.

b. Is framing OK?

After framing is installed, the drywall subcontractor verifies that it conforms with requirements; for example, whether it has all the correct types of backing, at the right location, and at the right height. The GC walks the site for interior partition walls and verifies whether work is ready to continue with in-wall rough-in.

c. Are rough-in and framing OK?

After rough-in is installed, the GC and related subcontractors verify whether the rough-in conforms with requirements. If OK, GC proceeds to authorize the wall closeup.

d. Is the finish level OK?

After wall finishes are completed per wall or section, the drywall subcontractor verifies whether the wall finishes conform with the expected requirements. Then the GC, architect, and end users, in some cases, assess the delivered work. If OK, GC calls the next trade with work assigned in the approved zone. Last, the subcontractor receiving the work verifies whether it meets their expectations to install the next scope. If OK, the GC releases the work for the subsequent subcontractor to start installing their scope of work.

12.14 Appendix 14: Quality Implementation Plan Template

This document establishes the Quality Implementation Plan (QIP) for [project name]. Our QIP sets expectations on how the entire project team will collectively manage, visualize, and execute quality expectations to reach desired outcomes throughout the project life cycle.

Roles and Responsibilities (R&R) for Quality

[GC] will identify all stakeholders who have a vested interest in each task and get aligned on the expected outcome of the work, and how completed work will be assessed. Stakeholders may include owners, end-users, designers, inspectors, contractors, and suppliers. **Exhibit 1** describes the project's R&R to deliver quality right the first time.

Distinguishing Features of Work (DFOW) Process

Purpose

DFOWs are aspects of the project that are unique or of high importance to its stakeholders, requiring increased attention and planning to achieve an agreed-upon outcome. The DFOW process requires the project team to work collaboratively to establish measurable acceptance criteria (MAC). MAC is the objective criteria, agreed upon by all scope-specific stakeholders, which will be used to assess the delivered work. DFOWs are not intended to divert attention away from other, more routine requirements. Identifying all requirements and making certain they are both properly understood is the first step in planning quality.

Process

The [GC] project team will analyze the project plans and specifications, generate the initial DFOW List, and review it with all scope-specific stakeholders to gain alignment. This list will be continually reviewed and updated throughout the project life cycle. Figure 12.10 shows the project's DFOWs process steps. **Exhibit 2** provides additional supporting documentation to assist the team in executing the DF process.

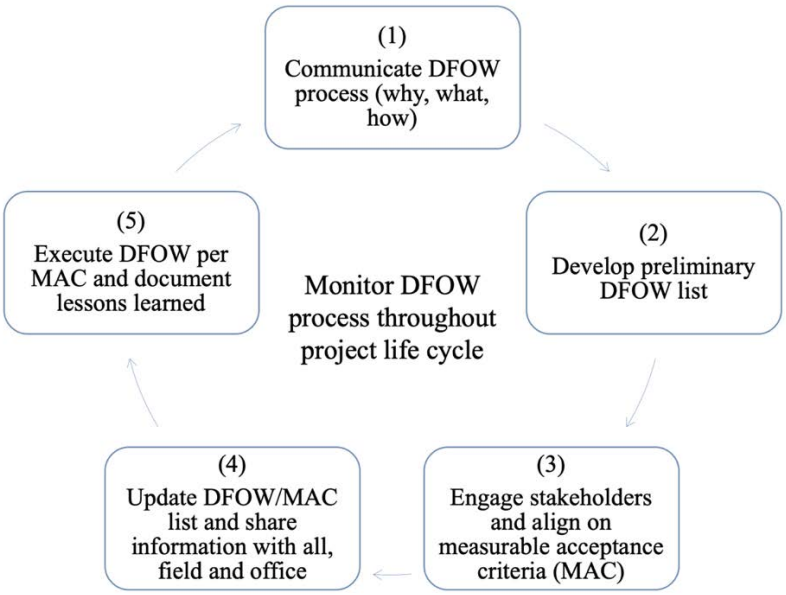

Figure 12.10: DFOW process

Communication

Quality discussions will be integrated into project meetings (Figure 12.11) to ensure that scope-specific quality expectations are clearly communicated to all stakeholders for such scope, including all those installing the work. **Exhibits 3** and **4** highlight the quality topics to be included in these meetings.

Quality kick-off	Held with each contractor before mobilizing
• In the quality kick-off, GC will explain R&R, process for acceptance of completed work, DFOW process and existing DFOWs for the specific scope pertaining to the trade, expectations for participation in the DFOW process and tracking quality in the field.	
Pre-installation	Held with each contractor prior to start installing work
• The GC team and the contractor completing the work will review the criteria by which the work will be inspected and will check craft understands expectations. All relevant information, including submittals, specifications, etc. are to be consulted in preparation for this meeting.	
Weekly coordination	Held with all contractors working on the project
• Team will discuss lessons learned from quality issues identied during the week, and upcoming milestones including tests and inspections.	

Figure 12.11: Quality Discussions in Project Meetings

In the field, we communicate quality expectations by establishing a Quality Right to Know area. We will communicate the expectations established during these meetings by leveraging boards and visuals via the quality right-to-know area (**Exhibit 5**).

Quality in the Field

Mockups

The team utilizes mockups to help establish construction procedures, installation sequence, material compatibility, and fit and finish. Mockups, once approved, will be the standard (benchmark) against which all subsequent installations are measured. Mockup acceptance criteria will be appropriately determined and documented. Mockups will be used for one or more of the following:

- Verification of design selections made under sample submittals
- Demonstration of aesthetic effects
- Demonstration of material and workmanship quality
- Assurance of successful installation between the scopes and systems, and the building interfaces

The project team will develop and track all mockups required to install the work successfully. It is especially important to identify mockups early in the pre-construction phase and incorporate them into the project schedule and budget.

First-in-Place (FIP)

FIP inspections are performed after the first representative segment of the scope of work has been completed. Items to be evaluated include, at a minimum:

- Ensure material and installation complies with contract documents and approved submittals
- Examination of the quality of workmanship
- Review of omissions or dimensional errors
- Evaluate associated documentation and spare parts
- Performance of system testing.

Field Quality Control and Inspections

Quality control onsite follows a proactive approach (Figure 12.12) where trade partners, GC, and third-party inspectors work together to track quality in the field.

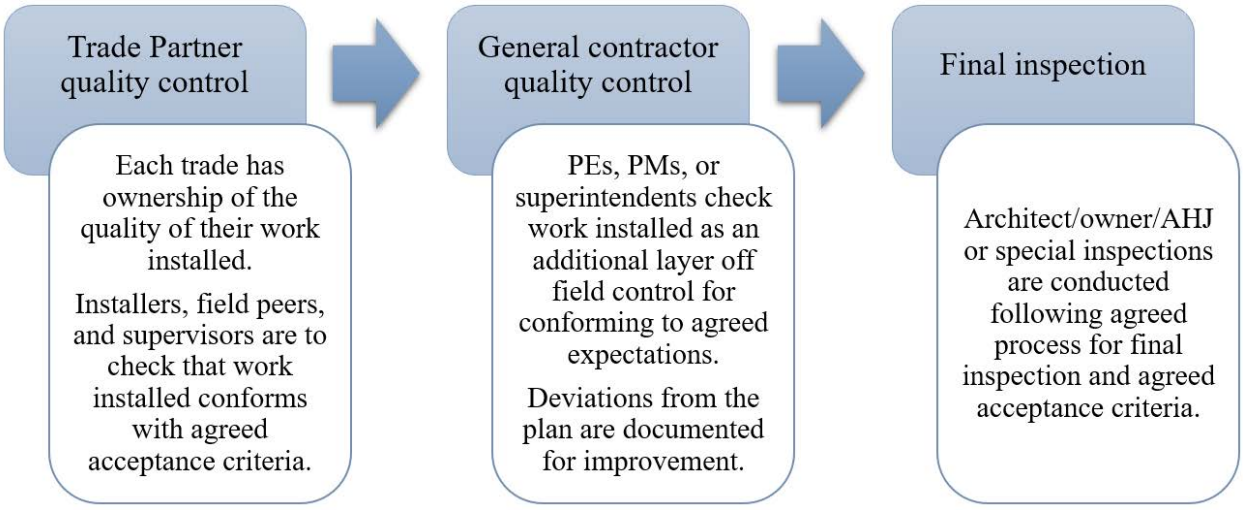

Figure 12.12: Project's QC Approach

Quality issues will be documented for learning at any instance of control when MAC is not met. As the items are corrected, they will be promptly reviewed and verified by [GC] and re-inspected by the person or team responsible for acceptance to ensure quality issues have been addressed.

Project Key Performance Indicators (KPIs)

The [GC] team will determine appropriate KPIs for the project and track them for continuous improvement purposes. KPIs will be regularly monitored, and actions for improvement will be determined when deemed necessary. **Exhibit 6** shows proposed Quality KPIs to track quality performance for the project.

Onsite Quality Training and Recognition Program

Training and recognition will be offered onsite to foster quality best practices and reward desired behaviors toward quality.

Onsite Orientation and All-Hands Quality Sessions

Everyone working on the project and project site must attend the orientation before starting work. As a best practice, the project will have a quality portion to the site orientation. In addition, periodic all-hands quality meetings, on a minimum monthly basis, will be held to reinforce the use of quality best practices and behaviors for quality with all craftworkers onsite.

Onsite Recognition Program

The project team will implement a recognition program to promote and recognize behaviors that support the quality culture. This program includes:

- Fostering a psychologically safe work environment:
  - ✓ Show that the project team appreciates those who speak up for quality, openly share expectations, and actively participate in preventing issues or detecting them early when they occur.
  - ✓ Promote a reporting culture by recognizing and rewarding a "good catch," whereby (1) quality issues or observations are identified or addressed early enough to prevent rework, or (2) issues are reported as soon as they are identified, allowing the team to learn and plan how to prevent the reoccurrence of such.
- Celebrating those who lead us to success and rewarding behaviors that drive quality:
  - ✓ Recognize one or more project team members at each all-hands site meeting and describe the individual's action to promote project quality. The intent is to promote leading by example.
  - ✓ Share successes with all. Implement a quality recognition board and post it at the field trailer office and right-to-know areas. The board's content will rotate as the set of recognition for individuals and specific actions that promoted project quality changes.

Exhibit 1: Roles and Responsibilities for Quality

Note: Customize this table to suit your project needs and resources.

	PM	PE	SUP	OA	TP
Setting up the team for success					
Organize and participate in onsite quality orientation					
Develop a quality recognition program					
Conduct quality kick-off meetings for all project stakeholders					
Identify and reach out to subject matter experts required and develop an engagement strategy					
Maintaining consistency					
Conduct quality pre-installation meetings with all trade partners					
Discuss quality issues in weekly coordination meetings					
Participate in daily site walks and check work is being performed as planned					
Managing DFOW process					
Identify preliminary DFOWs, project participants who need to be involved, and coordinate alignment meetings					
Update DFOWs list and define their respective MAC					
Executing and Pursuing continuous improvement					
Execute inspections per agreed MAC and hold trades accountable for quality delivered					
Define, track, and review the project's KPIs					
Review lessons learned due to quality issues on a weekly basis					
Implement a reporting culture approach for early identification of mistakes					

Legend:

PM	Project manager
PE	Project engineer
SUP	Superintendent

OA	Owner/Architect
TP	Trade partner

Exhibit 2: Project Distinguishing Features of Work

At a minimum, the project's DFOW tracker should include the following information:

Scope	DFOW	MAC	Relevant specifications and drawings	MAC alignment due date	Mockup or FIP required?	Stakeholders required

Additional information the project can track include:

- Mockup or FIP construction date
- Mockup or FIP approved date
- Construction schedule installation date
- Construction completion acceptance date

Mockups can be tracked as DFOWs if suitable for the project.

Exhibit 3: Quality Kick-Off Meeting Agenda

Quality kick-off is the initial conversation a GC has with each trade coming onsite, where the approach to managing quality on the project is introduced. In addition, critical quality elements are discussed to start planning the next steps as the trade gets onboarded. Agenda includes:

- Introduction to the project's QIP: We will review the quality plan, discuss the GC's approach to quality, and get aligned on the use of key terms such as DFOW, MAC, FIP, etc.
- Project-Specific DFOWs and MAC: The team will discuss the process of identifying project-specific DFOWs. This allows the stakeholder to start identifying DFOWs which are not explicitly called out in the contract document. The team will align on a strategy for project stakeholders to define quantitative and descriptive MAC. Existing DFOWs that the GC identified will be presented to guide the discussion with the trade.
- Process for accepting work: We will align on the final customer and discuss what this person/company commonly looks at or requires during inspections for acceptance of work.
- Plan for Mockups/FIP: The team will review the initially required mockups and FIP and align on strategy for identifying, planning, submitting, installing, and inspecting these.
- Plan for testing/inspections: The team will align on the required tests and inspections pertaining to the scope and how deviations will be documented. In addition, we will align on the method for scheduling inspections, documenting inspection results, and taking corrective action.

Exhibit 4: Pre-Installation Meeting Quality-Related Discussion Topics

Pre-install meetings will be held with all trades prior to putting work in place. Topics from schedule to safety, and quality are discussed during these meetings. The quality topics to review during these meetings are:

- Review quality expectations, including DFOWs and MAC if pertaining to the scope
- Review status of required submittals, RFIs, change orders, FIP, mockups, etc.
- Review inspection/testing process
- Review methods for protecting adjacent work
- Jobsite walk and review of site conditions.

Exhibit 5: Quality Right to Know Board

Transparency is essential to consistent and effective collaboration amongst all project stakeholders. We will create and maintain a Quality "Right-to-Know" board in a common area where all stakeholders can have access to review important information. The Quality Right-to-Know board will be located in places for maximum visibility for both craft and office workers. The Right-to-Know area on this project can include:

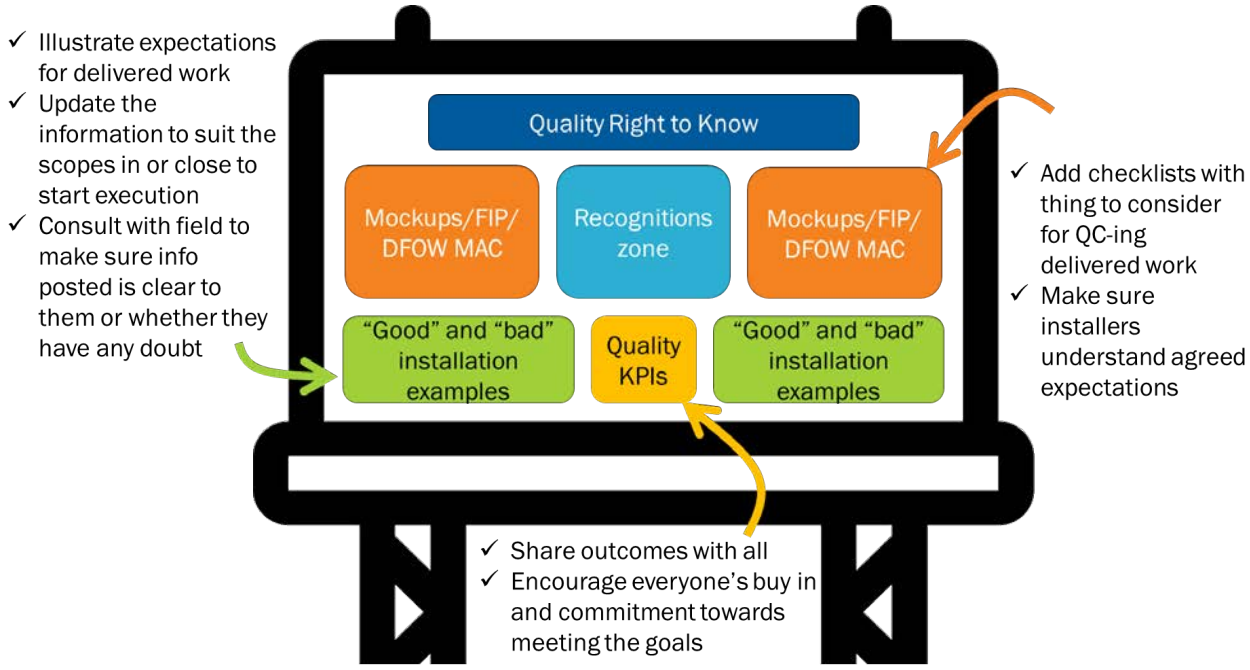

Figure 12.13: Content Sample of Quality Right-to-Know Board

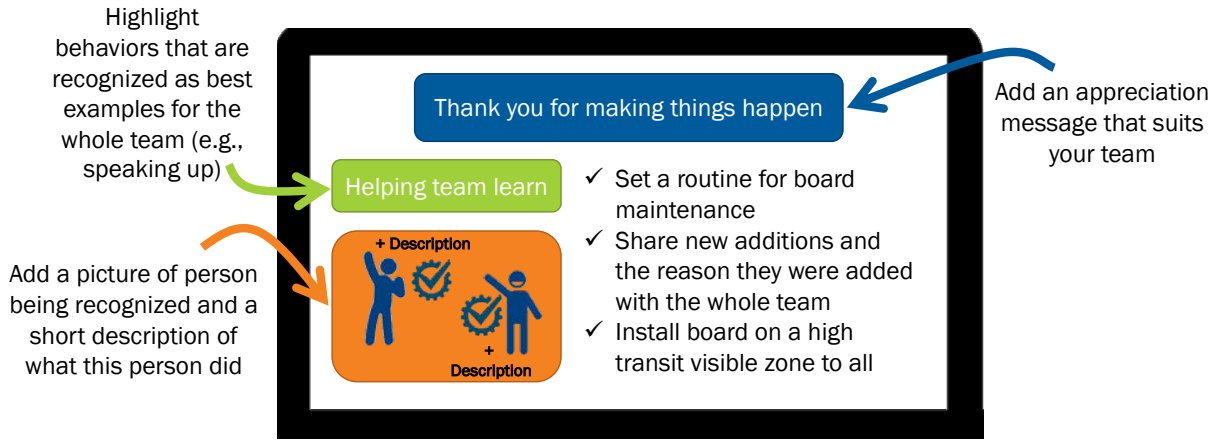

Figure 12.14: Content Sample of Recognition Board

Exhibit 6: Project's Key Performance Indicators (KPIs)

Note: Select and customize these metrics to suit your project needs and resources.
Metrics that can be used to assess quality performance are:

Metric	Criteria
Time for identification of issues	Earlier is better
Inspection pass/fail rate	Higher is better
Quality issues and % reported per trade partner	Higher trade partner reporting is better
% of pre-installation meetings held	Goal = 100%
Worker-hours of rework performed	Less is better
Frequency of staff quality walks per scope of work	Goal = 1 walk per person per day
Response time to resolve corrective actions	Less is better
Active and open issues by trade	Less is better
% of people that have received quality orientation onsite	Goal = 100%

12.15 Appendix 15: Factor Analysis for Survey Responses Case 2

Factor analysis for psychological safety in relation to supervisor sub-variable (PS1)

All questions were loaded close to or above 0.7 for the PS1 sub-variable (Figure 12.15).

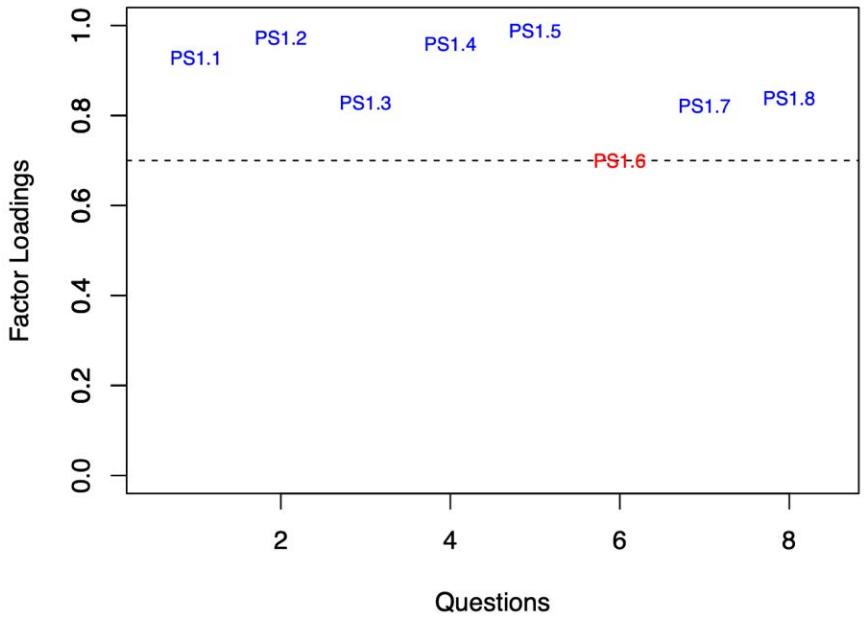

Figure 12.15: Factor Loadings for Psychological Safety in Relation to Supervisor Sub-Variable

Factor analysis for psychological safety in relation to peers sub-variable (PS2)

All questions were loaded above 0.7 for the PS2 sub-variable (Figure 12.16).

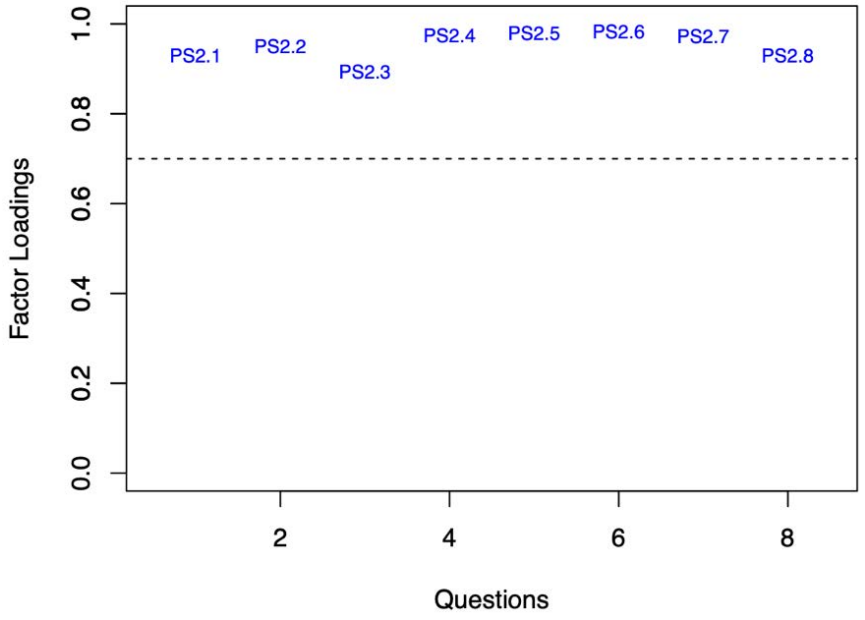

Figure 12.16: Factor Loadings for Psychological Safety in Relation to Peers Sub-Variable

Factor analysis for being respectful sub-variable (BQ1)

All questions were loaded above 0.7 for the BQ1 sub-variable (Figure 12.17).

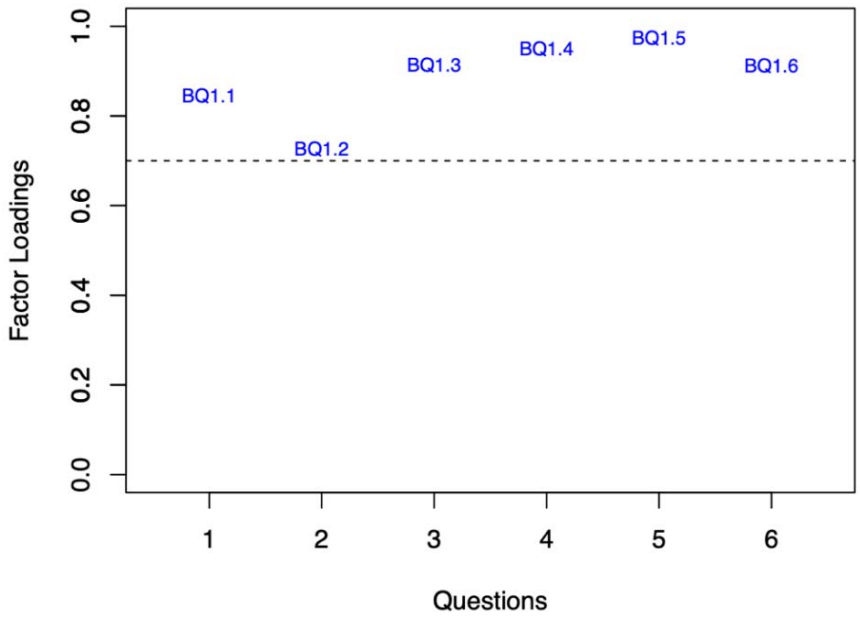

Figure 12.17: Factor Loadings for Being Respectful Sub-Variable

Factor analysis for active caring sub-variable (BQ2)

All questions but BQ2.2 "Members of my team inquire others to make sure there is a common understanding of expectations before proceeding" were above 0.7 (Figure 12.18). Participants, in both Spanish and English, reported this question to be confusing. I reworded this question for clarity: "Members of my team make sure there is a common understanding of quality expectations before building."

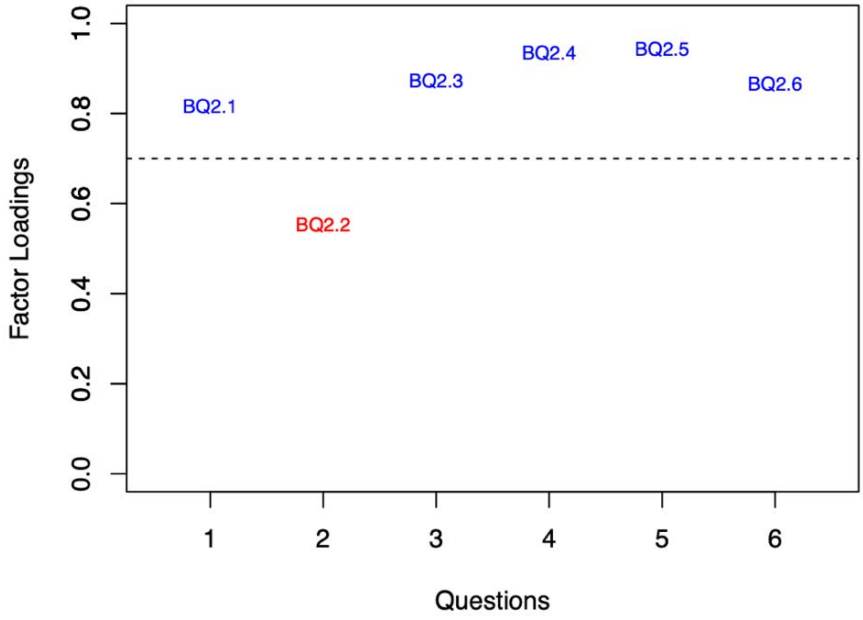

Figure 12.18: Factor Loadings for Active Caring Sub-Variable

Factor analysis for making reliable promises sub-variable (BQ3)

All questions were loaded above 0.7 for the BQ1 sub-variable (Figure 12.19).

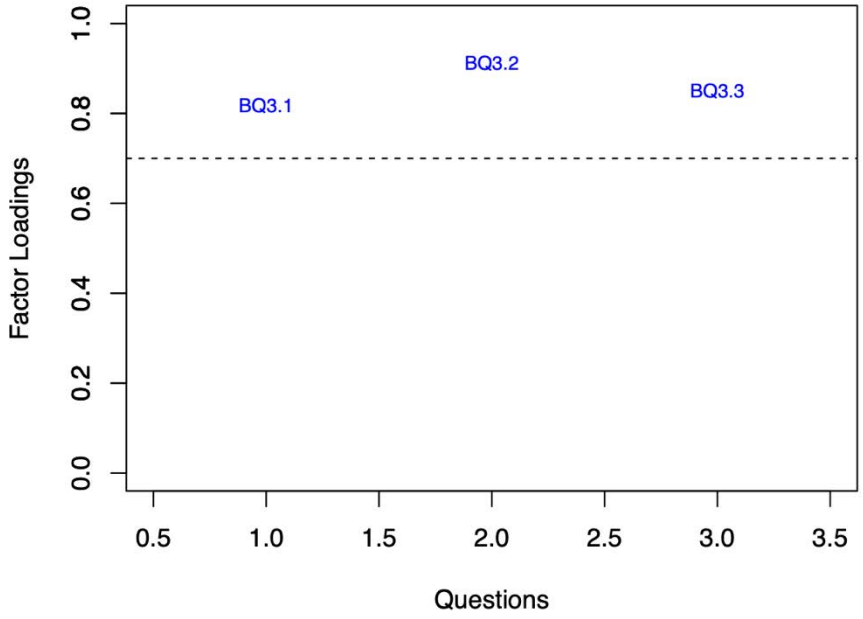

Figure 12.19: Factor Loadings for Making Reliable Promises Sub-Variable

Factor analysis for speaking up sub-variable (BQ4)

All questions were loaded above 0.7 for the BQ1 sub-variable (Figure 12.17).

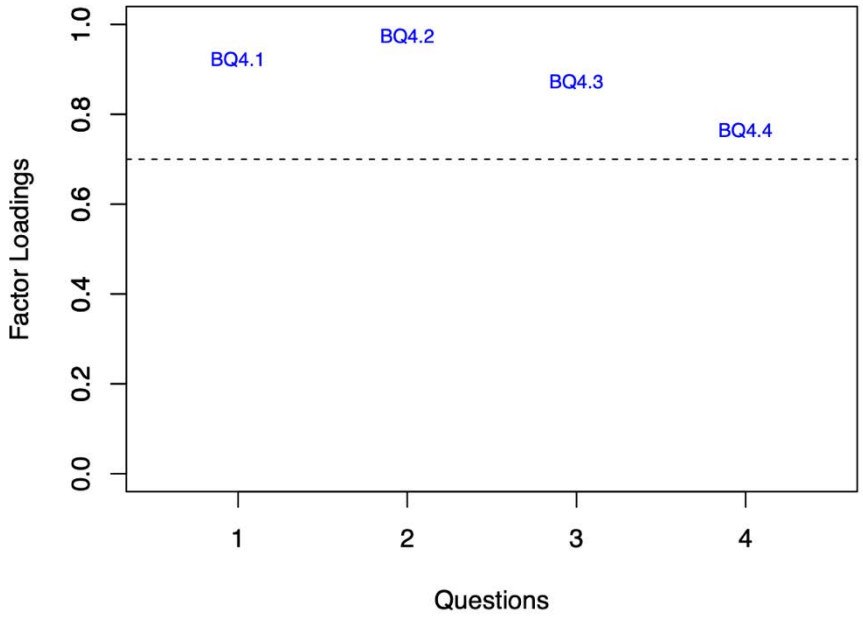

Figure 12.20: Factor Loadings for Speaking Up Sub-Variable

Factor analysis for being diligent sub-variable (BQ5)

All questions were loaded above 0.7 for the BQ1 sub-variable (Figure 12.21).

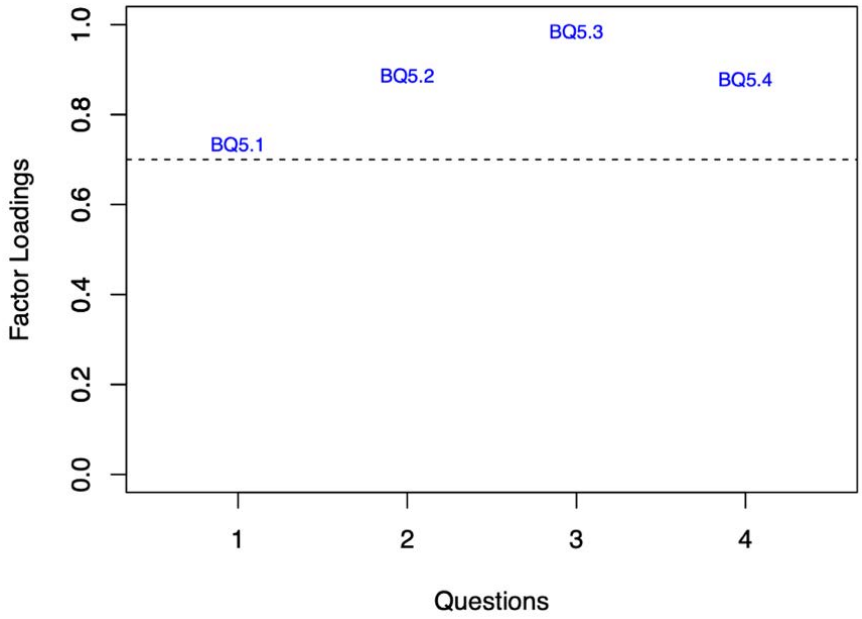

Figure 12.21: Factor Loadings for Being Diligent Sub-Variable

Factor analysis for active listening sub-variable (BQ6)

From Figure 12.22, I reworded BQ6.1 from "Members of my team listen to and encourage each other's input when understanding and aligning expectations" to "Members of my team listen to other's input to understand and align quality expectations." Similarly, I reworded BQ6.2 from "Members of my team listen to and encourage each other's input when planning how to build work to meet expectations" to "Members of my team listen to other's input to plan the work so that it meets agreed expectations." In addition, I reworded BQ6.3 from "Members of my team use exploring questions to promote discussions and better understand expectations" to "Members of my team use exploring questions and promote discussions to better understand quality expectations."

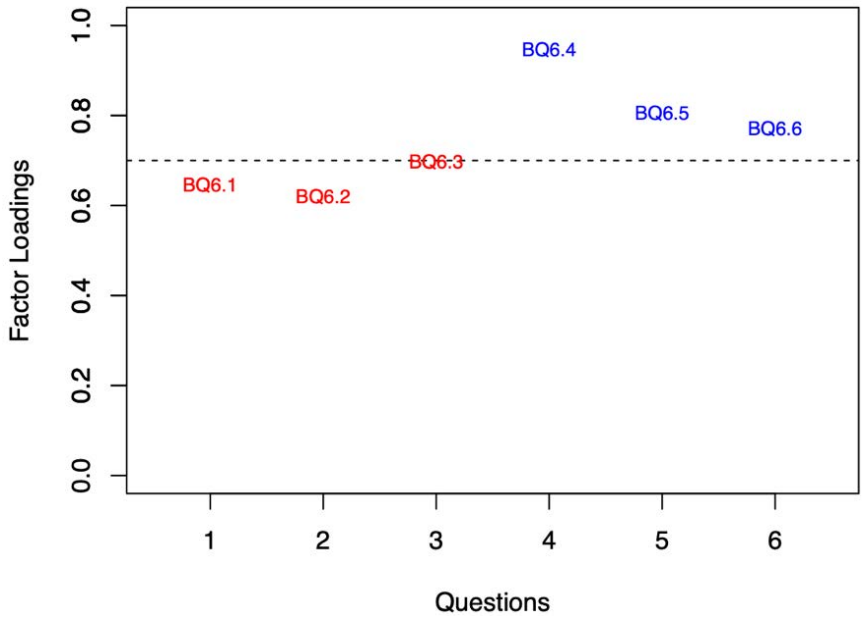

Figure 12.22: Factor Loadings for Actively Listening Sub-Variable

Factor analysis for active learning sub-variable (BQ7)

From Figure 12.23, I reworded BQ7.1 from "Members of my team review constantly their own progress and performance" to "Members of my team often review their progress and project performance." Similarly, I reworded BQ7.2 from "Members of my team document how work is done when building mockups or first-in-place installations to consistently build as expected later" to "Members of my team document how mockups or first-in-place installations are built so that the steps can be replicated consistently when building the rest of the project."

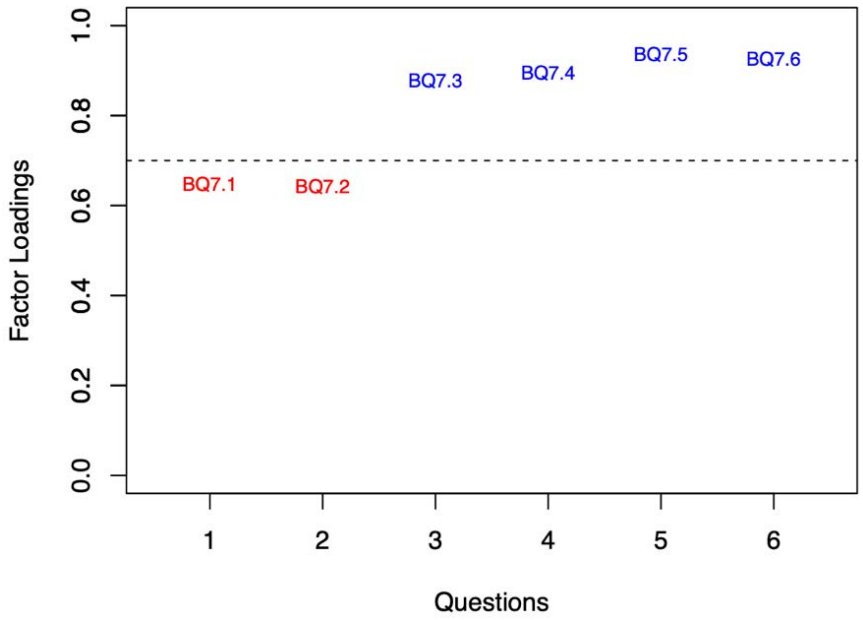

Figure 12.23: Factor Loadings for Learning Sub-Variable

Factor analysis for team performance sub-variable (TP1)

From Figure 12.24, two of the questions in the group were loaded below 0.7. However, due to the questions' significance in representing performance on quality, I kept both questions.

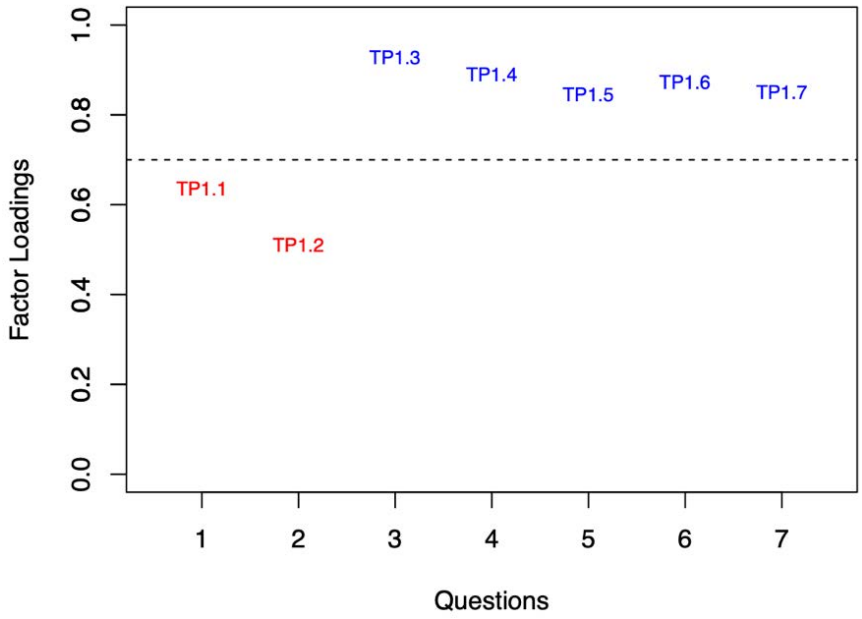

Figure 12.24: Factor Loadings for Team Performance Sub-Variable

12.16 Appendix 16: Quality Process for the Case 2 Project

Figures 12.25-12.31 describe the process steps the Case 2 team followed to build the drywall scope studied. As a convention, I numbered each activity describing who performed the step and what activity it was. Circle marks show the involvement of project participant(s) from a stakeholder group in an activity led by another. I explained these activities in more detail in Appendix 17.

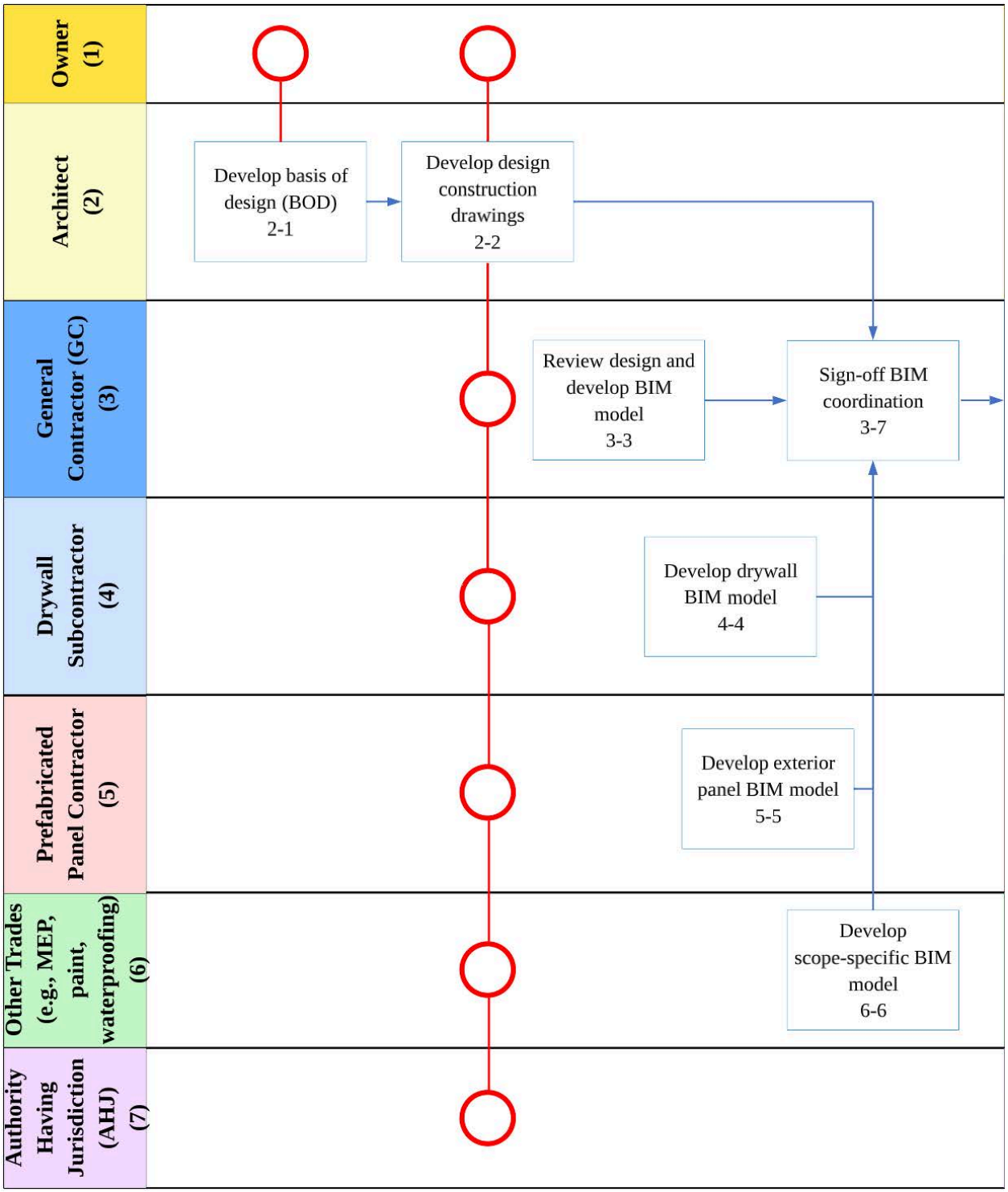

Figure 12.25: Case 2 Quality Management Process Map for Drywall Scope Studied (1/7)

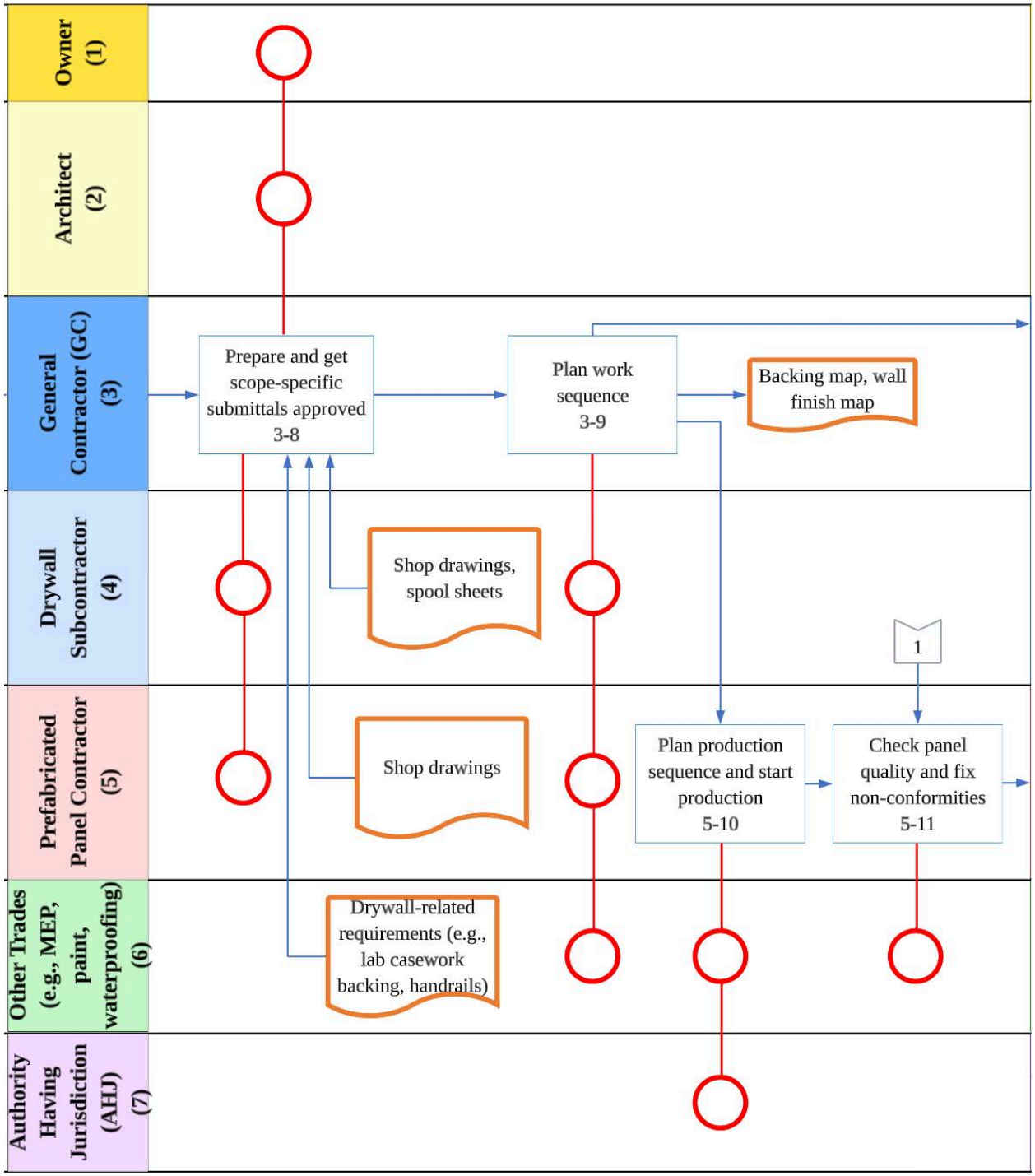

Figure 12.26: Case 2 Quality Management Process Map for Drywall Scope Studied (2/7)

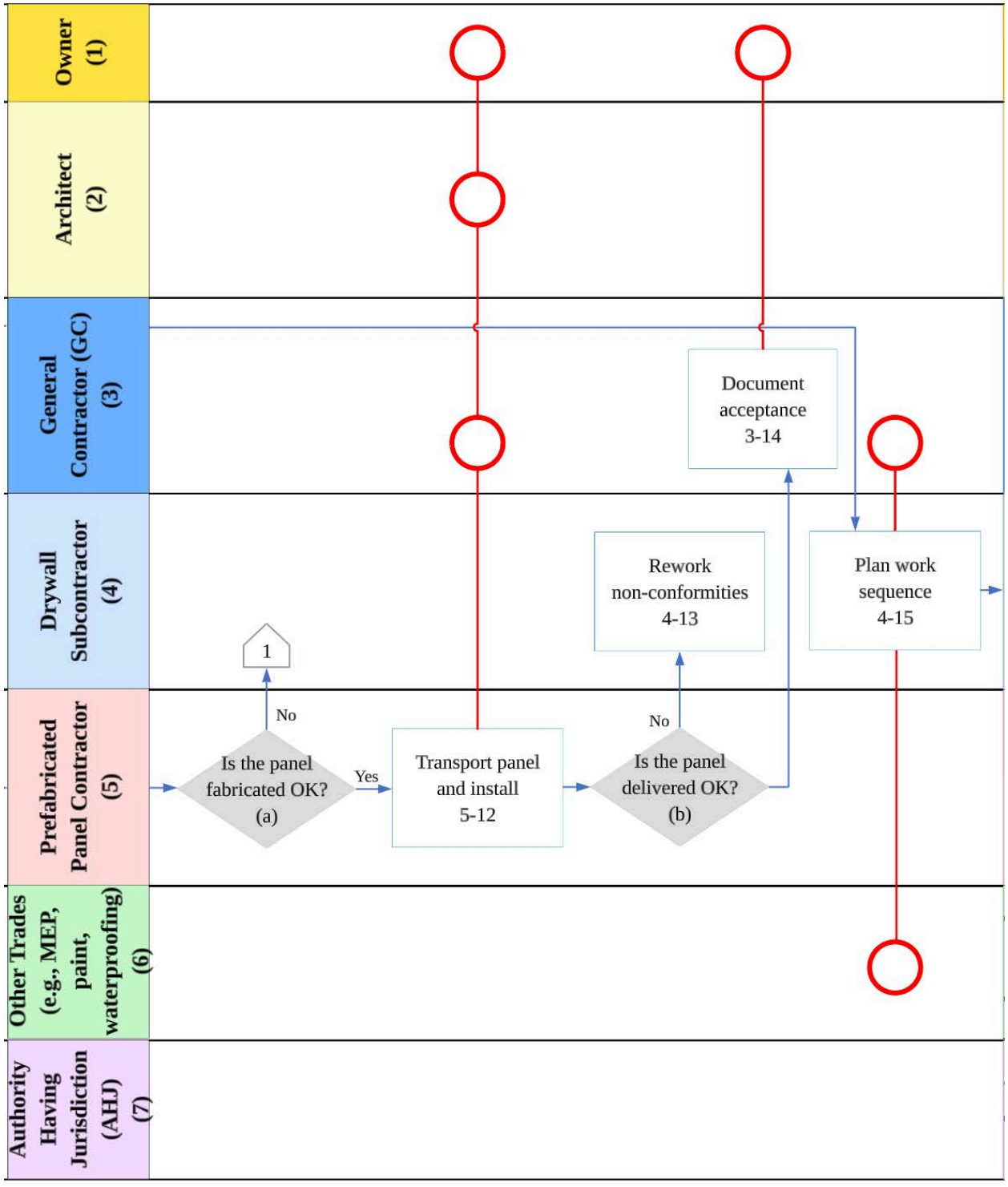

Figure 12.27: Case 2 Quality Management Process Map for Drywall Scope Studied (3/7)

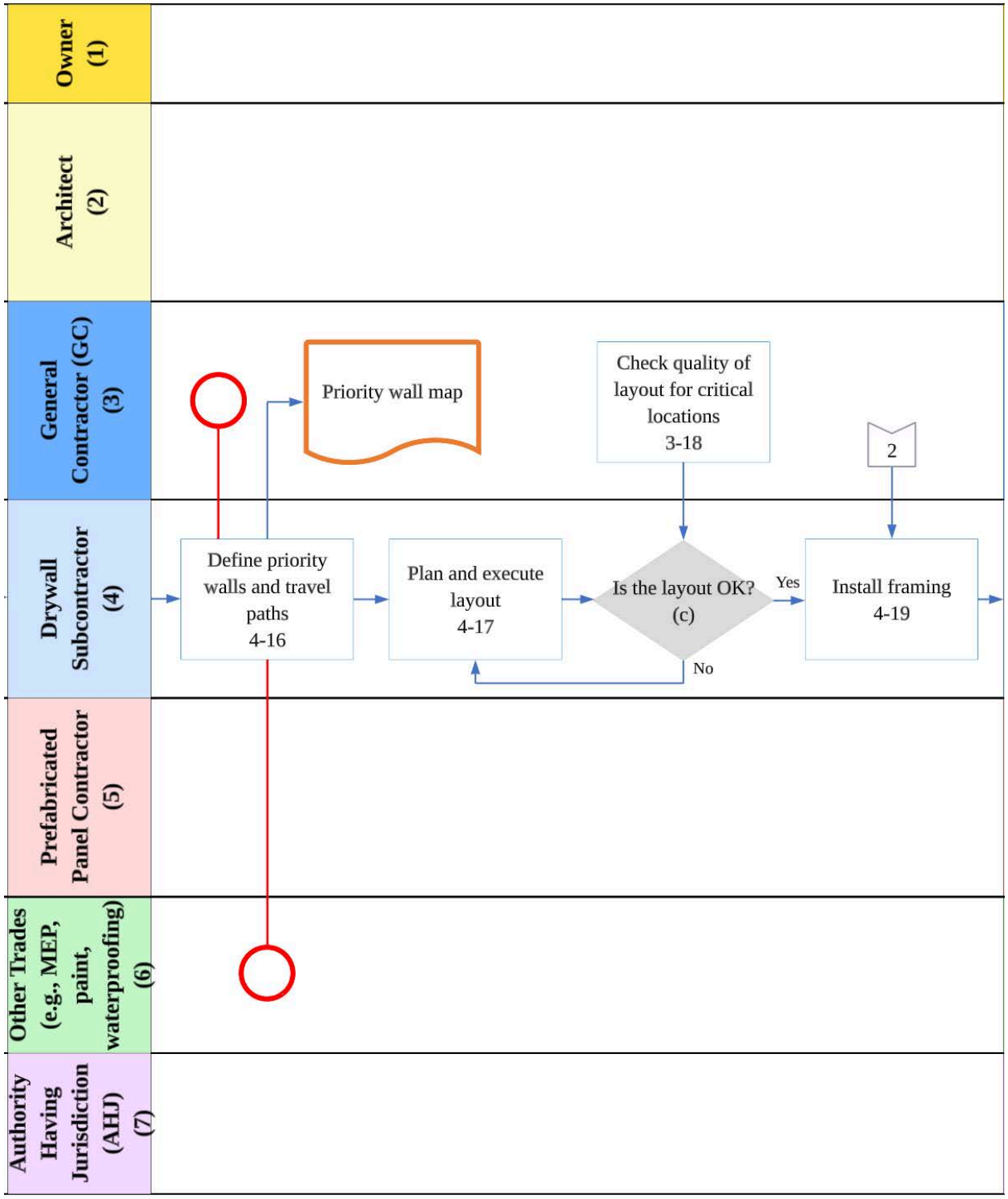

Figure 12.28: Case 2 Quality Management Process Map for Drywall Scope Studied (4/7)

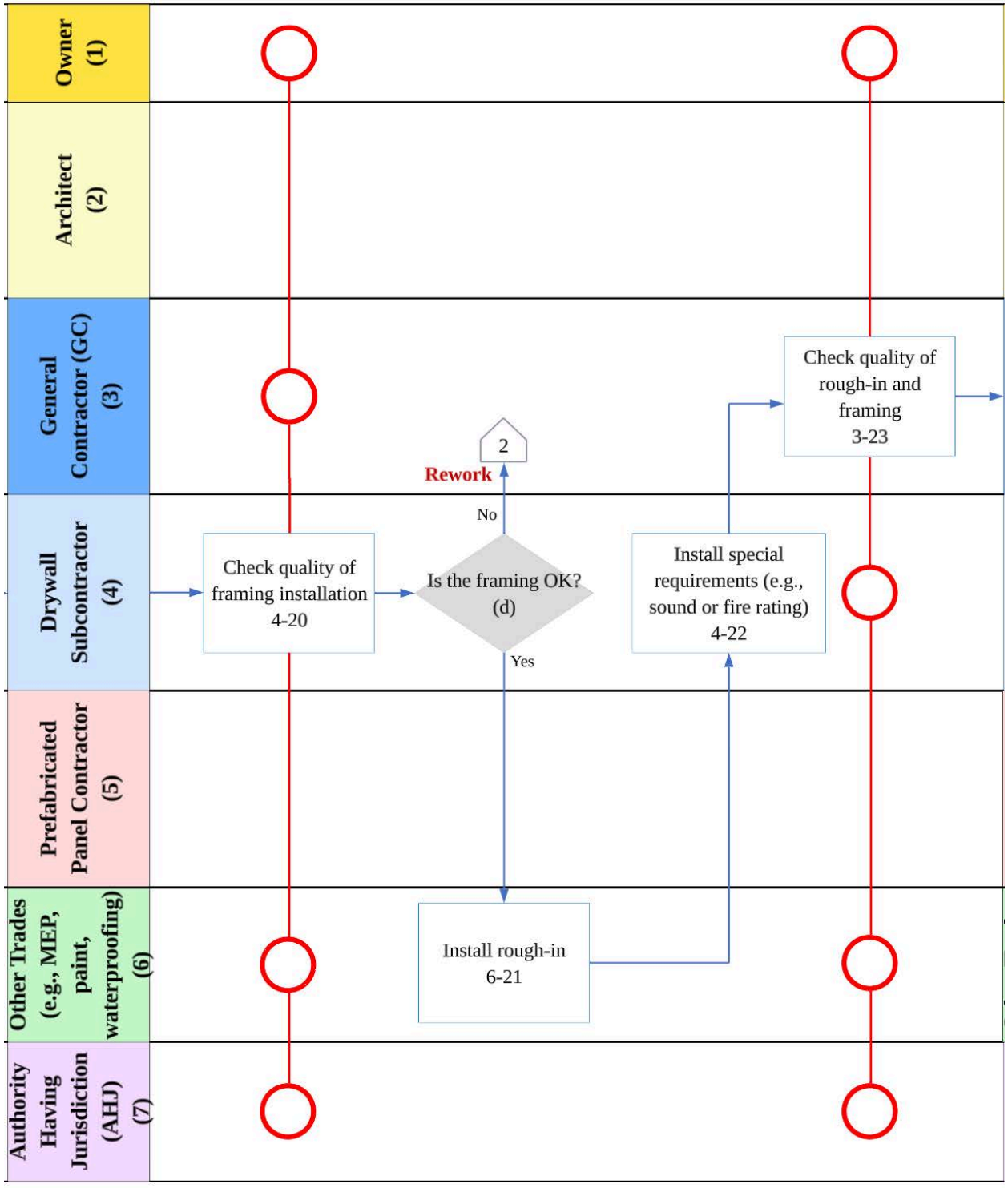

Figure 12.29: Case 2 Quality Management Process Map for Drywall Scope Studied (5/7)

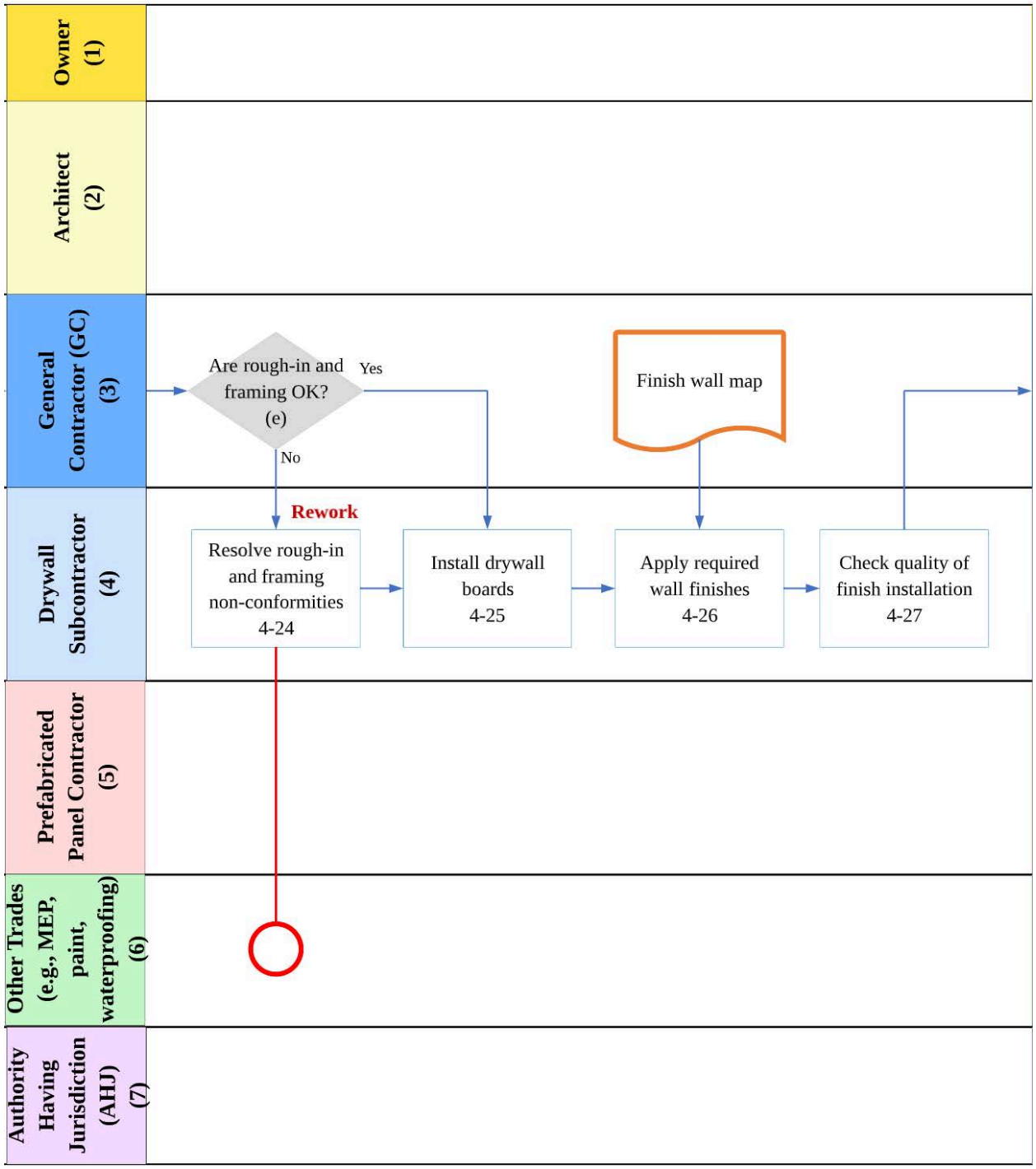

Figure 12.30: Case 2 Quality Management Process Map for Drywall Scope Studied (6/7)

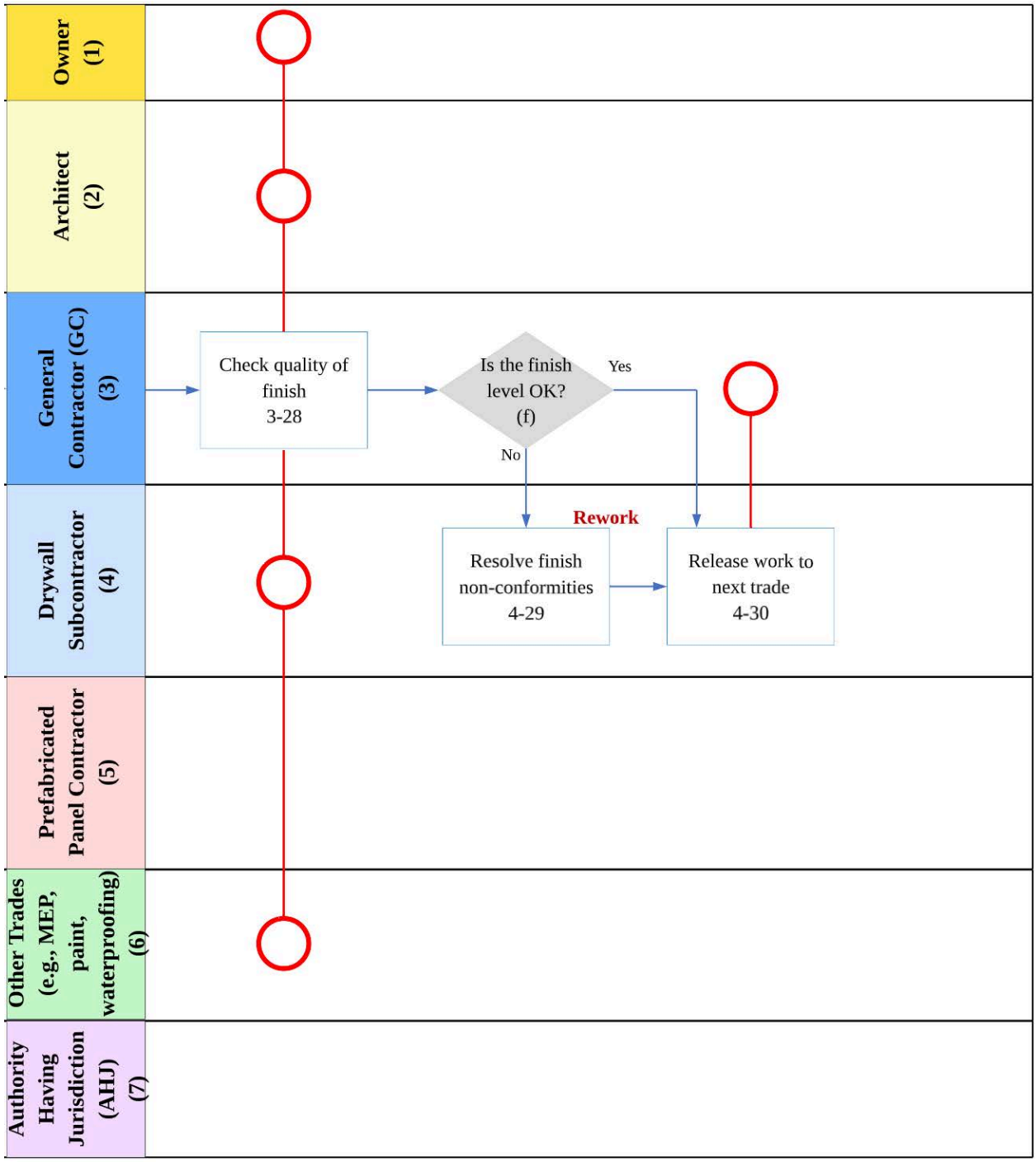

Figure 12.31: Case 2 Quality Management Process Map for Drywall Scope Studied (7/7)

12.17 Appendix 17: Description of Activities and Decision Nodes for Case 2 Workflow

Project Participants:

1. Owner
2. Architect
3. General Contractor (GC)
4. Drywall subcontractor
5. Prefabricated exterior panel contractor
6. Other subcontractors (MEPF, painting, flooring, waterproofing, etc.)
7. Authorities having jurisdiction (AHJ)

Process Activities Description:

1. **Develop basis of design (BOD):**
   The architects document key aspects of the design intent and describe considerations taken behind major design decisions in the BOD.
2. **Develop design construction drawings:**
   The architects progressively develop the design with input from the contractors.
3. **Review design and develop BIM model:**
   Each Prime contractor developed their own BIM model, and the GC coordinates the whole project model.
4. **Develop drywall BIM model:**
   The drywall subcontractor develops their scope-specific BIM model, including framing and drywall details.
5. **Develop exterior panel BIM model:**
   The exterior panel contractor develops panel BIM model in coordination with contractors who have related scopes such as waterproofing.
6. **Develop scope-specific BIM model:**
   Other trades with work related to drywall, such as mechanical, electrical, and piping subcontractors, develop their own scope-specific BIM model.
7. **Sign-off BIM coordination:**
   The GC coordinates the model sign-off once the relevant project participants agree that the model is substantially coordinated. The GC's superintendents participate in model coordination sessions to provide input.
8. **Prepare and get scope-specific submittals approved:**
   The GC and subcontractors prepare submittals for design approval that they will use for the assembly, fabrication, or installation of work onsite.
9. **Plan work sequence:**
   The GC coordinates work sequence among Primes and other subcontractors.
10. **Plan production sequence and start production:**
    The exterior panel contractor coordinates with the GC the production sequence depending on installation schedule, and starts producing panels.

11. **Check panel quality and fix non-conformities:**

    The exterior panel contractor checks the quality of the panels per agreed requirements, identifies non-conformities and fixes them.

12. **Transport panel and install:**

    The exterior panel contractor transports the panels and start installation.

13. **Rework non-conformities:**

    The drywall subcontractor fixes any non-conformity found in exterior panel once it arrives to site or it is installed.

14. **Document acceptance:**

    The GC documents conformity of work with agreed requirements.

15. **Plan work sequence:**

    The drywall subcontractor, in collaboration with other subcontractors and the GC, defines the sequence that suits the site conditions and project constraints.

16. **Define priority walls and travel paths:**

    The drywall subcontractor starts planning what they would like to build as priority walls. Once their expectations are clear, they coordinate with the GC and MEPF Primes to understand everyone's expectations and align them.

17. **Plan and execute layout:**

    The drywall subcontractor draws floor layout for walls following the sequence of work as planned.

18. **Check quality of layout for critical locations:**

    The GC verifies the accuracy of critical locations such as elevators, restroom walls, corridor walls, and areas with ADA requirements.

19. **Install framing:**

    The drywall subcontractor installs framing, including all framing needed for both scopes of this study, interior partition walls, and exterior metal stud framing.

20. **Check quality of framing installation:**

    The drywall subcontractor installers and foremen check the framing installed and verify whether it conforms with agreed requirements. If quality is not as expected, rework is triggered to fix non-conformities, and work is checked again.

21. **Install rough-in:**

    Subcontractors that have embedded work install their scope in the wall.

22. **Install special requirements:**

    The drywall subcontractor completes special requirements such as soundproofing, for which fiberglass or similar is installed inside the wall.

23. **Check quality of rough-in and framing:**

    The GC, Primes, and subcontractors whose work goes into the wall verify the conformity of requirements against what was built. The owner walks the site weekly with the GC to identify non-conformities. The AHJ verifies whether pin installation in the bottom track conforms with requirements.

24. **Resolve rough-in and framing non-conformities:**

    If any project participant finds non-conformities for the framing or wall rough-in, rework is triggered to fix these, and work is checked again.

25. **Install drywall boards:**

    The drywall subcontractor installs drywall boards following agreed requirements.

26. **Apply required wall finishes:**

    The drywall subcontractor applies finishes as required. I used the drywall finish signoff guide in Appendix 18 to guide the wall finish discussion.

27. **Check quality of finish installation:**

    The subcontractor verifies the conformity of wall finish delivered.

28. **Check quality of finish:**

    The GC verifies conformity of wall finish delivered against agreed requirements. The owner walks to inspect the work occasionally, especially for walls with high-end finishes.

29. **Resolve finish non-conformities:**

    If non-conformities are found for the wall finish, rework is triggered to fix these, and work is checked again.

30. **Release work to next subcontractor:**

    The GC, in coordination with the drywall subcontractor, hands over work to receiving trade.

Decision nodes:

a. **Is the panel fabricated OK?**

   After panels start fabrication, panel contractor checks quality of the panel as it gets built and before it leaves the shop.

b. **Is the panel delivered OK?**

   Once panels arrive at the site, the GC coordinates with the owner to inspect the panel in the truck and air before it is installed to verify it meets agreed expectations.

c. **Is the layout OK?**

   After layout sections are completed, the drywall subcontractor and GC verify the layout accuracy using critical control points.

d. **Is the framing OK?**

   After installing framing, the drywall subcontractor verifies that it conforms to requirements.

e. **Are the rough-in and framing OK?**

   After rough-in is installed, the GC and related subcontractors verify whether the rough-in conforms with requirements.

f. **Is the finish level OK?**

   After wall finishes are completed per wall or section, the drywall subcontractor verifies whether the wall finishes conform with the expected requirements. Then the GC and owner assess the delivered work. If OK, the GC releases the work for the subsequent subcontractor to start installing their scope of work.

12.18 Appendix 18: Drywall Finish Signoff Criteria Developed in Case 2

Wall Finish as a DFOW: Process Flow

Align Expectations

- Identify stakeholders
  - SPW drywall
  - GC
  - Client
  - O&M
  - GC
  - all other trades with related scopes
- Discuss applicable DFOW-MAC
- Align on MAC, define how finished appearance acceptance inspections will be conducted

Plan to Build as per MAC

- Share MAC with craft and make sure expectations are understood prior to start construction
  - Mockups or FIP
  - Spool sheets
  - QR codes with relevant drawings

Check built work against MAC

- Verify whether work complies with expectations before moving to next zone

Finish Requirements per Level

Quick Reference Guide GA 214 2017 - Levels of Finish Quick Reference Guide (pabcogypsum.com)

FINISHING LEVEL	Joint Taping – Flat and Interior Angles	Flat Joints – Additional Coats	Interior Angles – Additional Coats	ACCESSORIES – Additional Coats	FASTENERS – Separate Coats	SURFACE TREATMENT
0	None					
1	Tape Set in Joint Compound	None	None	Optional, unless specified in project documents	None	None
2	Tape embedded in joint compound and wiped with a joint knife, leaving a thin coat of joint compound over tape	None	None	1 coat	1 coat	
3		1 coat	1 coat	2 coats	2 coats	
4		2 coats	1 coat	3 coats	3 coats	
5		2 coats	1 coat	3 coats	3 coats	1 coat

Most Commonly Uses per Finish Level

- **Level 0** — Temporary construction or areas concealed from public view
- **Level 1** — Typically specified joint treatment in smoke barrier applications, and areas not normally open to public
- **Level 2** — Substrate for tile, and garages or warehouse storage
- **Level 3** — Areas with heavy or medium texture finishes before painting, or with heavy-duty grade wall covers
- **Level 4** — Areas with flat paint, or smooth wall covers
- **Level 5** — Areas with non-flat paint or glossy finishes, critical lighting (e.g., long light fixtures attached)

DFOW & MAC Guide

Lighting

- Normal lighting condition: Light in place when project is finished; in normal intensity and location
- Critical lighting condition: Strong sidelighting from windows or surface-mounted light fixtures

Normal Viewing position

- A viewing position at any angle provided it is established at a minimum distance of 5 ft perpendicular from the surface to be inspected
  PDCA says 39" for paint

Mockups

Recommended in standards to help all involved understand what is expected

Limitations of drywall

- Finished drywall surface isn't monolithic.
- Increased lighting accentuate surface variations, blemishes, and imperfections.