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Taxonomy of Trust and Maslow's Hierarchy of Needs in the Construction Industry

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ABSTRACT

Trust is vital in every facet of life, enabling collaborative efforts and valuing contributions from various individuals. This is particularly true in the construction industry, where teamwork is essential for success. Prior research has consistently demonstrated that heightened trust levels significantly contribute to better project outcomes and increased client satisfaction. Despite its critical role, the construction industry has yet to adopt a structured hierarchical perspective of trust that aligns with its unique demands. This study aims to fill this gap by validating a comprehensive taxonomy of trust specifically designed for the construction sector. Through literature review, this study identifies key trust indicators within the industry and integrates them with Maslow's Hierarchy of Needs to propose a practical framework for trust implementation. The derived taxonomy organizes trust into six distinct levels, ranging from reciprocal obligation to a shared collective purpose. This hierarchical approach to trust provides industry practitioners with a systematic method to foster trust-building practices, ultimately enhancing project efficiency and stakeholder satisfaction.

Key Words: Construction, Trust, Maslow's Hierarchy of Needs

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Introduction

Trust between stakeholders in construction projects decreases the cost of the project and improves the quality of the project (Strahorn et al., 2013; Gad & Shane, 2014). The U.S. Bureau of Labor Statistics (2022) identifies over 4.5 million construction managers and craftsmen actively working in the United States construction industry. Correspondingly, this significant number of individuals results in many and varied construction teams, thus creating a need for a workforce that values trust (Zolin et al., 2000). Project teams have strong interpersonal connections built on trust (Kereri & Harper, 2019; Ling & Tran, 2012). Trust has many diverse interpretations based on its applications in numerous sectors. However, few articles agree on a definition of trust in the construction industry. This current study does not strive to add another definition of trust to the body of knowledge. Instead, this study aims to expand upon what exists in the literature about trust's effect on the construction industry, mapping it to Maslow's Hierarchy of Needs (Maslow, 1958).

Maslow's Hierarchy of Needs is often used in economics and corporations as a model by which to view human motivation (Pichère & Cadiat, 2015). However, Maslow's model has weaknesses. Most notably it's western centric view of motivation (Bouzenita & Boulanouar, 2016). The goal of this study is to understand trust in construction through a U.S. lens so the western view that Maslow lends becomes a strength. In construction, how people are motivated is crucial to understand because ultimately it is the people who accomplish a project's completion (Hartman, 2003). By understanding how to motivate every member of the construction team, projects can be completed faster and at a higher quality (Markert, 2011).

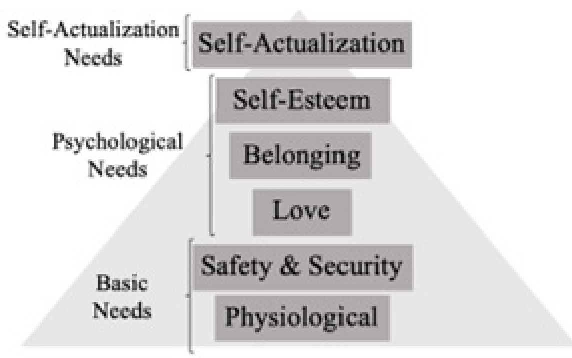

Figure 1. Maslow's Hierarchy of needs adapted from Maslow, 1958

Figure 1 shows Maslow's Hierarchy of Needs (1958) which was established to explain human motivation. The basis of needs is physiological needs such as food and water; once that need is met then one can pursue the subsequent needs: safety and security, love and belonging, self-esteem, and self-actualization (Maslow, 1958). Each of these five levels must be progressed through before attaining the next level. Therefore, before safety can even be considered, workers must be physically healthy and have their physiological needs met (Pichère & Cadiat, 2015). This concept is vital for construction as it is a dangerous industry. Safe conditions are mandatory before the three higher levels of needs can begin to be met. A similar hierarchical model of trust will be built in this paper through Maslow's hierarchy of needs.

Multiple trust-building exercises are employed within teams to improve the performance (Zolin et al., 2000). However, all tasks and activities can lead to different degrees of success in building trust (Gad & Shane, 2014). The objectives of this study are to (1) model the levels of trust based on existing research in the construction industry and (2) map it to Maslow's Hierarchy of Needs. The resulting taxonomy of trust can be utilized in future research to determine the value of various trust building exercises for construction professionals.

Methodology

A literature review was conducted following Okoli's (2015) guidelines. This method allowed for a broad understanding of the current status of trust research in the construction industry.

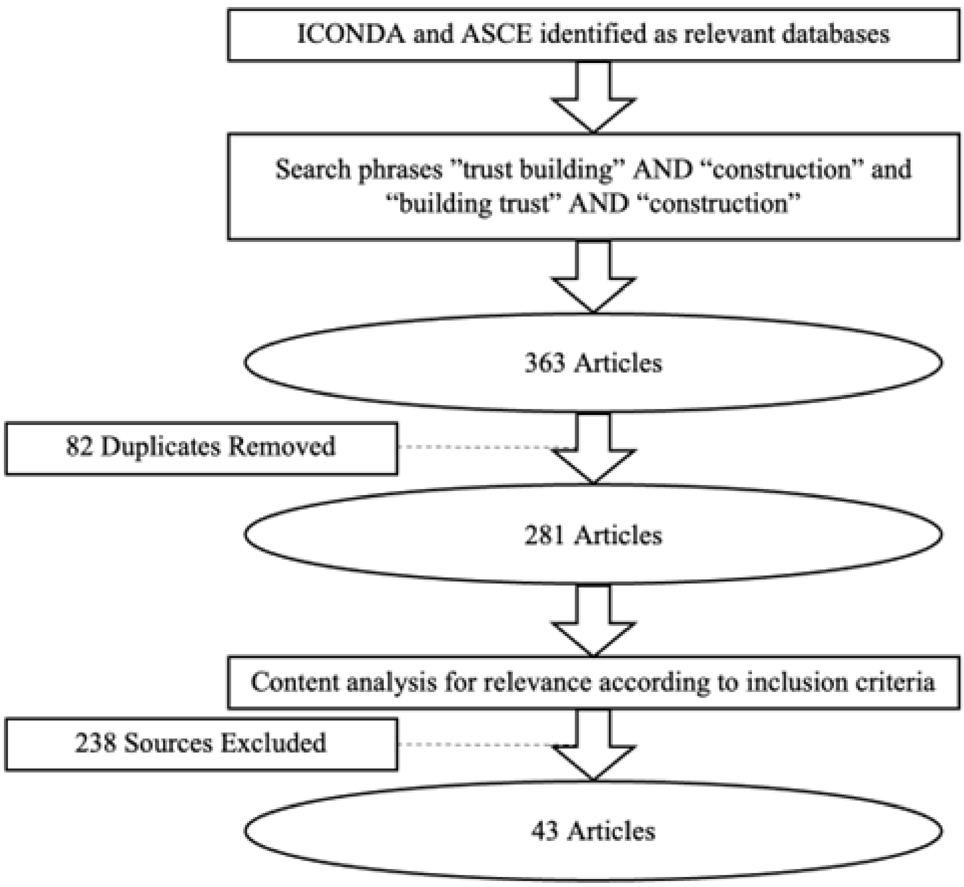

Figure 2. Methodology

A comprehensive literature search was conducted across two key databases to gather pertinent research on trust building within the construction industry: the International Construction Database (ICONDA) and the American Society of Civil Engineers (ASCE). The search queries employed were "trust building" AND "construction," alongside "building trust" AND "construction." From these searches, a maximum of 100 results from each query were considered, culminating in the initial identification of 363 relevant articles and book chapters. Subsequent refinement involved consolidating these findings and eliminating duplicates found across multiple searches, thereby narrowing the collection to 281 unique sources. The sources then were checked for four inclusion criteria: 1) was construction the field of study, 2) was "trust building" in reference to emotional trust, 3) was "trust" mentioned more than once, and 4) finally, was trust the focus of the study. These criteria were decided upon to eliminate sources that pertained to other fields of study or were not truly about trust but merely mentioned the term. A sample of the inclusion process is shown in Table 1.

Table 1. Sample of Content Analysis

Authors	Database	Inclusion Criteria 1	Inclusion Criteria 2	Inclusion Criteria 3	Inclusion Criteria 4	Excluded
Gad & Shane, 2014	ASCE	X	X	X	X	
Ren, Hassan, Carter, & Anumba, 2006	ICONDA		X	X	X	X
Castelblanco, Guevara, Rojas, Correa, & Verhoest, 2023	ASCE	X	X			X
Cheung, Zhu, & Yu, 2019	ASCE	X	X	X		X

To be included, all four inclusion criteria must be met. After the 281 unique references were evaluated based on the above criteria, 238 were excluded resulting in 43 sources remaining (see Table 3). The 43 sources included 35 journal articles, 7 conference papers, and 1 book chapter as shown in Table 2.

Table 2. Reference Types of Included Resources

Peer Reviewed Journal Articles	35
Conference Papers	7
Book Chapters	1

Results and Discussion

All 43 of these sources were reviewed and sorted into categories based on the aspect of trust the author(s) focused on. Table 3 demonstrates the distribution of each trust aspect's prevalence in the research and its connections with other aspects. Identification of each trust aspect was conducted by reading the articles to determine what themes prevailed throughout the article. Those themes became the aspects of trust.

As can be seen in table 3, most of the articles identified were regarding the implications of trust, with the second most common aspect being formal partnering.

Trust must be a common thread throughout the project process as a lack of trust poses a great risk to project success (Jelodar et al., 2016; Rahman & Kumaraswamy, 2012). In construction the project team is often made up of people who have never met, will not be geographically close, and who have little to nothing in common (Lu et al., 2016; Zolin et al., 2000). This prohibits trust from developing through interaction and time resulting in a need for trust to be intentionally developed through trust building exercises (Hartman, 2003).

In search of a hierarchical model of trust, nine of the 43 articles provided indicators of trust. Four of the nine articles analyzed that identified indicators also leveled those trust indicators. Figure 3 shows these indicators in a hierarchy.

Table 3. Matrix of Trust Aspect Covered

	Trust Building	Types of Trust	Implications of Trust	Formal Partnering	**Trust Indicators**
Trust Building	2	-	-	-	-
Types of Trust	1	1	-	-	-
Implications of Trust	1	5	10	-	-
Formal Partnering	2	0	3	4	-
Trust Indicators	0	0	4	1	0
Three Aspects			8		
Four Aspects			0		
Five Aspects			1		

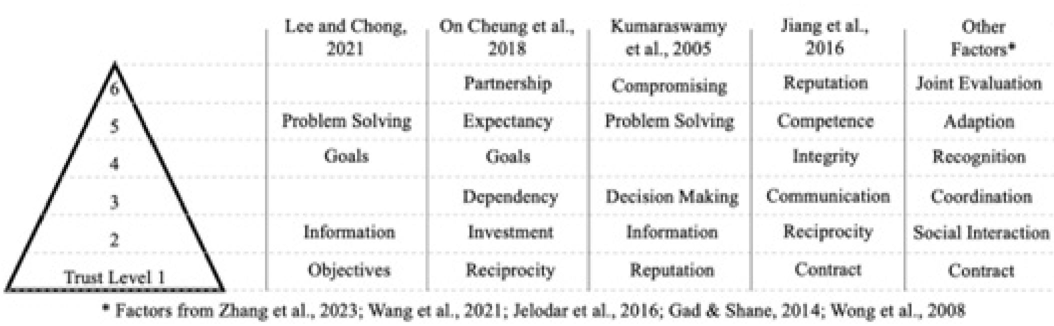

Figure 3. Indicators of Trust at various Levels

Lee and Chong (2021) build trust up as a series of decisions. The decision to share objectives precedes any other decision to trust. It is only through decisions to do all four of these that fully trusting relationships appear.

On Cheung et al. (2018) noted that it is through reciprocity of information, people, and knowledge that trust is first built. The reciprocity of all things builds trust up until a true partnership between entities is formed. This partnership is not always a partnering contract but often simply a shared understanding that each entity will look out for the other. The hierarchical view of trust developed from Kumaraswamy et al. (2005) is based on their survey data where they found that in trusting relationships, good reputation in the industry are most common and compromising is least common. Similarly to Maslow's Hierarchy (1958) where the most common and basic need is at the bottom, the Kumaraswamy et al. (2005) model puts the most common form of trust at the bottom of the pyramid. Jiang et al. (2016) creates their model of trust as a hierarchy of antecedents of trust. The claim that persists is that trust is developed through each of these six indicators.

Based on these indicators of trust created through analysis of nine separate articles, a pattern emerged of how trust is viewed in the industry. The requisite sharing of information shown in both Kumaraswamy et al. (2005) and Lee and Chong (2021) and the collaborative goals of Lee and Chong (2021) and On Cheung et al. (2018) were themes that persisted throughout the 43 relevant articles. Jiang et al. (2016) as well as Gad and Shane (2014) brought forth the idea of contracts as a starter of trust. Contracts begin trust by creating an obligation between parties. In addition to these three indicators of trust, three more common attributes of trust emerged (see Table 5). These six indicators can be defined as reciprocal obligation, sharing information, mutual respect, collaborative goals, common values, and collective purpose. From these six themes, a model of trust was developed to explain the progressive nature of trust.

Table 5. Overview of Taxonomy of Trust

Level	Summary	Authors
1. Reciprocal Obligation	Obligation is the most basic type of trust because it can be stipulated through a contract.	Zhang et al., 2023; Gad & Shane, 2014; Lee et al., 2020; Hartman, 2003; Lu et al., 2016; On Cheung et al., 2018; Pishdad-Bozorgi & Haymaker, 2014; Wong et al., 2008; Wong et al., 2005
2. Sharing Information	Communication and belief in the validity of the information communicated allows for more trust between parties.	Lee & Chong, 2021; Wang et al., 2021; Lee et al., 2020; Challender, 2017; Jiang et al., 2016; Kumaraswamy et al., 2005; Lee et al., 2022; On Cheung et al., 2018; Pishdad-Bozorgi & Haymaker, 2014; Rahmani et al., 2013; Wong et al., 2008; Wong et al., 2005; Zheng et al., 2019
3. Mutual Respect	Building a reputation of ability and competence gains respect which in turn allows for greater trust.	Lee & Chong, 2021; Challender, 2017; Kumaraswamy et al., 2005; Lu et al., 2016; Markert, 2011; On Cheung et al., 2018; Pishdad-Bozorgi & Haymaker, 2014; Yin et al., 2020
4. Collaborative Goals	Sharing goals allows for alignment that gives individuals a feeling of belonging.	Lee & Chong, 2021; Jelodar et al., 2017; Lee et al., 2022; On Cheung et al., 2018; Pishdad-Bozorgi & Haymaker, 2014; Strahorn et al., 2013; Wong et al., 2005
5. Common Values	Through common values one can see a reflection of oneself.	Challender, 2017; Lee et al., 2022; Li et al., 2021; Pishdad-Bozorgi & Haymaker, 2014; Wang et al., 2020; Zheng et al., 2017; Zuppa & Issa, 2008
6. Collective Purpose	Compatible ideals and motivations lead to the development of a collective purpose.	Challender, 2017; Hartman, 2003; Kumaraswamy et al., 2005; Strahorn et al., 2013; On Cheung et al., 2018; Zuppa & Issa, 2008

Table 5 provides an overview of the taxonomy of trust developed in this paper. These six levels in the taxonomy are not types of trust, rather they are phases one must progress through in trusting relationships. As in Lee and Chong's (2021) explanation of trust, the taxonomy of trust offers a series of decisions made to raise trust to the next level. Each level requires more trust than the prior level making this a hierarchical model of trust. The value of a hierarchy comes into play when creating trust building exercises. By establishing a taxonomy of trust, trust building exercises can be evaluated on whether and how they progress participants through the levels of trust.

Trust building exercises can be utilized in building intercompany and interpersonal trust. The taxonomy of trust can be utilized to understand both interpersonal and intercompany levels of trust; however, because the nature of construction projects leads to a lack of consistent personnel on jobs, it is important to focus on intercompany trust (Jelodar, 2016). As such intercompany trust is the focus of this paper.

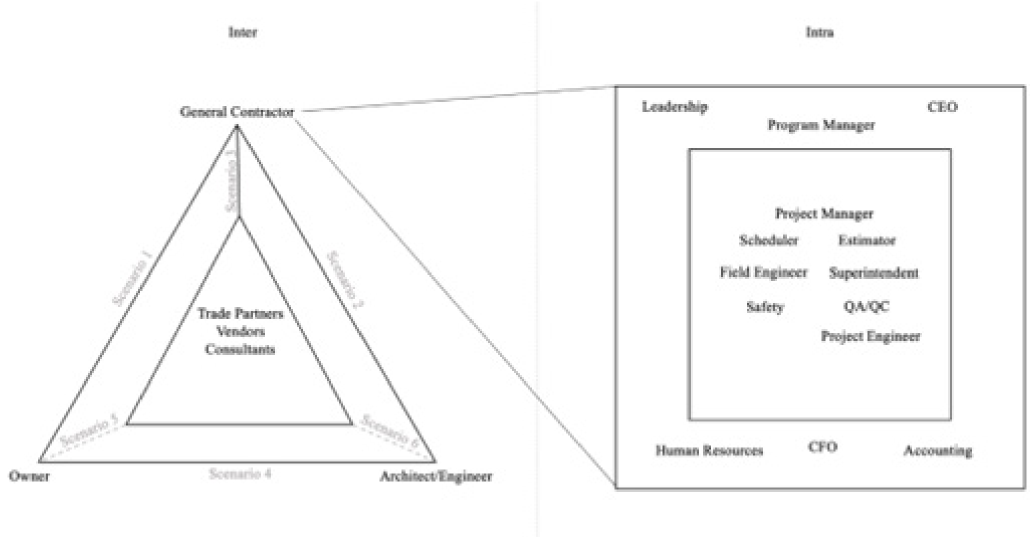

Figure 4. Intercompany versus Interpersonal relationships

Figure 4 depicts intercompany and interpersonal relationships. In addition, there are three scenarios being 1) general contractor and owner relationship in their initial project development, 2) general contractor and design firm on a design-build project, and 3) general contractor and trade partner working together for the first time.

Level		Scenario 1	Scenario 2	Scenario 3
Collective Purpose	6		X	
Common Values	5	X	X	
Collaborative Goals	4	X	X	X
Mutual Respect	3	X	X	X
Sharing Information	2	X	X	X
Reciprocal Obligation	Trust Level 1	X	X	X

Figure 5. Taxonomy of Trust

Figure 5 shows the applicability of the taxonomy of trust in various scenarios. As illustrated scenario 3 requires collaborative goals between trade partners and general contractors such as timeline and budget for this will encourage effective project completion. In addition, having trust between trade partners and general contractors decreases the severity of disputes (Li et al., 2021). Scenario 1 requires common values as development focus must be placed on what is most important to the values of both organizations. It is through this high level of trust that owners are more satisfied with project outcomes (Jiang et al., 2016; Ling & Tran, 2012). Finally, scenario 2 requires the most trust as working on a design build project requires two entities to become one, and for that to be successful everyone must be on equal footing with a collective purpose driving the processes (Gad & Shane, 2014; Ibrahim et al., 2011).

Maslow's Hierarchy of Needs can be mapped to the taxonomy of trust utilizing research on trust and the Hierarchy (see figure 6) (Maslow, 1958).

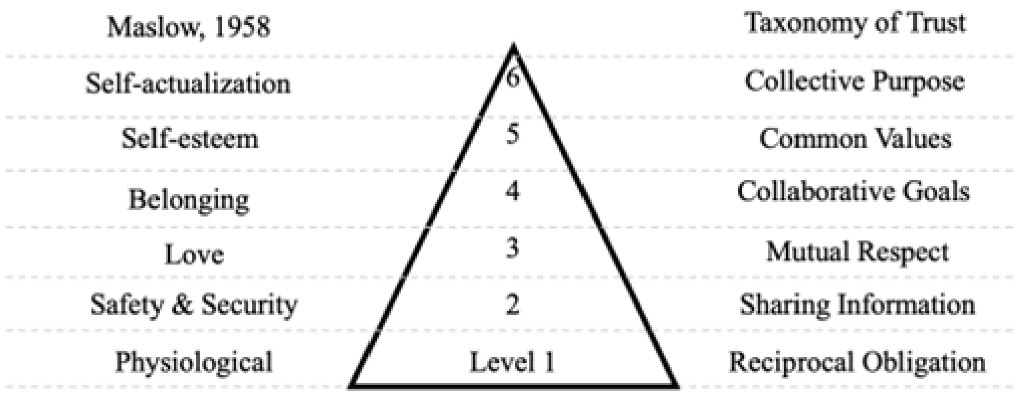

Figure 6. Hierarchy of Needs connection with taxonomy of trust

Reciprocal obligation is necessary for trust to be built (Gad & Shane, 2014). When a contract is signed, there is a mutuality of obligation between the two (or more) parties. A contract allows for trust to be given objectively since there is a legal agreement holding all parties accountable (Rahmani et al., 2013). While the agreement is objective, any subjective language within the contract affects trust (Zhang et al., 2023). In this way, reciprocal obligation is the lowest level of trust. This correlates with physiological needs in Maslow's Hierarchy since it is through obligation that trust can be built, and it is with physiological needs being met that further needs can be pursued (Pichère & Cadiat, 2015). The contract that allows for the obligation's existence draws the focus to physical attributes not emotional ones which aligns reciprocal obligation with physiological needs. Additionally, Maslow (1958) posited that without physiological needs met, there would be no anxiety to meet further needs. In this way, obligation is the lowest level of trust because without an obligation there is no anxiety or need to build trust for there is no relationship upon which to build it (Lee et al., 2020). Furthermore, there does not need to be any subjective feelings regarding the other party, just an understanding between parties that each must do what they agreed on or face some sort of consequence. While a contract can act as a trust mechanism by holding the parties accountable, this makes the obligation forced instead of voluntary (On Cheung, Zhu, & Lee, 2018). Utilization of a contract helps to solidify the details of the obligation, but with trust a contract is not required to ensure mutual obligation (Hartman, 2003). Whether or not there is a contract, trust begins with mutual reliance.

Sharing information brings forth another layer of trust. With this second layer of trust comes the second need: safety and security. When data is shared, there is a chance for it to be weaponized (Wang et al., 2020). For projects to succeed, the team members must trust each other enough to share information without fear (Zhang & Ng, 2012). Trivedi and Mehta (2019) note that employees' valuation of job security falls into this need for safety and security. Therefore, employees may be reluctant to share information with others for fear of losing their job. For information to be shared, employees must see it as not only necessary but encouraged, then and only then will they feel safe enough to share that information (Pishdad-Bozorgi & Haymaker, 2014). There are many types of information that can be shared, but all are relevant in reaching this level of trust. The most vital type of information is project specific details such as plans, specifications, and resources (Zheng et al., 2019). Between individuals the information is often personal (Wong et al., 2008). Both types of information help build relationships and solidify trust (Wang et al., 2021). In all information sharing there must also be trust that the information is factual and relevant (Jiang et al., 2016).

Mutual respect is often considered the basis for relationships; however, without obligation there is no need to build respect (Lu et al., 2016). The age-old adage, "respect is earned not given" is salient for the construction industry. Often respect is not established until work is completed, and one has "proven" themselves as worthy of respect (Challender, 2017). This ties into part of Maslow's third need: love and belonging. The love aspect can be connected to respect as it is through knowing and learning about another that respect can be earned (Maslow, 1958). Reaching the mutual respect level of trust requires giving up authority and believing in one another (Yin et al., 2020). Hakanen and Soudunsaari (2012) posit that respect is based on sharing information. This level of trust should exist between all members of the project team, with respect being a cornerstone of relationships between individuals and stakeholders (Ibrahim et al., 2011).

Collaborative goals allow both parties to see the benefit of their efforts (Pishdad-Bozorgi & Haymaker, 2014; Wong et al., 2005). Forming collaborative goals is often inhibited by misconceptions of where the other parties' interests lie; therefore, aligning goals between two individuals or groups can only truly happen when the prior three levels of trust are present (Strahorn et al., 2013). Without obligation there is no reason to align goals. Without shared information, there is no way to gain understanding of the other parties' interests. Without mutual respect, adjusting preconceptions about each other's interests will be a leap of faith instead of a logical decision. In construction where relationships are temporary, the alignment of goals and outcomes is especially vital because it is often the highest level of trust reached on a project (On Cheung et al., 2018; Jelodar et al. 2017). The second half of Maslow's love and belonging needs comes into play with goals (Maslow, 1958). The need for belonging is the need to be part of something larger than oneself. With the creation of collaborative goals, individuals gain the feeling of being part of a team and thus are self-motivated to dive further into the work and build better relationships with teammates (Pishdad-Bozorgi & Haymaker, 2014).

Establishing common values is the fifth level of trust and a large leap from goals. Goals can be achieved by two people with entirely different values. However, by sharing values completing those goals becomes a shared task instead of a task that is broken up to be completed (Lee et al. 2022). Common values are only possible when entities are aligned on lower levels of trust (Hakanen & Soudunsaari, 2012). Values are at their core motivations; they are individuals' beliefs that connect feelings to actions. Companies can have established values, but it is the individuals within the companies that create action, so the values of the companies are less important for building trust than individuals' values. Maslow's (1958) fourth need is self-esteem (Li et al., 2021). This need is characterized by a desire to have agency. It is through common values that people earn the trust of another enough to make decisions for the other (Pishdad-Bozorgi & Haymaker, 2014). With this agency comes the feeling of importance within a group. Those common values that give one agency motivate both individuals and groups to complete tasks. Finding common values leads to higher trust between parties as they find similar motivation (Schoonover et al., 2019).

Collective purpose requires vulnerability, belief in another, and evokes an elevated level of trust. It is through sharing a purpose that parties can be aligned, and the value of partnerships can be realized (Zuppa & Issa, 2008). Purpose is built from shared values and goals (Cook, 2009). It is difficult to reach a collective purpose because it requires setting aside individual gains for group achievements (Zheng et al., 2017). Additionally, for purpose to become shared, trust must be present early in the project (Strahorn et al., 2013). This can happen only by meeting the highest need: self-actualization (Maslow, 1958). With self-actualization comes acceptance and morality: a view of the whole not one's individual part. Uniting entities along a common purpose is the highest level of trust (Villachica, Stone, & Endicott, 2004).

This taxonomy of trust can be mapped back to Maslow's Hierarchy of Needs (see figure 6). The basis of Maslow's theory is that to pursue a higher need, the lower levels of the pyramid must be satisfied. In the same way that one must have safety and security before self-esteem, one must establish collaborative goals before gaining common values.

Conclusion

The current study leveraged the literature on Maslow's Hierarchy of Needs to develop a taxonomy of trust to define trust in the construction industry. The reliance on Maslow's Hierarchy may mean the taxonomy of trust is not universal as Maslow's Hierarchy is not universal. Relationships build from established obligations, and with a relationship comes a need to share information and expertise. When information is shared, relationships grow, and respect can be gained. To work on a goal with another, there must be respect or else there is no value gained by working together. Collaboration does not require believing another has the conglomerate's best interests at heart (Gad & Shane, 2014). But to advance beyond simple collaboration, values must become a commonality. The motivations of each party need to align for trust to grow further. The final level of trust 2 is collective purpose because that alignment of purpose establishes full trust. As two parties move through the levels of trust, the level of risk each member is taking increases (Wang et al., 2020). With the increase of risk comes the increase of rewards, for it is when collective purpose is established that collaborative productivity is most effective.

Various researchers have identified the implications and importance of trust to project success, but no established structure of trust that reflects the importance of trust throughout the lifecycle of the project has been defined. That connection presents a valuable area for future research. In addition, with this model as an overview of trust, exercises, education, and best practices for building trust throughout the phases of a project can be formulated.

References

Bouzenita, A. I., & Boulanouar, A. W. (2016). Maslow's hierarchy of needs: An Islamic critique. Intellectual Discourse, 24(1).

Castelblanco, G., Guevara, J., Rojas, D., Correa, J., & Verhoest, K. (2023). Environmental impact assessment effectiveness in public–private partnerships: Study on the Colombian toll road program. Journal of Management in Engineering, 39(2).

Challender, J. (2017). Trust in collaborative construction procurement strategies. Proceedings of the Institution of Civil Engineers-Management, Procurement and Law, 170(3), 115-124. https://doi.org/10.1680/jmapl.16.00018

Cheung, S. O., Zhu, L., & Yu, K. I. (2020). Will apology enhance construction dispute settlement? Journal of Legal Affairs and Dispute Resolution in Engineering and Construction, 12(1).

Cook, S. (2009). Building a High Performance Team: Proven techniques for effective team working. IT Governance.

Gad, G. M., & Shane, J. S. (2014). Trust in the Construction Industry: A Literature Review. In Construction Research Congress 2014 (pp. 2136–2145). https://doi.org/10.1061/9780784413517.217

Hakanen, M., & Soudunsaari, A. (2012). Building Trust in High-Performing Teams. Technology Innovation Management Review, 2(6), 38-41. https://doi.org/10.22215/timreview567

Ibrahim, C. K. I. Costello, S. B., & Wilkinson, S. (2011). Key Relationship Oriented Indicators of Team Integration in Construction Projects. International Journal of Innovation, Management and Technology, 2(6), 441-446.

Hartman, F. (2003). Thou Shalt Trust Thy Contracting Partner, But not do so Unreasonably. In Ten Commandments of Better Contracting (pp. 235–263). https://doi.org/10.1061/9780784406533.ch07

Jelodar, M. B., Yiu, T. W., & Wilkinson, S. (2017). Assessing Contractual Relationship Quality: Study of Judgment Trends among Construction Industry Participants. Journal of Management in Engineering, 33(1). DOI: 10.1061/(ASCE)ME.1943-5479.0000461

Jelodar, M. B., Yiu, T. W., & Wilkinson, S. (2016). Relationship-Quality Judgment Model for Construction Project Procurement: A Conjoint Measurement. Journal of Construction Engineering and Management, 142(7). https://doi.org/10.1061/(ASCE)CO.1943-7862.0001104

Jiang, W., Lu, Y., & Le, Y. (2016). Trust and project success: A twofold perspective between owners and contractors. Journal of Management in Engineering, 32(6). DOI: 10.1061/(ASCE)ME.1943-5479.0000469

Kumaraswamy, M. M., Ling, F. Y., Rahman, M. M., & Phng, S. T. (2005). Constructing relationally integrated teams. Journal of construction engineering and management, 131(10), 1076-1086. DOI: 10.1061/(ASCE)0733-9364(2005)131:10(1076)

Lee, C. Y., Chong, H. Y., Tanko, B. L., & Klufallah, M. (2022). Effect between trust in communication technology and interorganizational trust in BIM-enabled projects. Journal of Construction Engineering and Management, 148(8). DOI: 10.1061/(ASCE)CO.1943-7862.0002299

Lee, C. Y., & Chong, H. Y. (2021). Influence of Prior Ties on Trust and Contract Functions for BIM-Enabled EPC Megaproject Performance. Journal of Construction Engineering and Management, 147(7). https://doi.org/10.1061/(ASCE)CO.1943-7862.0002076

Lee, C. Y., Chong, H. Y., Li, Q., Wang, X. (2020). Joint Contract–Function Effects on BIM-Enabled EPC Project Performance. Journal of Construction Engineering and Management, 146(3). https://doi-org.libproxy.clemson.edu/10.1061/(ASCE)CO.1943-7862.0001766

Li, B., Gao, Y., Zhang, S., & Wang, C. (2021). Understanding the Effects of Trust and Conflict Event Criticality on Conflict Resolution Behavior in Construction Projects: Mediating Role of Social Motives. Journal of Management in Engineering, 37(6). https://doi.org/10.1061/(ASCE)ME.1943-5479.0000962

Ling, F. Y. Y., & Tran, H. B. T. (2012). Ingredients to engender trust in construction project teams in Vietnam. Construction Innovation, 12(1), 43-61. https://doi.org/10.1108/14714171211197490

Lu, P., Qian, L., Chu, Z., & Xu, X. (2016). Role of opportunism and trust in construction projects: Empirical evidence from China. Journal of management in engineering, 32(2). DOI: 10.1061/(ASCE)ME.1943-5479.0000401

Markert, C. D. (2011). Partnering: What must be done to avoid failure. Leadership and Management in Engineering, 11(2), 155-161. https://doi.org/10.1061/(ASCE)LM.1943-5630.0000115

Maslow, A. H. (1958). A Dynamic Theory of Human Motivation. In C. L. Stacey & M. DeMartino (Eds.), Understanding human motivation (pp. 26–47). Howard Allen Publishers. https://doi.org/10.1037/11305-004

Okoli, C. (2015). A guide to conducting a standalone systematic literature review. Communications of the Association for Information Systems, 37.

On Cheung, S., Zhu, L., & Wai Lee, K. (2018). Incentivization and Interdependency in Construction Contracting. Journal of Management in Engineering, 34(3). https://doi.org/10.1061/(ASCE)ME.1943-5479.0000601

Pichère, P., & Cadiat, A. C. (2015). Maslow's hierarchy of needs (C. Probert, Trans.). Lemaitre Publishing.

Pishdad-Bozorgi, P., & Haymaker, J. (2014). Effect of decision-making methods on trust. In Construction Research Congress 2014: Construction in a Global Network (pp. 857-866). DOI: 10.1061/9780784413517.088

Rahmani, F., Khalfan, M., Maqsood, T., Noor, M. A., & Alshanbri, N. M. (2013). How can trust facilitate the implementation of Early Contractor Involvement (ECI)? In Proceedings Procurement Systems: Selected Papers presented at the CIB World Building Congress Construction and Society (pp. 74-85). International Council for Building.

Rahman, M. M., & Kumaraswamy, M. M. (2012). Multicountry Perspectives of Relational Contracting and Integrated Project Teams. Journal of Construction Engineering and Management, 138(4), 469–480. https://doi.org/10.1061/(ASCE)CO.1943-7862.0000463

Ren, Z., Hassan, T. M., Carter, C. D., & Anumba, C. J. (2005). Agent-facilitated Trust Building in the SEEM Infrastructure. In CIB W-78 Conference Information Technology in Construction.

Schoonover, H. A., Grêt-Regamey, A., Metzger, M. J., Ruiz-Frau, A., Santos-Reis, M., Scholte, S. S. K., Walz, A., Nicholas, K. A. (2019). Creating space, aligning motivations, and building trust: a practical framework for stakeholder engagement based on experience in 12 ecosystem services case studies.

Ecology and Society, 24(1). DOI 10.5751/ES-10061-240111

Strahorn, S., Thayaparan, G., & Brewer, G. (2013). Mechanisms of trust and trust repair in relational contracting: a multiple perspective investigation of alliance projects. In CIB World Congress 2013 (pp. 5-9).

Trivedi, A. J., & Mehta, A. (2019). Maslow's Hierarchy of Needs-Theory of Human Motivation. International Journal of Research in all Subjects in Multi Languages, 7(6), 38-41.

U.S. Bureau of Labor Statistics. (2022). Occupational Employment and Wage Statistics. Retrieved from https://data.bls.gov/oes/#/indOcc/Multiple%20occupations%20for%20one%20industry

Villachica, S. W., Stone, D. L., & Endicott, J. (2004). Project alignment ensuring successful development and implementation from day one. Performance Improvement, 43(10), 9-15.

Wang, X., Yuhan Qiao, Y., Wang, D., Sheng, Z., & Newaz, M. T. (2021). Psychological Contract of Safety and Construction Worker Behavior: Felt Safety Responsibility and Safety-Specific Trust as Mediators. Journal of Construction Engineering and Management, 147(11). https://doi-org.libproxy.clemson.edu/10.1061/(ASCE)CO.1943-7862.0002185

Wang, D., Wang, Y., & Lu, Y. (2020). Impact of Regulatory Focus on Uncertainty in Megaprojects: Mediating Role of Trust and Control. Journal of Construction Engineering and Management, 146(12). https://doi.org/10.1061/(ASCE)CO.1943-7862.0001951

Wong, P. S., Cheung, S. O., & Ho, P. K. (2005). Contractor as Trust Initiator in Construction Partnering—Prisoner's Dilemma Perspective. Journal of Construction Engineering and Management, 131(10), 1045–1053. https://doi.org/10.1061/(ASCE)0733-9364(2005)131:10(1045)

Wong, W. K., Cheung, S. O., Yiu, T. W., & Pang, H. Y. (2008). A framework for trust in construction contracting. International Journal of Project Management, 26(8), 821–829. https://doi.org/10.1016/j.ijproman.2007.11.004

Yin, H., Yin, Y., Wang, D., Jiang, H., & Mu, Z. (2020, March). How to choose a trusted contractor? Ability, experience, and reputation. In Construction Research Congress 2020 (pp. 1203-1211). Reston, VA: American Society of Civil Engineers.

Zhang, L., Yao, H., Fu, Y., & Chen, Y. (2023). Comparing Subjective and Objective Measurements of Contract Complexity in Influencing Construction Project Performance: Survey versus Machine Learning. Journal of Management in Engineering, 39(4). https://doi.org/10.1061/JMENEA.MEENG-5331

Zhang, P., & Ng, F. F. (2012). Attitude toward knowledge sharing in construction teams. Industrial Management & Data Systems, 112(9), 1326-1347. DOI 10.1108/02635571211278956

Zheng, X., Lu, Y., & Chang, R. (2019). Governing Behavioral Relationships in Megaprojects: Examining Effect of Three Governance Mechanisms under Project Uncertainties. Journal of Management in Engineering, 35(5). https://doi.org/10.1061/(ASCE)ME.1943-5479.0000701

Zheng, X., Song, X., Zhang, S., & Gao, Y. (2017). Identification of Trust-Repair Strategies and Their Effectiveness in the Chinese Construction Industry. Journal of Management in Engineering, 33(6). https://doi.org/10.1061/(ASCE)ME.1943-5479.0000557

Zolin, R., Fruchter, R., & Levitt, R. (2000). Building, Maintaining and Repairing Trust in Global AEC Teams. Computing in Civil and Building Engineering, 874–881. https://doi.org/10.1061/40513(279)114

Zuppa, D., & Issa, R. (2008). Aligning interests key to developing trust in deploying collaborative technologies in construction. In CIB W78 2008 International Conference on Information Technology in Construction.

Root and Causes of Skilled Labor Shortage in Construction Industry: Comprehensive Literature Review

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ABSTRACT
The skilled labor shortage is well documented from a historical perspective via studies focusing various construction trades such as carpentry, mechanical, electric and plumbing, and tile setters. Causes of such shortages such as industry image, college as a preferred choice after high school, and construction being a last resort have been investigated extensively. Consequently, possible solutions ranging from amplifying shop classes in high school to intensifying recruiting efforts for union training programs have all been addressed throughout the last 40 years. However, recent studies have focused on identifying the magnitude and reach of the skilled labor gap while limited attention is given to the impacting factors that played a role in the decision to pursue an education and eventual career in construction, especially on the management side of the industry. This study, therefore, establishes the current state of existing body of knowledge in this area and identify gaps therein through a comprehensive literature review.

Keywords: Construction Labor Shortage; Construction Career;

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INTRODUCTION

Skilled labor shortage is gripping the skilled trades that make up with an ever growing gap illustrated by the findings of Ken Simonson, Chief Economist of the Associated General Contractors, May 2022 report that found construction unemployment at the all-time low level in the 22 year history of Simonson's reporting for the AGC of America of 4.5% (Simonsen, 2022). Akomah, Ahinaquah, and Mustapha (2020) identified areas of skilled labor shortage in the construction industry in central Ghana through a research questionnaire and found that skilled construction trades shortages included electricians, tile setters, and painters with motivating factors including socio economic conditions, external forces, job attractiveness among others. The approach of the paper is from a hypothetical position with a focus on a decision not made, and large variances to be allowed for.
Chini, Brown, and Drummond (1999), cited the change in vocational education and technology, economic changes as well as a shift toward open shop contracting steering young people away from the trades. They developed a two-phase approach with the first phase consisting of a demand to retain existing workers and streamline work processes and the second phase consisting of a longer term, recentering of construction education systems., While highly pertinent to the skilled labor shortage, their work does not investigate the decision-making process involved when choosing a career in the skilled trades. Koch (2007) investigated the decision-making process for students who decided to pursue an education and potentially a career in construction management (CM) and identified motivating factors and influences for those students in the decision-making process including family members, mentors, and role models as well as personal influences such as an interest in construction. And while this work focuses on the management/higher education path of the construction industry it both closely aligns with this research and provides clarity to the gap in the skilled labor in construction shortage body of knowledge.

Further review of the literature revealed that much of the existing data that makes up the body of knowledge on the topic of skilled labor shortage focused on the role of higher education as a potential source of relief. It, therefore, means that the role played by the trades in bridging the skilled labor shortage gap has not been explored extensively. Moreover, the questions asked and methods employed including surveys and analysis of existing data sources, regardless of the focus of the study, could lend themselves to a new study focused on the skilled trades in the construction industry by using CM majors as the subject samples. Additionally, while the existing body of knowledge in the skilled labor shortage in construction is robust and thorough, gaps caused by a narrowed focus on various impacts and influences exist. Specifically, the work done by Koch (2007) created a series of data points that present a potential for new inroads into the decision-making process of those that have recently started a new education and career path in the skilled construction trades.

GOALS AND OBJECTIVES

The overarching goal of this study is to establish the current state of the body of knowledge on skilled labor shortage in the construction industry. This will be accomplished by assessing the existing body of knowledge for skilled labor shortage across various industries including healthcare, agriculture, business, as well as construction. To achieve this goal, it is the aim of this research study to:

1. Review the labor shortage body of knowledge across various industries.
2. Assess the state of the body of knowledge of the skilled labor shortage with an emphasis on skilled trades in construction.
3. Identify gaps in the literature and provide areas of opportunity for future research.

In accomplishing these goals, it is the intent of researchers to provide insights for those who seek to develop additional workers and assist in the process of closing gaps and creating a more complete body of knowledge in the field of skilled labor shortage in construction.

METHODOLOGY

This study utilizes a comprehensive literature review methodology. The initial keyword of 'skilled labor shortage' was identified and searched using an extensive search using The LSU Library, Google Scholar, LSU Digital Commons, EBSCO Host providing 366,000 results. Due to the vast nature of papers found additional keywords were utilized by adding Boolean operators to identify the presentient topics of the skilled labor shortage thus narrowing the search further by focusing 40 years. Career decision making and influencing factors were two additional keywords that narrowed the scope of the research. Career decision making and influencing factors impact the process that individuals utilize to arrive at the conclusion to pursue a career in their given fields. On the other hand, the impact that industry image may play in the career decision making process was also considered narrowing the results to 150.

With these results in mind goals were identify for this literature review with the intent of establishing the current state of the body of work was further refined to the date range of 1993 to 2021to provide delineation and prevent impacts to the findings from work conducted during the pandemic. A qualitative analysis approach was used utilizing the pertinent keywords to identify focus of efforts and identify potential gaps in the body of knowledge in that timeframe and seek to utilize those gaps as opportunities for future research.

Furthermore, a comprehensive analysis and segmentation of the compiled works into tables by industry, identifying common themes, and developing concepts to develop a more robust body of knowledge.

Table 1 (see appendix A) presents a summary of the current skilled labor shortage research in across industries, trends by year, pertinent keywords including *Skilled labor shortage, Career decision making, Influences, and Industry image,* as well as methodology utilized.

To create a deeper understanding of the work represented in Figure 1 and Table 1 papers that address the construction industry specifically and focus on key concepts identified using the keywords were investigated more in more depth in the subsequent sections with the aim to narrow the findings further and add clarity to the state of practice.

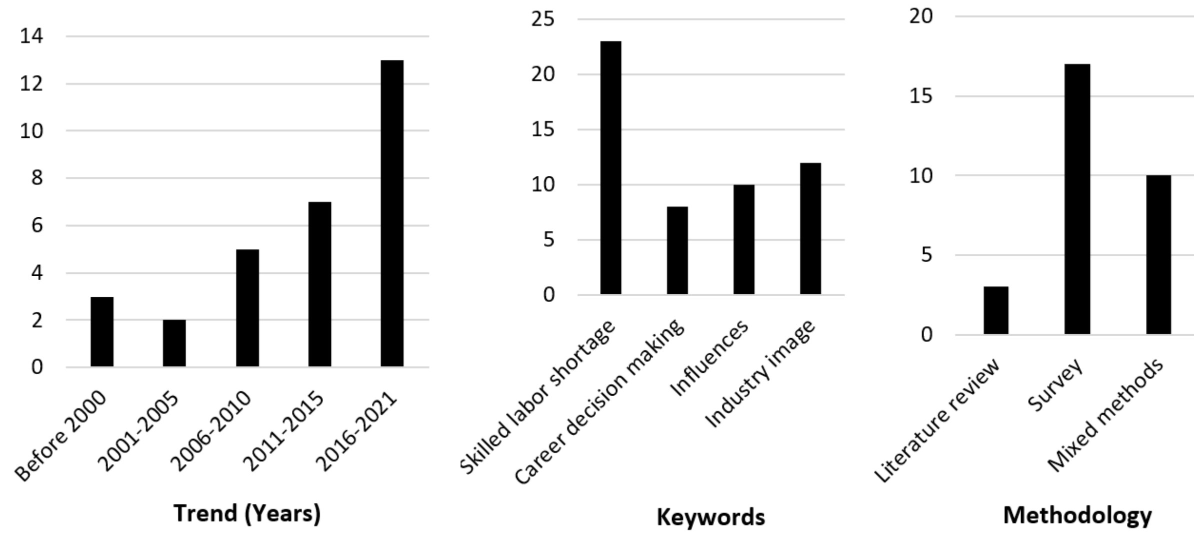

Figure 1. Chart summary from the frequency of Trend Year, Keywords, and Methodology in the literatures on Table 1

Pre-enrollment construction experience

Koch et al. (2007) sought to understand the relationship, if any, between construction related occupational experience and the decision to enter a construction management program at a 4 year university by asking "Do students who are enrolled in construction management programs have related occupational experiences before enrollment?" using a survey tool asked 257 construction management majors various questions focused on their paid, volunteer, and CTE experience as shown in table 2 (see appendix B).

Koch et al. (2009) investigated career influences and demographics of construction management students by asking "What are the career influences of construction management students?" students were asked to rate career decision influences by providing a list of potential influences, both people and situations were rated using a Likert scale with a range of 1 to 5. As shown in Table 2.

Pre-enrollment and construction experience summary

The Koch (2007) (2009) papers noted in Table 2, and expounded upon in this section, sought to identify the demographical information and influences and impacts that played a role in the making of the decision to pursue formal education in construction management with a study population consisting of students that were actively enrolled in an accredited construction management in a Midwestern state.

Demographic results consisted of age, gender, and geographical data framing a similar image to what you would find if you were to take a snapshot of the demographics that make up the current construction industry on the management side, while career influence findings identified "Interest in construction" as the leading influencing concept and "Fathers" as the leading person and previous construction experience was found to have little correlation to the decision-making process.

Moreover, survey tools were employed in both studies creating a framework of questions asked to construction management students that could be reframed and focused on the skilled trade portion of the construction industry with the intent of producing similar data.

Additionally, these papers provided insight into the decision-making process to pursue an education and potential career on the management side of the construction industry no direct findings related to the skilled constructions trades were present.

Mentors and motivating factor identification

Thevenin and Elliott (2015) developed a demographic profile of students and identified their relationships with both mentors and role models and associated 3 hypotheses:

1. H1: The influence of others on academic decisions (IM and SG constructs) is significantly and positively correlated with construction education self-efficacy (CESE).
2. H2: The influence of others on academic decisions (IM and SG constructs) is significantly and positively correlated with construction education motivation (CEM).
3. H3: CM students with a M/RM working in the construction industry will report a significantly higher level of influence of others on academic decisions (IM and SG constructs) than CM students with a M/RM who does not work in the construction industry.

Using a quantitative survey tool asked a participant pool consisting of undergraduate construction management students to quantify the influence of others their academic decisions and identify mentors from one of five categories: family members, friend/peer/significant other (spouse/partner), professor/instructor/academic advisor, co-worker/supervisor, other. Participants who identified as having a mentor were asked to rank the influence of the mentor, they identified their mentor's gender as well. Details in Table 3(see appendix C).

Mentors and motivating factor identification summary

Of the 679 total respondents 398 reported having a role model with 270 of those identified as family members and approximately 50% of the mentors identified working in the construction industry while 290 respondents reported having a mentor with 158 of the identified mentors coming from their own family with approximately 56% of the role models identified working in the construction industry.

Moreover, the work of Thevenin and Elliott (2015) provide insight into the roles of mentors and role models in the decision making process to pursue an education and potential career on the management side of the construction industry no direct findings related to the skilled constructions trades were present.

Motivating and influencing factors

Bigelow et al. (2021) developed both a qualitative and quantitative data stream from a population made up of 565 individuals working in the electrical construction trade sourced from NECA contractors with questioning aimed at identifying the motivating factors and influences that play a role in choosing to remain in the industry across age groups as electrical trades people move through their career towards management and eventually retirement. Details in Table 4 (see appendix D).

Motivating and influencing factors summary

Bigelow et al. (2021) established correlations in career selection for younger participants with the decision process for older participants to stay in their chosen careers as well as providing data showing that factors of "Salary/Wages" and "No other opportunities" received similar responses from the oldest and youngest participant groups.

Moreover, this work provided insight into the skilled trades in the construction industry and motivating factors to remain I the industry it was limited on the topic of the skilled labor shortage.

Personal opinions on construction industry career outlook, reward, and industry image

Haupt & Harinarian (2016)used a mixed approached surveying high school student, construction employees, and construction employers as well as focus groups with construction employers. The high school student groups were asked to answer questions on various topics applying a 5-point Likert scale to rate understanding of construction related career opportunities as well as their perceptions of working in the construction industry focusing on various topics of consideration, including but not limited to: industry image, reward, and career opportunity. Details in Table 5 (see appendix F).

Personal opinions on construction industry career outlook, reward, and industry image summary

Haupt and Harinarain (2016) found in this work that the South African construction industry image was predominantly negative with low wages, unsafe working conditions, male dominated, and a history of fraud and corruption with little to nothing being done to change the image of the construction industry in South Africa.

Moreover, this work employed a diverse population to accumulate a robust output it failed to segment responses resulting in a mixed survey response with no means of distinguishing between opinions of high school students and construction industry professionals and had no focus on the skilled labor shortage.

FINDINGS

Three goals for this literature review were outlined early in this study:

1. Review the labor shortage across various industries.
2. Assess the state of the body of knowledge of the skilled labor shortage with an emphasis on skilled trades in construction.
3. Identify gaps in the literature and provide areas of opportunity for future research.

Goal 1 revealed evidence that skilled labor shortage is not confined to a single industry rather a challenge that is present across a various industry including Medical, Business Entrepreneurship, and Construction.

Goal 2 revealed that the current body of knowledge is limited in scope and depth with most of the work that is focused on the skilled labor shortage in construction possess themes geared towards higher education and those that chose construction management as a career path with no focus on the decision-making process to pursue a career in the skilled construction trades.

Goal 3 has revealed gaps in the literature, including a lack of focus on the decision-making process to pursue a career in the skilled construction trades, and yielded several avenues for future research including a deeper understanding of the influences and motivating factors that impact the decision to pursue a career in the skilled construction trades.

CONCLUSION

The overarching results of this deep dive literature review is no work to investigate decision-making process to pursue a career in the skilled construction trades has been completed leaving a significant gap that needs to be investigated further.

Specific concepts have been revealed and provided a more robust look into the available literature in the areas of career decision making, influencing factors, and/or, industry image, and in doing so create a deeper understanding of the current state of the body of knowledge related to the skilled labor shortage leaving out a specific focus on the skilled labor side of the construction industry.

The gaps within the body of knowledge including a lack of focus on the skilled trades in the construction industry with little to no focus on the skilled trades in construction with the impacts of mentors and role models on the decision-making process to pursue a career in the skilled trades in construction to this end the need for an appropriate survey tool needs to be developed and implemented on a study population that has recently made the decision to pursue a career in the skilled construction trades.

DISCUSSION AND FUTURE WORK

Throughout this literature review several gaps in the current body of knowledge have been identified that spans across a myriad of industries with the construction industry being impacted by a skilled labor shortage with significant impacts including but not limited to schedule, pricing, and overall project outcomes.

Based on the findings, specifically the lack of focus on the skilled labor shortage in the skilled trades of the construction industry found in this literature review, a new survey tool will be developed with a focus on the decision-making process of skilled trades people currently working in the industry and the influences of mentors, role models, industry image, and influencing factors that impacted this process with the intent of this survey tool will be to quantify the impact of those variables on the decision-making process to pursue a career in the skilled construction trades.

Moreover, two companion papers will be developed, the first will discuss the process of the development of the survey tool to create a repeatable process for a deeper dive into the decision-making process to pursue a career in the skilled construction trades. The second paper will reveal findings from the pilot deployment of the developed survey tool and provide initial insights into the influencing and impactful factors as reported by those that have recently made the decision to pursue a career in the skilled construction trades.

REFERENCES

Admani, S., Caufield, M., Kim, S. S., Siegfried, E. C., & Friedlander, S. F. (2014). Understanding the pediatric dermatology workforce shortage: mentoring matters. *The Journal of Pediatrics, 164*(2), 372–375. e371.

Akomah, B. B., Ahinaquah, L. K., & Mustapha, Z. (2020). Skilled labour shortage in the building construction industry within the central region. *Baltic Journal of Real Estate Economics and Construction Management, 8*(1), 83–92.

Assaad, R., & El-adaway, I. H. (2021). Impact of dynamic workforce and workplace variables on the productivity of the construction industry: New gross construction productivity indicator. *Journal of Management in Engineering, 37*(1), 04020092.

Baldry, D. (1997). *The image of construction and its influence upon client's, participants and consumers.* Paper presented at the Proceedings of 13th Annual ARCOM Conference, Kings College Cambridge, September.

Bigelow, B. F., Perrenoud, A. J., Rahman, M., & Saseendran, A. (2021). An exploration of age on attraction and retention of managerial workforce in the electrical construction industry in the United States. *International Journal of Construction Education and Research, 17*(1), 3–17.

Buerhaus, P. I., Skinner, L. E., Auerbach, D. I., & Staiger, D. O. (2017). Four challenges facing the nursing workforce in the United States. *Journal of Nursing Regulation, 8*(2), 40–46.

Cappelli, P. H. (2015). Skill gaps, skill shortages, and skill mismatches: Evidence and arguments for the United States. *ILR Review, 68*(2), 251–290.

Carrier, E. R., Yee, T., & Stark, L. (2011). Matching supply to demand: Addressing the US primary care workforce shortage. *Looking Ahead, 5*(4), 1–7.

Charlton, D., & Kostandini, G. (2021). Can Technology Compensate for a Labor Shortage? Effects of 287 (g) Immigration Policies on the US Dairy Industry. *American Journal of Agricultural Economics, 103*(1), 70–89.

Chini, A. R., Brown, B. H., & Drummond, E. G. (1999, April 7 – 10). *Causes of the construction skilled labor shortage and proposed solutions.* Paper presented at the ASC Proceedings of the 35th Annual Conference, California Polytechnic State University - San Luis Obispo, California. http://ascpro0.ascweb.org/archives/1999/chini99.htm

Choi, J. O., Shrestha, P. P., Lim, J., & Shrestha, B. K. (2018). *An investigation of construction workforce inequalities and biases in the architecture, engineering, and construction (AEC) industry.* Paper presented at the Construction Research Congress 2018: Sustainable Design and Construction and Education. http://dx.doi.org/10.1061/9780784481301.007

Construction Industry Institute. (2018, July). *Improving the U.S. workforce development system.* Paper presented at the CII Annual Confrence, UT Austin. https://www.construction-institute.org/CII/media/Publications/publications/fr-335_ac18.pdf

Corney, T., & du Plessis, K. (2010). Apprentices' mentoring relationships: The role of "significant others" and supportive relationships across the work-life domains. *Youth Studies Australia, 29*(3), 18–26.

Dong, X., Men, Y., & Fujimoto, A. (2008). *The construction chart book*. CPWR-The Center for Construction Research and Training. https://www.cpwr.com/wp-content/uploads/publications/5th-Edition-Chart-Book-Final.pdf

Elliott, J. W., Thevenin, M. K., & Lopez del Puerto, C. (2016). Role of gender and industry experience in construction management student self-efficacy, motivation, and planned behavior.

International Journal of Construction Education and Research, 12(1), 3–17.

Escamilla, E., Ostadalimakhmalbaf, M., & Bigelow, B. F. (2016). Factors impacting Hispanic high school students and how to best reach them for the careers in the construction industry. *International Journal of Construction Education and Research, 12*(2), 82–98.

Federle, M. O., Rowings Jr, J. E., & DeVany, T. S. (1993). Model of career choice for craftworkers. *Journal of construction engineering and management, 119*(1), 105–114.

Foskett, N. H., & Hemsley-Brown, J. (1999). Invisibility, perceptions and image: Mapping the career choice landscape. *Research in Post-Compulsory Education, 4*(3), 233–248.

Haupt, T., & Harinarain, N. (2016). The image of the construction industry and its employment attractiveness. *Acta Structilia, 23*(2), 79–108.

Healy, J., Mavromaras, K. G., & Sloane, P. J. (2011). Adjusting to skill shortages: complexity and consequences. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.1958753

Karimi, H., Taylor, T. R., Goodrum, P. M., & Srinivasan, C. (2016). Quantitative analysis of the impact of craft worker availability on construction project safety performance. *Construction Innovation*, *16*(3), 307–322

Kashiwagi, D. T., & Massner, S. (2002, April 11 - 13). *Solving the construction craftperson skill shortage problem through construction undergraduate and graduate education.* Paper presented at the ASC Proceedings of the 38th Annual Conference, Virginia Polytechnic Institute and State University - Blacksburg, Virginia. http://ascpro0.ascweb.org/archives/cd/2002/pro2002/2002/Kashiwagi02c.htm

Koch, D. C. (2007). *Experiences and relationships that influence construction management students' career choice*. 43rd Annual Proceedings of the Associated Schools of Construction International, pp. 353–363.

Koch, D. C., Greenan, J., & Newton, K. (2009). Factors that influence students' choice of careers in construction management. *International Journal of Construction Education and Research, 5*(4), 293–307.

Krei, M., & Rosenbaum, J. (2001). Career and college advice to the forgotten half: What do counselors and vocational teachers advise? *Teachers College Record, 103*(5), 823–842.

Minooei, F., Goodrum, P. M., & Taylor, T. R. (2020). Young Talent Motivations to Pursue Craft Careers in Construction: The Theory of Planned Behavior. *Journal of construction engineering and management, 146*(7), 04020082.

Sheldon, G. F., Ricketts, T. C., Charles, A., King, J., Fraher, E. P., & Meyer, A. (2008). The global health workforce shortage: role of surgeons and other providers. *Advances in surgery, 42*, 63–85.

Simonsen, K. (2022). *Construction employment stalls as industry unemployment rate falls to 4.5 percent, lowest ever for april, highlighting difficulty filling jobs*. Data Digest. https://www.agc.org/news/2022/05/06/construction-employment-stalls-industry-unemployment-rate-falls-45-percent-lowest-ever-april

Thevenin, M. K., & Elliott, J. W. (2015). *Construction management students' mentors and role models: Developing a demographic profile.* Paper presented at the Proceedings of the ASC 51st Annual International Conference. http://ascpro0.ascweb.org/archives/cd/2015/paper/CERT339002015.pdf

Wang, Y., Goodrum, P. M., Haas, C., Glover, R., & Vazari, S. (2010). Analysis of the benefits and costs of construction craft training in the United States based on expert perceptions and industry data. *Construction Management and Economics, 28*(12), 1269–1285.

Wilkinson, L., & Kelly, M. (2018). *Continuing to build a more diverse workforce in the highway trades: 2018 evaluation of the ODOT/BOLI highway construction workforce development program*. Final report submitted to the Oregon Bureau of Labor and Industries and Oregon Department of Transportation.

Zellweger, T., Sieger, P., & Halter, F. (2011). Should I stay or should I go? Career choice intentions of students with family business background. *Journal of business venturing, 26*(5), 521–536

Appendix A.

Table 1. Summary of the literature in terms of the Trend Year, Keywords, and Methodology that used in previous research

Industry	Author	Trends (years)					Keywords				Methodology		
	Author	Before 2000	2001-2005	2006-2010	2011-2015	2016 - 2021	Skilled labor shortage	Career decision making	Influences	Industry image	Literature review	Survey	Mixed methods
Non-Construction	Zellweger, Sieger, and Halter (2011)				x			x	x			x	
	Buerhaus, Skinner, Auerbach, and Staiger (2017)					x	x		x		x		
	Sheldon et al. (2008)			x			x						
	Carrier, Yee, and Stark (2011)				x		x				x		
	Admani, Caufield, Kim, Siegfried, and Friedlander (2014)				x		x	x				x	
	Charlton and Kostandini (2021)					x	x						x
	Foskett and Hemsley-Brown (1999)	x					x	x	x	x			x
Construction	Baldry (1997)	x					x			x		x	
	Healy, Mavromaras,				x		x			x			x

	and Sloane (2011)												
	Dong, Men, and Fujimoto (2008)			x			x						
	Construction Industry Institute (2018)					x						x	x
	Haupt and Harinarain (2016)					x	x			x			x
	Minooei, Goodrum, and Taylor (2020)					x	x	x	x	x		x	
	Wang, Goodrum, Haas, Glover, and Vazari (2010)			x			x	x				x	
	Wilkinson and Kelly (2018)					x			x			x	
	Federle, Rowings Jr, and DeVany (1993)	x					x			x		x	
	Kashiwagi and Massner (2002)		x				x		x	x			x
	Escamilla, Ostadalimakhmalbaf, and Bigelow (2016)				x					x		x	
	Cappelli (2015)				x		x				x		
	Krei and Rosenbaum (2001)		x					x				x	
	Akomah et al. (2020)				x		x					x	
	Corney and du Plessis (2010)			x			x		x			x	

	Koch, Greenan, and Newton (2009)			x			x	x	x	x		x	
	Choi, Shrestha, Lim, and Shrestha (2018)				x		x			x		x	
	Bigelow, Perrenoud, Rahman, and Saseendran (2021)					x	x		x	x		x	x
	Healy (Healy et al., 2011)			x			x						x
	Karimi, Taylor, Goodrum, and Srinivasan (2016)				x		x						x
	Thevenin and Elliott (2015)			x				x		x		x	
	Elliott, Thevenin, and Lopez del Puerto (2016)				x				x			x	
	Assaad and El-adaway (2021)				x		x						x

Appendix B.

Table 2. Experiences and relationships that influence construction management students' career choice. & Factors that influence students' choice of careers in construction management as found in the work completed by Koch et al. (2009)

Focus	Question	Response/Results
Industry related work experience	Did you participate in construction work experience through vocational program in high school?	Yes – 15% No – 85%
Industry related work experience	How many total months of construction related experience had you completed as a volunteer?	A – less than 1 month B - 1-3 months C – 4-7 months D – 8-12 months E –12-18 months F –18-24 months G -over 24 months
Industry related work experience	How many months of paid construction related work experience had you completed before entering the program?	A. Less than 1 month– 36% B. 1-3 mon. – 10% C. 4-7 months - 10% D. 8-12 months – 7% E. 12-18 months – 8% F. 18-24 months – 5% G. over 24 months – 22%
Influences	1) Interest in construction	1. No Influence – 3% 2.Signficant Influence – 4% 3. Significant Influence – 15% 4. Greatest Influence – 33% 5. Greatest Influence – 45%
Influences	2) Hands-on type work activity	1.No Influence – 6% 2.Signficant Influence – 4% 3. Significant Influence – 21% 4. Greatest Influence – 30% 5. Greatest Influence – 45%
Influences	3) Inside vs Outside work	1. No Influence – 18% 2.Signficant Influence – 7% 3. Significant Influence – 25% 4. Greatest Influence – 24% 5. Greatest Influence – 26%
Influences	(4) Your father	1. No Influence – 26% 2.Signficant Influence – 17% 3. Significant Influence – 20% 4. Greatest Influence – 15% 5. Greatest Influence – 22%
Influences	(5) Career job placement	1. No Influence – 32% 2.Signficant Influence – 12% 3. Significant Influence – 20% 4. Greatest Influence – 19% 5. Greatest Influence – 15%
Influences	(6) Work/Volunteer experience	1. No Influence – 29%

		2.Signficant Influence – 16% 3. Significant Influence – 22% 4. Greatest Influence – 19% 5. Greatest Influence – 13%
Influences	(7) Work supervisor	1. No Influence – 53% 2.Signficant Influence – 12% 3. Significant Influence – 14% 4. Greatest Influence – 13% 5. Greatest Influence – 8%
Influences	(8) Teacher	1. No Influence – 51% 2.Signficant Influence – 17% 3. Significant Influence – 16% 4. Greatest Influence – 9% 5. Greatest Influence – 9%
Influences	(9) College friend	1. No Influence – 51% 2.Signficant Influence – 14% 3. Significant Influence – 18% 4. Greatest Influence – 12% 5. Greatest Influence – 5%
Influences	(10) Your mother	1. No Influence – 43% 2.Signficant Influence – 29% 3. Significant Influence – 16% 4. Greatest Influence – 7% 5. Greatest Influence – 5%
Influences	11) Family business	1. No Influence – 64% 2.Signficant Influence – 7% 3. Significant Influence – 6% 4. Greatest Influence – 8% 5. Greatest Influence – 15%
Influences	(12) Co-worker	1. No Influence – 58% 2.Signficant Influence – 13% 3. Significant Influence – 13% 4. Greatest Influence – 10% 5. Greatest Influence – 7%
Influences	13) Your aunt, uncle or cousin	1. No Influence – 57% 2.Signficant Influence – 14% 3. Significant Influence – 15% 4. Greatest Influence – 8% 5. Greatest Influence – 6%
Influences	(14) College advisor	1. No Influence – 60% 2.Signficant Influence – 16% 3. Significant Influence – 12% 4. Greatest Influence – 9% 5. Greatest Influence – 3%
Influences	(15) High school friend	1. No Influence – 58% 2.Signficant Influence – 17%

		3. Significant Influence – 17% 4. Greatest Influence – 5% 5. Greatest Influence – 2%
Influences	(16) Your brother or sister	1. No Influence – 66% 2.Signficant Influence – 15% 3. Significant Influence – 10% 4. Greatest Influence – 5% 5. Greatest Influence – 4%
Influences	(17) Other relative	1. No Influence 2.Signficant – 66% Influence – 6% 3. Significant Influence – 6% 4. Greatest Influence – 4% 5. Greatest Influence – 6%
Influences	(18) High school counselor	1. No Influence – 78% 2.Signficant Influence – 12% 3. Significant Influence – 7% 4. Greatest Influence – 3% 5. Greatest Influence – 1%

Appendix C.

Table 3. Construction management students' mentors and role models: Developing a demographic profile (Thevenin, 2015)

Focus	Question	Response
Mentors	Do you have a mentor? In this study, a "mentor" is considered a person who has influenced your academic decisions by actively giving advice, encouraging (or discouraging), supporting, providing information, or helping you make decisions.	Yes - 52% No - 48%
Mentors	Identify the person whom you consider a mentor. If you have more than one mentor, answer based on the mentor that has the greatest influence on your academic decisions:	a) Family Member – 56% b) Friend, Peer, or Significant Other (Spouse, Partner) – 16% c) Professor, Instructor, or Academic Advisor – 21% d) Co-Worker or Supervisor – 5% e) Other – 2%
Mentors	What is the gender of the mentor identified?	Male – 81% Female – 19%
Mentors	Does the mentor identified work in the construction industry?	Yes – 61% No – 39%

Role Models	Do you have a role model? In this study, a "role model" is considered a person who, either by doing something or by being admirable to you in one or more ways, has had an impact on the academic decisions you have made in your life. Role models may be people you know personally, or they may be people you simply know of.	Yes – 74% No – 26%
Role Model	Identify the person whom you consider a role model. If you have more than one role model, answer based on the role model that has the greatest influence on your academic decisions: *In this study, "someone I know of, but do not know personally" is considered a person who you do not know personally, but know of, such as through the media or through historical account.	a) Family Member – 69% b) Friend, Peer, or Significant Other (Spouse, Partner) – 19% c) Professor, Instructor, or Academic Advisor – 5% d) Co-Worker or Supervisor – 5% e) Someone I know of, but do not know personally – 2%
Role Model	What is the gender of the role model identified?	Male – 85% Female – 15%
Role Model	Does the role model identified work in the construction industry?	Yes – 56% No – 44%

Appendix D.

Table 4. An exploration of age on attraction and retention of managerial workforce in the electrical construction industry in the United States (Bigelow, 2021)

Factor	Influence	<30	31-40	41-50	51-60	60+
Career advising	Positive None Negative	35% 65% 0%	35% 63% 2%	22% 74% 4%	28% 63% 9%	5% 63% 33%
Family Influence	Positive None Negative	65% 38% 2%	54% 44% 2%	68% 30% 3%	63% 34% 3%	68% 32% 0%
Salary/Wages	Positive None Negative	87% 14% 0%	83% 11% 5%	85% 13% 1%	87% 9% 4%	67% 29% 4%
Industry Image	Positive None Negative	65% 22% 14%	42% 52% 6%	43% 46% 11%	58% 37% 6%	56% 39% 5%
No other opportunities	Positive None Negative	22% 49% 30%	19% 71% 11%	18% 75% 8%	18% 65% 1%	21% 59% 20%

Career opportunities	Positive None Negative	84% 16% 0%	69% 29% 2%	64% 34% 1%	18% 77% 22%	67% 32% 1%
Available training	Positive None Negative	65% 32% 0%	54% 41% 4%	61% 39% 1%	69% 26% 5%	59% 44% 2%

Appendix F

Table 5. The image of the construction industry and its employment attractiveness (Haupt, 2016)

Focus	Question	Response/Results
Industry Image	A career in construction is prestigious.	1=Extr. Neg. – 8.4% 2= Neg. – 15.6% 3= Neut. – 47.5% 4= Posi. – 23.5% 5= Extr. Pos. – 5.9%
Industry Image	It is better to work in an office that it is to work outside on site.	1=Extr.Neg. – 26.3% 2= Neg. – 9.5% 3= Neut. – 26.3% 4= Posi. – 16.8% 5=Extr.Pos. – 21.2%
Reward	The construction industry pays well.	1=Extr. Neg. – 4.5% 2= Neg. – 8.4% 3= Neut. – 31.8% 4= Posi. – 34.6% 5=Extr.Pos. – 20.7%
Industry Image	a career in construction is better than a career in other industries	1=Extr.Neg. – 18.4% 2= Neg. – 27.9% 3= Neut. – 39.1% 4= Posi. – 8.9% 5= Extr. Pos. – 5.6%
Career Opportunity	there are more career advancements opportunities in the construction industry	1=Extr. Neg. – 7.8% 2= Neg. – 14.0% 3= Neut. – 28.5% 4= Posi. – 24.6% 5=Extr.Pos. – 25.51%
Reward	A career in construction is rewarding as results can be seen	1=Extr. Neg. – 2.2% 2= Neg. – 10.1% 3= Neut. – 29.1% 4= Posi. – 31.3% 5= Extr.Pos. – 27.4%
Reward	a job in the office does not pay more than a job on site	1=Extr.Neg. – 14.5% 2= Neg. – 11.2% 3= Neut. – 30.7% 4= Posi. – 20.1% 5= Extr.Pos. – 23.5%

Industry Image	the construction industry is not a male dominated industry	1=Extr.Neg. – 21.8% 2= Neg. – 19.0% 3= Neut. – 21.2% 4= Posi. – 11.2% 5= Extr.Pos. – 26.8%

Mixed Reality for in-field Construction Activities: A Systematic Literature Review to Identify Challenges and Solutions

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Abstract

With the new industrial revolution, "Industry 4.0," it is important to understand and incorporate the new standards and technologies evolving in the market. Industry 4.0 relies on the integrated use of big data and analytics coupled with various technologies to help make decisions and manage projects. This revolution has brought Mixed Reality (MR) into the construction field. Mixed reality (MR) offers significant benefits for smart industries, such as enhancing productivity, training, manufacturing, error correction, assembly, and packaging processes. But how feasible are Mixed Reality Technologies (MRTs) considering the high initial investment required for acquiring devices, subscribing to services, planning and implementing solutions, and training staff? Studies have shown that in the long run, MRTs provide high results and involve many stakeholders. It is proved that using MR for complex and lengthy projects can make the project run smoother and be completed in less time. MR makes service coordination easier and can produce models resulting in fewer construction errors. Even though there are many advantages to MR, many issues and gaps in the industry have yet to be overcome. This is making it harder to incorporate MRTs at this stage. This paper documents findings through a systematic literature review of the challenges and methods to overcome those challenges related to using MR for construction activities.

Keywords: Mixed Reality, Industrial Revolution, ROI, Industrial Layout Planning

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Introduction

The fourth industrial revolution, also known as Industry 4.0, is the integration of intelligent digital technologies into manufacturing and industrial processes. It involves a set of technologies that include industrial Big Data and Analytics, Autonomous Robots, Simulation, Horizontal and Vertical System Integration, Internet of Things, Cybersecurity, Cloud, Additive Manufacturing, and AR (Sodhi, 2020). Industry 4.0 enables smart manufacturing and the creation of intelligent factories (Ersoy, 2022). It aims to improve productivity, efficiency, and flexibility while allowing more intelligent decision-making and customization in manufacturing and supply chain operations. Industry 4.0 is the result of the evolution of industrial productivity since the beginning of the Industrial Revolution. Industry manufacturing progressed from water and steam power machines to electrical and digital automated production (Stanic et al., 2018). This last environment made manufacturing processes more complex, automatic, and sustainable so that people can operate machines efficiently, effectively, and consistently (Turel & Akis, 2019).

Industry 4.0 is not only playing a role in manufacturing but is also impacting construction. The construction industry's reluctance to embrace the full potential of new technologies and its sensitivity to IT expenditure has been noted, highlighting the need for clear benefits before adoption (Niu et al., 2016). Industry 4.0 has been identified as an opportunity for the construction industry to achieve higher efficiency in productivity, business models, and the value chain (Lee & Park, 2022). Industry 4.0 has inspired the adoption of new technologies, process changes, and more efficient work methods, dubbed Construction 4.0 (Forcael et al., 2020). With the implementation of Industry 4.0-related technologies and cyber-physical systems, construction has begun to see similarities in increased production and management parallel to the evolution within the manufacturing industry (You & Feng, 2020; Hämäläinen & Salmi, 2022).

Reasons why Industry 4.0 technologies have worked well in the construction industry include the fact that the construction industry already deals with large volumes of heterogeneous data, which is expected to increase exponentially with the commoditization of technologies such as sensor networks and the Internet of Things (Bilal et al., 2016). The highly interdisciplinary, fragmented, and temporary project organizations in the construction industry have made it difficult to meet project requirements regarding cost, time, and productivity, indicating the need for the digital transformation of stakeholder management (Prebanić & Vukomanović, 2021). The urgent need to improve understanding of the construction industry's digital transformation to leverage the benefits of broader adoption of the Industry 4.0 paradigm has been underscored (Li et al., 2022).

One of the areas being adopted as part of Construction 4.0 is the use of advanced visualization technologies like Mixed Reality (MR) and Augmented Reality (AR). Whereas Virtual Reality (VR) entirely immerses the user within a virtual world and has no reference to the real world they are in, MR and AR blend the two where virtual objects are placed within the real world where both can be viewed simultaneously (Pincjer et al., 2018). The use of MR in manufacturing and construction is expanding. In the manufacturing industry, MR applications contribute to multiple functions, including planning, design, production, monitoring, quality control, training, maintenance, and human-robot interaction (Santoso et al., 2021) and offer advantages of improved productivity, reduced workload, and enhanced creativity (Pasquale et al., 2022). MR assists with safety-related applications in construction, including training, hazard monitoring, and preconstruction planning (Moore & Gheisari, 2019). Quality control and project consistency have also been explored (Noruwa et al., 2022). Building Information Modeling (BIM) based MR helps facilitate knowledge exchange between design, production, and construction professionals (Sebastian et al., 2018). The combination of BIM within an MR environment has helped with inspections of construction sites and visualization of construction activities (Mori et al., 2019). Other areas are being explored to make BIM-based MR more valuable to the industry by integrating different sensor technologies (Ogunseiju et al., 2021). There are, however, still barriers.

This paper utilizes a systematic literature review to understand the common barriers and potential methods for overcoming these challenges when utilizing MR for construction planning and field layout.

Literature Review

AR is essential in engineering as it provides intuitive and effective human interfaces and suitable content development (Nee et al., 2012). AR-based facility layout planning has proven to be able to check and visualize the position of a new machine to be added to the existing layout in real time. The re-layout became flexible and easy with effective visualization in this real-time AR system (Tan et al., 2021). However, extreme analysis of the selected layout is essential to create a practical layout, which can be done through static and dynamic simulation (Kokkas et al., 2019). These simulations bring the real and virtual environments together, converging BIM, Virtual reality, and Augmented reality capabilities. This combined platform reduces the rework of design changes in three main areas: redesign, maintaining the flow of information, and delivering solutions for design changes, which can be costly in terms of time and effort (Panya et al., 2023).

Fiorentino et al. (2002) created an MR-based application called Space Design. It is an innovative Mixed Reality (MR) application for the aesthetic design of free-form curves and surfaces. Compared to former CAD programs, Space Design provides 3D visualization and navigation, real-time editing, and intuitive interaction. Later, Lee et al. (2008) proposed a touchscreen-based mobile MR hardware Mirage to reduce the efforts of modeling the physical space. Lee et al. (2011) Constructed a computer-simulated mixed-reality environment for virtual factory layout planning to create greater precision in a 3D digital manufacturing environment of virtual objects, extending the application areas for digital manufacturing technology and giving users a better sense of immersion. Recently, Da Col (2021) conducted a study on improving the MR from Hand gestures to a brain-computer-based interface. With these advances in MR, many studies have been done to implement MR in the operations and maintenance phases. Some such studies are (Zhao et al., 2022) Intelligent Construction and Management of Landscapes through Building Information Modeling and Mixed Reality, (Mourtzis et al., 2020) Intelligent Predictive Maintenance and Remote Monitoring Framework for industrial equipment based on mixed reality, (Müller et al., 2021) Real-time combination of material flow simulation, digital twins of manufacturing cells, an AGV, and a mixed-reality application. These studies show that using MR from the primary stage till the operational stage can reduce maintenance by approximately 10%.

With the recent trends of AI, combining it with MR could have excellent potential for innovative industries to increase production speed, workforce training, and improved manufacturing, error handling, assembly, and packing (Devagiri et al., 2022). This could lead us to a future where the system can handle the errors. No algorithms can fully evaluate and select layouts automatically according to the mentioned qualitative criteria without consulting the planner (Burggraef et al., 2021). Making qualitative target criteria machines interpretable is the next step ahead.

Cost Impacts and ROI of MR Technology

Devagiri et al. (2022) argued that mixed reality (MR) could offer significant benefits for intelligent industries, such as enhancing productivity, training, manufacturing, error correction, assembly, and packaging processes. However, the question that is raised is whether MR is economically viable, considering the high initial investment required for acquiring devices, subscribing to services, planning and implementing solutions, and training staff. Common costs associated with the technology adoption include device acquisition and maintenance, software subscriptions, project planning/execution for its use, and user training (Brown et al., 2021).

An actual return on investment is hard to calculate. In one case study, Brown et al. (2021) identified a 177% return on investment over a three-year period. Efficiencies in planning, design, production, monitoring, resource management, and optimization of cash flow are other noted benefits that are not easily quantifiable (Santoso et al., 2021; Aguguom, 2020).

Mixed Reality Investments can lead to benefits by:

1. Ensuring consistent and high-quality service delivery to customers, which can be compromised by technical glitches or human errors (Distat Co., 2018).
2. Avoiding costly and time-consuming rework, which can result from missed or overlooked issues during the planning, design, and construction phases when using traditional processes (Brown et al., 2021).
3. Streamlining and accelerate the sales, planning, and design processes, which can involve multiple stakeholders and complex data (Dai et al., 2019).
4. Facilitating collaboration and communication among designers, engineers, site workers, and customers, who may have different expectations and preferences regarding the project outcomes (Dai et al., 2019).
5. Reducing the expenses and inefficiencies associated with training field employees, who may travel long distances or spend time away from work (Katika et al., 2019).
6. Coping with the challenges of hiring and retaining qualified workers, who may be scarce or in high demand in specific markets or sectors (Brown et al., 2021).
7. Minimizing the reliance on physical models, such as architectural maquettes, which can be expensive to

produce and transport and may not reflect the latest changes or updates (Katika et al., 2022).

Opportunities Identified for Mixed Reality Investments include:

1. Provide instructions to improve worker speed, quality, and safety, including heads-ups and hands-free instructions. MR can enable workers to perform tasks to minimize errors, increase efficiency, and avail themselves of step-by-step guidance, sensory information, and feedback (Katika et al., 2019).
2. Empower workers with self-guided learning. Mixed reality can offer immersive and interactive training experiences, allowing workers to learn new skills and practice scenarios at their own pace and convenience (Distat Co., 2018).
3. To enable sales and better service, demonstrate plans and models in 3D to customers. Mixed reality can help customers visualize products and solutions in their real context, enhancing their understanding and satisfaction (Brown et al., 2021).
4. To find out what is happening and to obtain the support of on-site workers and important stakeholders, overlay designs will be carried out at physical locations. Mixed reality can facilitate collaboration and communication among project teams, enabling them to review designs, detect problems, and make decisions in real-time (Dai et al., 2019).

Objectives For Mixed Reality Investment include:

1. Providing immersive and interactive simulations of real-world scenarios, the aim is to speed up training and lower training expenses (Katika et al., 2019).
2. Enabling remote collaboration, guidance, and inspection of hazardous environments, the aim is to protect health and safety (Dai et al., 2019).
3. Allowing visualization, annotation, and modification of 3D models on a real scale and context, the aim is to accelerate the design and planning phases (SphereGen Technologies, 2023).
4. Improve learning and knowledge retention by enhancing engagement, feedback, and memory recall (Brown et al., 2021).
5. Facilitating communication, coordination, and consensus, the aim is to improve alignment and buy-in for office teams, site staff, and customers (Dai et al., 2019).
6. Providing hands-free access to information, instructions, and assistance, the aim is to accelerate task completion (McKinsey & Company, 2021).
7. Improving the quality of work by reducing errors, rework, and waste (Dai et al., 2019).
8. Empowering workers with self-service tools and resources will reduce the demand for leadership and experts and their stress (Brown et al., 2021).
9. Delivering projects on time and within budget to reduce pass-along costs for customers of delays and rework (Brown et al., 2021).
10. Exceeding customer expectations, addressing customer needs, and creating customer delight to improve CX (Brown et al., 2021).
11. Showcasing innovation, expertise, and excellence to strengthen brand image (McKinsey & Company, 2021).
12. Building trust, loyalty, and satisfaction increases customer retention, enrichment, and advocacy (Brown et al., 2021).
13. Demonstrating value, differentiation, and competitive edge to increase contracting win rates (Brown et al., 2021).

Training Efficiency

MR is a powerful tool for training employees, as it allows the trainees to see the instructions and procedures they need to follow on the actual objects and components they are working with, in their natural environment and in real-time. This way, they can learn technical skills in a more contextual, in-situ, and transparent manner, without having to rely on abstract or ambiguous information from manuals, videos, or lectures (Lopez et al., 2021). Research has shown that training time can be reduced by up to 20% with MR compared to traditional methods. In addition, MR can also significantly reduce training costs (Distat Co., 2018). According to a Forrester report, AEC (architectural, engineering, and construction) companies that use MR for employee training can save up to $22 per labor hour and reduce training time by 50% (Brown et al., 2021). This reduction is seen as AEC companies have many company-specific skills and processes, especially MR, as well as standard processes, pre-configured instructions, and 2D models that can be easily converted into MR content.

Field Task Worker Productivity

The design reviews, installs, and inspections performed by the AEC (architectural, engineering, and construction) field crew can be done more quickly and precisely by employing remote collaboration and design visualization tools (Pieper, 2022). As a result, project completion times, cost savings, work quality, and customer satisfaction have all increased significantly. Productivity increased by 20% for 30% of the field labor tasks, and the amount of work was cut by 75%, saving $44 per hour (Brown et al., 2021). The possible ROI (return on investment) rises with project complexity.

Task Worker Productivity

By enabling more accurate and efficient operations, MR has revolutionized the AEC (architectural, engineering, and construction) sector. A study done by Forrester states that the adoption of MR technologies in the AEC Companies led up to a 60% gain in efficiency and a 50% decrease in rework on 15% of onsite operations, with on an average can cost up to $44 per hour (Brown et al., 2021). They list their savings. Additionally, MR assists AEC firms in addressing the complex projects and demands of projects requiring high accuracy, teamwork, and innovation. With the aid of MR and AEC (architectural, engineering, and construction), businesses may use features like immersive visualization, real-time collaboration, spatial data collecting, and contextual information delivery in both physical and digital worlds (Katika et al., 2019).

Leader Productivity

MR can reduce up to 50% of the workloads of construction and engineering leaders, which directly impacts AEC (architectural, engineering, and construction) firms in achieving a 35% increase in productivity, saving up to $55 per hour. The benefits of this approach are shorter design phases, faster buy-in from stakeholders, increased sales and customer enablement, reduced instruction time, and decreased errors and delays, which leads to wasted labor and rework (Brown et al., 2021).

Specialized Expert Productivity

Companies in the AEC (architectural, engineering, and construction) industry have seen significant increases in productivity and efficiency using AR and MR. AEC (architectural, engineering, and construction) professionals can spend less time and money on traveling to remote locations, performing complex tasks, and training using AR/MR devices and applications (*Accelerate Time to Market With Dynamics 365 Remote Assist for HoloLens 2 - Microsoft Dynamics 365 Blog*, 2021). A recent study by Forrester states that AEC companies using AR/MR solutions reduced annual labor and training hours per expert by up to 35%, saving $34,320 per expert. Additionally, they reduced the number of visits by 75 man-hours per month, saving 90% of the labor required per visit and saving up to $92 per hour (Brown et al., 2021).

Travel and Incidental Savings

By avoiding expert travel, AEC (architectural, engineering, and construction) companies can save an average of $2,000 per trip, and by avoiding field staff travel, they can save up to $50 per trip (Brown et al., 2021). Expert trips are cheaper and less likely to involve last-minute bookings and significant international travel, as experts are often in the same country as their destination due to the need to meet regional norms and standards.

Most norms and standards require the export from the same country or constitution.

Operational Cost Savings

By entering into MR technologies, AEC (architectural, engineering, and construction) firms can lower their operating costs and consumables expenses significantly. MR enabled them to train their staff more efficiently, using less physical materials and equipment. They can also use MR to enhance their design, testing, and demonstration processes, saving time and money (*Accelerate Time to Market With Dynamics 365 Remote Assist for HoloLens 2 - Microsoft Dynamics 365 Blog*, 2021). AEC companies can achieve the following reductions (Brown et al., 2021):

1. 80% fewer consumables costs for training each employee, from $1,000 to $200
2. 10% fewer consumables cost for design, testing, and demonstration per expert and leader, from $200,000 to $180,000
3. 50% less personal protective equipment (PPE) costs per user, from $268 to $134
4. 0.3% less operating costs as a percentage of revenue, from 95.9% to 95.6%

Employee Well-being

Employee well-being is an intangible factor that cannot be directly linked to an organization's bottom line but is an important element that can influence the organization's performance. The health and happiness of the employees can affect their productivity, creativity, engagement, loyalty, and retention. Ignoring employee well-being can negatively affect the organization, causing increased absenteeism, turnover, stress, and conflict. Therefore, investing in employee well-being is a moral duty and a strategic decision that can benefit the organization in the long run (McKinsey & Company, 2021).

Safety

Remote Assist and Guides enhance the safety of your workforce. MR enables a specialist to collaborate virtually with a technician. The risk of misunderstanding instructions is minimized as the specialist can see what the technician sees. With Guides, safety benefits are amplified by using simulations. Integrating Guides and the HoloLens allows trainees to interact virtually with hazardous equipment (Dai et al., 2019). Wrong decisions in a simulated environment protect trainees from possible physical harm. Procedures can be practiced until they are confident working with equipment, giving the employee and manager more confidence. Moreover, a Guide can be designed to include features that alert a guide operator of perilous operations within a process (SphereGen Technologies, 2023).

Employee Engagement and Innovation

Employee engagement is a critical factor for workplace satisfaction. By adopting cutting-edge technology such as HoloLens 2, Remote Assist, and Guides, employees can experience new excitement and interest in their work. Moreover, employee engagement is not just driven by the novelty of these technologies but also by their practical benefits. When employees see how this technology simplifies their work, they are eager to use it and even propose new ways to create value for the organization (SphereGen Technologies, 2023).

Productivity

MR innovation can improve the execution and well-being of workers and organizations. Workers who utilize MR instruments can work more effectively and appreciate their errands more. Organizations that invest in MR technologies can achieve better results, increase efficiency, and contribute to their worker fulfillment (SphereGen Technologies, 2023).

Issues and Gaps

Even though there are many advantages of MR, many issues in the industry are yet to be overcome. Some of the issues and gaps are discussed below. Where appropriate, solutions from the literature are connected. Gaps and areas still in need of future research to overcome the challenges are also noted.

Issue #1: Market Perception

MRTs have faced issues within the market due to a general lack of knowledge about their uses (Delgado, et al., 2020a) and the perception that they are considered immature technologies (Sodhi., 2020; Delgado, et al., 2020b). MRTs with their differences in uses, specifications, and protocols for development remain a fragmented industry (Martinez et al., 2014). Like many technologies in their early adoption stage within construction, there is a general aversion to adopting MRT (Sodhi, 2020) and the demand for MR within the AEC industry is insufficient to drive change (Delgado, et al., 2019). Some of the lack of demand is lack of client interest in using MR as well as lack of time for companies to explore its use (Delgado, et al., 2020a; Delgado, et al. 2020b).

One way to overcome the challenges related to technology perception and interest is users to be informed about MRT applications and benefits. Users also doubt privacy and security, which need to be communicated and appropriately explained (Modawal, 2020). All of these are common concerns that arise when even a new generation of technology comes into the market, and over time, with Industry 4.0, MR and XR will likely become the new face of the construction industry (Devagiri et al., 2022).

Issue #2: Employee Perception and Skills

To gain a better perception of the technology, workers need to feel comfortable with using that technology. However, with workloads and labor shortages, there is limited opportunity to experience MRTs in actual working conditions (Delgado et al., 2020a; Dunston et al., 2007). Some perceive the use of MRTs as a cause of job insecurity and a threat when workers do not understand how to use the technology (Delgado et al., 2020b; Duston et al., 2007). It is difficult for companies who are not familiar with the technology to access the experts' knowledge skills (Delgado, et al., 2020b) and skills of new graduates who may have access to the technologies during their education (Delgado et al., 2019).

Issue #3: Financial Investment in Technology

Some of the main issues and challenges that need to be overcome for broader adoption in the AEC industry include the cost of hardware and training (Sodhi, 2020). MRTs require high initial capital investment (Delgado, et al., 2019; Brown et al., 2021). Companies, especially smaller firms, have limited resources to finance technologies that they are not sure if they will use (Delgado, et al., 2020a; Sodhi, 2020). Proof of concepts can help in providing realistic use cases for the successful implementation of the technology (Modawal, 2020).

Issue #4: Technical Challenges

This is the area where a lot of research is beginning to focus and more research needs to be done. In order for a technology to be widely adopted it needs to work effectively and efficiently. MRTs require specialized high-processing equipment and other requirements for processing (Delgado, et al., 2020b; Dunston et al., 2007) due to the time-consuming algorithms to assist in tracking and orienting the device in space (Martinez et al., 2014). They also need to be set up correctly with the model (Sodhi, 2020) and may require significant modeling effort (Dunston et al., 2007). To aid in processing power and accuracy, there are limits to the size of 3D models to be displayed (Delgado, et al., 2020a; Duston et al., 2007). Because of the need for high processing power and keeping down the size of the device, there are also battery limitations for using MRTs (Delgado et al., 2020a).

Some of the technical challenges most relevant for the AEC industry is the difficulty in translating changes back to a BIM model (Delagado et al., 2020b) and tracking the model in the environment (Martinez et al., 2014). Additionally, MR technology often requires ample space for their use to recognize where they are within the environment (Duston et al., 2007) while only producing a narrow field of view (Delagado et al., 2020b). Additionally, there are challenges with multiple-user capabilities for interacting with a model within the MR environment (Delagado et al., 2020b).

The physical size and configuration of the technology can also be challenging. Most MR systems utilize uncomfortable and heavy HMDs (Head-mounted displays) (Delgado et al., 2020b). The weight and balance of the HMD can affect the user's experience. (Ito et al., 2020)

The industry is responding to some of these challenges and improvements have been made. The space requirements for the MRTs have been constantly improving with the growth of technology. Now, the latest technology can be used for smaller environments and indoor spaces (DiSTI Corporation, 2017). The Field of view for MRTs has been increasing from HoloLens v1, which has 34 degrees (Caggianese & Gallo.,2021), to Microsoft HoloLens 2, which has a field of view of 52 degrees (Bezmalinovic, 2023). Resolution is also improving from "blocky" low resolution to human eye resolution. Peuhkurinen & Mikkonen (2021) Evaluated the implementation of a real-time ray tracer that works at human-eye resolution.

Specifically for the AEC industry, recent studies have shown that importing mixed reality data to BIM is possible. (Liu, 2023) has proposed a workflow to import the MR data into BIM without little complications and data loss.

With time, technical advancement has happened. Now, MRTa has much higher accuracy in tracing and mapping. One such example is HOTA, created by (Luiten et al., 2020).

Issue #5: Health and Safety

Beyond the weight of the device as a possible encumbrance to the user, there are some other health concerns that users need to be aware of. Users can experience motion sickness, nausea, sweating, and headaches leading to vomiting when using MR devices (Liagkou et al., 2019). This can also be a challenge in the AEC industry, where the device would be used in addition to other required personal protective equipment.

Issue #6: Ownership and Standards

Another challenge to the adoption of MR within the AEC industry is the lack of standards for data exchange (Delgado et al., 2020b). As with the adoption of other collaborative technologies, the industry is slow to move with uncertainties of data security and ownership of using information created while using MR (Martines et al., 2014). There are no legal standards available to protect the privacy and ownership of the project within a MR environment and it will take time to better understand the best method for this type of project execution (Marr, 2022).

Future Work

MR has much scope in the future. This research has already shown that MRTs are to be developed in the future to cater to the needs of the users and the shareholders to make it more economically and technically feasible. Much more research is needed to implement MR in the construction industry successfully, especially in the construction of factories and manufacturing facility layout design. MRTs can be improved by utilizing enhanced virtual constraints and creating more editing functionalities that can be incorporated into the BIM models. Also, the user interface can be significantly improved via better visualization, voice and gesture recognition, context-driven commands, and more intelligence in capturing the user's intention (Fiorentino, 2003). These aspects can be the driving force for our future work.

MR has opened many new areas for research. A few of them are

1. To further understand and improve the systematic guidelines for using MRTs for layout planning and create a more extensive user base.
2. To further explore the brain-computer-based interface. Its application in different industries and the technology required to support this. Industry 4.0 is going to bring many changes in our lives and lifestyles. So, research in this field is needed for better adaptation in the coming future.
3. AR, VR, and MR have brought in a new perspective of human-computer interaction than the mouse, keyboard, or touch screen, which traceable controllers, hand gestures, voice commands, etc can do. Inventing new theories and methods for effective user interactions is essential for Industry 4.0 (Gong, 2019). Therefore, further research in this area is essential to the future manufacturing industry.
4. With the whole world leading towards sustainability, MR could be an excellent resource for the construction industry. MR can contribute to sustainable development to understand and meet the economic, social, environmental, and technological challenges (Chen et al., 2019).
5. There is limited consideration of potential improvement measures and future scenarios through predictive capabilities (Thiede et al., 2023). There are only a few publicly available approaches directly linked to energy needs, emissions, and mainly material demand in the production sector compared to other application areas. Further dwelling in this area is needed soon.

Conclusion

Mixed Reality is an innovation that can combine real and virtual environments, making immersive and interactive encounters. MR has numerous applications in different sectors, such as education, well-being care, amusement, and industry. Accessibility, safety, education, and remote work are important in today's society, and MR can offer all these opportunities. However, MR requires a considerable amount of initial investment and a high level of expert labor. Therefore, it is essential to study the economic feasibility and return on investment (ROI) of MR projects to identify the best practices and strategies for implementing them successfully. In this report, we have gone through some studies conducted to analyze the MR projects. Most of them have concluded that they have achieved positive outcomes and reduced costs. However, these outcomes are achieved in a duration of time, these are not immediate results and have a payback period. In the long run, provide high results and involve many stakeholders. MR opened many gates for the construction industry. It has also been proved that using MR for complex and lengthy projects such as factor layout planning can make the project easy and can be completed in less time. MR makes coordination of services easy and can produce models reflecting fewer construction errors and fast construction. It reduces the reworks and helps stakeholders and designers to understand the project's vision much more even before the project is started; it even helps understand the sustainability factors of the project. It creates much safer environments for the workers by enabling designers to do the safety study remotely. Even though incorporating MRTs seems complicated at this stage, further study in this area can lead to these technologies being commonplace for the next generation of workers.

REFERENCES

Accelerate time to market with Dynamics 365 Remote Assist for HoloLens 2 - Microsoft Dynamics 365 Blog. (2021, June 17). *Microsoft Cloud Blogs*. Retrieved October 14, 2023, from https://cloudblogs.microsoft.com/dynamics365/bdm/2021/06/17/accelerate-time-to-market-with-dynamics-365-remote-assist-for-hololens-2/

Aguguom, T. A. (2020). Cash flow optimality and investment returns: investors expectations in listed manufacturing firms in nigeria. Asian Journal of Economics, Business and Accounting, 39-50. https://doi.org/10.9734/ajeba/2020/v16i430247

Bezmalinovic, T. (2023, March 16). Augmented Reality: Hardware and Definitions. *MIXED Reality News*. Retrieved November 9, 2023, from https://mixed-news.com/en/augmented-reality-hardware-and-definitions/

Bilal, M., Oyedele, L., Qadir, J., Munir, K., Ajayi, S., Akinade, O., … & Pasha, M. (2016). Big data in the construction industry: a review of present status, opportunities, and future trends. Advanced Engineering Informatics, 30(3), 500-521. https://doi.org/10.1016/j.aei.2016.07.001

Brown, B., Luk, K., Son, L., & Casildo, E. (2021, November). *The Total Economic Impact™ Of Mixed Reality Using Microsoft HoloLens 2.* Retrieved October 14, 2023, from https://tools.totaleconomicimpact.com/go/microsoft/HoloLens2/

Burggraef, P., Adlon, T., Hahn, V., & Schulz-Isenbeck, T. (2021). Fields of action towards automated facility layout design and optimization in factory planning–A systematic literature review. *CIRP Journal of Manufacturing Science and Technology, 35*, 864-871.

Caggianese, G., & Gallo, L. (2021). Field of View Limitation-Driven Design of a Mixed Reality Game for Heritage Sites. In C. Ardito et al. (Eds.), *Human-Computer Interaction – INTERACT 2021. INTERACT 2021. Lecture Notes in Computer Science(12936)*, Springer, Cham. https://doi.org/10.1007/978-3-030-85607-6_51

Chen, D., Heyer, S., Seliger, G., & Kjellberg, T. (2019, March 9). Integrating sustainability within the factory planning process. *Science Direct*. Retrieved October 23, 2023, from https://www.sciencedirect.com/science/article/abs/pii/S0007850612000698

Da Col, S. (2021). Mixed Reality Application for Inspection and Validation in Industrial Environments: Human Performance and Brain-Computer Interface Advantages over Gestures (Doctoral dissertation, University of Windsor (Canada)).

Dai, F., Olorunfemi, A., Peng, W., Cao, D., & Luo, X. (2019, March 9). Can mixed reality enhance safety communication on construction sites? An industry perspective. *Science Direct*. Retrieved October 14, 2023, from https://www.sciencedirect.com/science/article/abs/pii/S0925753520304069

Delgado, J.M.D., Oyedele, L., Ajayi, A., Akanbi, L., Akinade, O., Bilal, M., & Owolabi, H. (2019). Robotics and automated systems in construction: Understanding industry-specific challenges for adoption. *J. Build. Eng., 26*, 100868.

Delgado, J.M.D., Oyedele, L., Beach, T., & Demian, P. (2020a). Augmented and virtual reality in construction: Drivers and limitations for industry adoption. *J. Constr. Eng. Manag., 146*, 04020079.

Delgado, J.M.D., Oyedele, L., Demian, P., & Beach, T. (2020b). A research agenda for augmented and virtual reality in architecture, engineering, and construction. *Adv. Eng. Inform., 45*, 101122.

Devagiri, J.S., Paheding, S., Niyaz, Q., Yang, X., & Smith, S. (2022). Augmented Reality and Artificial Intelligence in industry: Trends, tools, and future challenges. *Expert Systems with Applications*. https://doi.org/10.1016/j.eswa.2022.118002

Distat Co. (2018, August 27). ROI of Augmented Reality (AR) For Technical Training – 3 User Cases Study. *Distat Co.* Retrieved October 16, 2023, from https://www.distat.co/post/roi-of-augmented-reality-ar-for-technical-training-3-user-cases-study

DiSTI Corporation. (2017, August 15). How 3D Graphics Lower System Costs for Automotive User Interfaces. *DiSTI Corporation.* Retrieved November 10, 2023, from https://disti.com/wp-content/uploads/2021/05/Using_Virtual_and_Mixed_Reality_Technologies_DiSTI.pdf

Elshafey, A., Saar, C.C., Aminudin, E.B., Gheisari, M., & Usmani, A. (2020). Technology acceptance model for Augmented Reality and Building Information Modeling integration in the construction industry. *Journal of information technology in construction, 25*.

Ersoy, Y. (2022). The advantages and barriers in implementing of industry 4.0 and key features of industry 4.0. The Journal of International Scientific Researches, 7(3), 207-214. https://doi.org/10.23834/isrjournal.1122471

Fiorentino, M., de Amicis, R., Monno, G., & Stork, A. (2002, October). Space Design: A mixed reality workspace for aesthetic industrial design. In *Proceedings. International Symposium on Mixed and Augmented Reality (pp. 86-318)*. IEEE.

Fiorentino, M. (2003, January 06). Space design: a mixed reality workspace for aesthetic industrial design. *IEEE*. Retrieved September 6, 2023, from https://ieeexplore.ieee.org/document/1115077/citations#citations

Forcael, E., Ferrari, I., Opazo-Vega, A., & Pulido-Arcas, J. A. (2020). Construction 4.0: a literature review. Sustainability, 12(22), 9755. https://doi.org/10.3390/su12229755

Hämäläinen, M. and Salmi, A. (2022). Digital transformation in a cross-laminated timber business network. Journal of Business &Amp; Industrial Marketing, 38(6), 1251-1265. https://doi.org/10.1108/jbim-01-2022-0003

Ito, K., Tada, M., Ujike, H., & Hyodo, K. (2021). Effects of the Weight and Balance of Head-Mounted Displays on Physical Load. *Applied Sciences, 11*(15), 6802. https://doi.org/10.3390/app11156802

Katika, T., Konstantinidis, F. K., Papaioannou, T., Dadoukis, A., Bolierakis, S. N., Tsimiklis, G., & Amditis, A. (2019, March 9). Exploiting Mixed Reality in a Next-Generation IoT ecosystem of a construction site. *2022 IEEE International Conference on Imaging Systems and Techniques (IST)*. Retrieved October 17, 2023, from https://ieeexplore.ieee.org/abstract/document/9827726

Kokkas, A., & Vosniakos, G. C. (2019). An Augmented Reality approach to factory layout design embedding operation simulation. *International Journal on Interactive Design and Manufacturing (IJIDeM), 13*, 1061-1071.

Lee, G. A., Kang, H., & Son, W. (2008, March). Mirage: A touchscreen-based mixed reality interface for space planning applications. In *2008 IEEE Virtual Reality Conference (pp. 273-274)*. IEEE.

Lee, J., Han, S., & Yang, J. (2011). Construction of a computer-simulated mixed-reality environment for virtual factory layout planning. *Computers in Industry, 62*(1), 86-98.

Lee, B. and Park, S. (2022). A study on the competitiveness for the diffusion of smart technology of construction industry in the era of 4th industrial revolution. Sustainability, 14(14), 8348. https://doi.org/10.3390/su14148348

Li, H., Han, Z., Zhang, J., Philbin, S. P., Liu, D., & Ke, Y. (2022). Systematic identification of the influencing factors for the digital transformation of the construction industry based on lda-dematel-anp. Buildings, 12(9), 1409. https://doi.org/10.3390/buildings12091409

Liagkou, V., Salmas, D., & Stylios, C. (2019). Realizing virtual reality learning environment for industry 4.0.

Procedia Cirp, 79, 712–717.

Liu, Z. (2023, June 19). Immersive Technologies-Driven Building Information Modeling (BIM) in the Context of Metaverse. *MDPI*. Retrieved November 9, 2023, from https://www.mdpi.com/2075-5309/13/6/1559#metrics

Lopez, M. A., Terron, S., Lombardo, J. M., & Gonzalez-Crespo, R. (2021, July). Towards a solution to create, test and publish mixed reality experiences for occupational safety and health learning: Training-MR. International Journal of Interactive Multimedia and Artificial Intelligence, 7(2). https://www.ijimai.org/journal/sites/default/files/2021-11/ijimai7_2_18_0.pdf

Luiten, J., Ošep, A., Dendorfer, P., et al. (2021). HOTA: A higher order metric for evaluating multi-object tracking. International Journal of Computer Vision, 129(6), 548-578. https://doi.org/10.1007/s11263-020-01375-2

Marr, B. (2022, October 2). 5 problems and solutions of adopting extended reality technologies like VR and AR. Forbes. Retrieved November 9, 2023, from https://www.forbes.com/sites/bernardmarr/2021/06/18/5-problems-and-solutions-of-adopting-extended-reality-technologies-like-vr-and-ar/?sh=4879d5163f23

Martínez, H., Skournetou, D., Hyppölä, J., Laukkanen, S., & Heikkilä, A. (2014). Drivers and bottlenecks in the adoption of augmented reality applications. Journal of Multimedia Theory and Applications, 2(1), 27-44.

McKinsey & Company. (2021, April 1). *What employees are saying about the future of remote work*? McKinsey. Retrieved October 16, 2023, from https://www.mckinsey.com/capabilities/people-and-organizational-performance/our-insights/what-employees-are-saying-about-the-future-of-remote-work

Modawal, A. (2020, November 9). Know the challenges of adopting MR solutions and how to handle them. Softweb Solutions. Retrieved November 9, 2023, from https://www.softwebsolutions.com/resources/challenges-of-adopting-mixed-reality-solutions.html

Mori, Y., Wada, M., Maki, S., & Tsukahara, S. (2019). Development of the simulator for carrying a lifted load in large plant construction. Proceedings of the International Symposium on Automation and Robotics in Construction (IAARC). https://doi.org/10.22260/isarc2019/0081

Moore, H. and Gheisari, M. (2019). A review of virtual and mixed reality applications in construction safety literature. Safety, 5(3), 51. https://doi.org/10.3390/safety5030051

Mourtzis, D., Angelopoulos, J., & Panopoulos, N. (2020). Intelligent predictive maintenance and remote monitoring framework for industrial equipment based on mixed reality. Frontiers in Mechanical Engineering, 6, 578379. https://doi.org/10.3389/fmech.2020.578379: https://doi.org/10.3389/fmech.2020.578379

Müller, M., Mielke, J., Pavlovskyi, Y., Pape, A., Masik, S., Reggelin, T., & Häberer, S. (2021). Real-time combination of material flow simulation, digital twins of manufacturing cells, an AGV, and a mixed-reality application. Procedia CIRP, 104, 1607-1612.

Nee, A. Y., Ong, S. K., Chryssolouris, G., & Mourtzis, D. (2012). Augmented reality applications in design and manufacturing. CIRP annals, 61(2), 657-679.

Niu, Y., Lu, W., Chen, K., Huang, G., & Anumba, C. J. (2016). Smart construction objects. Journal of Computing in Civil Engineering, 30(4). https://doi.org/10.1061/(asce)cp.1943-5487.0000550

Noruwa, B. I., Arewa, A., & Merschbrock, C. (2020). Effects of emerging technologies in minimising variations in construction projects in the uk. International Journal of Construction Management, 22(11), 2199-2206. https://doi.org/10.1080/15623599.2020.1772530

Ogunseiju, O., Akanmu, A., & Bairaktarova, D. (2021). Mixed reality based environment for learning sensing technology applications in construction. Journal of Information Technology in Construction, 26, 863-885. https://doi.org/10.36680/j.itcon.2021.046

Panya, D. S., Kim, T., & Choo, S. (2023). An interactive design change methodology using a BIM-based Virtual Reality and Augmented Reality. Journal of Building Engineering, 68, 106030.

Pasquale, V. D., Simone, V. D., Miranda, S., & Riemma, S. (2022). Smart operators: how augmented and virtual technologies are affecting the worker's performance in manufacturing contexts. Journal of Industrial Engineering and Management, 15(2), 233. https://doi.org/10.3926/jiem.3607

Pentenrieder, K., Bade, C., Doil, F., & Meier, P. (2007, November). Augmented Reality-based factory planning application tailored to industrial needs. In 2007 6th IEEE and ACM International Symposium on Mixed and Augmented Reality (pp. 31-42). IEEE.

Peuhkurinen, A., & Mikkonen, T. (2021, February 10). *Real-time Human Eye Resolution Ray Tracing in Mixed Reality*. SciTePress. Retrieved November 9, 2023, from https://www.scitepress.org/Papers/2021/102057/102057.pdf

Pieper, C. (2022, August 23). *A Comprehensive Guide to ROI in 3D & Augmented Reality*. Threekit. Retrieved October 17, 2023, from https://www.threekit.com/guide-to-roi-in-3d-and-augmented-reality

Pinćjer, I., Design, N. S., Milić, N., Puškarević, I., & Miketić, N. (2018). Conversion of virtual reality into a mixed reality. Proceedings of 9th International Symposium on Graphic Engineering and Design. https://doi.org/10.24867/grid-2018-p70

Prebanić, K. R. and Vukomanović, M. (2021). Realizing the need for digital transformation of stakeholder management: a systematic review in the construction industry. Sustainability, 13(22), 12690. https://doi.org/10.3390/su132212690

Santoso, H. B., Baroroh, D. K., & Darmawan, A. (2021). Future application of multisensory mixed reality in the human cyber—physical system. South African Journal of Industrial Engineering, 32(4). https://doi.org/10.7166/32-4-2551

Sebastian, R., Olivadese, R., Piaia, E., R, D. G., Bonsma, P., Braun, J., … & Riexinger, G. (2018). Connecting the knowhow of design, production and construction professionals through mixed reality.. https://doi.org/10.20944/preprints201808.0238.v1

Sodhi, H. (2020). A glimpse of industry 4.0 in modern industrialization. IEJ, 13(5). https://doi.org/10.26488/iej.13.5.1239

SphereGen Technologies. (2023, August 23). *Return on Investment for HoloLens 2, Remote Assist, and Guides*. Return on Investment for HoloLens 2, Remote Assist, and Guides. Retrieved October 15, 2023, from https://www.spheregen.com/return-on-investment-hololens2/

Stanić, V., Hadjina, M., Fafandjel, N., & Matulja, T. (2018). Toward shipbuilding 4.0 - an industry 4.0 changing the face of the shipbuilding industry. Brodogradnja, 69(3), 111-128. https://doi.org/10.21278/brod69307

Tan, C. H., Yap, H. J., Musa, S. N., Chang, S. W., Sivadas, C. S., Hisaburi, A. S., ... & Baharudin, L. H. (2021). Augmented reality assisted facility layout digitization and planning. Journal of Mechanical Science and Technology, 35(9), 4115-4123.

Thiede, S., Damgrave, R., & Lutters, E. (2023, March 20). Mixed reality towards environmentally sustainable manufacturing – overview, barriers, and design recommendations. Science Direct. Retrieved October 24, 2023, from https://www.sciencedirect.com/science/article/pii/S2212827122000518

Turel, M. and Akiş, E. (2019). industry 4.0 and competitiveness. Pressacademia, 3(6), 204-212. https://doi.org/10.17261/pressacademia.2019.1132

Wang, X., & Dunston, P. S. (2007). Design, strategies, and issues towards an augmented reality-based construction training platform. Journal of Information Technology in Construction, 12, 363-380.

Yin, J.-H., Chng, C.-B., Wong, P.-M., Ho, N., Chua, M., & Chui, C.-K. (2020). VR, and AR in human performance research—An NUS experience. Virtual Reality & Intelligent Hardware, 2, 381-393.

Yin, K., He, Z., Xiong, J., Zou, J., Li, K., & Wu, S.-T. (2021). Virtual reality and augmented reality displays: Advances and future perspectives. Journal of Physics: Photonics, 3, 022010.

You, Z. and Feng, L. (2020). Integration of industry 4.0 related technologies in construction industry: a framework of cyber-physical system. IEEE Access, 8, 122908-122922. https://doi.org/10.1109/access.2020.3007206

Zhang, F., Chan, A. P., Darko, A., Chen, Z., & Li, D. (2022). Integrated applications of building information modeling and artificial intelligence techniques in the AEC/FM industry. Automation in Construction, 139, 104289.

Zhao, X., Li, M., Sun, Z., Zhao, Y., Gai, Y., Wang, J., ... & Huang, L. (2022). Intelligent construction and management of landscapes through building information modeling and mixed reality. Applied Sciences, 12(14), 7118.

Computer-Integrated Construction Management with Procore

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ABSTRACT

The construction industry faces difficulties in managing the enormous amounts of data generated at each stage of a project, impacting project coordination and decision-making. Currently the industry is facing the issue of a lack of interoperability among the multiple software programs being used for different functions. To address this lack of interoperability, there is a need for an integrated environment that allows seamless flow of data between different functions. Among the few software tools that have emerged in recent year, Procore, a cloud-based construction project management software, has emerged as a widely used solution in the industry, enabling collaboration among all stakeholders involved in a construction project.

This paper aims to investigate various comprehensive project management software, with emphasis on Procore, and evaluate its ability to provide a platform to integrate various construction functions. It demonstrates how to integrate Procore with other construction management software to create a unified platform for all construction management needs. Finally, it discusses the limitations of the present state of integration and provides recommendations for fully integrated software solutions.

KEYWORDS

Construction, Construction Management, Procore, Computer-Integration, Project Management

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INTRODUCTION

The construction industry plays a vital role in the United States economy, employing over 7.6 million individuals and generating nearly $1.4 trillion annually through the contributions of more than 745,000 employers (AGC 2022). However, this industry faces difficulties in managing the enormous amounts of data generated at each stage of a project, and lacks integration of data to ensure seamless project coordination and accurate decision-making (Bello et al. 2021). One of the primary issues is the use of individual software programs for different functions. Most of these stand-alone software provide comprehensive capabilities for their function but they lack interoperability. To address this lack of interoperability, there is a need for an integrated environment that allows seamless flow of data between different software programs. A few software tools have emerged in recent years but Procore, a cloud-based construction project management software, has emerged as a widely used solution in the industry, enabling collaboration among all stakeholders involved in a construction project.

Data is a crucial component of digital transformation, and effective data management is essential for decision-making and managing projects in the construction industry. Adopting a comprehensive and integrated project management solution based on emerging tools such as Procore, can help improve project management, facilitate timely communication among all parties, identify potential conflicts quickly, reduce data errors, and improve overall efficiency in the construction industry.

Procore is a software platform that provides a collaborative environment for various users and applications, offering features such as asset management, accounting, job costing, and an intelligent construction document platform (Procore 2023). Quick and accurate project management decisions can be achieved by integrating scheduling, estimating, BIM, and document management software. Procore has shown promise in integrating with various individual software to a great extent. However, further efforts are needed for fully integrating scheduling, estimating, BIM, and document management tools to create a centralized information flow that enables efficient management of all construction management functions on a single platform (Ashoka & Syal 2023).

RESEARCH OBJECTIVES AND METHODOLOGY

This paper aims to investigate comprehensive project management software, with emphasis on Procore, and evaluate its ability to provide a platform to integrate various construction functions. The first objective is to demonstrate the integration of Procore with other construction management software to create a unified platform for all project needs. This objective will involve implementing the integration of various individual software with Procore. These modules will help understand the current state of integration and the challenges associated with it. The second objective is to discuss the capabilities of the present state of integration and provide recommendations for a fully integrated software solution.

The research methodology included a review of existing literature and individual software to understand the present state of the construction management software. An in-depth analysis of Procore and its integration capabilities was reviewed. A senior representative from Procore was interviewed to gain insight into future growth and expansion plans. Various integration modules were developed to demonstrate Procore’s ability to integrate with other software platforms and assesses its interoperability in two phases: 1) by examining the integration capabilities of software developed internally by Procore, and 2) by exploring integration with external software, such as Primavera P6, Autodesk Revit, and Navisworks. Based on the integrated modules, literature review and the interviews, the research identified strengths and limitations of various integrated solutions and discussed made recommendations for improvements.

LITERATURE AND SOFTWARE REVIEW

This section provides literature and software review of three topics: key integration software other than Procore, current state of Procore and its integration capabilities, and the future integrated-related plans of Procore. It shows that Procore has the potential to integrate multiple construction functions using its platform, thus helping towards streamlining and improving construction management processes.

Key Integrated Software

In recent years, few cloud-based systems have introduced integrated solutions for the construction industry. These software solutions are designed for both general contractors and subcontractors, and for specific industries such as residential or commercial construction. Procore is a major player in the market, alongside Autodesk Construction Cloud, Oracle Construction Management Software, and Trimble ProjectSight.

Autodesk Construction Cloud is a web-based management software that allows owners, designers, and contractors to collaborate on a single platform. It offers a centralized document management solution, takeoff tool, and analytical tools for clash avoidance and issue management. It also provides integrations with over 200 partners, including 3D repo, ESRI, and Microsoft Dynamic suite (Autodesk Construction Cloud 2022).

Oracle Construction Management Software delivers a full suite of cloud-based solutions that securely connect project teams, processes, and data. It provides software for core project activities such as schedule management, project cost controls, design and construction coordination, and payment and financial management. It also offers real-time field collaboration, compliance management, and invoicing tools. Oracle provides integration across its own software and has partnered with other software developers such as Reconstruct and Raken (Oracle CM Software 2022).

Trimble ProjectSight is a relatively new construction management solution that offers integrated solutions consisting of internal software modules but offers limited integration with software outside of the Trimble software group. The Trimble software group includes document management, field management, and budget and cost management tools (Trimble Projectsight 2022).

Current State of Procore

Procore has emerged as a dominant player in the construction management industry in recent years, after being established in the early 2000s. The company began as a small project document management provider but has since developed into a major provider that offers software solutions for various construction project management functions. Procore currently provides tools for all three phases of construction - preconstruction, construction, and postconstruction; as well as financial management and workforce management. Procore's cloud-based platform can connect all parties involved in a construction project, including architects, designers, owners, general contractors, specialty contractors, and material suppliers, with complete visibility and real-time project details. The software has the ability to be accessed on desktops, mobile devices, and tablets, allowing for collaboration across teams and projects. Procore is designed to reduce miscommunications and manual entry errors while proactively course-correcting to stay on schedule and budget. It also maintains pertinent historical data for dispute or claims resolution (Procore 2023).

Currently, Procore features over 400+ integrations with multiple software developers or vendors to facilitate easy and efficient data transfer. Procore Marketplace is a third part app development initiative, that invites and assists the software and construction community to submit ideas, become partners, and develop apps to integrate with the Procore platform. Procore Marketplace allows its users to develop their apps across following categories (Procore Marketplace 2023):

1) Accounting
2) Analytics
3) Asset & Facilities Management
4) BIM
5) Bidding
6) Customer Relationship Management (CRM)
7) Climate Technologies / Sustainability
8) Commissioning
9) Document Management
10) Drones
11) Estimating & Takeoff
12) Field Communications
13) Field Productivity
14) Legal & Compliance
15) Portfolio Management
16) Procurement & Materials Management
17) Progress Documentation
18) Quality & Safety
19) Resource Management
20) Risk Management
21) Scheduling
22) Site Cameras
23) Timekeeping
24) Tool/Equipment Tracking
25) Weather

Procore has made great strides in integrating key functions of the construction industry. The following sections summarize the integration of Procore with Building Information Modelling, Takeoff and Estimating, and Scheduling (Procore 2023, Procore Marketplace 2023).

1. Building Information Modelling: In the past 10-15 years, collaboration processes for exchanging 2D drawings and data have been modified with the development and introduction

of BIM technology. Singh et al. (2011) presented a theoretical framework for a BIM-based multidisciplinary collaboration platform, which included construction industry's BIM requirements and a framework for creating and integrating design-specific models. Procore and other software developers have benefited from such research, which provided them the background to make integrations possible. Procore has collaborated with various software such as Cintoo Cloud, iConstruct Clash, cmBuilder.io, etc. by grouping clashes using pre-set templates, provide issues for Procore to view on its observation tools, and view, share, distribute, and analyze laser scan data. Figure 1 outlines the broader steps involved in the integration of BIM software with Procore.

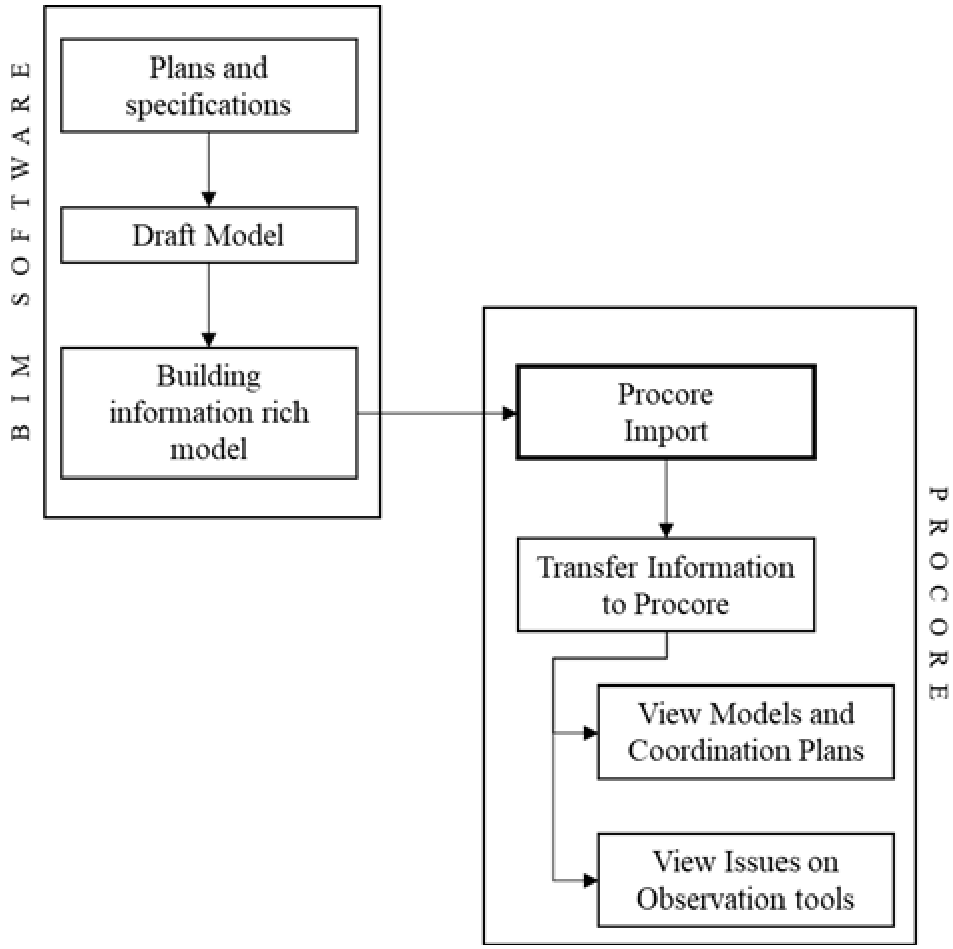

Figure 1: Building Information Modeling (BIM) to Procore Integration

2. Takeoff and Estimating: In the pre-construction phase, accurately estimating the cost of a construction project is crucial for acquiring projects and ensuring profitability. However, traditional manual quantity take-off procedures are prone to human errors and can result in lost information. Procore has developed its internal estimating software, as well as, created plugins or application programming interfaces (APIs) in partnership with other software developers such as ProEst and cmbuilder.io. As a result, Procore users can create detailed cost estimates, perform digital takeoffs, and transfer data between awarded projects and Procore Financials. A flowchart outlining the basic steps to integrate estimation with Procore is provided in Figure 2.

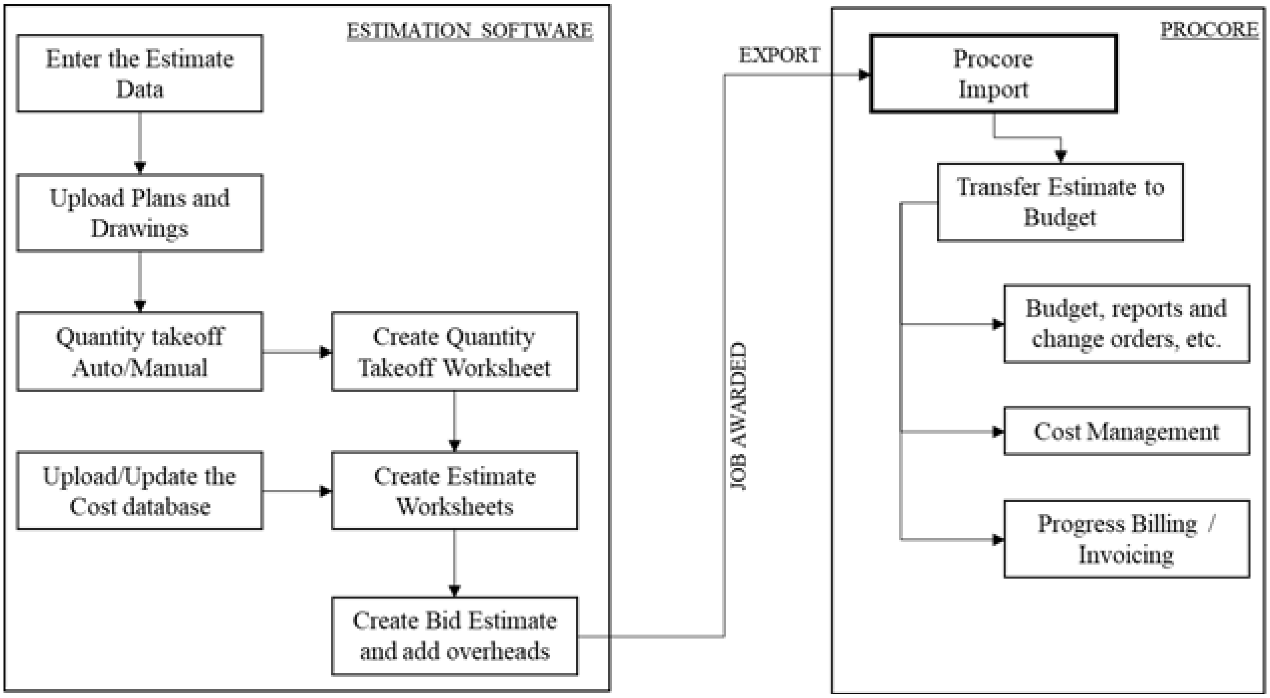

Figure 2: Estimation to Procore Integration

3. Scheduling: In construction projects, project management and related documentation involve extensive information exchange with scheduling. However, due to the traditional stand-alone software systems, significant information is lost during this process. Syal et al. (1991) recognized this issue long ago and developed a framework that identified the interfaces between estimating, scheduling, and project management software, in order to facilitate information flow between these activities. Procore has developed API or plugins to enable its users to transfer data easily. These plugins allow a Procore user to upload schedules, view and sort them based on the status of work and filter tasks by person or trade. The available plugins support Microsoft Project, Oracle Primavera P6, and others. Figure 3 shows the broader steps involved in integrating scheduling with Procore.

Future Integration-Related Plans of Procore

Procore is a growing construction management software with over 400 integrations across different platforms. The company's vision is to create a single-source software for all construction management needs. To achieve this, Procore is partnering, integrating, and purchasing different third-party applications to offer powerful technology solutions. Some of the key integration solutions include Procore Pay, Procore Connect, AI applications, AR/VR applications, visual information tool on project site, etc. (Procore 2023).

"Procore Pay" is a connected platform designed to embed payments functionality into its project management platform. It will reduce payment friction by expediting invoice review, providing payment options, and streamlining lien wavier. It is Procore's key innovation in partnership with Goldman Sachs Transaction Banking. Procore is also developing a secure connection platform called "Procore Connect" to enable teams and other stakeholders to synchronize data for up-to-date drawings.

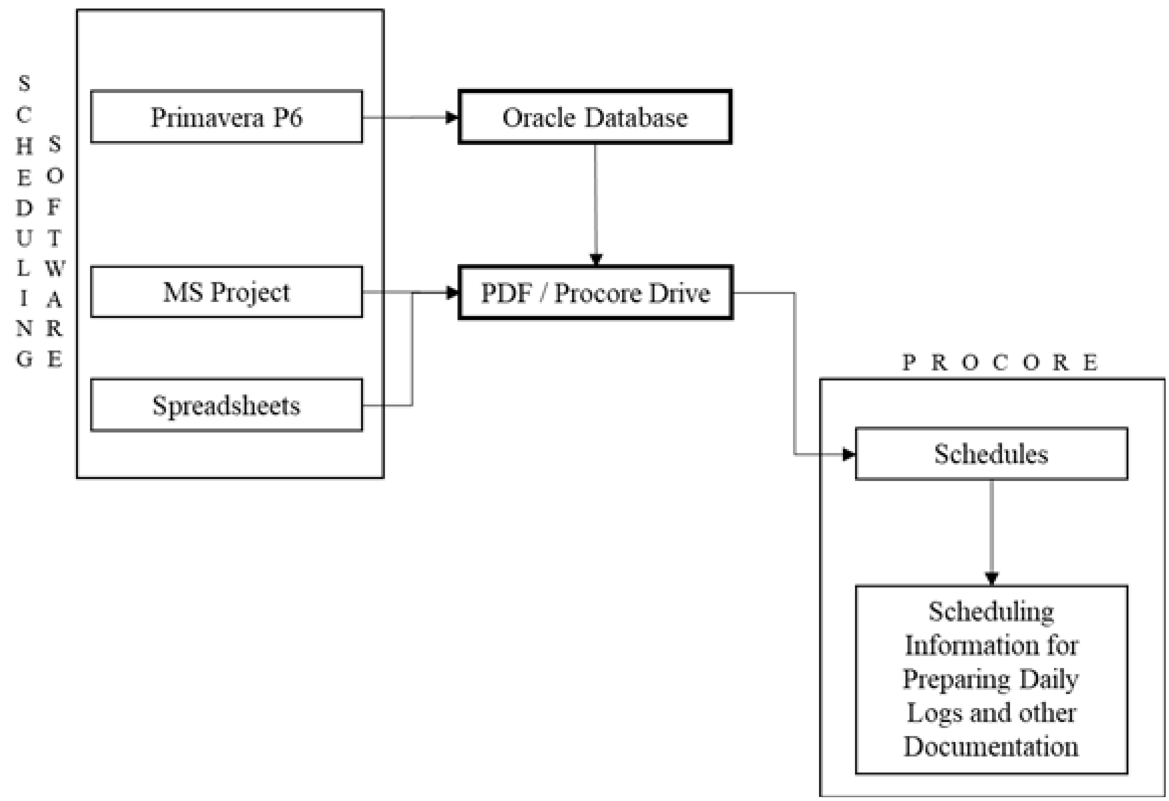

Figure 3: Scheduling to Procore Integration

Procore is investing in predictive analytics and incorporating construction intelligence by unlocking data and artificial intelligence to help users run projects more efficiently. Procore is also planning to integrate Augmented Reality (AR) and Virtual Reality (VR), into its platform soon, possibly in 2024-25.

Procore is partnering with EarthCam, a provider of live camera content, who unveiled a new line of imaging solutions to serve a variety of jobsite visual information needs. These include worksite access management, safety violations, PPE compliance, and live weather data. Procore is also partnering with Willow, a digital twin solutions provider for smart infrastructure and real estate, to assist owners to streamline the transition of digital deliverables from the construction to handover and operations phases in a more structured and efficient manner.

PROCORE INTEGRATION MODULES

In order to understand the current state of integration of various software with Procore, it is important to understand the characteristics of individual software including their data import-export capabilities. By using an example building project, the authors implemented integrated modules of common construction software with Procore in order to understand the ease or challenges of their integration. The software used were: Procore, Autodesk Revit, Autodesk Navisworks, Procore Estimation and Oracle Primavera P6.

Autodesk Revit and Navisworks are BIM programs that aid in the design, collaboration, and visualization of construction projects. Procore Estimating is a cloud-based construction estimating tool introduced by the Procore company. Oracle Primavera P6 is a project management tool that helps with planning, scheduling, and controlling of projects. The following sections describe integration of each of these software with Procore.

Building Information Modelling and Procore

Autodesk Revit is a 3D modeling software that allows users to create a detailed building model. The Procore VDC plugin enables the direct integration of the model with Procore, which transfers grids and locations within the project. This location data can be used for preparing daily logs, inspection reports, or adding photos to specific locations. Autodesk Revit can also facilitate quantity takeoff of all building elements. This software can be used to prepare a takeoff workbook that can integrate with Procore Estimation. The flowchart in Figure 4 outlines the integration (Autodesk Revit 2022).

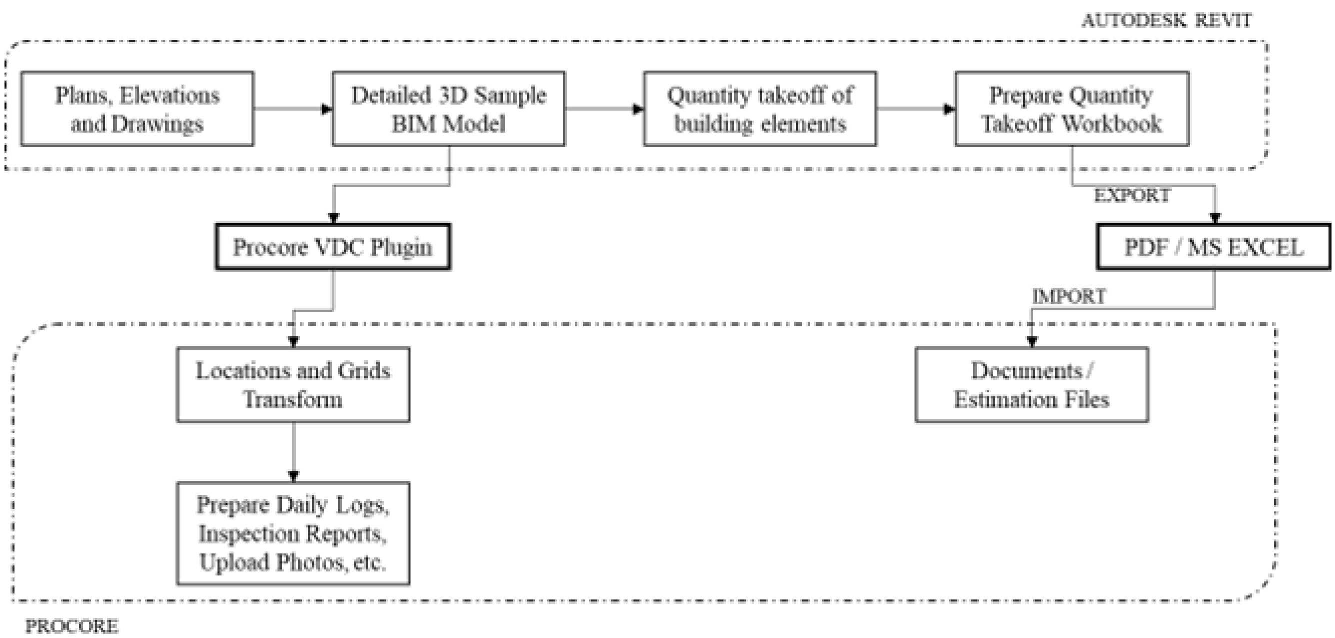

Figure 4: Integration of Autodesk Revit with Procore

Autodesk Navisworks is another software tool used for BIM integration with Procore. The detailed 3D sample model created using Autodesk Revit can be published as an NWD document, which can be opened using Autodesk Navisworks. Views and walkthroughs can be created and integrated with the view model tool available on Procore. This allows Procore users to navigate, orbit, and measure the model. Another use of Navisworks is for clash detection, which can be directly linked to Procore using the Procore Navisworks plugin. This data is transferred directly to the create coordination issues tool on Procore, which can assist project managers in viewing, tracking, preparing RFIs, preparing reports, and managing the clashes through subcontractor meetings and coordination processes (Figure 5).

The above-noted sections show that integrating BIM with Procore can offer numerous benefits to construction project management, such as efficient quantity takeoff, clash detection, and coordination between project stakeholders.

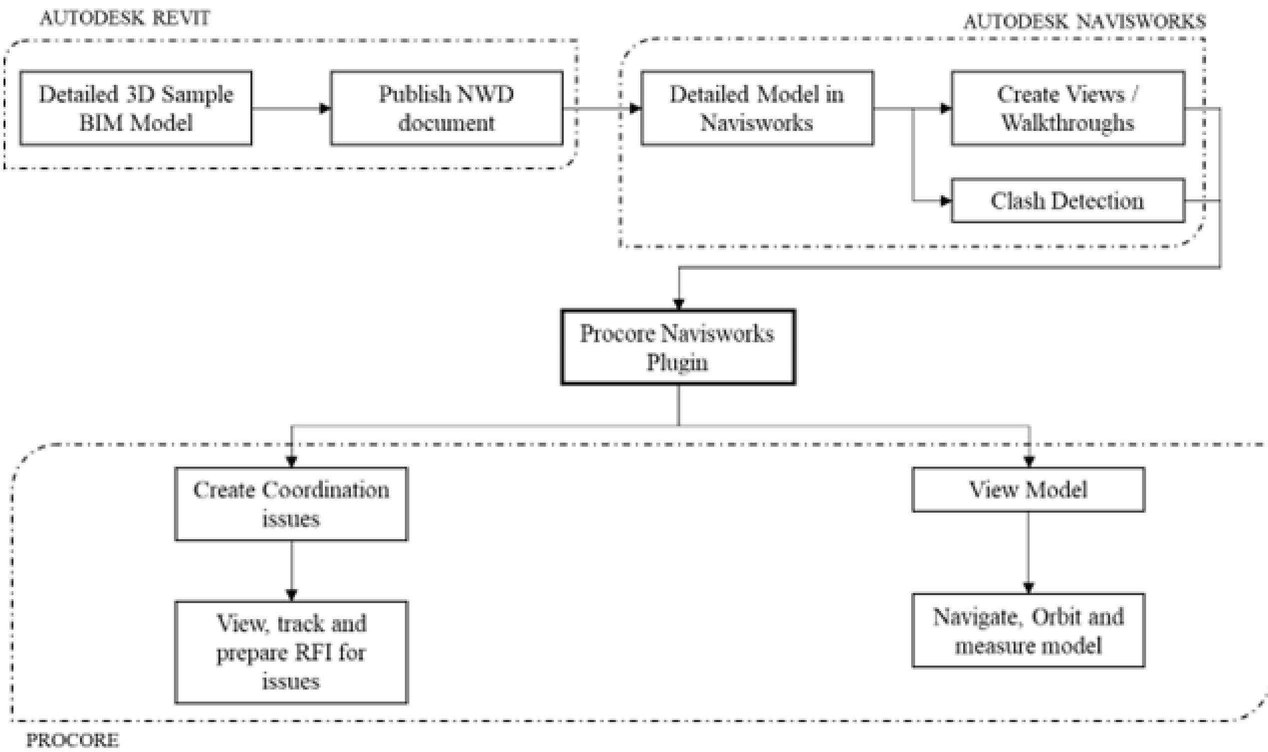

Figure 5: Integration of Autodesk Navisworks with Procore

Procore Estimation and Procore

Procore Estimation is a construction estimating software tool introduced by the Procore company. It includes the capability of performing quantity take-off from plans and drawings (Procore Estimation 2023).

To integrate Procore Estimating with Procore, a project must first be created in Procore. This project can be accessed directly by Procore Estimation. Once the project is established, plans, elevations, and drawings can be uploaded to it. The quantity take-off of all building elements can be performed manually or using the auto takeoff tool. The takeoffs are sent to bid estimate to add overheads, and the data is either exported to Procore internally through the plugin or through PDF or e-mail to documents or estimation folder. The data transferred directly through the Procore plugin can be viewed in the budget functions of the Procore window. This data can be used to create change orders, prime contracts, subcontracts, prepare reports, etc. The flowchart in Figure 6 depicts the steps from estimation to project management software.

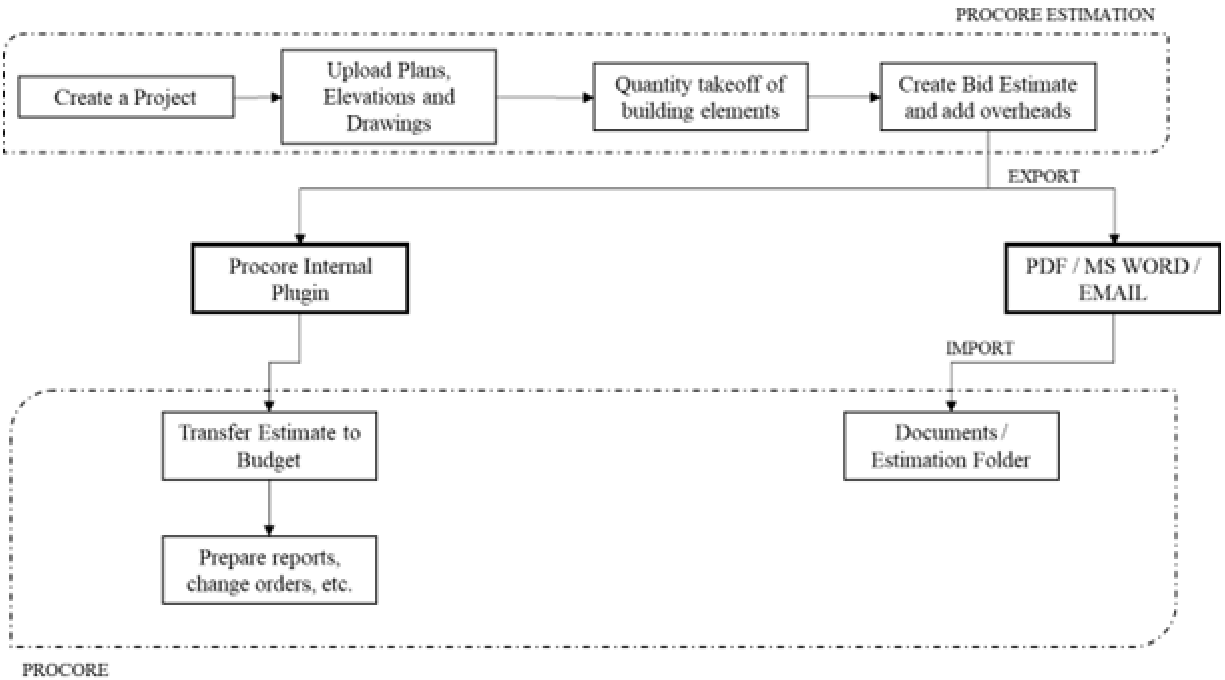

Figure 6: Integration of Estimation with Procore

Primavera P6 and Procore

With the help of Procore software, integrating a project schedule with project management documentation has become easier, providing access to real-time information on completed tasks and enabling the creation of daily reports and inspection reports.

To integrate the schedule, a detailed sample schedule is created in P6 Primavera software (Oracle 2022), forwarded to the Oracle database, and exported as an “xer” file to Procore Drive, or a share drive. Later, this file is imported into Procore via the schedule option, and the schedule can be viewed in different formats, such as a calendar view, a list view, or a look at schedule view. Using the schedule, daily logs, inspection reports, progress tracking, and look-ahead schedules can be prepared on Procore (Figure 7).

FINDINGS AND DISCUSSION

There are few ongoing efforts to provide a comprehensive integrated solution in construction project management, and among them, Procore has emerged as a promising effort. It offers an array of resources for managing construction cost and time, finances, and labor across all stages of the construction process. It enables global access to project details and can be viewed from various devices. Procore is committed to enhancing its integrations with other software tools. Furthermore, Procore is exploring the possibility of integrating accounting tools into its platform soon and improving its integration with estimation tools. Some specific discussions for each type of integration including observations and recommendations are provided below. Recommendations are based on the observations and the limitations noted during the implementation of the integration modules in the earlier sections.

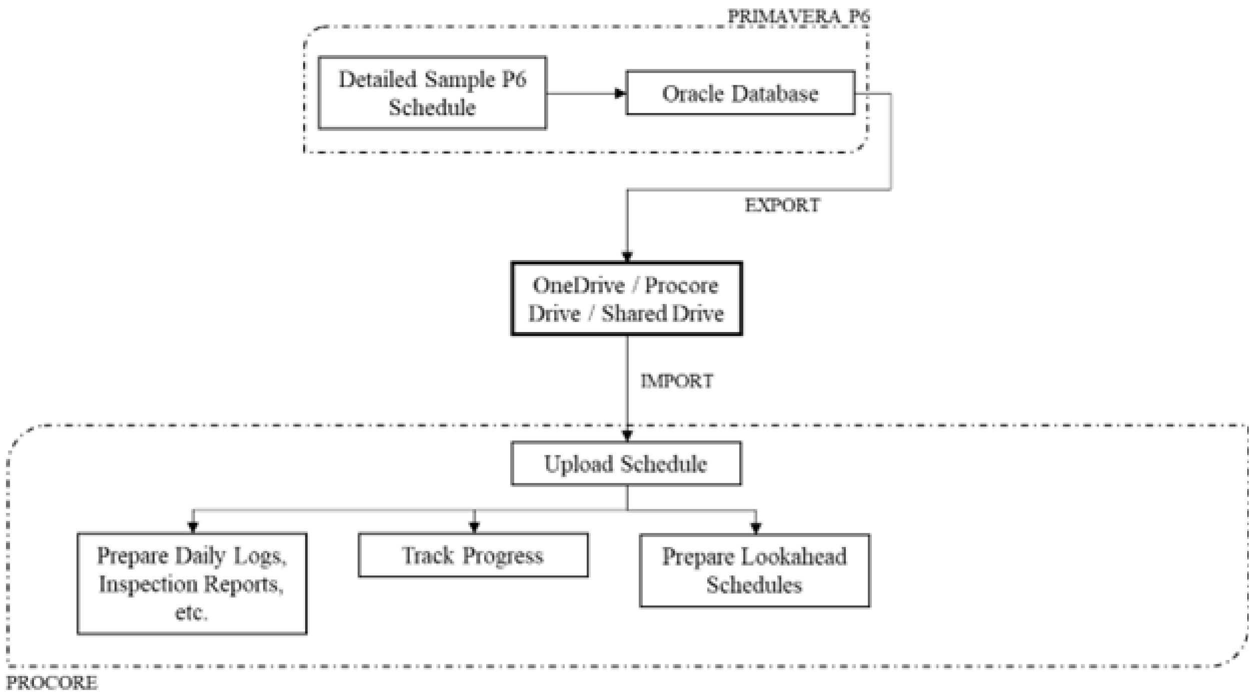

Figure 7: Integration of Schedule with Procore

IA. BIM (Autodesk Revit) and Procore

The purpose of this integration was to enable data transfer from the Building Information Modeling (BIM) software to a standardized format accessible by Procore. A detailed 3D model was utilized to export information to Procore about the locations, grids, and quantity take-off data of building elements. The import of locations and grids was facilitated by Procore VDC plugin, whereas the takeoff data was imported as an MS Excel or a PDF file.

Observations:

1. Autodesk Revit presents good capabilities for quantity take-off from the 3D model.
2. Exporting quantity take-offs to MS Excel or PDF formats and then importing in Procore was easy.
3. Beyond locations, grids, and quantity take-off data, the Revit model could not be further integrated with Procore, e.g., be viewed in Procore.

Recommendations:

1. If the Revit model can be viewed in Procore, it will enhance the coordination and the collaboration among project teams.
2. Even though Revit accurately estimates the components, it fails to group related elements. This integration would be better if Revit could recognize and group related components automatically.

IB. BIM (Autodesk Navisworks) and Procore

The main objective of this integration was to take the integration of the 3D BIM model with Procore further so it can be used for clash detection and coordination among project stakeholders. In order to achieve this objective, the 3D model created in Revit was converted into a Navisworks document file, which was utilized to create various perspective views and walkthroughs. The Procore-Navisworks Plugin was utilized to check for the issues related to clashes, and these issues were accessible on both Procore and Navisworks.

Observations:

Overall, Navisworks demonstrated better integration with Procore than Revit. Thus, for 3D model integration the best path found by this study was to follow:

Autodesk Revit □ Autodesk Navisworks □ Procore.

1. Information flow between Autodesk Revit and Navisworks worked well.
2. Issues related to clashes once created in Navisworks can be accessed on both Procore and Navisworks.

Recommendations:

1. While the model was fully operable on the Procore workspace, it was not feasible to create section views. Adding "create model sections and views" can highly benefit project teams in accessing the models on site.

II. Procore Estimation to Procore

This integration links estimates from Procore Estimation with Procore project management functions. Procore Estimation is a software application designed to make the estimation process efficient by permitting users to import plans and drawings into its platform. It has an automated takeoff tool that can generate takeoff workbooks from imported drawings. These quantities can be linked with cost databases to produce comprehensive project estimates. The estimates can be linked with budget function in Procore that can give users the ability to manage costs and create various financial reports. These estimates can also be exported as MS Word or PDF files.

Observations:

1. Overall, this integration works well since it involves linking two Procore products.
2. Procore Estimation can perform take-off automatically by importing plans and drawings.
3. Once a project is awarded, the estimates can be sent to Procore budget directly for cost management and invoicing.

Recommendations:

1. Once the estimation is integrated, it does not allow the take-off line items to be exported

as activities in the schedule. If this option was possible, it would allow for the transferring of estimate data to scheduling software. That, in turn, can be used to resource and cost load the schedules for project controls.

III. Primavera P6 Scheduling to Procore

The aim of integrating Primavera P6 with Procore was to be able to use the project schedule for managing on-site construction activities, e.g., reflecting schedule activities in daily logs. With the existing level of integration involving import of schedule in Procore, it was observed that Procore currently lacks the functionality to extract cost and resources from the construction schedule, which is necessary for utilizing scheduling information for project management.

Observations:

1. Procore can import schedules from Primavera P6 and align it with its calendar.
2. Procore can allow users to track progress, create lookahead schedules and view Gantt charts.
3. The imported schedule activities are automatically reflected in the daily logs.

Recommendations:

1. Currently, the integration between Procore and Primavera P6 is one directional. If the schedules are updated on Procore, these are not automatically updated on Primavera P6. In order to take full advantage of this integration, a plugin should be developed to create a two-way integration.
4. The imported schedule activities are automatically reflected in the daily log, but the corresponding resources are not reflected.
2. If the schedule in P6 is cost loaded, that information does not get reflected in Procore's budget option. Reflecting the cost loaded schedules in Procore financial management would assist in invoicing and cost management.

SUMMARY

Procore is rapidly emerging and expanding as a comprehensive construction project management software, with over 400 integrations across various platforms. The company's primary objective is to become a one-stop-shop for all construction management needs by collaborating, integrating, and purchasing third-party applications. Some of the key Acquisitions that Procore in the last 5 years include: project management software group Honest Buildings in July 2019, estimating software provider Esticom in October 2020, and construction artificial intelligence companies Avata Intelligence in November 2020, and INDUS.AI in July 2021.

Procore is investing in predictive analytics, machine learning, and artificial intelligence to provide smarter and more efficient project management solutions. Procore is constantly striving to integrate emerging technologies, including data analytics, artificial intelligence (AI), design innovations, and machine learning, into the construction industry. Furthermore, the company is incorporating augmented and virtual reality to expedite project approval times and improve user navigation.

One of the most promising topics discussed during a recent meeting with a key Procore executive was the integration of AI-driven analytics to enhance data capabilities. Additionally, Procore is partnering with other companies to incorporate AR/VR technology into its platform, creating standalone software that can work alongside Procore's existing platform. The company is also developing a Construction Network platform to serve as a space for professionals in the construction industry to connect, collaborate, and share knowledge.

Overall, there is a great need for flexible and adaptable construction management software with integration capabilities with other commercially available software frequently used in the construction industry. Such integrated software solutions are necessary for efficient handling of information flow between design and project management and among various project management functions. These integrated solutions will improve efficiency and reduce human error by elimination of repeated data inputs leading to accuracy of data and time saving.

In conclusion, while computers have been used in construction management for over four decades, the industry has not progressed as much as other sectors. The difficulties in integrating different software programs have led to delays and overspending in construction projects. However, the development of an all-in-one software environment that caters to all construction management needs, such as Procore, has the potential to solve these long-standing problems. The authors envision that, in the near future, various construction management software will be available as a fully integrated software suite, that will provide a more efficient and effective solution for managing construction projects.

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REFERENCES

Aladag, H., Demirdögen, G., and Isik, Z. (2016). "Building Information Modeling (BIM) Use in Turkish Construction Industry." Procedia Engineering, 161(2016), pp. 174-179.

Ashoka, V. and Syal, M. (2023). "Computer Integrated Construction Management with Procore," MSCM Research Report, CM Program, School of Planning, Design and Construction, Michigan State University, East Lansing, MI

AGC - Associated General Contractors of America (2022). "Construction Data." Available at: https://www.agc.org/learn/construction-data (Dec. 04, 2022).

Autodesk (2022). "Design and build with BIM (Building Information Modeling)." Available at: https://www.autodesk.com/industry/aec/bim (Nov. 20, 2022).

Autodesk Navisworks (2022). "About Navisworks." Available at: http://www.autodesk.com/

productsnavisworks/overview (Nov. 20, 2022).

Autodesk Revit (2022). "What does Revit do?" Available at: http://www.autodesk.com/products/revit-family/overview (Nov. 20, 2022).

Bello, S. A., Oyedele, L. O., Akinade, O. O., Bilal, M., Delgado, J. M. D., Akanbi, L. A., Ajayi, A. O., and Owolabi, H. A. (2021). "Cloud computing in construction industry: Use cases, benefits and challenges," Automation in Construction, 122.

Bluebeam (2022). "Construction Software for Innovators." Available at: https://www.bluebeam.com (Nov. 20, 2022).

Craig, D. (2022) "The Future of Contech," Procore Jobsite. Accessed at: https://www.procore.com/jobsite/the-future-of-contech/?utm_medium=Social&utm_source=LinkedIn&utm_campaign=SOC-22-LinkedIn-Organic&utm_term=US&utm_content=Procore_Jobsite-Article-The-Future-Of-Contech (Dec. 10, 2022).

Cudahy, G. (2022). The Key to Intelligent Connectivity in a World Awash with IoT Data? Making Decisions at the Edge. Forbes Technology Council. Available at: https://www.forbes.com/sites/forbestechcouncil/2022/03/04/the-key-to-intelligent-connectivity-in-a-world-awash-with-iot-data-making-decisions-at-the-edge/?sh=7edee9054b13 (Nov. 20, 2022).

DocuSign (2022). "How the construction industry uses electronic signatures." Available at: https://www.docusign.com/sites/default/files/resource_event_files/Construction-RedesignedInfographic_Rnd7.pdf (Oct. 27, 2022).

Gargari, M, T., and Elzarka, H. M. (1998). "Integrated CAD/KBS approach for automating preconstruction activities." J. Construction Engineering and Management, 124, pp. 257-262.

Narayan, K. L., Mallikarjuna Rao, K., and Sarcar, M. M. M. (2008). Computer Aided Design and Manufacturing. Prentice Hall of India, New Delhi, India.

NBS – United States (2017). "Top 10 BIM terms explained!" Available at: https://www.thenbs.com/knowledge/top-10-bim-terms-explained (Oct. 25, 2022).

Ohaski, Y., and Mukimo, M. (1985) "Computer-Aided Engineering in the Construction Industry," Engineering with Computers, Vol. 1, no. 2, (1985).

Oracle (2021). "Oracle's Primavera P6 Professional Project Management." Available at: https://www.oracle.com/applications/primavera/products/project-management.html (Nov. 20, 2022).

Oracle Construction Management Software (2022). "Construction Management Software Powers Core Project Activities." Available at: https://www.oracle.com/industries/construction-engineering/construction-management-software/ (Nov. 20, 2022).

Procore (2023). "About Procore." Available at: https://www.procore.com/construction- os/core/ (July 20, 2023).

Procore Estimation (2023). "About Procore Construction Takeoff and Estimation Software."

Available at: https://www.procore.com/estimating (July 20, 2023).

Procore Marketplace (2023). "Procore App Marketplace." Available at: https://marketplace.procore.com/ (July 20, 2023).

Rathmann, C. (2022) "Toric AI-Driven Construction Analytics Penetrate Large Contractors, Owners with Funding and Procore Integration," Accessed at: https://www.forconstructionpros.com/construction-technology/article/22030633/toric-announces-procore-integration-and-venture-funding (Dec. 10, 2022).

Sage 300 Construction and Real Estate (2022). "About Sage 300 Construction and Real Estate." Available at: https://www.sage.com/en-us/products/sage-300-construction-and-real-estate/timberline/ (Nov. 20, 2022).

Singh, V., Ning, G., and Wang, X. (2011). "A theoretical framework of a BIM-based multidisciplinary collaboration platform." J. Automation in Construction Management. 20, pp. 134-144.

Syal, M. G., Parftt, M. K., and Willenbrock, J. H. (1991). "Computer-integrated design/drafting, cost estimating, and construction scheduling." Housing Res. Ctr. Series Report No. 11, The Pennsylvania State Univ., Univ. Park, Pa.

Trimble ProjectSight (2022). "Project Management Software for Designers and Contractors" Available at: https://projectsight.trimble.com (Dec. 15, 2022).

SUSTAINABILITY OF APPAREL EXPORTING INDUSTRY FACILITIES IN SOUTH ASIA

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ABSTRACT

The apparel industry's contribution to the gross domestic product in South Asian countries is significant and provides livelihoods for millions of people in this region. Although this industry's contribution towards the economy is substantial, its negative impact on the environment and the working conditions have always been critical issues of concern. The two countries of emphasis in this research, Bangladesh, and India, have experienced numerous garment factory accidents in the form of building collapses, factory fires, and boiler explosions, which have killed and injured thousands of workers. These incidents have brought attention on the need to improve poor facilities and working condition. As a result, it was felt that implementing sustainable practices in the apparel facilities will result in better facilities and improved working conditions and, that would lead to increased employee productivity and fewer occupational hazards, illnesses, and mishaps. This aspect is especially emphasized by the importers in the United States, who believe that an effective method for a factory facility to implement sustainable practices is by obtaining an international green building certification, such as, the Leadership in Energy and Environmental Design (LEED).

The main objective of this research is to analyze recent LEED certified apparel factories in South Asia to compile data and strategies with the goal to help promote LEED certification for this industry. To achieve this goal, 17 LEED certified apparel factories in Bangladesh and India were investigated to highlight the LEED credits that were either most frequently adopted or avoided. Among those 17 factories, one factory that received the highest LEED Platinum score was then studied in detail, as a case study project, to understand the different strategies employed by them to earn LEED credits. Based on the literature review, LEED credit analysis, and lessons learned from the case study, different strategies for LEED implementation were compiled. The authors envision that the lessons learned, and the strategies outlined in this research will promote the adoption of the sustainable practices for the facilities and operations of the apparel exporting factories.

KEY WORDS

Sustainable Facilities, LEED Certification, Renewable Energy, Apparel Factories, South Asia

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INTRODUCTION

The apparel industry is a major source of exports and foreign exchange for South Asian countries such as Bangladesh and India. Additionally, employment in apparel production represents a significant share of total manufacturing employment in these countries, especially for women (Keane and Velde, 2008). The apparel manufacturing industry has grown continuously in recent years. As of 2020, Bangladesh has approximately 4,300 apparel factories with a revenue of $33 billion and India has over 4,100 factories with over $16 Billion in revenue (BGMEA, 2020; TEXMIN, 2019). Currently, India has a share of just 5% of the global textile and apparel export market, while Bangladesh has a 6.8% share of global garment exports. Both countries are trying to increase their share to as much as 35% of the global market by 2025 (Apparel Resources, 2020).

In recent years, these two countries have experienced numerous garment factory accidents in the form of building collapses, factory fires, and boiler explosions, which have killed and injured thousands of workers. These incidents have brought attention on the need to improve poor facilities and working condition. Several major companies from the United States are major importers of apparel from these countries they feel that implementing sustainable practices in the apparel facilities will result in better facilities and improved working conditions and, that would lead to increased employee productivity and fewer occupational hazards, illnesses, and mishaps (Open Sourced Workplace, 2019). They feel that an effective method for a factory facility to implement sustainable practices is by obtaining an international green building certification, such as, the Leadership in Energy and Environmental Design (LEED). The advantages of following an internationally adopted certification system such as LEED is that it is accepted by all stakeholders including factory management, governments, workers' welfare groups in India, Bangladesh, and USA, and most importantly, the US companies and customers.

Conditions in the Apparel Industry

The overall emphasis on conditions in the apparel industry include facilities, energy consumption, working conditions, waste management and pollution. A series of recent building collapses and accidents have put the focus on the facilities, factory operations, and working conditions. These accidents made the apparel industry stakeholders, especially the international importers, realize the need to focus on the poor facilities, unsustainable operations, and difficult working conditions in the apparel factories (Bick et al., 2018; Solanki, 2019; Anilkumar and Syal, 2021).

<u>Factory Accidents:</u> A very important reason to focus on apparel industry facilities is due to a series of recent building collapses, factory fires, and other avoidable industrial accidents that led to many injuries and deaths. One such factory accident was the Rana Plaza Collapse of 2013 which occurred due to compromised structural integrity of the building, as it was built on a filled-in pond and lacked structural stability. Approximately 1,000 people were killed, and more than 2,000 were injured. Another notable factory accident was the Tazreen Fashion Factory Fire of 2012, where the impact was magnified due to the lack of sufficient emergency exits. In this accident, 100 people were killed while more than 200 were injured. Even though the fire started due to an electrical short circuit, the large amount of fabric and yarn in the factory and narrow and inadequate fire exits exacerbated the situation (Chowdhary and Tanim, 2016; Reuters, 2019).

<u>Energy Consumption and GHG Emissions:</u> Electricity is consumed in large quantities for textile manufacturing at different stages of operations including desizing, scouring, bleaching, dyeing, and printing. The use of electricity and the factory processes result in the emission of greenhouse

gasses at the rate of 1.2 billion ton annually, which represents around 10% of the global carbon emissions (Hasanbeigi, 2012; Islam, 2016).

Poor Working Conditions: Many of these factories have poor working conditions for their production staff. The workers are subjected to poor indoor air quality caused by chemicals from materials and machines, smoke, dust mites, mold spores, radon, and other gases. Often, they have to stand or sit in the same position for long periods while being exposed to dust, excess heat, and chemicals. These hazards expose them to ergonomic and psychosocial problems including backache, spondylitis, Achilles' heel, and respiratory and eyesight issues (Chowdhary and Tanim, 2016; Bick et al. 2018).

Solid Waste Disposal: Waste management is a significant challenge in the apparel industry. Solid waste is produced at different stages of textile production and includes packaging waste, lint, wipes, rags, filters, and fabric scraps. These are often disposed of in landfills, where these wastes often take more than 200 years to decompose. Harmful chemicals used in textile dyeing, bleaching, printing etc., can leach out into the groundwater (Babu et al., 2007).

Water Pollution: Large quantities of water are consumed at almost every stage of textile manufacturing process, including desizing, scouring, bleaching, and washing. After the water is used, it is contaminated with a wide range of chemicals, dyes, starch, fats, waxes, chlorine, acids, alkalis, and salts. Exposure to this water can cause hemorrhage, skin ulceration skin, nausea, stress, and contact dermatitis in human beings and it can be toxic to aquatic life (Pattnaik et. al., 2018; Samantha et al., 2019).

Sustainable Facilities in the Apparel Industry

Recent media coverage of the environmental and working conditions in South Asian apparel factories has made various stakeholders aware of the issues facing this industry. In addition, news coverage of accidents in these facilities has led to further focus on the poor facility conditions, unsustainable operations, and the poor working conditions in the international forums. This negative exposure prompted various stakeholders including factory owners, government agencies, labor unions and most of all, the international importers, to look for various solutions to stem this tide of negative publicity. One main solution that started to emerge is the demand for sustainable practices in both the facilities themselves and the operations in these facilities. The general belief is that introducing sustainable practices in the facilities will also have positive impact on the working conditions in the factories and it will result in increased employee productivity and fewer occupational hazards, illnesses, and mishaps. This will then in turn enhance the overall revenue and the international reputation of the organization (Open Sourced Workplace, 2019). This concept is supported by earlier work conducted by Potbhare et al. (2009), who noted that in developing countries, green building initiatives must identify, among other criteria, the necessary motivations for adopting organizations.

As the industry began implementing sustainable practices, the widely accepted method for sustainable facilities and operations was to either build new factories or upgrade the existing factories using internationally accepted green building guidelines or certifications. International green building certifications were found to give workers and other stakeholders a strong sense of confidence that the certified facility will provide safer and better working conditions as it will be better engineered and will incorporate sustainable practices in design, construction, operations, and maintenance (Rani and Jamal, 2018; Hasan et al, 2018). Furthermore, Kaur et al. (2014) found that educational programs about green features in factories can change stakeholder knowledge and perceptions about the role that green features play in improved indoor environments and working conditions.

Despite the importance of international green building rating systems, issues such as high renovation costs, difficulty in meeting credit prerequisites, and unavailability of the required data for certification submittals, as well as resistance to make changes in existing buildings, lack of skilled professionals, technical difficulty in retrofitting, and lack of awareness among stakeholders were found to be barriers that must be overcome before wider adoption (Jain et al., 2013).

The most popular green building certification systems used by most factories in recent years is LEED – Leadership in Energy and Environmental Design, developed and promoted by the U.S. Green Building Council. It includes a set of rating systems for the design, construction, operation, and maintenance of green buildings, homes, and neighborhoods (Vierra, 2019, USGBC, 2020; Anilkumar & Syal, 2021). These include:

- LEED Building Design and Construction (BD+C)
- LEED for Interior Design and Construction (ID+C)
- LEED for Building Operations and Maintenance (O+M)
- LEED for Neighborhood Development (LEED ND)
- LEED for Homes
- LEED for Cities and Communities

It should be noted that in Bangladesh, LEED certification is heavily focused on the textiles industry. Of 211 LEED-certified projects in Bangladesh as of April 2024, over 95% were textile manufacturing facilities (GBIG, 2024).

The two rating systems most used by the apparel factories were LEED BD+C and LEED O+M. LEED BD+C is mainly used for new factories whereas LEED O+M is mainly used for upgrading existing factories. The current version of these guidelines is version 4.1, but all the factories analyzed in this research were certified under version 3 - 2009. In each guideline, a facility is evaluated based on a maximum of 110 credits and meeting certain prerequisites under various categories, as shown in Table 1 (USGBC, 2020).

Depending on the credits earned out of the maximum 110 credits, a facility can achieve different levels of certification. These certification levels and the associated credits are (all prerequisites must be met in each case):

- Certified 40-49 credits
- Silver 50-59 credits
- Gold 60-79 credits
- Platinum 80-110 credits

Table 1: Categories and Credits for LEED BD+C and LEED O+M

LEED BD+C: New Construction v4.1		LEED O+M: Existing Buildings v4.1	
Integrative Process	- 1 Cr	Integrative Process	- n/a
Location and Transportation	- 16 Cr	Location and Transportation	- 15 Cr
Sustainable Sites	- 10 Cr	Sustainable Sites	- 10 Cr
Water Efficiency	- 11 Cr	Water Efficiency	- 12 Cr
Energy and Atmosphere	- 33 Cr	Energy and Atmosphere	- 38 Cr
Materials and Resources	- 13 Cr	Materials and Resources	- 8 Cr
Indoor Environmental Quality	- 16 Cr	Indoor Environmental Quality	- 17 Cr
Innovation	- 6 Cr	Innovation	- 6 Cr
Regional Priority	- 4 Cr	Regional Priority	- 4 Cr
TOTAL POINTS	110	TOTAL POINTS	110
LEED BD+C: New Construction v3 - 2009		**LEED O+M: Existing Buildings v3 - 2009**	
Sustainable Sites	- 26 Cr	Sustainable Sites	- 26 Cr
Water Efficiency	- 10 Cr	Water Efficiency	- 14 Cr
Energy and Atmosphere	- 35 Cr	Energy and Atmosphere	- 35 Cr
Materials and Resources	- 14 Cr	Materials and Resources	- 10 Cr
Indoor Environmental Quality	- 15 Cr	Indoor Environmental Quality	- 15 Cr
Innovation	- 6 Cr	Innovation	- 6 Cr
Regional Priority	- 4 Cr	Regional Priority	- 4 Cr
TOTAL POINTS	110	TOTAL POINTS	110

Research Scope

Although LEED documentation provides detailed roadmap for a factory to get LEED certified, these details are developed by US Green Building Council (USGBC) and focus on the issues and standards particular to United States. Therefore, there is a need to analyze LEED and its implementation in South Asian factories to understand strategies used in these countries, in an effort to promote greater adoption of LEED certification. This research analyzes 17 LEED certified apparel factories, as of Summer 2020, in India and Bangladesh to compile a list of LEED credits that are most frequently adopted and avoided.

The researchers elected to analyze garment factories in India and Bangladesh together due to the status of LEED and garment factory certification in the two neighboring countries. Bangladesh's LEED movement has been heavily affected by the LEED movement in India. For that reason, the research team wanted to explore differences and similarities in the approach to achieving certification between similar building types in the two countries. Additionally, India is competing with Bangladesh for garment exporting opportunities, adding some market pressure to the adoption on LEED standards for garment manufacturing facilities in the two countries.

An in-depth case study of the factory with the highest LEED Platinum score was then conducted in order to understand best practices that were adopted. Finally, the strategies used for LEED implementation are compiled and discussed with the goal to promote adoption of sustainable practices by new candidates in South Asia.

LEED CREDITS DATA COLLECTION AND ANALYSIS

It was found that in recent years, few factories in Bangladesh and India took the lead in pursuing LEED certification. In order to understand the level and scope of sustainable practices for the apparel industry in these countries, a list of all apparel, garment, and textile factories that were certified under LEED BD+C or LEED O+M was compiled from the USGC's online database (LEED Projects, 2020). The detailed scorecards of these factories were reviewed to identify the LEED credits that were most often achieved or avoided. The results were then analyzed to determine different categories and credits in terms of ease of adoption in the apparel industry.

Data collection procedures are described below and depicted in Figure 1. A list of all LEED-certified and LEED-registered garment factories located in Bangladesh and India was obtained from the US Green Building Council's online project database. While LEED v4.1 was the current version of LEED at the time the study was initiated, there was a larger and more diverse pool of textile factory projects certified under LEED v3, both LEED BD+C (new factories) and LEED O+M (existing factories). Thus, these projects were selected as they represented a more robust set of cases with more complete and comparable data among cases. Only projects that had already received certification from USGBC were retained for analysis. After sorting the facilities based on these criteria, LEED scorecards were reviewed for each project and descriptive statistics for these projects were developed, as discussed below. From these projects, the highest-scoring LEED platinum factory in Bangladesh (Tarasima Apparel Limited) was selected for further analysis as a detailed case study. Case study analysis was conducted through document review related to individual LEED credit submittals, technical reports, and construction documents obtained from the facility owner.

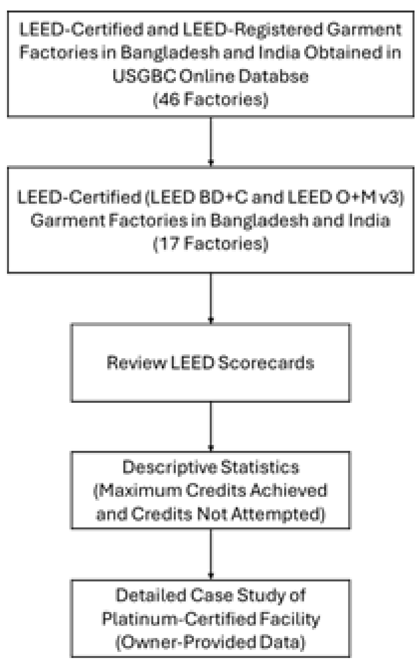

Figure 1. Data Collection Method

Thirteen factories were analyzed in Bangladesh; these included 3 platinum, 7 gold, 2 silver, and 1 certified. Out of 13 factories, 11 were certified under LEED BD+C and 2 were LEED O+M certified (Table 2). Four gold-certified factories were analyzed in India. These factories were evenly divided among LEED BD+C v3-2009 and LEED O+M v3 - 2009 (Table 3).

As can be seen in Figure 2, project locations are distributed across Bangladesh and primarily in the northern and southern states of India. According to the Koppen Climate Classification System (Peel et al., 2007), Bangladesh is located primarily in tropical and temperate climate zones, as are the factories located in India. While this variability in climate zones might present a cause for concern for a consistent analysis of which LEED points were chosen, more important than climate conditions is the similarity in sociocultural attitudes between India and Bangladesh.

Table 2: LEED Certification Details of Factories in Bangladesh

Factory Name	Location	LEED Guideline used for Certification	Certification Level and Points
Tarasima Apparels Ltd	Dhaka, Bangladesh	LEED O+M: Existing Buildings v3 - LEED 2009	Platinum - 93/110
Mithela Textile Industries Limited	Dhaka, Bangladesh	LEED BD+C: New Construction v3 - LEED 2009	Platinum - 91/110
Green Textile Limited Unit 3	Mymensingh, Bangladesh	LEED BD+C: New Construction v3 - LEED 2009	Platinum - 88/110
Ananta Apparels Ltd	Narayanganj, Bangladesh	LEED BD+C: New Construction v3 - LEED 2009	Gold - 67/110
Regency Garments Ltd - Unit 1	Chittagong, Bangladesh	LEED BD+C: New Construction v3 - LEED 2009	Gold - 65/110
Soorty Textiles BD Limited	Comilla, Bangladesh	LEED BD+C: New Construction v3 - LEED 2009	Gold - 65/110
Hela Clothing Bangladesh Ltd	Chittagong, Bangladesh	LEED BD+C: New Construction v3 - LEED 2009	Gold - 63/110
Regency Garments Limited - Unit 3	Chittagong, Bangladesh	LEED O+M: Existing Buildings v3 - LEED 2009	Gold - 63/110
Dird Composite Textile Ltd - Building 2	Gazipur, Bangladesh	LEED BD+C: New Construction v3 - LEED 2009	Gold - 60/110
Hamza Clothing Ltd	Dhaka, Bangladesh	LEED BD+C: New Construction v3 - LEED 2009	Gold - 62/110
Univogue Garments Company Limited	Chittagong, Bangladesh	LEED BD+C: New Construction v3 - LEED 2009	Silver - 52/110
Dird Composite Textile Ltd - Building 1	Gazipur, Bangladesh	LEED BD+C: New Construction v3 - LEED 2009	Silver - 55/110
Green Textile Limited	Mymensingh, Bangladesh	LEED BD+C: New Construction v3 - LEED 2009	Certified - 48/110

Table 3: LEED Certification Details of Factories in India

Factory Name	Location	LEED Guideline used for Certification	Certification Level and Points
Evolv clothing co pvt ltd factory bldg.	Kanchipuram, India	LEED BD+C: New Construction v3 - LEED 2009	Gold 60/110
Madura Clothing - Unit Fashion Craft	Bangalore, India	LEED O+M: Existing Buildings v3 - LEED 2009	Gold 67/110
KGI Clothing Pvt Ltd	Chittoor, India	LEED BD+C: New Construction v3 - LEED 2009	Gold 61/110
Madura Clothing - Haritha Apparels	Ramnagar, India	LEED O+M: Existing Buildings v3 - LEED 2009	Gold 69/110

Figure 2. Locations of Factories Included in the Study - Map data source: Google Maps

The LEED credits for these factories were analyzed and compiled under the following four factors:

- Maximum available credits achieved by all the factories (Table 4)
- Maximum available credits achieved by a majority of the factories (Table 5)
- Credits not attempted by any of the factories (Table 6)
- Credits not attempted by a majority of the factories (Table 7)

Credits obtained for the 17 cases were analyzed individually (i.e., for an individual project) and longitudinally across the entire set of projects to detect emerging patterns about the frequency with which certain credits were sought, related credits that were sought, and to understand which credits were sought least frequently.

Table 4 lists the credits that were achieved by all the factories, whereas Table 5 lists the credits achieved by more than half of the 17 cases. Similarly, Table 6 lists the credits not attempted by any of the factories, whereas Table 7 lists credits not attempted by more than half of the 17 cases. The tables show the LEED BD+C and LEED O+M credits in separate columns. It should be noted that all the factories analyzed were certified under LEED v3 - 2009, therefore categories and credit descriptions vary a little from the current version of LEED v4.1 (LEED Projects, 2020).

Tables 4 through 7 provide insight into the LEED credits that were preferred and those that were avoided by the apparel industry in Bangladesh and India. In new facilities, most credits under sustainable sites, water efficiency, innovation, and regional priority were very popular, whereas, in existing factories, most credits related to building commissioning, sustainable purchasing, solid waste management, green cleaning, and regional priority category were very popular. On the other hand, new factories seemed to avoid credits related to brownfield development, building and material reuse, indoor chemical and pollutant source control, and thermal comfort, whereas existing factories seemed to avoid credits related to reducing particulates in air distribution and sustainable cleaning equipment. Some reasons for this may include that light pollution reduction is not a widely known and culturally-accepted practice; there is more perceived value in spending facility improvement budgets on indoor thermal comfort. Additionally, the concept of brownfields is not s well developed in Bangladesh as in India and other pats of the world. One of the sustainable sites credits related to LEED-certified design and construction, that was not earned by any of the LEED O+M certified factories, can be only earned if an existing facility was originally built and certified as per any of the LEED guidelines.

Table 4: Maximum Available Credits Achieved by All the Factories

LEED BD+C: New Construction v3 - LEED 2009	LEED O+M: Existing Buildings v3 - LEED 2009
SS_SUSTAINABLE SITES 1. Alternative transportation- public transportation access 2. Alternative transportation- low-emitting and fuel-efficient vehicles 3. Alternative transportation- parking capacity **WW_WATER EFFICIENCY** 1. Water efficient landscaping 2. Water use reduction **IO_INNOVATION** 1. Innovation in design 2. LEED Accredited Professional **REGIONAL PRIORITY** 1. Heat island effect- Non roof 2. Water efficient landscaping	**SS_SUSTAINABLE SITES** 1. Building exterior and hardscape management plan 2. Integrated pest management, erosion control, and landscape management 3. Alternative commuting transportation 4. Heat Island effect - nonroof **WW_WATER EFFICIENCY** 1. Water performance measurement 2. Additional indoor plumbing fixture and fitting efficiency **EA_ENERGY AND ATMOSPHERE** 1. Existing building commissioning – implementation **MR_MATERIAL AND RESOURCES** 1. Sustainable purchasing - ongoing consumables 2. Sustainable purchasing - electric-powered equipment 3. Solid waste management - waste stream audit 4. Solid waste management - ongoing consumables 5. Solid waste management - durable goods **EQ_INDOOR ENVIRONMENTAL QUALITY** 1. Green cleaning - high performance green cleaning program 2. Green cleaning - custodial effectiveness assessment 3. Green cleaning - indoor chemical and pollutant source control **REGIONAL PRIORITY** 1. Performance measurement - building automation system 2. Water performance measurement 3. Additional indoor plumbing fixture and fitting efficiency 4. Water efficient landscaping

Table 5: Maximum Available Credits Achieved by a Majority of the Factories

LEED BD+C: New Construction v3 - LEED 2009	LEED O+M: Existing Buildings v3 - LEED 2009
SS_SUSTAINABLE SITES 1. Site Selection 2. Development Density and community connectivity 3. Alternative transportation- bicycle storage and changing rooms 4. Stormwater design- Quality control 5. Heat island effect- Non roof 6. Heat island effect- Roof **WW_WATER EFFICIENCY** 1. Innovative wastewater technologies **EA_ENERGY AND ATMOSPHERE** 1. Optimize energy performance 2. Enhanced commissioning 3. Measurement and verification **MR_MATERIAL AND RESOURCES** 1. Construction waste management 2. Recycled content 3. Regional materials **EQ_INDOOR ENVIRONMENTAL QUALITY** 1. Increased ventilation 2. Construction IAQ Management plan-during construction 3. Low emitting materials- adhesives and sealants 4. Low emitting materials- paints and coatings 5. Low emitting materials- flooring systems **REGIONAL PRIORITY** 1. On-site renewable energy 2. Storm water design- quantity control	**SS_SUSTAINABLE SITES** 1. Stormwater quantity control **EA_ENERGY AND ATMOSPHERE** 1. Optimize energy efficiency performance 2. Existing building commissioning - investigation and analysis 3. On-site and off-site renewable energy 4. Emissions reduction reporting **MR_MATERIAL AND RESOURCES** 1. Sustainable purchasing - furniture **EQ_INDOOR ENVIRONMENTAL QUALITY** 1. Indoor air quality best management practices - indoor air quality management for facility additions and alterations 2. Green cleaning - purchase of sustainable cleaning products and materials 3. Green cleaning - indoor integrated pest management **IO_INNOVATION** 1. Innovation in operations 2. LEED Accredited Professional 3. Documenting sustainable building cost impacts

Table 6: Credits not Attempted by Any of the Factories

LEED BD+C: New Construction v3 - LEED 2009	LEED O+M: Existing Buildings v3 - LEED 2009
SS_SUSTAINABLE SITES 1. Brownfield redevelopment **MR_MATERIAL AND RESOURCES** 1. Building reuse-Maintain existing walls, floors and roof 2. Building reuse- Maintain interior non-structural elements 3. Material reuse **EQ_INDOOR ENVIRONMENTAL QUALITY** 1. Indoor chemical and pollutant source control 2. Controllability of systems- Thermal comfort	**SS_SUSTAINABLE SITES** 1. LEED certified design and construction **EQ_INDOOR ENVIRONMENTAL QUALITY** 1. Indoor air quality best management practices - reduce particulates in air distribution 2. Green cleaning - sustainable cleaning equipment

Table 7: Credits not Attempted by a Majority of the Factories

LEED BD+C: New Construction v3 - LEED 2009	LEED O+M: Existing Buildings v3 - LEED 2009
SS_SUSTAINABLE SITES 1. Site development- protect or restore habitat 2. Light pollution reduction **EA_ENERGY AND ATMOSPHERE** 1. On-site renewable energy 2. Green power **MR_MATERIAL AND RESOURCES** 1. Rapidly renewable materials 2. Certified wood **EQ_INDOOR ENVIRONMENTAL QUALITY** 1. Outdoor air delivery monitoring 2. Construction IAQ Management plan-before occupancy 3. Low emitting materials- composite wood and Agri-fiber products 4. Thermal comfort- Design 5. Thermal comfort- Verification	**SS_SUSTAINABLE SITES** 1. Site development - protect or restore open habitat 2. Heat Island effect – roof 3. Light pollution reduction **EA_ENERGY AND ATMOSPHERE** 1. Existing building commissioning - ongoing commissioning 2. Performance measurement - building automation system 3. Enhanced refrigerant management **MR_MATERIAL AND RESOURCES** 1. Sustainable purchasing - reduced mercury in lamps **EQ_INDOOR ENVIRONMENTAL QUALITY** 1. Indoor air quality best management practices - outdoor air delivery monitoring 2. Indoor air quality best management practices - increased ventilation 3. Controllability of systems – lighting 4. Occupant comfort - thermal comfort monitoring 5. Daylight and views

CASE STUDY FACTORY

In order to better understand the implementation of LEED credits, the LEED Platinum-certified Tarasima Apparel Limited factory campus was further reviewed in detail as a case study. Tarasima Apparel Limited (TAL) is an apparel and fashion company located in Dhaka, Bangladesh. It has a campus of apparel factories including a washing facility with a gross floor area of 480,000 sq. ft. It is recognized as the highest scoring LEED-certified factory in South Asia. It was certified under LEED O+M: Existing Building (v2009) and scored 93 out of a maximum of 110 points, as outlined in Table 8 (Tarasima LEED, 2016; Bitopi Group, 2017, Anilkumar & Syal, 2021; Innowell, 2016; Berkel, 2017).

Table 8: LEED Credits Scorecard of Tarasima Apparel Limited

LEED O+M: Existing Buildings (v2009) PLATINUM Certified - July 2016	**Total Points Earned - 93/110**
SUSTAINABLE SITES: 22 / 26 SSc1 LEED certified design and construction 0 / 4 SSc2 Building exterior and hardscape Mgmt plan 1 / 1 SSc3 Integrated pest Mgmt, erosion control, and landscape mgmt. 1 / 1 SSc4 Alternative commuting transportation 15 / 15 SSc5 Site development - protect or restore open habitat 1 / 1 SSc6 Stormwater quantity control 1 / 1 SSc7.1 Heat island effect - nonroof 1 / 1 SSc7.2 Heat island effect - roof 1 / 1 SSc8 Light pollution reduction 1 / 1 **WATER EFFICIENCY: 14 / 14** WEp1 Minimum indoor plumbing fixture and fitting efficiency REQUIRED WEc1 Water performance measurement 2 / 2 WEc2 Additional indoor plumbing fixture and fitting efficiency 5 / 5 WEc3 Water efficient landscaping 5 / 5 WEc4 Cooling tower water Mgmt 2 / 2 **ENERGY & ATMOSPHERE: 25 / 35** EAp1 Energy efficiency best Mgmt practices - planning, documentation ... REQUIRED EAp2 Minimum energy efficiency performance REQUIRED EAp3 Fundamental refrigerant Mgmt REQUIRED EAc1 Optimize energy efficiency performance 8 / 18 EAc2.1 Existing building commissioning - investigation and analysis 2 / 2 EAc2.2 Existing building commissioning - implementation 2 / 2 EAc2.3 Existing building commissioning - ongoing commissioning 2 / 2 EAc3.1 Performance measurement - building automation system 1 / 1 EAc3.2 Performance measurement - system-level metering 2 / 2 EAc4 On-site and off-site renewable energy 6 / 6 EAc5 Enhanced refrigerant Mgmt 1 / 1 EAc6 Emissions reduction reporting 1 / 1 **MATERIAL & RESOURCES: 9 / 10** MRp1 Sustainable purchasing policy REQUIRED MRp2 Solid waste Mgmt policy REQUIRED MRc1 Sust. purchasing - ongoing consumables 1 / 1 MRc2.1 Sust. purchasing - electric-powered equipment 1 / 1 MRc2.2 Sust. purchasing - furniture 0 / 1 MRc3 Sust. purchasing - facility alter. & additions 1 / 1 MRc4 Sust. purchasing - reduced mercury - lamps 1 / 1 MRc5 Sust. purchasing - food 1 / 1 MRc6 Solid waste Mgmt - waste stream audit 1 / 1 MRc7 Solid waste Mgmt - ongoing consumables 1 / 1 MRc8 Solid waste Mgmt - durable goods 1 / 1 MRc9 Solid waste Mgmt - facility alter. & addn. 1 / 1	**INDOOR ENVIRONMENTAL QUALITY: 13 / 15** EQp1 Minimum IAQ performance REQUIRED EQp2 Environmental Tobacco Smoke (ETS) control REQUIRED EQp3 Green cleaning policy REQUIRED EQc1.1 IAQ best Mgmt practices - IAQ mana... 1 / 1 EQc1.2 IAQ best Mgmt practices - outdoor air delivery mo... 1 / 1 EQc1.3 IAQ best Mgmt practices - increased ventilation 1 / 1 EQc1.4 IAQ best Mgmt practices - reduce particulates in ... 0 / 1 EQc1.5 IAQ best Mgmt practices - IAQ mana... 1 / 1 EQc2.1 Occupant comfort - occupant survey 1 / 1 EQc2.2 Controllability of systems - lighting 1 / 1 EQc2.3 Occupant comfort - thermal comfort monitoring 1 / 1 EQc2.4 Daylight and views 1 / 1 EQc3.1 Green cleaning - high performance green cleaning program 1 / 1 EQc3.2 Green cleaning - custodial effectiveness assessment 1 / 1 EQc3.3 Green cleaning - purchase of sustainable cleaning products and material 1 / 1 EQc3.4 Green cleaning - sustainable cleaning equipment 0 / 1 EQc3.5 Green cleaning - indoor chemical and pollutant source control 1 / 1 EQc3.6 Green cleaning - indoor integrated pest Mgmt 1 / 1 **INNOVATION: 6 / 6** IOc1 Innovation in operations 1 / 1 IOc2 LEED Accredited Professional 1 / 1 IOc3 Documenting sustainable building cost impacts 1 / 1 **REGIONAL PRIORITY CREDITS: 4 / 4** EAc1 Optimize energy efficiency performance 0 / 1 EAc3.1 Performance measurement - building automation system 1 / 1 EAc3.2 Performance measurement - system-level metering 0 / 1 WEc1 Water performance measurement 1 / 1 WEc2 Additional indoor plumbing fixture and fitting efficiency 1 / 1 WEc3 Water efficient landscaping 1 / 1

In the sustainable sites category, Tarasima scored 22 out of 26 points by earning all the available points except LEED certified design and construction, which provides 4 points if the facility was previously built and certified under any other LEED guidelines. The strategies adopted by the factory included carbon emission-free exterior cleaning, reduced use of chemical fertilizers, planting local trees and shrubs, heavy emphasis on less carbon emission-based commuting options, collection of stormwater for gardening, reducing heat island effect by coating all parking and building roofs with high albedo coating, etc. In the water efficiency category, it scored all 14 points by implementing conductivity meters and automatic controls, low-flow faucets and dual flush toilets, the use of treated water for flushing and landscaping, and efficient cooling tower water management.

In the energy and atmosphere category, the project scored 25 out 35 points. It scored all available points in every credit except in the optimize energy efficiency performance credit, where it scored 8 out of 18 points. Strategies used in this category included using steam traps in irons, thermic fluid-driven dryers, and onsite renewable energy solutions.

In the material and resources category, Tarasima scored 9 out of 10 points. The only point it missed out on was related to sustainable purchasing - furniture. It earned 13 out of 15 points in the indoor environmental quality category, scoring all available points in every credit except indoor air quality best management practices- reduce particulates in air distribution, and green cleaning - sustainable cleaning equipment.

The case study factory scored maximum points in the innovation and regional priority categories. Overall, it implemented several innovative approaches that helped them to earn points in innovation as well as across many other categories. Some of these approaches are summarized in the following sections (Tarasima LEED, 2016; Bitopi Group, 2017, Anilkumar & Syal, 2021; Innowell, 2016; Berkel, 2017).

Waste Treatment and Recycling

The Tarasima apparel factory implemented several strategies to treat and dispose of waste generated in its processes. These include - waste water treatment, rainwater harvesting, factory waste incineration, and biogas plant.

<u>Waste Water Treatment</u>: The factory has an effluent treatment plant with a capacity of around 40 CFM which works on electro catalytic oxidization technology. It removes the toxic and non-toxic materials and chemicals from water disposed after being used in the factory processes (Figure 3). After the treatment, the waste water can be reused for different purposes such as toilet flushing (Bitopi Group, 2017).

<u>Rainwater Harvesting</u>: The factory installed a comprehensive rainwater harvesting system. This water is used in sustainable landscaping irrigation, industrial water needs, and toilet flushing.

<u>Factory Waste Incineration</u>: The factory installed a 2-ton incineration boiler that uses factory waste as combustion fuel. The factory waste consists of fabric waste, thread cones, carton boxes, and paper. This waste disposal process helps minimize the volume and disposal costs of the wastes generated at the factory which would have otherwise been disposed of in the landfills.

<u>Biogas Plant</u>: This plant produces biogas, a methane-rich natural gas from non-recyclable factory waste such as the food waste. Instead of disposing the food waste, the factory uses it as feedstock for its biogas plant and uses the output for cooking operations.

Figure 3: Effluent Treatment Plant

Energy Management

The energy management strategy at Tarasima included the use of skylights, high volume low speed (HVLS) fans, thermal oil heaters, and solar panels.

<u>Skylights:</u> This factory uses prismatic skylights extensively to bring in the sunlight. In addition to the benefit of daylight for workers' health and productivity (Singh et. al., 2010), it also enables the factory to dim or turn off electrical lights for parts of the day, leading to energy conservation.

<u>High Volume Low Speed (HVLS) Fans</u>: These fans are set on top of the sewing area to evenly distribute the air as shown in Figure 4. These fans help with the ventilation requirements and with boosting the effectiveness of the HVAC system (Bitopi Group, 2017).

Figure 4: HVLS Fans in the Sewing Area

<u>Thermal Oil Heaters</u>: Thermal oil heaters operate at atmospheric pressure and achieve temperatures up to 300^{o}C. These heaters are unlike conventional boilers, which use water/steam as heat transfer fluid, and are more energy efficient.

<u>Solar Panels</u>: This factory installed 125kw capacity solar panels on the roof top (Figure 5). These panels provide an average of 5% of total electricity required by the factory (Bitopi Group, 2017).

Figure 5: Rooftop Solar Panels

COMMONLY USED STRATEGIES FOR LEED CERTIFICATION IN APPAREL FACTORIES

Based on the literature review, LEED credit analysis of 17 apparel factories in Bangladesh and India and a detailed case study analysis of the highest scoring LEED Platinum factory, the authors observed and identified commonly used strategies that can help promote sustainability considerations by the apparel industry in South Asia. It is an important consideration for two primary reasons :1) LEED BD+C and LEED O&M standards are more suitable for commercial building projects, and are not designed specific to apparel production facilities, and 2) these guidelines are based on issues and standards particular to United States. The strategies and discussions in the following section will assist the apparel industry in selecting the most effective and achievable LEED credits and navigating them efficiently.

Sustainable Sites

All the certified factories considered a majority of credits in this category. The points that are not being considered include those which relate to rehabilitation of environmentally contaminated lands and the natural wildlife and their habitat. Since these countries have regulations related to redevelopment of environmentally contaminated lands but have very few incentives, attempting these credits may involve dealing with high levels of regulations and bureaucracy leading to extra investment from the owners.

For existing factories, LEED credits can be readily obtained for building exterior and hardscape management plan by using green cleaning chemicals, using the Carpet and Rug Institute (CRI) certified vacuum cleaners, adopting carbon free exterior cleaning methods, and using ecofriendly paints and sealants. For new construction, choosing the location appropriately is important. This gives factory owners the freedom to choose many methods to attain points for building exterior and hardscape management plan.

Factories in South Asia are located in or near urban centers that experience the heat island effect. Most factories earned points in this area by providing covered parking, using high Solar Reflective Index (SRI) roof coverings, and by planting trees around the hardscaped areas of the site. Most of the factories encouraged planting locally available trees. The use of skylights and providing windows on higher levels of the buildings were practices followed by many factories to reduce light pollution and to provide better working conditions. The use of non- chemical and less toxic pesticides were also observed to be widely adopted. Most of the cases used innovative means to reuse stormwater and rainwater. Worker dormitories were also located close to the factories and the use of bicycles was encouraged among the workers, which led to earning alternative transportation points.

Water Efficiency

Water efficiency is a critical category for apparel factories as all of them seriously considered every credit by exploring ways to reduce outdoor and indoor water use. This results from the high priority placed on this area owing to the fact that apparel manufacturing involves the use of large quantities of expensive water and strict government regulations regarding disposal of wastewater.

Some of the steps taken to reduce outdoor water use included constructing rainwater collection reservoirs and using collected water for landscaping and use of treated water from effluent treatment plants for flushing and landscape applications. To reduce indoor water use, the main strategies used were the installation of water meters to measure water usage, the use of low flow indoor plumbing fixtures and fittings, dual flush toilets, and prismatic taps.

Energy and Atmosphere

This category received a very high level of attention because of two main reasons - it is the credit category with the greatest number of available points and the high cost of energy due to energy shortage. Common strategies included energy efficient vapor absorption chillers, spilt system air conditioners, ventilation fans with evaporative coolers, air compressors with variable frequency drives, energy efficient automatic knitting machines, steam traps in irons, thermic fluid driven dryers, and energy efficient lighting systems.

Most factories used building commissioning and performance measurement credits because of the availability of professionals and consultants in the area who were able to provide effective guidance and support. Onsite renewable energy systems, such as solar panels, were found to be less popular because of the high first costs of such installations.

Material and Resources

For the material and resources category, use of low mercury lamps and ENERGY STAR certified electric powered equipment were adopted in all the factories. Most factories implemented rapidly renewable materials and raw materials from sustainable sources, such as 100% cotton yarn and 100% Better Cotton Initiative (BCI) cotton and organic cotton yarn. Construction of an effluent treatment plant helped to treat the waste from people and production processes and that was reused for landscaping and toilet flushing purposes. Solid waste management credits were widely attempted including reuse and recycling of factory process waste and also, building material such as bricks, concrete, and wood.

Indoor Environment Quality

This category received significant attention from some organizations where indoor environmental quality was recognized as critical to the working conditions, and therefore to the health productivity levels of workers. These factories may have realized this link on their own or it may have been emphasized by international importers and workers' welfare groups. Unfortunately, many factories did not see the connection and overlooked credits in this category, especially the credits dealing with lighting and thermal comfort.

Some of the common strategies observed were the development of a comprehensive cleaning program, training plan for the use of cleaning chemicals, use of sustainable cleaning chemicals, carbon free exterior cleaning products, CRI certified vacuum cleaners, and skylights and higher windows. Other commonly used strategies included design of a proper ventilation systems and prohibition on smoking within the factory campus.

Innovation

This category provides avenues to increase the overall LEED score and sometimes helps to reach a certification threshold, therefore, most factories attention to this category. The common strategies include providing innovative measures that result in increased energy or water efficiency, as discussed in the case study section.

Regional Priority

The regional priority category provides an incentive for achieving credits that address geographically specific environmental priorities. Most of the factories earned points in this category. Common strategies included the deployment of a building automation system for optimized energy and water management, installation of conductivity meters to monitor water consumption quantities and patterns, and a separate metering connection to calculate the water savings due to the use of rainwater collection systems.

SUMMARY AND CONCLUSIONS

The apparel industry is an economically significant industry sector in South Asia, with around $50 billion revenue in 2020 for Bangladesh and India. It has gained notoriety in recent years due to its perception of negative impact on the environment because of its heavy reliance on limited resources and high level of process waste, working conditions, and several factory accidents. These headlines have caused industry stakeholders to focus on poor facilities and working conditions. It was felt by key stakeholders that implementing sustainable practices in the manufacturing facilities will lead to better built and operated facilities with improved working conditions that would lead to increased employee productivity and fewer occupational hazards, illnesses, and mishaps. This aspect was especially emphasized by the importers in the United States, who believe that an effective method for a factory facility to implement sustainable practices is by obtaining an international green building certification, such as, the Leadership in Energy and Environmental Design (LEED).It led to a push to build new or upgrade existing factories in accordance with LEED certification.

The main objective of this research was to examine the LEED certified apparel factories in the region with the goal to come up with ways to promote LEED certification for this industry sector. Extensive literature review was conducted and seventeen major LEED certified apparel factories in Bangladesh and India were analyzed to compile the most adopted and the most avoided LEED credits. The highest rated LEED Platinum factory was then investigated in detail, as a case study factory, to understand the different strategies adopted by them to earn LEED credits. Based on the above-noted steps, a list of most avoided and most implemented LEED credits, along with the strategies that were commonly used by the apparel industry for their implementation, were identified.

Some of the limitations of this research included the lack of focus on geopolitical differences in South Asian countries, absence of input from the users, and no specific discussion on building safety. In an indirect way, LEED certification helps towards better design and construction of the facilities since local building codes may not be always strictly enforced. Even with lax enforcement of building codes containing safety provisions, LEED requirements are audited by an independent third party and are fully enforced. Such LEED enforcement ensures a certain level of engineering design and construction compliance. Moreover, in the case of LEED certified factories, regulators and factory owners were seen to be indirectly influenced to enforce building codes in order to prevent the LEED reviewers from finding building codes-related deficiencies that would cast them in a bad light. Still, LEED certification alone, may not guarantee accident-free safe infrastructure. Therefore, incorporating certifications related to building safety and workers' occupational health would be welcome additions to LEED certified apparel factories.

Almost all the factories that achieved LEED certification did so to satisfy stakeholders, especially importers and workers' welfare groups in the United States, and to remain competitive. They found that LEED certification gave strong sense of confidence to the stakeholders, especially the U.S. consumers that their products are manufactured at a sustainable facility with good working conditions. In the process, they also realized that LEED certified facilities can lead to the higher worker satisfaction and productivity.

Despite these perceptions and benefits, there are several apparel companies that are sitting on the fence and are unsure about moving forward with LEED certification. The authors hope that the analysis, the case study, and the strategies discussed in this paper will encourage other members of the apparel industry in South Asia, as well as, in other apparel exporting countries to move forward with adopting sustainability practices for their facilities and

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REFERENCES

Anilkumar, S.L., and Syal, M.G. (2021). "Sustainability of Apparel Industry Facilities in India and Bangladesh," MSCM research report, Construction Management Program, School of Planning, Design and Construction, Michigan State University, MI.

Apparel Resources. (2020). "India and Bangladesh together can achieve 35% share in the global textile market." http://in.apparelresources.com/business-news/trade/india-bangladesh-together-can-achieve-35-share-global-textile-market/ (Accessed March 19, 2021).

Babu, B. R., Parande, A. K., Raghu, S. and Kumar, T. P. (2007). "Cotton Textile Processing: Waste Generation and Effluent Treatment", The Journal of Cotton Science, 11(1), 141-153.

Berkel, R. V. (2017). "Water efficiency in textile processing: Good Practices and Emerging Technologies", Roundtable on Waterless Processing, Textiles India 2017 Conference, Gandhinagar, India. http://www.gcpcenvis.nic.in/PDF/Water_Efficiency_in_Textile_Processing_Good_Practices_and_Emerging_Technologies.pdf (Accessed March 19, 2021)

BGMEA (2020). The Bangladesh Garment Manufacturers and Exporters Association (BGMEA), http://www.bgmea.com.bd (Accessed May 11, 2020)

Bick, R., Halsey, E., and Ekenga, C. C. (2018). "The global environmental injustice of fast fashion", Environmental Health 17, 19(1).

Bitopi Group (2017). "Tarasima Apparel Limited, Dhaka, Bangladesh." http://www.bitopi-group.com/OurPortfolio/Portfolio (Accessed March 19, 2021)

Chowdhury, M. F. and Tanim, T. R. (2016). "Industrial accidents in Bangladesh Apparel Manufacturing Sector: An analysis of the two most-deadliest accidents in history", Asian Journal of Social Sciences and Management Studies, 3(2), 115- 126.Envoytextiles (2017) [Online] Available: https://www.envoytextiles.com/ (Accessed March 19, 2021)

GBIG (2024). The Green Building Gateway: Bangladesh. Downloaded from https://www.gbig.org/places/77/activities?page=1 on April 30, 2024.

Hasan, M. F., Alam, M. R., Mow, N. Hasan, S. M. A., and Mamtaz, R. (2018). "Recycling potential of textile solid waste", *International Journal of Research in Environmental Studies*, 5(1), 91-102.

Hasanbeigi, A., and Price, L. (2012). "A review of energy use and energy efficiency technologies for the textile industry.", Renewable and Sustainable Energy Reviews, 16(6), 3648-3665.

Innowell (2016). Innowell Consultants, India - Tarasima Apparel Project, https://innowellgroup.com/projects/sq-celsius-2-valuka-bangladesh-2/ (Accessed June 25, 2020).

Islam, I. (2016). "Energy consumption determinants for apparel sewing operations: an approach to environmental sustainability", Doctor of Philosophy, Kansas State University, Kansas. https://core.ac.uk/download/pdf/77977794.pdf (Accessed August 28, 2020).

Jain, M., Mital, M., and Syal, M. (2013). "LEED-EB implementation in India: An overview of catalysts and hindrances," OIDA International Journal of Sustainable Development 6(12): 23-31.

Kaur, G.P., Gupta, P., and Syal, M. (2014). "Empowering stakeholders towards better working conditions through green factories: An action research in India ," OIDA International Journal of Sustainable Development 7(1): 25-36.

Keane, J. and Velde, D. W. (2008). "The role of clothing and textile industries in growth and development strategies", Thesis in Investment and growth program, Overseas Development Institute, Britain. https://www.odi.org/sites/odi.org.uk/files/odi-assets/publications-opinion-files/3361.pdf (Accessed January 6, 2021).

LEED Projects (2020). "LEED Projects Database, U.S. Green Building Council." https://www.usgbc.org/projects (Accessed November 2020).

Open Sourced Workplace (2019). "What is a Sustainable Workplace? (6 Ways to Create a Sustainable Work Environment)" https://www.opensourcedworkplace.com/news/what-is-a-sustainable-workplace-6-ways-to-create-a-sustainable-work-environment (Accessed March 19, 2021)

Pattnaik, P., Dangayach, G., and Bhardwaj, A. (2018). "A review on the sustainability of textile industries wastewater with and without treatment methodologies," Reviews on Environmental Health, 33 (2018), pp. 163-203

Peel, M.C., Finlayson, B.L., and McMahon, T.A. (2007) "Updated world map of the Koppen-Geiger climate classification," Hydrology and Earth System Sciences, 11, 1633-1644.

Potbhare, V., Syal, M., and Korkmaz, S. (2009). "Adoption of green building guidelines in developing countries based on U.S. and India experiences," Journal of Green Building 4(2): 158-174.

Rani, S. and Jamal, Z. (2018). "Recycling of textiles waste for environmental protection," International Journal of Home Science 2018; 4(1): 164-168

Reuters (2019). "Grief and neglect - 10 factory disasters in South Asia." https://www.reuters.com/article/us-india-fire-workers-factbox/factbox-grief-and-neglect-10-factory-disasters-in-south-asia-idUSKBN1YE1PT (Accessed March 20, 2021).

Samanta, K. K., Pandit, P., Samanta, P., & Basak, S. (2019). "Water consumption in textile processing and sustainable approaches for its conservation". Water in Textiles and Fashion, 3(1), 41–59.

Singh, A., Syal, M., Grady, S. and Korkmaz, S. (2010). "Impact of Green Work Environments on Occupant Health and Productivity," American Journal of Public Health, vol. 100(9), 1665-1668.

Solanki, V. (2020). "Workers' well-being in apparel industry: A study in Punjab", Research Thesis, Master of Science in Resource Management and Design Application, Lady Irwin College, University of Delhi, New Delhi, India.

Tarasima LEED (2016). "Tarasima Apparel Limited – LEED Overview and Scorecard," https://www.usgbc.org/projects/tarasima-apparels-limited (Accessed June 25, 2020)

TEXMIN (2019) "Textile Ministry of India, India's Export in Textiles and Apparel," http://texmin.nic.in/sites/default/files/7a.%20Export%20of%20Textiles.pdf (Accessed June 25, 2020)

Vierra, Stephanie (2019). "Green Building Standards and Certification Systems, Whole Building Design Guide," https://www.wbdg.org/resources/green-building-standards-and-certification-systems (Accessed May 11, 2020)

USGBC (2020). "LEED Rating Systems." https://www.usgbc.org/leed (Accessed November 2020)