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Using Delphi Panels to Assess Construction Safety Research to Practice: A Narrative Review

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Using Delphi Panels to assess construction safety research to practice: a narrative review

INTRODUCTION:
Despite ongoing efforts to improve site safety, the construction field still accounts for a disproportionate injury rate and remains one of the most dangerous industries for workers. The Delphi Method is a systematic procedure that is employed to achieve a reliable consensus among a selected panel of experts. This project's purpose was to review relevant papers and research on Delphi Panels and their potential use in assessing whether construction safety and health research findings are being used by target audiences of workers and contractors to reduce injuries and illnesses (research to practice). A secondary objective of this review was to understand the parameters of panel selection, composition, and analysis. This project will help contribute to the broader dissemination and implementation field.

The Delphi method was developed in the mid-1950's by a group of researchers in the fields of forecasting and planning at the RAND Corporation (Dalkey & Helmer, 1963). The method has since been applied in numerous research areas and settings including real estate, finance, environmental health, construction safety and health, and construction and engineering management (Gupta & Clarke, 1996). The method is described as a structured communication and consensus building approach among a group of qualified experts focused on a multifaceted and complex problem (Ameyaw et al., 2016). It is an iterative process where consensus is reached often through multiple rounds of feedbacks from the selected experts (Hallowell & Gambatese, 2010). Linstone (1978) identified two circumstances where Delphi techniques are most appropriate: (1) "The problem does not lend itself to precise analytical techniques but can benefit from subjective judgments on a collective basis" and (2) "Individuals who need to interact cannot be brought together in a face-to-face exchange because of time or cost constraints." The Delphi method is useful when objective data and experimental research is not possible or when empirical evidence is lacking (Hallowell & Gambatese, 2010).

The Delphi method has been increasingly accepted in the field of construction research in areas as varied as procurement selection (Chan et al., 2001), measuring complexity for building projects (Xia & Chan, 2012), international construction (Gunhan & Arditi, 2005), selection of team members (Kumaraswamy & Anvuur, 2008), the role of design in construction safety (Gambatese et al., 2008), and assessing the impact of safety programs (Hallowell, 2010). This study aims to thoroughly review recent construction related papers that employ the Delphi technique and to report their methods of choosing panel experts, the number of panel members employed, the number of rounds or iterations, attitude ranking, and techniques used for achieving consensus.

METHODS:
To identify relevant papers for the main review, the reviewer used currently available tools to search both the published literature and the "grey literature" of unpublished manuscripts, dissertations, and reports. Original research and review articles were reviewed and summarized. The following databases were included: Academic Search Complete, ArticleFirst, Business Search Complete, Proquest, Google Scholar, and ScienceDirect. The following terms were used: Delphi, Delphi panel, Delphi method, Delphi technique, construction, construction safety, and surveillance. Very little research has been done that directly addressed the use of the Delphi Method with safety research to practice in construction, i.e., one review was identified to guide methodology. A broader net was therefore cast to capture a larger number of studies that were judged to be relevant.

An additional search was conducted based on a 2016 review, "Application of Delphi method in construction engineering and management research: A quantitative perspective" by Amenyaw and colleagues. This review examined construction studies published in the top-tier journals that employed

Delphi panels as the primary or secondary research method. These papers were published between 1990 and 2012 in the ten selected journals: (1) Construction Management and Economics (CME), (2) Journal of Construction Engineering and Management (JConstr.EM), (3) Engineering, Construction and Architectural Management (ECAM), (4) Journal of Management in Engineering (JME), (5) International Journal of Project Management (IJPM), (6) Automation in Construction (AC), (7) Building Research and Information (BRI), (8) Building and Environment (BE), (9) Journal of Civil Engineering and Management (JCiv. EM), and (10) Journal of Facilities Management (JFM). The articles included ones from researchers such as Gambetese, who have done extensive research on safety and health in construction. Additional papers published since the review were identified using the same method as Amenyaw et al. by searching the same journals used in their review. The Amenyaw review along with the updated literature search represent all current, relevant articles presenting Delphi panel use in construction research.

Abstracts for all articles included in the review can be found after the reference section.

RESULTS AND DISCUSSION:

Delphi panels to assess translation of construction safety and health research into practice:
We investigated the use of Delphi Panels in construction safety and health research. This review failed to locate any articles that described utilizing Delphi Panels to gauge the diffusion and dissemination of safety innovations across regional or national firms within the US construction industry.

However, a total of 13 articles were found which directly addressed questions posed by CPWR listed below that are related to how conceptually sustainable panels could be used to periodically assess current workplace safety practices and culture, to determine and investigate the impact of current research in the field, and to determine impactful, efficient, and sustainable research to practice strategies. An additional four were identified that used Delphi Panels more broadly, to monitor the construction field over time.

We also utilized the same research strategy as Ameyaw et al. to search for published articles between 2013-2018 that could inform the use of Delphi panel studies. Ameyaw et al. identified 88 papers. Excluding articles that did not use the Delphi method as its primary or secondary research method, this review identified 33 additional papers.

The following is a summary of the structure and functions of Delphi Panels based on the literature review.

<u>How are panel members recruited?</u>
Panelists are purposefully selected to apply their knowledge to a concept raised in the study based on the criteria that is developed from the research questions under investigation. No information was provided in the reviewed literature about addressing or disclosing conflicts of interest; however, this should be taken into account while selecting panelists in order to minimize bias.

<u>What is the membership composition of the Panel?</u>
In order to be considered a Delphi study, panelists must be qualified as experts using stated criteria prior to starting the first round of data collection. Unlike a random survey, the Delphi methodology recognizes participants through their expertise, which can lead to higher return rates (Stitt-Gohdes & Crews, 2004).

A successful Delphi study depends on a research objective and thorough selection of expert panelists (Chan et al., 2001). “Experts” in this regard refers to professionals and/or researchers that have special

and relevant knowledge and experience and who meet a set of criteria established by the primary investigators including relevant publications, professional qualifications, and work experience (Hallowell, 2008).

Broadly speaking these are the main qualification criteria: education, experience, size of organization, professional qualifications, and authorship. In a specific example where a Delphi panel was established to identify interrelationships of highly effective safety program elements for small-scale construction projects (Hallowell, 2008), criteria included:

1) Primary or secondary author of at least three peer-reviewed scientific journal articles on the topic of injury prevention in construction
2) At least three presentations on a safety-related topic at a national or international conference
3) Member of a national construction safety committee (e.g., ASCE site safety, CII Safety Community of Practice)
4) At least 5 years of professional experience in the construction industry with safety management responsibilities
5) Faculty member at an accredited institution of higher learning with a research or teaching focus on injury prevention in construction
6) Author or editor of a book or book chapter on the topic of injury prevention in construction
7) Advanced degree in the field of civil engineering, construction engineering, occupational safety and health, or other fields directly related to this study, from an institution of higher learning (minimum of a BS); and Designation as a Professional Engineer (PE), Certified Safety Professional (CSP), Associated Risk Manager (ARM), or a Licensed Architect (AIA)

The majority of the identified papers in the second search (20 out of 33) indicated specific requirements for their selection of experts. Like the Ameyaw et al. paper, there were two sets of qualification criteria for expert panelists that were adopted. One was listing specific requirements. For instance, Shadid (2018) stated that to be included, experts must 1) be at the director level or above having strategic decision responsibilities, 2) a verbal or written commitment to complete the study phases is necessary to accept the subject and 3) their company has to be of grade “A” or “B” according to the Qatari Central Tenders Committee standard. The second set of qualification criteria identified was a flexible point system. For example, Sierra et al.’s (2015) work on social sustainability in Chilean Public Infrastructure required experts to score at least 2 from a list of 7 specific criteria. For the 13 studies that did not list specific criteria, authors mainly stated that a purposive sampling technique was used and that panelists were qualified in their field and available to participate.

<u>How many members are required for a Delphi Panel?</u>

Literature on Delphi panels indicates that panel size can range from 10 into the hundreds (Skulmoski, Hartman, & Krahan, 2007; Linstone & Turoff, 1975). A panel size of 30 has been demonstrated as providing satisfactory reliability (Dalkey, 1972; Delbecq et al., 1975) although small, homogeneous samples between 10 and 12 are common in Delphi panel research (Linstone & Turoff ,1975; Wilhelm, 2001) because consensus is able to be reached with a smaller panel size (i.e., these panels are more efficient at consensus reaching). While existing construction literature is inconclusive regarding the ideal size of a Delphi panel size, Hallowell and Gambatese (2010) have advocated for a minimum panel size of between 8 and 12 individuals. The variation in numbers of Delphi panelists is due to several factors, including the scope or nature of the problem investigated, the number of experts who are available, and resources available to the investigators including time and money (Ameyaw, 2016).

Generally, the number of panelists depends on the number of experts available on the particular topic, the expected volume of data and time requirements, and the ability and sophistication of the facilitator. Past studies that focused on the impact the number of panelists have on the level of accuracy of the

Delphi method have concluded that the appropriate number of panelists for the typical Delphi study ranges from 8 to 15.

How are surveys/interviews distributed and collected?
This can be completed through questionnaires sent to respondents. The amount of time between each round (i.e. one week/month) should take into consideration the number of items in the questionnaires.

How many rounds are needed?
Iteration is a critical quality of the Delphi method, because through each round the group can be brought to a consensus (Linstone & Turoff, 1975). Through the use of both iteration and anonymity, dominance bias can be eliminated while reducing the Von Restorff (i.e., "isolation") effect (Hallowell, 2009). However, extant literature shows that there is no clear and specific guidance on the ideal number of rounds in Delphi studies. Researchers therefore tend to settle on differing number of rounds given their criteria for reaching a level of consensus. Additionally, investigators should always consider and factor in issues of attrition, participant fatigue, cost, and the time participants must give to participate in Delphi panels (Hasson et al., 2000).

Based on studies included in this review, Delphi results are most accurate after rounds two or three and results become less accurate with additional rounds (Chan et al., 2001; Xia et al., 2011).

In the second round of literature review, more than 60% (20) of the studies found consensus after two rounds. This is in line with Ameyaw et al.'s review where 40 out of the 88 studies reached consensus after two iterations and is also consistent with Dalkey et al.'s (1970) observation that Delphi results are more accurate after two rounds. However, it should also be noted that in the case of Ceric (2014) and Zahoor et al. (2017), multiple participants dropped out between the first and second iterations, indicating that the accuracy of later rounds may have decreased with increasing attrition.

How is feedback provided to panelists?
Providing feedback allows expert panelists to anonymously consider the opinions and experiences of other members without being subjected to time consuming discussions, which are also prone to dominance and collective unconscious biases. The literature review found that feedback is usually provided in terms of quantitative statistics (i.e., means and medians) from previous rounds. Few other details of providing feedback to panelists was given, so it is unclear how these statistical estimates were shared with panelists, i.e., what type of written interpretation or summary was provided, what tools were used, or strategies for ensuring that panelists read the feedback.

How were expert opinions quantified?
30 out of the 33 papers adopted a Likert scale in order to quantify expert opinions, compared to 41 out of the 88 papers found in Ameyaw et al.'s review. The scales ranged from a 3-point scale to an 11-point scale, with the five-point Likert scale being the most common. This is consistent with Ameyaw et al.'s study. In order to sustain measurement accuracy, Hsu and Standford (2007) recommended that attitude scales used in Delphi studies should range over five points due to the small sample sizes Delphi studies usually employ. Rad et al. (2016) utilized a Saaty scale, which is standard for the Analytical Hierarchy Process (Pamučar et al., 2016). While some studies used only scales to quantify opinion, it was also common to utilize different methods in different rounds. For instance, Gil et al. (2016) used open-ended questions in the 1st round and a 3-point Likert scale in the 2nd round. The 3rd round was an opportunity for respondents to reconsider answers based on 2nd round results. Che et al. (2013) asked panelists to provide independent frequency and severity ratings for 25 highway construction tasks while Tymvios and Gambatese (2016) only employed open-ended questions.

How is consensus among panelists statistically assessed?

The Delphi method was originally developed by the Rand Corporation study in order to obtain the most reliable consensus opinion from a group of experts (Calhoun, 2010). With consensus building being a critical and integral part of the Delphi method, the method of achieving consensus varies depending on multiple factors including construction and research methodology. It is therefore not possible to recommend an ideal level of consensus in the varied construction areas of study. However, consistent with Ameyaw el al.'s review, three techniques were identified in measuring consensus: Deviation, Kendall's coefficient of concordance (W), and Chi-square ($\chi 2$). Additionally, Che et al. (2015) used a technique called the intraclass correlation coefficient (ICC), which combines interrater agreement (IRA) and interrater reliability (IRR), while Rad et al. (2017) adopted an integrated method based on Chiclana et al. (2018).

Deviation was the most common tool for measuring consensus, consistent with Ameyaw et al.'s findings. Also consistent with the review is there is no common agreement on the minimum value of standard deviation where the consensus could be accepted. For instance, Shadid (2018) accepted the ratio 10% while Luai et al. (2017) accepted 30%. Nine identified Delphi papers used Kendall's coefficient of concordance. The W value represents the degree of agreement between the panel members. The value considers the variations between the rankings of mean of different variables (Hon et al., 2012). 100% consensus is achieved with a concordance coefficient of "1" (Ameyaw et al., 2016). Only one study (Chan et al., 2016) employed the chi-square method, which is recommended when the number of evaluated variables is larger than seven (Siegel & Castellan, 1988). Delphi panelists reach a consensus when the computed Chi- square value is larger than the critical Chi-square value (Ke et al., 2010, 2011; Hon et al., 2012). One study (Cheng & Lu, 2015) did not clarify how consensus was measured, stating only that results were "merged" from 1st to 2nd round.

CONCLUSIONS

This review builds upon existing literature demonstrating that the Delphi method is a robust tool for identifying, evaluating, and forecasting in construction safety research and research to practice. Within the papers identified for this review, construction researchers are more likely to recruit an expert panel of between 8 and 20 members for two or three rounds of consensus building. Likert scales are most commonly used and consensus is reached from a variety of techniques including standard deviation and Kendall's coefficient of concordance. Currently, the Delphi method has not been used widely in construction safety and health research; however, the method has potential for greater use in this type of research to assess the extent to which research findings are being adopted on construction sites and influencing safety and health outcomes. Emerging research using Delphi panels in construction safety and health research can use the parameters of other Delphi panels, as outlined in this review, to guide the development and implementation of Delphi panels for those purposes.

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Summary of initial article search for articles describing Delphi panels in construction research

The following databases: Academic Search Complete, ArticleFirst, Business Search Complete, Proquest, and ScienceDirect. Using the terms: Delphi, Delphi panel, Delphi method, Delphi technique, construction, construction safety, surveillance

Citation	Abstract	Methodology
Sourani, A. & Sohail, M. (2015). The Delphi Method: Review and Use in Construction Management Research. International Journal of Construction Education and Research, 11(1), 54-76. doi: 10.1080/15578771.2014.917132	The Delphi Method is a systematic procedure that is normally employed to achieve a reliable consensus among a selected panel of experts. It can be utilized for different purposes, such as the study or definition of areas of considerable uncertainty and/or a lack of agreed knowledge. Although the method has been used in different fields, few studies have used Delphi in construction research. This could be attributed to the limited awareness of the method, the lack of clear guidance in relation to its operation and the variations in its application. This article, which draws on a review and synthesis of the relevant literature and the authors' observation and experience of applying the method, critically reviews Delphi, provides guidance into its use, discusses such use in construction management research and demonstrates it through a case study. Furthermore, the article addresses the learning areas/benefits that could be obtained as a result of employing Delphi in students' research projects through another case study. Such learning areas/benefits could include deep learning; knowledge generation; criticality; skills development; feedback; development of identity and career plans; simultaneous learning and application of research approaches and self-validation; and flexibility, diversity, and efficiency issues.	1. Synthesizes available literature on Delphi, provides a comprehensive and consistent guidance on areas related to the use of Delphi where little guidance has been available (e.g., in relation to discussing the position of Delphi within the qualitative/quantitative debate and clarifying the level of structure adopted on commencing a Delphi Study) 2. Illustrates the issues outlined in (1) through a case study that has employed Delphi 3. Provides insight into the learning benefits that could be obtained as a result of employing Delphi in students' research projects using a second case study.
Lines, B.C., Perrenoud, A., Sullivan, K.T., & Smithwick, J. (2015). Implementing New Project Delivery Strategies: Development of a Web-Based Multimedia Tool to Support Owner	For large public organizations, implementing a new project delivery strategy for architecture, engineering, and construction (AEC) services requires significant organizational change. A key	Delphi method employed to develop a framework for delivering organizational training through the utilization of information and communication technologies.

Project Team Training. International Journal of Construction Education and Research, 11(2), 140-160. doi: 10.1080/15578771.2014.930541	challenge is how to address the specific needs of multiple individual AEC projects while maintaining organization-wide consistency. Numerous barriers exist to hinder successful implementation, and the delivery of training content to various stakeholder interests must address role-specific modifications to work processes. The Delphi method is employed to develop the framework for delivering organizational training through the utilization of information and communication technologies (ICT) to create a centralized process training tool that can be accessed by multiple distributed AEC project teams. Key aspects of the tool are presented, as well as feedback from experts in the implementation of value-based project delivery regarding the tool's effectiveness in distributing training content, minimizing key technical barriers to change, and optimizing the allocation of training resources between project- and organizational-level aspects of implementation. Application of the tool within a project delivery change effort was demonstrated to reduce the in-person training requirements needed for project teams to accomplish work tasks. The framework for an ICT-based process training tool is a key contribution of this research and may be considered by industry practitioners.	A centralized process training tool was created that can be accessed by multiple distributed architecture, engineering, and construction project teams
Calhoun, M.E. (2015). "Synergistic Effects among Leading Indicators of Construction Safety Management." Order No. 3740159, University of Alaska Fairbanks.	Safety performance in the construction industry has improved significantly since the Occupational Safety and Health Act was enacted in 1970. Despite these improvements, annual accident statistics indicate the construction industry remains one of the most dangerous for workers. However, there are some construction companies that defy these statistics and have an exemplary safety record. Many of these companies have adopted a zero-accident vision and measure their safety performance using both leading and lagging indicators. Safety performance has traditionally been measured with only lagging	1. Generate data through interviewing twenty-five small contractors to identify leading indicators used by each small contractor and identify challenges to implementation when an indicator was not being used. Results were analyzed to find the total percentage of use for each indicator and their relationship to the contractor's total recordable injury rates. 2. The Delphi method was used to assemble two expert panels to quantify the pairwise synergistic effects among thirteen leading indicators from the perspective of an owner and a contractor.

	indicators that have included recordable injury rates, experience modification rates, days-away-restricted-transferred, among many others. Unfortunately these indicators are recorded after an accident has occurred, resulting in management only being able to take a reactive approach. Conversely, a proactive approach uses leading indicators to alert management before an accident occurs. Previous research has found thirteen leading indicators that are connected to a strong safety performance for construction projects. However, several researchers and safety management experts recommend only monitoring and measuring two to three indicators on a project due to the resources required. Determining which leading indicators to monitor can be a difficult process for management new to this proactive approach. In an effort to help the construction industry, the first phase of data collection for my dissertation benchmarked the knowledge and use of leading indicators by interviewing twenty-five small contractors. The purpose of the interview was to identify leading indicators used by each small contractor and identify challenges to implementation when an indicator was not being used. The results were analyzed to find the total percentage of use for each indicator and their relationship to the contractor's total recordable injury rates. Two leading indicators were found to be linked with a safer total recordable injury rate and both indicators included having high percentages of workers employed for more than five years. The second and third phase of data collection for my dissertation focused on large owner and contractor companies who typically have had a better safety	3. Results can serve as an aid to management that are beginning to take a more proactive approach towards measuring and monitoring safety performance.

	performance in comparison to small contractors. The Delphi method was used to assemble two separate expert panels to quantify the pairwise synergistic effects among thirteen leading indicators from the perspective of an owner and a contractor. The expert panel from the perspective of the owner found the leading indicators with the greatest synergistic impact included pre-task planning, project management team safety process involvement, housekeeping program, owner safety walkthroughs, worker observation process, owner participation in worker orientation sessions, and stop work authority. The other panel from the perspective of a contractor found the indicators with most synergistic impact were pre-task planning, near-miss reporting, worker observation process, an auditing program, and project management team safety process involvement. The results from this study can serve as an aid to all management that are beginning to take a more proactive approach towards measuring and monitoring safety performance.	
Yusuwan, N.M., & Adnan, H. (2014). Developing a framework for a successful extension of time (EoT) application; eliciting expert opinion via delphi survey. European Conference on Research Methodology for Business and Management Studies (06): 450-457	This paper provides an overview of the Delphi technique and its suitability for on-going PhD research. The objectives of the Delphi survey in the proposed research are threefold. First, it is to validate findings obtained from earlier questionnaires and semi-structured interviews conducted with experienced practitioners. Second, it is to weigh and rank factors for a successful Extension of Time (EoT) application. Third, is to weigh and rank the importance of initiatives that can be taken by professionals to decrease the probability of failure of such claims. This paper does not reveal the outcomes of the research, but focuses on understanding the Delphi technique and how it is judged to be one of the most suitable strategies of data collection for the proposed	Reviews Delphi technique, covering its strengths and flaws and activities to be performed for its implementation.

	research. The discussion covers the features and characteristics of Delphi technique, its strengths and flaws, activities to be performed for its implementation, and also its implementation in this research. In addition, previous research conducted by scholars that utilised the same technique will also be reviewed and examined. Therefore, this paper aims to provide an insight into how the Delphi technique may provide some guidance to other researchers when considering methods for their research.	
Hallowell, M.R. (2008). A formal model for construction safety and health risk management. Ph.D. diss., Oregon State University	Despite recent efforts to improve site safety, construction still accounts for a disproportionate injury and illness rate. According to the 2007 injury and illness data released by the National Safety Council, the construction industry has a fatality and disabling injury rate that is approximately three times higher than the all-industry average. The transient, unique, and complex nature of construction projects makes safety management exceptionally difficult. Most construction safety efforts are applied in an informal fashion under the premise that simply allocating more resources to safety management will improve site safety. Currently, there is no mechanism by which construction site safety professionals may formally select safety program elements for a particular process. This dissertation describes a research effort that introduces, populates, and validates a formal method to evaluate construction safety risk and strategically match safety program elements to construction processes. The decision scheme introduced, based on the application of Newton's third law, assumes that every construction activity is associated with specific safety risks and that each safety program element is capable of mitigating a portion of such	Field observations, industry survey, and Delphi method to quantify safety risks associated with the construction of concrete formwork. 8-15 members, 3 rounds

	risks. Using the high-risk process of constructing concrete formwork as an example, the theoretical model was populated. Data was obtained using the Delphi method, a systematic and interactive research technique for obtaining the judgment of a panel of independent experts. The results of this research include the quantification of probability and severity values for ten mutually-exclusive and all-inclusive safety risks associated with thirteen worker-activities required to construct concrete formwork. Additionally, the study quantified the probability and severity reduction values resulting from the implementation of thirteen safety program elements. The data can be used to improve safety management techniques in several ways. First, cumulative risk may be tracked throughout a work period allowing safety managers to identify and avoid periods of exceptionally high safety risk. Second, safety managers may strategically select safety program elements based on the ability to reduce portions of specific risks. Finally, the balance between cumulative risk and the safety mitigation can be evaluated. The results of this research indicate that the highest risk activities for formwork construction are form lubrication and preparation, ascending and descending ladders, and accepting and loading materials with a crane. The most effective safety program elements are upper management support and commitment, subcontractor selection and management, and employee involvement in safety management and planning. The risk values for formwork construction and the risk reduction values associated with safety program elements can be used to determine the appropriate scope and focus	

	of safety and health management efforts. The methods used to quantify these values may be applied to any construction process or safety program.	
Hallowell, M. Techniques to Minimize Bias When Using the Delphi Method to Quantify Construction Safety and Health Risk. Paper presented at Building a Sustainable Future - Proceedings of the 2009 Construction Research Congress, 2009, 1489-1498.	The dynamic and transient nature of construction projects makes construction engineering and management research particularly challenging. For example, experimental research on safety, risk management, innovation, and technology forecasting is often unrealistic due to the sensitivity and complexity of these topics. The Delphi technique, originally developed by the Rand Corporation to study the impact of technology on warfare, allows researchers to maintain significant control over bias in a well-structured, academically-rigorous process using the judgment of qualified experts. The Delphi method is particularly useful when objective data is unattainable, there is a lack of empirical evidence, experimental research is unrealistic or unethical, or when the heterogeneity of the participants must be preserved to assure validity of the results. In this paper, the authors review eight forms of bias that literature in the field of social psychology identifies as detrimental to judgment-based studies such as the Delphi method. Additionally, several techniques are reviewed that should be incorporated into the Delphi method to control for the identified biases. Special attention is focused on the use of these techniques when using the Delphi method to identify and quantify construction safety and health risks.	Systematic review of 8 forms of bias detrimental to judgement-based studies such as the Delphi method
Musonda, I. & Agumba, J. (2013). Experience of using delphi method in construction health and safety research. 7th International conference on Construction in the 21st Century, Bangkok, Thailand.	This paper discusses the Delphi method which is an inductive approach to research. It has been argued that Delphi method is an essential vehicle of reaching consensus in issues that cannot be resolved in a once off discussion. This paper reports on the experiences achieved by the authors in using the Delphi method among a group of experienced	2 case studies where the Delphi method is used among a group of experienced health and safety (H&S) in the construction industry in South Africa

	health and safety (H&S) experts in two separate case studies in the construction industry in South Africa. The first case study used three rounds of iteration whilst the second case study used four rounds of iteration. The authors argue that the Delphi method is a comprehensive method of attaining consensus on challenging issues of H&S in the construction industry. Furthermore the method requires proper communication to achieve the required results.	
Li, Y. & Wang, C. "Based on the Delphi method of deep excavation safety risk analysis,"2010 International Conference on Artificial Intelligence and Education (ICAIE), Hangzhou, 2010, pp. 347-349. doi: 10.1109/ICAIE.2010.5641503	To prepare the construction and the construction of underground project risk assessment is necessary. The choice of evaluation theories the correctness of the evaluation result has an important influence. The paper briefly introduces the basic ideas of Delphi method. It focuses on the application of Delphi method for deep excavation engineering risk assessment procedure and standard. The analysis results show the Delphi method applied in underground engineering feasibility of risk analysis, scientific and reasonable.	Used the more perfect experts marking method (Delphi method) to analyze the risk of deep foundation pit engineering
Ameyaw, E. E., Hu, Y., Shan, M., Chan, A. C., & Le, Y. (2016). Application of Delphi method in construction engineering and management research: A quantitative perspective. Journal Of Civil Engineering & Management, 22(8), 991-1000. doi:10.3846/13923730.2014.945953	The Delphi method has been used as a main research method by a growing number of researchers in the Construction Engineering and Management (CEM) field in the past two decades. Although a number of studies are available on the use of Delphi, few researchers fully examine the potential of the Delphi method in the combined use of statistical techniques, which is an inevitable trend for future Delphi research. This paper aims to review the combined use of Delphi and other quantitative methods in the CEM field based on a structured literature review of 88 relevant papers. All of the 88 papers are systematically identified from ten well-known peer-reviewed CEM journals published in the period of 1990–2012. Topic coverage, application requirements, and statistical	Systematic review of combined use of Delphi and other quantitative methods in the CEM field. 88 Delphi papers were reviewed.

	techniques in the 88 Delphi papers are reviewed. The mix use of the Delphi method with three advanced modelling methods, such as Fuzzy sets, Analytical Hierarchy Process, and Analytical Network Process is also examined. These review results provide practical references for researchers having interests in applying Delphi method in CEM research.	
Walls, D.B. (2013). World-class safety program. Ph.D. diss., Dallas Baptist University.	This safety research project explores the key factors that contribute to world-class safety programs for firms in the construction industry. A world-class safety program for this study is defined as a safety culture supported by all employees, and a work environment where accidents are not tolerated; zero accident mentality. This study used the Delphi methodology to identify the leadership qualities and safety processes that a company's leadership employs to influence an overall successful safety program in their organizations. The Delphi methodology obtained subjective judgments from the Delphi expert panel (55 members participated) to create objective safety information through an iterative process that is beneficial to the entire construction industry. The Delphi panel members were composed of 75% from subcontractor trades, 18% from construction managers, and 7% from construction trade associations. The Delphi expert panel reached consensus on 67 leadership qualities and 85 safety processes that improve safety performance. The 67 leadership qualities were consolidated to eight major leadership quality categories which include commitment, integrity, accountability, competence, value people, visionary, lead by example, and culture. The 85 safety processes were consolidated to four major safety process categories which include learning organization, structure, measurement and culture.	The study uses Delphi method to explore leadership qualities and safety processes that affect the overall success of the safety program of construction organizations. 55 participants Final product included 8 major leadership qualities and 4 safety process categories

Calhoun, M.E. (2010). Quantifying the effectiveness of pair-wise interactions among safety program elements through a cross-impact analysis. Ph.D. diss., University of Colorado at Boulder	The current construction safety and health management strategy is informal and safety program elements are selected without consistency across the industry. This is especially true for small construction companies who typically operate with a limited safety and health management budget. To guide these small construction firms, this study develops a tool to maximize the effectiveness of their current safety program. This study uses the Delphi method to gain consensus among thirteen experts in the field of construction safety and health. The experts quantify the interrelationships of the following highly-effective safety program elements: emergency response planning; first aid facilities; frequent safety inspections; job hazard analysis; project based safety incentives; record keeping and accident analysis; safety and health committees; safety and health orientation; site-specific safety manager; site-specific safety plan; subcontractor selections and compliance; substance abuse programs; training and regular safety meetings; upper management support; and worker participation and involvement. The interrelationships that are quantified determine the percent increase each safety program element has on the effectiveness of the other safety program elements. Through this cross-impact analysis a decision support system is developed that will help construction managers select the most effective safety program elements for their present safety program.	To quantify the pairwise interactions among highly effective safety program elements, a cross-impact analysis was conducted using the Delphi method. Delphi panel included a mix of six academics and four professionals. The Delphi study was conducted over a four-month period with one month dedicated to each survey round and one month for the initial expert qualification. The expert qualification was completed with a two-page questionnaire that was emailed to any respondents that agreed to participate. The length of each Delphi round consisted of a month in duration. This was deemed necessary because each panelist was asked to provide 210 ratings per round for all three rounds. For each of these rounds, an individualized survey was made for each of the participants to minimize the biases that were discussed in the previous chapter. Once the surveys were created they were emailed to all participants with the exception of one that was mailed due to their remote location. The statistical response was aggregated after round 1 and presented in the individualized survey for round 2. This was also done after round 2 and in the event the participant deviated from the median by 10% above or below the median, they were asked to provide justification for their outlying response. These responses were also presented in round 3 for all the participants to consider.
Raiola, J.A. (2014). Assessment of future employment and competency skills in building information modeling: A delphi study. Ph.D. diss., Indiana State University	Many mainstream architecture, engineering, and construction (AEC) professionals are using Building Information Modeling (BIM). Although more and more firms are using BIM and this trend is forecast to continue, it is unclear what skills and competencies a construction manager will need in five years related to BIM. This research aims to	Delphi panel to determine what skills and competencies a construction manager will need in five years related to Building Information Modeling.

	answer that question through the use of a Delphi panel comprised of AEC professionals. The panel consists of members with the following qualifications: a minimum of eight years industry or academic experience or a combination of the two, a minimum of three years BIM experience, and membership in a nationally recognized professional organization. The results of the three round Delphi study identified skills and competencies in the following areas related to construction management: cost estimating (78 skills and competencies), scheduling and control (85 skills and competencies), project administration (71 skills and competencies), contract documents (29 skills and competencies), and other skills that were not in other categories (20 skills and competencies). In addition, this study reached consensus on descriptors that individual firms (24 descriptors) and construction mangers (22 descriptors) will need to possess to maintain or increase BIM usage in five-years. Although the panel identified many "new" BIM related construction management skills and competencies, "traditional" skills and competencies are a top response in each respective category. Within these "traditional" skills was the reinforcement of soft skills. BIM is a collaborative project management system so many soft skills are more important than with traditional project management systems. BIM requires some efficient communication along with strong soft skills, an area reinforced by the findings of this research. Furthermore, this research concluded that as BIM diffuses into the construction community, social systems interested in increasing BIM usage should augment "traditional" skill sets with the "new" BIM	

	related skills and competencies. Any academic programs seeking to implement BIM related topics into existing courses should do so in a careful manner. This research revealed in five-years BIM will continue to enter the mainstream. Building Information Modeling theory suggests that AEC industry will completely change because of BIM. However, this is not the entirely the case. This research discovered that soft skills are more important because of BIM diffusion. This research will be of particular interest to industry and academic programs seeking to increase BIM usage, or begin development of curriculum that incorporates BIM. The results include a consensus of the most important skills and competencies related to BIM for a construction manager to possess, as ranked by mean and standard deviation.	
Afshari, A.R. (2015). Selection of construction project manager by using Delphi and fuzzy linguistic decision making. Journal Of Intelligent & Fuzzy Systems, 28(6), 2827-2838. doi: 10.3233/IFS-151562	Selecting a suitable project manager for construction projects is one of the most important decisions made by construction firms. Although many studies have investigated this problem, no systematic and valid method for specifying the requirements criteria has been presented in criteria selection stage. The main objective of this paper is to develop a systematic method in order to identify the best candidate for construction project manager selection by using Delphi method and fuzzy linguistic evaluation. The models were validated using a case study of construction project manager selection in a project based company. The results show that the proposed model performs very well in selecting construction project manager and can improve efficiency in decision making process.	Two stages: First, in new systematic criteria eliciting method based on Delphi, after literature review and three rounds of data gathering, the hierarchical structure of criteria for construction project manager selection is constructed. Second, fuzzy linguistic evaluation is used to calculate the weights of criteria and candidate ratings then with aggregating method the linguistic values are transferred to crisp utility value of the candidates.

Given this search did not identify methods guiding the use of panels to monitor the field over time, we went back to search more specifically for this.

Citation	Abstract	Methodology
Esmaeili, B. (2012). *Identifying and quantifying construction safety risks at the attribute level* (Order No. 3527285). Available from ProQuest Dissertations & Theses A&I. (1095099789).	The number of injuries and fatalities is disproportionally high when compared with other industries. In addition to physical pain and emotional suffering experienced by the victims and their families, these incidents have staggering societal costs. Therefore, investing in construction safety and developing innovations that improve safety is critical. The dissertation includes five manuscripts. The first explores the diffusion patterns of traditional injury prevention practices using common innovation diffusion models. The implications of the findings are that the construction industry has now reached saturation with respect to traditional injury prevention strategies and new safety innovations are needed. One of the most recent advancement in the preconstruction safety management strategies, that is proved to be highly effective, is to integrate safety risk data in to the schedule of project. Therefore, the second and third papers identify safety risks of common highway construction work tasks and their temporal and spatial interactions using the Delphi method and integrate them into a decision support system to produce predictive plots of safety risk over time based on the temporal and spatial interactions among concurrent activities. While, the results indicate that integrating safety risk data with schedule of project is highly effective, using the current methods to quantify safety risks for every individual task that can be experienced is infeasible with current risk modeling and data collection approaches. To address this limitation, the forth paper presents an attribute-based risk identification and analysis method that helps safety managers to identify and model the safety risk independently of specific activities or trades. The fundamental attributes that cause accidents are identified and their associated risks	1. Explores the diffusion patterns of traditional injury prevention practices using common innovation diffusion models. 2. Identify safety risks of common highway construction work tasks and their temporal and spatial interactions using the Delphi method and integrate them into a decision support system to produce predictive plots of safety risk over time based on the temporal and spatial interactions among concurrent activities. 3-4.Demonstrating an attribute-based risk identification and analysis method that helps safety managers to identify and model the safety risk independently of specific activities or trades. 5.Using the attribute-based risk management concept and proposes several safety predictive models to determine the outcome of possible injuries in early phases of a project

	quantified by conducting reliable content analysis on 1771 accident reports from the National databases. The last paper uses the attribute-based risk management concept and proposes several safety predictive models to determine the outcome of possible injuries in early phases of a project. This research yield robust data and mathematical forecasting models that can be to objectively, accurately, and reliably predict hazardous conditions based on the identifiable attributes that characterize the workplace. It is expected that the findings of this research will transform the current risk analysis techniques and the created database have the potential to be applied to information models and emerging construction technologies.	
Suermann, P. C. (2009). *Evaluating the impact of building information modeling (BIM) on construction* (Order No. 3392751). Available from ProQuest Dissertations & Theses A&I. (304884140).	This research assessed the impact of Building Information Modeling (BIM) implementation on construction projects according to six primary key performance indicators (KPIs) commonly used in the construction industry as accepted metrics for assessing project performance. These include: quality control (rework), on-time completion, cost, safety (lost man-hours), dollars/unit (square feet) performed, and units (square feet) per man hour. In the first research phase, data was collected through a survey instrument intended to assess practitioners' perceptions about the impact of BIM on the six KPIs. Three iterations of the survey were conducted and it was determined that the highest ranking KPIs in order of most favorable responses were quality control, on time completion, and units per man hour. The second tier of favorable responses included overall cost and cost per unit. In this second phase of research, projects were evaluated through interviews and case studies on-site at two U.S. Army Corps of Engineer (USACE) Districts in Seattle, WA and Louisville, KY to determine their KPIs through embedded research. In the third phase of research, quantitative results were gathered	The objective of this dissertation is to create a robust risk database and develop new risk management techniques. To achieve these objectives, an attribute-based risk identification and analysis method is presented that helps designers to identify and model the safety risk independently of specific activities or trades

	from the USACE construction productivity database interface: the Resident Management System (RMS). Subsequently the pilot projects were compared to a control dataset consisting of similar facilities across the USACE using traditional approaches through benchmarks aligned with metrics similar to the KPIs used in the surveys. Both BIM-based projects demonstrated statistically significant (favorable and unfavorable) performance differences when compared to the control dataset. Finally, an evaluation tool was developed and validated for implementing a construction productivity measurement system to supplement existing procedures suitable for evaluating construction productivity differences on BIM-based projects.	
Behm, M. (2004). *Establishing the link between construction fatalities and disabling injuries and the design for construction safety concept* (Order No. 3138452).	Construction remains the most hazardous industry in the United States in terms of the aggregate number of fatalities. Twenty percent of all occupational related fatalities occur in construction; approximately three construction workers die per calendar day. Moreover, this trend has been prevalent for too long. One method to reduce this trend is to involve architects and design engineers in considering construction safety during the design process. The concept of designing for construction safety is a viable intervention to improve worker safety. However, in the United States many barriers (legal, contractual, regulatory) exist that prevent this intervention from becoming part of a standard practice within the construction industry. Four-hundred and fifty construction accidents from two databases were analyzed and a link to the design for construction safety concept was determined. An objective investigation model was developed to make these determinations. A significant link between the concept of designing for construction safety and construction fatalities and disabling injuries was established. Specific construction project parameters	Establishing the link between the design for construction safety concept and construct fatalities and disabling injuries and then determining the extent/magnitude of that link. Done through: 1. Locating list of construction fatalities and disabling injuries where sufficient information existed to make a determination that the design for construction safety concept was not linked in the incident 2. Developing model based on previous research that enables the construction accidents to be evaluated consistently from a design perspective 3. Utilizing model to evaluate if the design for construction safety concept was linked to the accident and determining specifically how the design for the construction safety concept was linked 4. Analyzing the relationships between those accidents that were linked to the design for construction safety concept to

	linked to the concept of designing for construction safety include the minimization of risk due to falls through and from roofs, skylights and structural steel construction; and the minimization of risk due of contact with electric and other utilities. It is recommended that the concept of designing for construction safety be considered by regulatory agencies, insurance companies, and the United States' construction industry as one intervention of a comprehensive safety agenda to reduce the disproportionate number of fatalities and disabling injuries.	the various project parameters
Cwalina, A. M. (2013). *Organizational practices leading to a positive safety culture: A delphi approach* (Order No. 3587238). Available from ProQuest Dissertations & Theses A&I. (1426846270).	A positive safety culture has been shown to contribute to a firm's ability to avoid or reduce the occurrence of occupational accidents and injuries. In American workplaces alone 3,582 people died and 5.1 million people were disabled in 2009 and the cost to corporate America was $169 billion and an additional productivity loss of 95 million work days. The economic cost to each American household is about $1,200. Firms that establish and maintain a positive safety culture are able to achieve a competitive advantage in the market. While much research exists showing the relationship between safety culture and accident reduction, less guidance is found on how companies might achieve such improvement through cultural change. Attempts have been made to determine the factor structure of safety culture, that is, the identification of the antecedents of a positive safety culture. However, to date no general consensus has emerged among researchers about the exact elements of the factor structure. Research methodologies have been blamed for biasing the research results and thereby causing the lack of consensus. This dissertation uses a different methodology, the Delphi method combined with Hofstede's well-known onion model of	Researchers of safety culture have not been able to report a general consensus regarding the factor structure of that culture, i.e. the antecedents of safety culture. Delphi methodology was used to determine if organizational practices lead to the establishment or maintenance of a positive safety culture.

	organizational culture, to determine those organizational practices that lead to a positive safety culture. Delphi is a mixed methodology that begins with an exploratory approach followed by the more traditional quantitative method. The exploratory front-end was deemed appropriate given that prior traditional survey instruments most likely introduced researcher bias through a myopic view of safety culture. Delphi also differs by utilizing purposeful sampling versus random sampling which provides a high level of expertise to inform the research. After four rounds of inquiry with a panel of experts, a consensus was reached on 18 organizational practices that lead to a positive safety culture. This research adds to the understanding of safety culture, provides useful information for both practitioners and academic researchers, and offers launch points for extensions of the research.	

Additional articles identified based on update of the Ameyaw 2016 review paper

Citation	Abstract
Che Ibrahim, C. I., Costello, S. B., & Wilkinson, S. (2013). Development of a conceptual team integration performance index for alliance projects. Construction Management & Economics, 31(11), 1128-1143. doi:10.1080/01446193.2013.854399	Project alliancing, also known as collaborative contracting, is designed to foster integration practice between multidisciplinary teams involved in delivering construction projects. If continuous improvement in project alliances is to be achieved through the use of integrated teams, a means of assessing how well teams integrate and how that integration changes over time needs to be introduced. As part of a wider study to develop an assessment tool for team integration in road construction alliance projects, key indicators (KIs) are identified for measuring team integration practice. It is necessary to identify not only the relevant KIs, but also which indicators are dominant, thereby focusing the attention of owners and non-owner participants (NOPs) on those that will have the greatest impact on alliance team integration. Seventeen experienced road construction alliance practitioners participated in four rounds of a Delphi questionnaire to identify the KIs. The resulting seven team integration practice KIs were: team leadership; trust and respect; a single team focus on project objectives and key result areas (KRAs); collective understanding; commitment from project alliance board; creation of single and co-located alliance team; and free flow communication. A conceptual alliance team integration performance index (ATIPI) was then developed based on the identified KIs and their relative significance. The ATIPI takes the form of a linear additive weighting model, consisting of a measure for each of the identified KIs and a corresponding weighting coefficient, identified as part of this research. A linear additive weighting model is considered appropriate based on the lack of correlation between the KIs, thus suggesting that they can be considered as independent variables in the ATIPI. The measures for each KI will be determined as part of future research and will result in a fully working model for the ATIPI.
Esmaeili, B., & Hallowell, M. (2013). Integration of safety risk data with highway construction schedules. Construction Management & Economics, 31(6), 528-541. doi:10.1080/01446193.2012.739288	The construction industry is characterized by a relatively high injury and illness rate compared to other industries. Within the construction industry, the highway construction and maintenance sector is one of the most dangerous. To improve safety in this sector, proactive methods of safety improvement and reliable risk data are needed. The safety risk quantification is the first step towards integrating safety data into design and planning. To enhance the current preconstruction safety practices, safety risks of highway construction and maintenance tasks were quantified and a decision support system was developed and tested that integrates safety risk data into the project schedules. Relative safety risks were quantified for 25 common highway construction tasks using the Delphi method. To ensure valid and reliable results, experts were selected according to rigorous requirements and multiple controls were employed to decrease cognitive biases. The data were incorporated into a decision support system called Scheduled-based Safety Risk Assessment and Management (SSRAM) that facilitates integration of safety risk data with project schedules. The resulting data-driven system produces predictive plots of safety risk over time based on the temporal and spatial interactions among concurrent activities. To test the utility of the decision support system and the validity of the underlying risk data, the system was tested on 11 active case study projects in the US. It was found that the database and associated decision support tool produce accurate and reliable risk forecasts that increase the viability of existing safety preconstruction activities.

Luai, M., El-Sabek, L.M. & McCabe, B.Y. (2017). Framework for Managing Integration Challenges of Last Planner System in IMPs. Journal of Construction Engineering and Management, 144(5). https://doi.org/10.1061/(ASCE)CO.1943-7862.0001468	International megaprojects (IMPs) have a poor record of budget and schedule overruns. Lean Construction methods and the associated Last Planner System (LPS) have been successfully implemented in many projects, but the application of the LPS in IMPs is limited due to integration challenges and organizational behavior issues inherent in IMPs. Integration herein refers to the interfaces between subprojects in a megaproject. This paper introduces the IMPact framework to address integration challenges. A modified two-round Delphi method was used to identify, verify, and rate integration challenges. Thirty-one challenges were identified. After the development of the framework, the nominal group technique confirmed its internal validity. Finally, external validation was achieved in a focus group study. The measurement system of the proposed framework was tested on a real IMP. The validated framework provided a conceptual practical solution, based in LPS, to address the challenges within and across subprojects. It is intended to be an adaptive roadmap to address these challenges and potentially improve the performance of IMPs.
Murphy, M. E., Perera, S., & Heaney, G. (2015). Innovation management model: a tool for sustained implementation of product innovation into construction projects. Construction Management & Economics, 33(3), 209-232. doi:10.1080/01446193.2015.1031684	Technological advancement and demand for economic growth are driving product innovation in the construction industry. However there is concern that the industry lacks the mechanisms to effectively implement new products. Recent studies have developed a method for identifying and evaluating the risks which impact on new technology adoption and two constructs were generated for improving implementation rates. The aim is to investigate whether the constructs can be integrated to develop a practical tool for use by project stakeholders desirous to generate innovation. Process modelling, statistical analysis and failure mode and effect analysis are used to align the constructs into a test model (TM). Three rounds of Delphi gain a consensus on the TM outputs and the results produce the innovation management model (IMM). The IMM is a simple process flowchart which establishes the prioritized sequence of stakeholder activities required to implement a new technology at key stages in the project process. The IMM has implications for selection of procurement methods and will instill confidence in stakeholders to adopt new technologies. Additionally it provides a risk-based approach for stakeholder competency mapping and for sustaining product innovation in construction projects.
Shadid, W.K. (2018). A framework for managing organizations in complex environments. Construction Management & Economics, 36(4), 182-202. doi:10.1080/01446193.2017.1343483	The complex environments of today's markets makes managing organizations in complexity and turbulence a concern for senior managers, and necessitate developing a dynamic strategic framework to cope with complexity in managing organizations. This paper demonstrates a study that was conducted to value a structured set of management principles and sub-elements by a panel of experts to develop a conceptual framework to manage in complex and very high dynamic environments. The panel consisted of 22 senior level managers of grade "A" companies in the construction industry in Qatar State using a two-round Delphi technique. The study developed two frameworks. The first framework is for managing complexity in the construction sector. The second one is the primary general framework, which forms a basis for a generalized framework for other industries. This study participates in developing valuable management practices in complex environments to tackle uncertainty, unpredictability, disorder, rapid changes and non-linearity, which would be of great help for leaders, senior managers and practitioners who operate in complex environments.

Afshari, A.R. (2017). Methods for Selection of Construction Project Manager: Case Study. Journal of Construction Engineering and Management, 143(12). https://doi.org/10.1061/(ASCE)CO.1943-7862.0001400	The main objective of this paper is to develop a systematic method for identifying the best among the candidates in the process of construction project manager selection by applying two methods. The proposed method combines the Delphi method and the fuzzy linguistic evaluation to enhance selection. The outcome of this study addresses the issue of high error in decision making, which is a very common problem in the construction industry. The models were examined using a case study in a project-based organization for selecting the most suitable project construction manager, in which three candidates under 14 different subcriteria are evaluated and prioritized by three decision makers. The results show that the proposed model performs very well and can improve efficiency in the decision-making process.
Alshubbak, A., Pellicer, E., Catalá, J., & Teixeira, J. C. (2015). A Model for identifying owner's needs in the building life cycle. Journal Of Civil Engineering & Management, 21(8), 1046-1060. doi:10.3846/13923730.2015.1027257	Building life cycle is a process which covers not only the construction phase but also the feasibility, the design and the operation phases. Identifying the owner's needs in all phases of this process is of paramount importance for achieving satisfactory results for the building project. Additionally, the owner's needs should be fulfilled by the work scope of every stakeholder involved in the project. Nevertheless, these needs are not always adequately considered in building projects. Thus, the purpose of the research reported in this paper has been to develop a model that allows for the identification of the owner's needs in all phases of the building life cycle. The article presents a six level classification system for the information required in the project and a two-dimensional model that maps the life cycle and the logical actions to be undertaken in each phase. The model has been corroborated and improved by applying the Delphi technique to a panel of ten experts in two rounds. The practical use of the model is through the systematic application of a series of questionnaires built upon the information classification system for determining the owner's needs. The paper details the operation phase of the model as an illustrative example and a case study on a residential building project of twelve apartments in Spain.
Ameyaw, E.E., & Chan, A.P. (2015). Evaluating key risk factors for PPP water projects in Ghana: a Delphi study. Journal Of Facilities Management, 13(2), 133-155. doi:10.1108/JFM-10-2013-0051	Purpose – This paper aims to report on the partial findings of a research project on risk allocation in public–private partnership (PPP) water projects. It identifies risk factors encountered in PPP water infrastructure projects, evaluates their associated risk levels and presents an authoritative risk factor list to assist the sector institutions to understand the important risks associated with such projects in Ghana. Design/methodology/approach – A ranking-type Delphi survey was conducted to develop a rank-order list of critical risk factors. Findings – Twenty critical risk factors with high impact on water PPPs were established. The top-five risks relate to foreign exchange rate, corruption, water theft, non-payment of bills and political interference. Originality/value – Being the pioneering study, it holds implications for practitioners. By prioritising the risks according to their relative impacts on the success of water PPP projects, public and private participants will become more aware of and leverage efforts and scarce resources to address those significant factors with serious consequences on projects objectives. The paper adopts a research approach that can be used by future researchers in similar environments where PPP is novel and experts are hard to find.

Ameyaw, E. E., Hu, Y., Shan, M., Chan, A. C., & Le, Y. (2016). Application of Delphi method in construction engineering and management research: A quantitative perspective. Journal Of Civil Engineering & Management, 22(8), 991-1000. doi:10.3846/13923730.2014.945953	The Delphi method has been used as a main research method by a growing number of researchers in the Construction Engineering and Management (CEM) field in the past two decades. Although a number of studies are available on the use of Delphi, few researchers fully examine the potential of the Delphi method in the combined use of statistical techniques, which is an inevitable trend for future Delphi research. This paper aims to review the combined use of Delphi and other quantitative methods in the CEM field based on a structured literature review of 88 relevant papers. All of the 88 papers are systematically identified from ten well-known peer-reviewed CEM journals published in the period of 1990–2012. Topic coverage, application requirements, and statistical techniques in the 88 Delphi papers are reviewed. The mix use of the Delphi method with three advanced modelling methods, such as Fuzzy sets, Analytical Hierarchy Process, and Analytical Network Process is also examined. These review results provide practical references for researchers having interests in applying Delphi method in CEM research.
Austin, R.B., Pishdad-Bozorgi, P. & de la Garza, J.M. (2015). Identifying and Prioritizing Best Practices to Achieve Flash Track Projects. Journal of Construction Engineering and Management, 142(2). https://doi.org/10.1061/(ASCE)CO.1943-7862.0001061	This paper presents the initial findings of an ongoing research effort focused on identifying, quantifying, and ranking essential industry practices for the successful delivery of faster fast-track, or Flash Track, projects. The research data collection involves literature search, engineering, procurement, construction industry interviews, and discussions with an industry expert panel. This research has extensively explored and analyzed U.S. and international practices and has deeply explored project execution practices in industries other than construction, including manufacturing, shipbuilding, and software engineering/development. The methodology employed in this research entails deployment of a three-round Delphi process and an Analytic Hierarchy Process to produce a comprehensive list of prioritized recommendations on essential Flash Track practices. This paper contributes to the body of knowledge by identifying and ranking 18 industry best practices essential to successfully manage the unique challenges and risks inherent in Flash Track projects. This research finds that planning, execution, and organizational practices are the most essential considerations for successful Flash Tracking. It also highlights the central role of trusting relationships and fully integrated work teams and, in doing so, extends earlier studies calling for innovative approaches, rethinking prevailing practices, and entertaining a new paradigm in Flash Track projects.
Ceric, A. (2014). Minimizing communication risk in construction: a Delphi study of the key role of project managers. Journal Of Civil Engineering & Management, 20(6), 829-838. doi:10.3846/13923730.2013.802739	All significant construction projects involve the project owner and the contractor, as well as their project managers. Following up on recent research into the multiple principal-agent problem, which was applied to the minimization of communication risk in construction projects, the focus here is on communication issues between the four project parties. Recent research has shown that the relationship between the project owner and the contractor is paramount for risk minimization before the contract between them is signed. However, the relationship between project managers is dominant for risk minimization after the contract is signed. To further explore risk minimization at this stage of the project, the Delphi method was employed. A panel of highly-experienced project managers working for both project owners and contractors was asked several rounds of questions in an attempt to arrive to a consensus concerning the most important relationships between project parties in terms of risk minimization after the contract is signed. The relationship between the two project managers tops the ranking, thus focusing further research. As they are both agents, and as there is no contract between them, this offers a fresh challenge for the principal-agent theory.

Chan, A. C., Wong, F. W., Hon, C. H., Ali Javed, A., & Lyu, S. (2017). Construction safety and health problems of ethnic minority workers in Hong Kong. Engineering Construction & Architectural Management (09699988), 24(6), 901-919. doi:10.1108/ECAM-09-2015-0143	Purpose With increasing employment of ethnic minority (EM) workers from different nationalities to mitigate the growing demand for a construction workforce, the safety and health problems of these workers have become a significant concern. The purpose of this paper is to identify and rank according to severity the safety and health-related problems confronted by EM construction workers. Design/methodology/approach Grounded theory approach was employed to construct the main categories and subcategories of the construction safety and health problems of EM workers. A two-round Delphi survey of 18 experts, who are highly experienced in managing EM workers, was conducted to rank the relative severity of the identified safety and health problems. Findings A total of 14 subcategories and 4 categories of construction safety and health problems of EM workers were identified. Among the 14 subcategories, the most urgent and serious ones were insufficient safety materials and training in their native language, insufficient safety staff from EM origin, and safety communication barriers. In addition, safety and health problems at the corporate and governmental levels are also worth paying attention. Originality/value This study contributes to the update on the existing body of knowledge on safety and health problems encountered by EM construction workers and revelation of their peculiar situation in Hong Kong. Findings of the study will be of value to various stakeholders in formulating safety and health measures for EM construction workers.

Chan, A.P.C, Javed, A.A., Lyu, S. & Hon, C.K.H. (2016). Strategies for Improving Safety and Health of Ethnic Minority Construction Workers. Journal of Construction Engineering and Management, 142(9). https://doi.org/10.1061/(ASCE)CO.1943-7862.0001148	The construction industries of developed countries are faced with an aging workforce and a shortage of recruits. It is common for migrant workers/ethnic minorities (EMs) who are already part of the society to join the construction industry. With increasing involvement of EMs in the construction industry, effective strategies for improving their safety and health are urgently needed. The existing body of knowledge is mainly derived from research conducted in English-speaking countries with Western cultures. Research on safety of migrant/EM construction workers in multidialect Asian countries with Eastern cultures has been lacking. This study aimed to identify various strategies for improving the safety and health of EM construction workers from the Asian perspective. Twenty-two face-to-face semistructured interviews were performed with safety professionals in Hong Kong followed by two rounds of Delphi survey with 18 safety experts to verify the interview findings and rank the relative importance of the strategies. The study unveiled 14 strategies for improving the safety performance of EM workers. The three most important ones identified were (1) to provide safety training in EM native languages, (2) that government and industry associations should play an active role in promoting health and safety awareness of EM workers, and (3) to encourage EM workers to learn the local language. This study contributes to filling the research gap by evaluating the strategies for improving safety of migrant/EM construction workers in Asian countries with Eastern cultures in which English is not the first language. Research findings would assist occupational health and safety experts and relevant stakeholders in designing strategies for improving the safety and health of EM workers, which will ultimately improve overall safety performance of the construction industry.
Che Ibrahim, C.I., Costello, S. B., & Wilkinson, S. (2015). Establishment of Quantitative Measures for Team Integration Assessment in Alliance Projects. Journal Of Management In Engineering, 31(5), 1-11. doi:10.1061/(ASCE)ME.1943-5479.0000318	The ability to sustain and consistently drive integration practice is vital for alliance teams as it promotes a collaborative culture and the continuity of equitable relationships to improve project performance. An alliance team integration performance index (ATIPI) has been previously developed based on seven weighted key indicators for alliance projects as follows: team leadership; trust and respect; a single team focus on project objectives and key results areas; collective understanding; commitment from project alliance board; creation of single and collocated alliance team; and free-flow communication. The ATIPI provides a point of reference for alliance teams to monitor, measure, and improve the performance of their integration practice. Given that the ATIPI is still at a conceptual stage, an appropriate measure, preferably objective, needs to be established. Consequently, the main objective of this paper is to identify quantitative measures for each key indicator to provide an objective assessment based on quantitative evidence. Initially, structured face-to-face interviews with five alliance practitioners were conducted to recommend the appropriate quantitative measures. Then, two successive rounds of a Delphi questionnaire survey with 17 experts were conducted to rate the measures recommended by the initial group of five interviewees. Finally, a set of quantitative measures was recommended based on their levels of importance, measurability, and obtainability, to assess each of the seven weighted key indicators. The identified quantitative measures provide an enhancement to the existing ATIPI model in terms of the objective quantification of the key indicators. This will also help fill a knowledge gap by strengthening researchers' and academics' understanding and existing knowledge on measuring team integration.

Cheng, M., & Lu, Y. (2015). Developing a risk assessment method for complex pipe jacking construction projects. Automation In Construction, 5848-59. doi:10.1016/j.autcon.2015.07.011	Pipe jacking (PJ) construction is a highly complex and uncertain process so that performing an accurate risk assessment is essential to the success of a project. This study presents an innovative risk assessment model which combines fuzzy inference with failure mode and effect analysis (FMEA) to improve the effectiveness of existing risk assessment methods for pipe jacking construction. The proposed model maps the relationship between occurrence (O), severity(S), and detection (D) with the level of criticality of risk events in three steps: fuzzification, fuzzy rule-based inference, and defuzzification. A case study of a PJ construction project for water transmission in Shanghai, China is presented to demonstrate and validate the proposed method. A total of 31 potential risks was identified according to the PJ construction procedure and two-round Delphi questionnaire surveys. By using the proposed fuzzy-FMEA approach, the most critical risks in the PJ construction process can be identified, in particular, the shaft structure construction, jacking operation, and steel pipe segments welding. The proposed method overcomes the inherent weaknesses of traditional FMEA method and provides a reliable and distinguishable risk ranking system by properly reflecting the complexity of PJ construction environment. The study also provides a comprehensive risk identification and evaluation tool for industrial practitioners who manage or involve with PJ construction projects.
Cheng, Y. (2014). An exploration into cost-influencing factors on construction projects. International Journal Of Project Management, 32(5), 850-860. doi:10.1016/j.ijproman.2013.10.003	Construction cost overrun is a common problem in construction industries. The objective of this research is to extract the key cost-influencing factors with new concept and methods to help control the expenditure. Hence, this research adopts the Modified Delphi Method (MDM) with 2 groups and 2 rounds and Kawakita Jiro method (KJ) to consolidate the experts' opinions and identify and rank the key factors that affect project costs. Ninety cost-influencing factors are collected from literary review and interviews with experts with practical cost control experiences in the construction companies (Group 1). The KJ method is used to consolidate these factors into 4 categories and down to a total of 42 factors. 2 rounds of questionnaires are then conducted to filter the key factors. In order to verify views of those in the first group, Group 2 consists of experienced experts from the public sectors, consulting firms and construction companies as a comparison. Results of the analysis indicate that there are 16 key cost-influencing factors. Severity Index computation was then adopted to rank these key cost-influencing factors. The study renders that clearly defined scope of project in the contract and cost control are the major determinants for cost overrun.

Chong, H., & Oon, C. K. (2016). A practical approach in clarifying legal drafting: Delphi and case study in Malaysia. Engineering Construction & Architectural Management (09699988), 23(5), 610-621. doi:10.1108/ECAM-04-2015-0059	Purpose Legal drafting is one of the root causes for interpretation errors and misunderstandings in construction contracts. Moreover, most construction personnel do not have legally trained background. Therefore, the purpose of this paper is to determine the feasible use and practicality of Plain English in clarifying legal drafting in Malaysian construction contracts. Design/methodology/approach Two research approaches were adopted, namely, Delphi research and case study. The Delphi method was to elicit local experts' knowledge and consensus view on the given examples of restructured contract provisions. Next, an actual case study was conducted to examine and substantiate the research findings by critically reviewing the latest and revised standard form of contract for its Plain English usage. Findings The Delphi research shows that all the restructured contract provisions were agreed by the local experts; whereas the case study reveals that significant changes and the acceptance of Plain English in most of the contract provisions. Originality/value The research renders insightful references in clarifying legal drafting in construction contracts based on the empirical evidence and the use of Plain English from the Malaysian scenario. It also contributes into the resolution of contractual differences and conflicts caused by the misunderstandings or interpretation problems.
Gharaibeh, H.M. (2014). Cost Control in Mega Projects Using the Delphi Method. Journal of Management in Engineering, 30(5). doi: 10.1061/(ASCE)ME.1943-5479.0000218	A major driver to project success is the ability to manage the project cost effectively. Despite agreement among scholars and practitioners on the importance of managing the project cost, major projects continue to experience excessive cost overruns. The purpose of this paper is to investigate the issue of project cost control in major power transmission projects, and to understand the reasons behind cost overrun. The author used a Delphi method to identify problems of controlling the project cost, suggests solutions to overcome these problems, and identifies lessons learned. The study used a three-round semistructured questionnaire with two different project teams to compare and validate findings from one project team to another. Key findings from the study helped to shed some light on the complexity of the learning process itself, and to understand why lessons learned are not truly learned and mistakes are repeated from past to future projects. The paper concludes with specific practices and a set of recommendations that should be implemented by project teams to help in managing the cost of mega projects.

Gharaibeh, H.M. (2013). Managing the Cost of Power Transmission Projects: Lessons Learned. Journal of Construction Engineering and Management, 139(8). https://doi.org/10.1061/(ASCE)CO.1943-7862.0000665	A major driver to project success is the ability to manage the project cost effectively. Despite the agreement among scholars and practitioners on the importance of managing the project cost, excessive cost overruns continue to occur on major power transmission projects. In this paper, the author, through a Delphi method, will discover problems of managing the project cost, suggest solutions to overcome these problems, and identify lessons learned from these projects. The study was conducted with two different project teams in the same organization in Canada. Key findings from this study will highlight similarities and differences between the two cases in terms of how each team managed the project cost and learned from it. The paper will contribute to the body of knowledge by identifying lessons learned from power transmission projects on how to manage the project cost and by suggesting solutions to overcome the problem of cost overrun in these projects.
Giel, B., & Issa, R. A. (2016). Framework for Evaluating the BIM Competencies of Facility Owners. Journal Of Management In Engineering, 32(1), 1-15. doi:10.1061/(ASCE)ME.1943-5479.0000378	The adoption of building information modeling (BIM) in the design and construction phases of building projects has increased considerably in recent years; however, its use in postconstruction is still lagging. Much of this is because of the lack of experience by owner organizations in using BIM during operations and maintenance (O&M). The architecture, engineering, construction, and operations (AECO) industry is undergoing a major paradigm shift that will require building owners to develop lifecycle-oriented BIM strategies. Consequently, owners will play a vital role in improving the maturity of future BIM-assisted projects through their requirements documentation, assessment of the quality and accuracy of BIM deliverables, and continued application of BIM during facilities management (FM). The primary objective of this research study was to develop a framework for building owner organizations to use in the assessment of their BIM competency. Using the Delphi technique, 66 critical factors that are influential in the evaluation of owners' BIM competency were identified and prioritized on the basis of the perceptions of 21 prequalified BIM experts. The data derived from the Delphi phase were then used to propose an assessment tool that allows owners to evaluate their operations across three diverse competency areas and 12 specifically tailored competency categories. These evaluations can then be used by owners to assess and expand their technical knowledge, improve their current BIM requirements, and increase the efficiency of their postconstruction operations.
He, Q., Luo, L., Hu, Y., & Chan, A. P. (2015). Measuring the complexity of mega construction projects in China—A fuzzy analytic network process analysis. International Journal Of Project Management, 33(3), 549-563. doi:10.1016/j.ijproman.2014.07.009	Mega construction projects in China are usually very complicated in nature, thus evaluating and understanding these complexities are critical to the success of these megaprojects. However, empirical studies related to the measurement of the complexity of megaprojects remain lacking. This paper aims to fill this gap by developing a complexity measurement model based on the Shanghai Expo construction project in China using fuzzy analytic network process (FANP). Firstly, a complexity measurement model consisting of 28 factors, which are grouped under six categories, namely, technological, organizational, goal, environmental, cultural and information complexities, is formulated through literature review using the content analysis technique. The model is then refined by a two-round Delphi survey conducted in the case megaproject. Finally, the refined model and suggestions for its application are provided based on the survey results. The model is believed to be beneficial for scholars and serve as reference for professionals in managing megaprojects.

Kraft, E., & Molenaar, K. R. (2015). Quality Assurance Organization Selection Factors for Highway Design and Construction Projects. Journal Of Management In Engineering, 31(5), 1-9. doi:10.1061/(ASCE)ME.1943-5479.0000289	A project quality assurance organization (QAO) assigns project quality responsibilities and relationships, both for design and construction. In the highway sector, all project quality roles and responsibilities have historically been assigned to the state highway agency (SHA), an accepted and well-understood industry practice. However, increasing use of alternative project delivery methods and reductions in SHA staffing are having an impact on traditional QAO practices. SHAs are increasingly selecting alternative QAOs, but they are making these selections in an ad hoc manner because of limited staff knowledge and experience, and a lack of guidance from the research community. Highway design and construction quality research focuses almost exclusively on inspections, observations, corporate quality, warranties, and materials testing, resulting in a gap in the research about shifts in project quality roles and responsibilities. This research extends the civil engineering quality management body of knowledge by identifying factors that influence the selection of QAOs and rating the appropriateness of the QAOs for each selection factor. Because of the complexity of the topic, scope of the decision process, and the limited project data available, structured interviews and the Delphi method were chosen to explore the selection factors. The research discovered 10 factors: project size, project complexity, project delivery method, project schedule sensitivity, availability of agency project staff, agency project staff experience, agency culture, industry ability to manage their own quality, trust between agency and industry, and amount of quality risk to shift away from the agency. The research provides the highway industry with new understanding of the effects that each selection factor has on the fundamental QAOs. This fundamental knowledge will allow SHAs to make more informed QAO selections.
Mayo, G., & Issa, R. A. (2016). Nongeometric Building Information Needs Assessment for Facilities Management. Journal Of Management In Engineering, 32(3), 1-12. doi:10.1061/(ASCE)ME.1943-5479.0000414	Building information modeling (BIM) tools hold promise for owners in terms of collecting the information needed for facility operations. The introduction of BIM technology has increased the need for project teams to deliver information earlier in the project timeline. BIM has been a catalyst for process change in the architecture, engineering, and construction (AEC) industry in terms of earlier decision making and in identifying the need for more precise and accurate information throughout the design and construction process. Because of the use of collaborative project delivery methods, and the owner's participation on the project team, the same catalyst is now forcing owners to decide and specify in more detail their informational needs and deliverables. To date, owners are dependent on broad recommendations regarding what information they should collect as well as what methods may be used to collect it. To assist owners with specific recommendations, this study examined a microlevel view of the information required for owners to help them specify their closeout deliverables. The methodology included a Delphi panel of facility management personnel employed by universities in 18 states who were surveyed to establish a consensus resulting in a basic list of building information needs. The Delphi panel questions addressed the issue from the perspective of providing value as determined by the perceived need for product information in operations and maintenance (O&M), as well as the frequency of use of the product information categories. The final research results provide an established base list of product information needs for specifying project deliverables, i.e., a list of products and product formats, which can be used by owners integrating BIM in their facilities management (FM) efforts.

Moussavi Nadoushani, Z. S., Akbarnezhad, A., Ferre Jornet, J., & Xiao, J. (2017). Multi-criteria selection of façade systems based on sustainability criteria. Building & Environment, 12167-78. doi:10.1016/j.buildenv.2017.05.016	The environmental and economic impacts of alternative façade systems have been widely investigated in previous studies. However, sustainable design requires reconciliation between economic, environmental and social impacts; the three pillars of a sustainable system, and selection of façade only based on environmental impacts may not always provide a sustainable solution. Through a case study, this paper presents a systematic methodology for selection of the façade system for a building by accounting the social, economic, and environmental impacts of the decision. A comprehensive list of sustainability criteria for selection of façade systems is presented and discussed in detail. The selected sustainability criteria are then applied to identify the most sustainable facade system, among five different alternatives including double brickwork, aluminium composite panel, ceramic cladding, Autoclaved Aerated Concrete (AAC) panels and concrete blocks, to replace the existing worn façade of an actual building. Delphi technique, a method of eliciting and refining group judgments, is used to identify applicable sustainability criteria and their relative pair-wise importance scores, while AHP is used to identify the global relative importance weights for different sustainability criteria and rank different alternative façade systems.
Olawale, Y., & Sun, M. (2015). Construction project control in the UK: Current practice, existing problems and recommendations for future improvement. International Journal Of Project Management, 33(3), 623-637. doi:10.1016/j.ijproman.2014.10.003	The aim of this study is to address the main deficiencies with the prevailing project cost and time control practices for construction projects in the UK. A questionnaire survey was carried out with 250 top companies followed by in-depth interviews with 15 experienced practitioners from these companies in order to gain further insights of the identified problems, and their experience of good practice on how these problems can be tackled. On the basis of these interviews and syntheses with literature, a list of 65 good practice recommendations have been developed for the key project control tasks: planning, monitoring, reporting and analysing. The Delphi method was then used, with the participation of a panel of 8 practitioner experts, to evaluate these improvement recommendations and to establish their degree of relevance. After two rounds of Delphi, these recommendations are put forward as “critical”, “important”, or “helpful” measures for improving project control practice.
Rad, E. M., Ming, S., & Bosché, F. (2017). Complexity for Megaprojects in the Energy Sector. Journal Of Management In Engineering, 33(4), 1-13. doi:10.1061/(ASCE)ME.1943-5479.0000517	Megaprojects are characterized by their large-scale capital costs, long duration, and extraordinary levels of technical and process complexity. Empirical data demonstrate that these projects experience alarming rates of failure. One of the main causes of such project failure is the high level of complexity and the absence of effective tools for assessing and managing it. This study developed a new project complexity assessment method that is specifically aimed at megaprojects in the energy sector. The assessment method contains a taxonomy of 51 complexity indicators and their consolidated weights, which are established through a novel Delphi and analytic hierarchy process (AHP) group decision-making method. Numerical scoring criteria for all indicators were defined on the basis of a synthesis of existing knowledge of megaprojects to facilitate the application of the new method. The method was reviewed and evaluated by experts and tested through a case study of an energy megaproject.

Sacks, R., & Pikas, E. (2013). Building Information Modeling Education for Construction Engineering and Management. I: Industry Requirements, State of the Art, and Gap Analysis. Journal Of Construction Engineering & Management, 139(11), 1. doi:10.1061/(ASCE)CO.1943-7862.0000759	As building information modeling (BIM) becomes increasingly standard practice in the construction industry, universities providing construction engineering and management education seek to incorporate BIM concepts and skills in their degree programs. The goal of this research was to compile a framework for BIM education that lays out the necessary topics and the levels of achievement required at each stage of degree programs. Industry's requirements for graduate engineers were elicited through surveys, workshops, analyses of job advertisements, and in-depth interviews. An outline of 39 topics in three broad classifications was established. Targets for competency in each topic were developed using the cognitive domain of Bloom's taxonomy, which expresses the learning objectives on six levels (from understand to evaluate). Gap analysis, which compared the state of the art in leading universities to industry requirements, led to the compilation of a framework for the development of BIM content for undergraduate and graduate construction engineering and management degree programs. The requirements and framework are intended to provide educators with essential knowledge as they develop and implement BIM content in their programs.
Seyis, S., & Ergen, E. (2017). A decision making support tool for selecting green building certification credits based on project delivery attributes. Building & Environment, 126107-118. doi:10.1016/j.buildenv.2017.09.028	The Green Building (GB) certification process embodies detailed requirements and specifications that lead to additional tasks for project teams, which increases complexity levels of the entire project delivery process. Previous studies show that if the GB certification credits to be fulfilled are selected without considering project team attributes, then elevated levels of time, money, and labor could get wasted while attempting to meet the additional requirements of GB certification. The aim of this study is to develop a multi-attribute decision making (MADM) support tool to be used by GB experts to select the appropriate GB certification credits based on the project team attributes. The developed framework with relative weights assigned via the Delphi method was used to perform the MADM analysis, which employs the hybrid use of the Multi Attribute Utility Technique (MAUT) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). This paper presents the developed MADM tool (i.e., GB-CS tool) and the relative weights of the attributes that were determined following expert opinions. To validate the tool, a case study was conducted at a LEED-registered residential project. The results show that the GB-CS Tool was successful in ranking the GB certification credits to be selected. This hybrid MADM tool can be used for preventing disruptions and bottlenecks in GB project delivery processes by assisting the owners/GB consultants in effectively selecting suitable GB certification credits based on the project team attributes. Thus, with the assistance of the GB-CS tool, root causes of waste can be mitigated in the GB project delivery process, decreasing associated hidden costs.

Seyis, S., Ergen, E., & Pizzi, E. (2015). Identification of Waste Types and Their Root Causes in Green-Building Project Delivery Process. Journal of Construction Engineering and Management, 142(2). https://doi.org/10.1061/(ASCE)CO.1943-7862.0001038	Time-related and cost-related waste through design and construction phases of the Green Building (GB) project delivery process are much higher than that of Nongreen Buildings (NGBs). Although prior studies have identified some waste types and related root causes for GB projects, a comprehensive classification of process waste and root causes encountered in GB project delivery does not exist in the literature. The objectives of this study are (1) to identify and classify waste types and associated root causes observed in design and construction phases of GB project delivery process, and (2) to rank the classified waste types and root causes based on their effects on time and cost increases during design and construction phases. To achieve the first research objective, an extensive literature review and a case study with three GB projects were conducted, and the identified root causes and waste types were represented in an Ishikawa diagram. To achieve the second research objective, two rounds of the Delphi method were performed with 12 panelists who are qualified in GBs and accredited by various areas of expertise. The findings include the following: (1) 6 major types of waste, and 4 types of primary root causes with 16 types of secondary root causes, (2) an Ishikawa diagram for representing the cause–effect relationship between waste and associated root causes, and (3) ranking of the identified waste types, and primary and secondary root causes in design and construction phases of GB project delivery process based on their significance. The contributions of this study are a comprehensive classification of waste and associated root causes for the GB project delivery process, a description of their relationships, and a ranking of waste types, and primary and secondary root causes in terms of their negative impacts on the GB delivery process in terms of time and cost. The findings of this study can be utilized for developing models and/or tools in the future that would allow the owners to detect existing root causes and potential waste in GB project delivery processes.
Sierra, L.A., Pellicer, E. & Yepes, V. (2015). Social Sustainability in the Lifecycle of Chilean Public Infrastructure. Journal of Construction Engineering and Management, 142(5). https://doi.org/10.1061/(ASCE)CO.1943-7862.0001099	To enhance concern for the social aspects of sustainability and to delineate the criteria to be considered at each stage of the lifecycle of an infrastructure, this paper aims to determine the relevance of a set of criteria that evaluate social sustainability throughout the lifecycle of a public civil infrastructure. This research presents the results of a case study applying the Delphi method to 24 Chilean experts consulted in a series of three rounds. In addition, binomial statistical tests and Kendall's coefficient were used to show the convergence of the experts. Thus, it was identified that of 36 initial criteria assessed at each stage of the lifecycle, the consideration of 20 is required at the design stage, 29 at the construction stage, 33 during operation, and 27 at demolition. The most relevant criteria, per lifecycle stage, were Stakeholder Participation (design and demolition stages), External Local Population (design stage), Internal Human Resources (construction and demolition stages), Macro-Social Action of Socioenvironmental Activities (construction stage), and Macro-Social Action of Socioeconomic Activities (operation stage).

Tymvios, N. &Gambatese J.A. (2016). Direction for Generating Interest for Design for Construction Worker Safety—A Delphi Study. Journal of Construction Engineering and Management, 142(8). https://doi.org/10.1061/(ASCE)CO.1943-7862.0001134	Decisions made prior to construction impact the safety of construction workers. Past research has shown that there is a link between design decisions and fatalities. Prevention through Design (PtD) is a concept that attempts to identify and mitigate hazards early in the design process with the goal of eliminating the risks of injury to workers and/or damage to facilities during construction. PtD is a required practice in some countries, primarily because of legislation. In the United States, however, PtD is not well known by design professionals and there is opposition to its practice. The objective of this paper is to present the results of a Delphi study, in which the Delphi panel was tasked to identify: (1) the construction industry group with the most influence to generate interest in PtD in the United States, (2) the method with which that interest can be achieved, and (3) the industry group that should be targeted with that method. The Delphi panel came to a consensus that owners have the greatest influence to generate interest, and they should be the group to be targeted using the business case method.
Valdes-Vasquez, R. & Klotz, L.E. (2013). Using the Concept-Mapping Method for Empirical Studies in Construction Research. Journal of Construction Engineering and Management, 139(10). https://doi.org/10.1061/(ASCE)CO.1943-7862.0000720	The concept-mapping method has enabled research advances in medicine and psychology. This method also seems well suited for many of the questions facing construction researchers, but its use remains limited in construction research. Concept mapping helps solicit and organize ideas from experts and stakeholders. This method can be used to categorize results into various clusters that may have competing explanations or backgrounds. It also allows for comparing results among group of participants. This method integrates qualitative group tasks of idea generation, sorting, and rating with two quantitative analyses, multidimensional scaling, and cluster analysis. One of the relevant findings of using these analyses is the creation of visual maps, which can help develop action plans and frameworks. This paper is meant as a guide for applying the concept-mapping method to construction research. Although examples for using this method in construction engineering and management are presented in this paper on the basis of the development of a sustainability framework, the emphasis is on general principles to show how various construction research topics could be explored by using this method.

Wong, J. K., & Kuan, K. (2014). Implementing 'BEAM Plus' for BIM-based sustainability analysis. Automation In Construction, 44163-175. doi:10.1016/j.autcon.2014.04.003	Escalating energy costs and the need to improve energy efficiency have increased public awareness of the need to reduce energy consumption over a building's entire lifecycle, and have prompted efforts to integrate green and sustainable building initiatives into the conventional building design, construction and operation processes. Sustainable building rating systems are being increasingly adopted to assess the sustainability performance of building design and construction. Building information modelling (BIM)-based technologies are regarded as a potentially useful vehicle for helping project stakeholders to capture complete design and project information, and to make the best use of the available design data for sustainable design and sustainability rating analysis. While experience from the Leadership in Environmental Energy and Design (LEED) programme in the US has demonstrated the great potential of integrating BIM with building assessments, it is anticipated that BIM can also be effectively integrated with the Hong Kong 'BEAM Plus' sustainable building rating system. This study uses a two-stage method (i.e. a Delphi study and a case study) to explore the potential use of BIM in the case of a residential building project seeking BEAM Plus sustainable building certification in Hong Kong. The Delphi study indicated that 26 out of 80 credit points could potentially be achieved with the support of the documentation produced by BIM (i.e. Autodesk Revit). Detailed procedures for conducting and testing a BIM-based BEAM Plus sustainability analysis are described. The proposed BIM–BEAM Plus assessment framework is then verified using two sampled public housing modular flat models. The complexity of the BIM–BEAM Plus application depends on the project size, the extent of the model development detail and the nature of the project.
Xia, B., & Chan, A. P. (2012). Measuring complexity for building projects: a Delphi study. Engineering Construction & Architectural Management (09699988), 19(1), 7-24. doi:10.1108/09699981211192544	Purpose – The aim of this study is to identify complexity measures for building projects in the People's Republic of China (PRC). Design/methodology/approach – A three-round of Delphi questionnaire survey was conducted to identify the key parameters that measure the degree of project complexity. A complexity index (CI) was developed based on the identified measures and their relative importance. Findings – Six key measures of project complexity have been identified, namely: building structure & function; construction method; the urgency of the project schedule; project size/scale; geological condition; and neighboring environment. Practical implications – These complexity measures help stakeholders assess degrees of project complexity and better manage the potential risks that might be induced to different levels of project complexity. Originality/value – The findings provide insightful perspectives to define and understand project complexity. For stakeholders, understanding and addressing the complexity help to improve project planning and implementation.

Yi, H., Chan, A. C., & Yun, L. (2015). Understanding the Determinants of Program Organization for Construction Megaproject Success: Case Study of the Shanghai Expo Construction. Journal Of Management In Engineering, 31(5), 1-10. doi:10.1061/(ASCE)ME.1943-5479.0000310	Program management is increasingly regarded as a key approach to improving the performance of a construction megaproject through the coordinated management of its constituent projects. However, previous studies have seldom provided a pragmatic program management framework that can fully address the requirements of clients in managing construction megaprojects. Therefore, based on a case study of the Shanghai Expo construction, this study aims to identify the principal program organization factors (POFs) that are determinants of the program organization established by a client to manage a megaproject. Mixed research methods, such as case study, literature review, interviews, Delphi survey, and archival methods, are employed in this study. Consequently, 12 principal POFs, grouped under three main categories (environmental capability, core capacity, and motivational capability of the client's program organization to manage its construction megaproject), are identified: (1) contextual understanding, (2) program strategy, (3) program leadership, (4) scope management, (5) program governance, (6) matrix organizational structure, (7) program management office, (8) use of project breakdown structure and work breakdown structure tools, (9) partnering with key stakeholders, (10) technology management, (11) communication management, and (12) team building. These research findings will help scholars and professionals, particularly those in China, to appreciate the key issues in managing megaprojects through program organization.
Zahoor, H., Chan, A. C., Gao, R., & Utama, W.P. (2017). The factors contributing to construction accidents in Pakistan: Their prioritization using the Delphi technique. Engineering Construction & Architectural Management (09699988), 24(3), 463-485. doi: 10.1108/ECAM-01-2016-0027	Purpose - The highest number of accidents in proportion to the employment rate is found in construction industry among all industries in Pakistan. The purpose of this paper is to identify and prioritize the contributory factors of accident causation that can significantly reduce the rate of accident in the construction industry. Design/methodology/approach - In total, 32 contributory factors of accident causation were identified through a triangulation strategy comprising eight face-to-face semi-structured interviews with the academic and industry experts coupled with a comprehensive literature review. Delphi survey was then conducted among the four respondent groups (clients, contractors, safety official and academia) to prioritize these factors. A consensus was achieved among the respondent groups after conducting two rounds of Delphi survey. Finally, the results were validated using the technique of inter-rater agreement (IRA) analysis. Findings - All the shortlisted accident causation factors were graded as "important" to "extremely important". Moreover, a "moderate" to "strong level" agreement was developed among the respondent groups. The three most significant factors were highlighted as "poor enforcement of safety rules and regulations by the Government agencies", "insufficient allocation of safety budget and safety incentives by the client", and "insufficient provision of safety training and resources by the contractor." Practical implications - The findings will help the key stakeholders to prioritize their energies towards achieving zero accident in the construction industry. Moreover, addition of academic experts as one of the respondent groups will enhance the linkages between the academia and the industry practitioners. Originality/value - Besides highlighting the underlying causes of construction accidents in Pakistan, a detailed methodology is presented in this study for the analysis and validation of the Delphi survey data, which can be extrapolated in other regions and industries for elements prioritization. The findings of the study can also be generalized for other developing countries having similar work environment. The results validation through the use of IRA analysis is an addition to the field of construction safety research. The study also authenticates the applicability of IRA analysis to assess the agreement level among the respondents.

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