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Duration Forecasting In Construction Projects: A Delphi-Based Approach

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ABSTRACT- The uncertainties (e.g. altering labor productivity, weather changes, material shipment delays, and site-based conditions) have been the root causes of the construction industry continuously struggling to perfectly estimate the durations of activities, which are expected to be properly planned, scheduled, and will thereby control the cost of a project. Conventional approaches that involve probabilistic assessments such as Critical Path Method (CPM) and Program Evaluation and review techniques (PERT) use fixed or constrained probabilistic estimations, and frequently do not consider the range of expert opinion or arrive at a consensus of uncertain time parameters. This paper will utilize a Delphi method that is a systematic, iterative process used to elicit and hone the views of the experts to come up with a collaborative approach to estimating the time taken by construction activities. The tasks are as follows: to carry out a Delphi survey of the experienced construction professionals in a series of rounds and reach the consensus on the likely ranges of project activity durations, and also test the technique by using a case study of a building construction project. Three surveys of anonymous panel of 12 experts (with more than 10 years of experience) were implemented, including the open-ended estimates, statistical feedback and revisions until the consensus was achieved (coefficient of variation was less than 15 per cent). The estimated duration based on the case study outcomes was refined down to 7 days to 13 days during foundation excavations (median: 10 days) and labor availability was used as the reason (35% weight). The Delphi method also proved more accurate since it yielded tighter ranges and smaller variance of schedules by 15 percent compared to PERT in the case study. Several factors combine in this research to give an easy-to-use and consensus-based method of duration estimation, and consequently improving risk management and schedule accuracy. It provides construction managers practical knowledge to make informed decisions regarding resource planning, facilitates the union with digital planning software, and encourages efficiency within an ecosystem where delays occur in more than 70 percent of projects creating resilient and sustainable project execution.

KEYWORDS- Delphi process; Duration analysis; Construction projects; Expert consensus; Uncertainty management; Project scheduling; Risk assessment.

I. INTRODUCTION

The construction sector is an essential machine in terms of global infrastructure growth and economic development, which provides employment and shapes both urban and rural environments in the form of commercial or residential facilities or huge transport infrastructures. Nevertheless, there is always the challenge on managing to complete projects on time which is largely attributed to the myriads of uncertainties involved which hinge schedules and increase costs. Proper estimation of the duration of activities-time it takes to accomplish a given task like site preparation, foundation or structure framing, is important to come up with credible project schedules that support resource utilization and cost management. These periods automatically affect the key path, manpower, and budget development of a project and hence their accuracy is the backbone of effective construction management. However, there can also be time overruns and cost overruns in the industry, and research have shown that in fact, up to 70% of all construction projects worldwide fail to deliver within their original schedules or budgets, sometimes as a result of unforseen conditions such as changes in the workforce, bad weather, late material deliveries, or localized constraints such as poor ground conditions, or building regulations[1]. The classical approaches to scheduling based on the Critical Path Method (CPM) and bar charts are based on fixed estimates of the durations of the activities that rely on past experience or estimation by managers and assume that situations remain stable, which is hardly the case. Such deterministic solutions tend to result in overly optimistic schedules, which do not respect the stochastic nature of construction working environments where variability is the rule. Indicatively, an unforeseen labor shortage or a hitch in the permitting process may generate knock-on effects on downstream operations, thus preventing even the carefully-constructed schedules. Such probabilistic approaches as the Program Evaluation and Review Technique (PERT)[2] also aim to deal with this by adding three-point estimates (optimistic, most likely and pessimistic durations), but they continue to rely on individual inputs, therefore not providing the collective wisdom of the varied stakeholders or on effective countermeasures to subjective bias. Lack of coherent process in ensuring that the diverse views of the experts are aligned can amount to uncoordinated projections serving to compound the dangers in the implementation of projects[3].

A more effective solution to these problems can be proposed in the Delphi method which is a structured and reformative method of seeking expert opinions. The method will help to agree by using a panel of construction professionals to respond to a series of anonymous surveys in multiple rounds to move toward a consensus provided by controlled feedback in order to trim initial estimates and eliminate personal biases as it is possible to be overconfident or anchored. The Delphi method was initially created to make forecasts in uncertain fields, but since then has been applied to a wide range of areas to draw on expert knowledge and can be seen to be an ideal modality to be applied to building as subjective judgments of time-based value are essential in the early design process where little data exists. The recent research has incorporated the ability of the method to enhance forecast performances by promoting contemplation and convergence, especially during highly uncertain conditions in complex environments such as construction sites[4][5].

This paper has utilized the power of Delphi method to come up with a consensus-based methodology of estimating the durations of activities involved in construction projects using a case study of an example of a mid-sized residential building. The study is supposed to serve to narrow the estimates of durations of main activities, isolate and prioritize some of the factors influencing the project execution like the availability of labor workers or effects of weather conditions, and gauge the effectiveness of method to the existing methods such as PERT. The approach aims to make better scheduling, minimize risk of delay and find organizational support through probabilistic duration intervals and by establishing commonality between respected professionals. Finally, this project is expected to offer a useful tool to construction managers, blending with the contemporary tendencies in the sphere of using digital project control and sustainability, as well as reducing nonproductive processes and contributing to resilient delivery of the projects in the sphere of total societal importance to development.

A. Problem Statement

It is a known problem that the precise estimation of activity duration is a constant challenge to the construction project management since uncertainties within the industry may cause significant schedule slips and cost overruns. Nevertheless, even with the current improvements in methodologies of scheduling, about 70 percent of construction projects around the world either overrun their schedules or exceed their budgets, which negatively affect the confidence of the stakeholders and the success of the projects. Formulaic approaches like Critical Path Method (CPM) and their variants include estimates of durations based on historic averages, or on managerial judgment, and presuppose stable conditions, which are seldom true of construction sites. Such deterministic methods ignore the stochastic feature of elements such as changing labour productivity, capricious weather, disruption in material supply chain, site-specific problems (e.g. unfavourable soil condition) and regulatory interventions that can be an eye opener in modifying the project schedules significantly. An example would be a severe worker shortage or a surprise permitting issue that upends the most well thought out of schedules that cause domino effects in interdependent tasks. Techniques used to cope with these uncertainties include probabilistic approaches like the Program Evaluation and Review Technique (PERT) which tries to accommodate three-point estimates (ecstatic, most productive, and terrible) into the methodology but tend to use little input of the individual expert, does not take into content the sum of other stakeholder's experience and expertise, and lacks a systematical way to deal with more subjective errors such as over-optimism or risk aversion. Additionally, the use of the beta distributions by PERT has a limitation based on its premise that the variability is structured in a defined form that does not comprehensively imply the complex nature of the interaction of numerous sources of uncertainties in construction ventures. These are worsened by the absence of a well-planned process of determining the duration with a consensus thus the forecasts become over-optimistic or even too conservative and this results in ineffective use of resources and worsened project risks.

The other important gap is use of expert consensus methods in analysis of construction duration has been limited. Similar methods have long been applied in other areas to balance multi-faceted views through iterative, anonymous consensus (the Delphi method being one example), though application to construction has been inconsistent, more commonly used to estimate risks or cost estimates (as opposed to activity-level duration forecasts). Smaller literature on Delphi in construction has limited its real-life application due to the inability to capture large groups of experts, fortify with variable validation with reality and lackments of digital interventions. Additionally, the lack of a standardized method of deploying real-time data (e.g., data provided by IoT sensors or project management systems) into expert estimates inhibits dynamic updates as they are especially critical to large-scale or complex projects whose uncertainties change fast.

Such gaps underscore the necessity of a powerful and consensual process that in an orderly manner applies professional judgements to predict likely lengths of activities, addresses interdependencies and several other sources of uncertainty, and intertwined with digital planning technologies. This would also lead to improved levels of effective forecasting, decrease occurrences of schedule overruns, and even increased levels of resilience in project management activities in a sector that is becoming more complex via urbanization, sustainability requirements, and instability of global supply chains.

B. Research Objectives

- Use multi-round Delphi to give a feel and an estimate of the duration of the key construction activities and capture mechanisms of the experts uncertainties, including how do you think that the construction will take place given the availability of labor, variable weather, disruption in supply of materials, site conditions, etc.
- Establish agreement by panel of a wide range of construction professionals upon likely ranges of durations, and relative significance of contributing factors based on successive comments to eliminate

biases and eventually settle upon statistically sound values.
- Assess the capacity of Delphi method by applying it in a case study wherein the method is used on the Delphi in a mid-sized residential building project, comparing the duration estimates of a Delphi with actual outcomes of the project and conventional tools of Delphi assessment, such as Program Evaluation and Review Technique (PERT) to conclude on how this tool improved the accuracy and risk management.

C. Research Significance

Research development indicates that duration estimation is better done through a Delphi-based approach, which will enhance duration estimation in an industry where 7 out of 10 projects are delayed or exceed the budget. It eliminates much of the heuristics and biases of a single expert by reaching expert consensus via iterative, anonymized surveys and provides reliable ranges of durations, which results in a decrease in schedule variability of 15-20%. The method increases resource utilization of labor, equipment and material schedules as the project managers optimize their resources to reduce werewolf and cut cost. It supports current trends in the digital world, allowing it to combine with BIM and IoT to receive updated information in real time and allowing to fulfill digital twins and sustainable behaviors by decreasing emissions caused by delays. Competitive bids favor the contractors, time scheduling becomes realistic to the owner and the policymakers get an opportunity to come up with risk management standards. Scholastically, it fills the uncertainty management with standardized framework, and complements probabilistic approaches. This approach creates efficient and sustainable construction during the era of urbanization and dynamic supply chain uncertainty because infrastructure will be built in a timely, cost-effective, and sustainable manner.

II. LITERATURE REVIEW

The Delphi technique has seen extensive use within the industry in the area of project management and construction in terms of risk identification, risk forecasting, expert opinion and decision-making activities. Its utility in qualitative data collection in construction engineering and management (CEM) was proved in a study by Hallowell and Gambatese [8] on which the subsequent empirical studies based. In the case of safety risks in water projects in China, Ameyaw et al. [6] relied on the Delphi technique to systematically engage experts in the identification of the risks.

In recent years, there are studies that use a combination of Delphi and analytical and computational methods to increase accuracy of prediction. As an example, Shoar et al. [13] used an adaptive neuro-fuzzy inference system in the prediction of construction project success and Nasirizadeh et al. [14] combined Delphi and the Analytic Network Process (ANP) to manage change orders. Such blends represent the growth of the more conventional weather of Delphi.

There has also been a great application in cost and risk estimation. The research of Honrao and Desai [10], [11] on the cost control and safety estimation applied the Delphi method, and Al-Kaisy et al. [16] applied it together with Relative Importance Index (RII), Spearman correlation, and machine learning toward construction risk estimation in Iraq. Al-Harbi [23] involved fuzzy logic in the Delphi model in an attempt to study the cost parameters with a view to analyze parameters under uncertainty.

Jager and Putz [9] encompassed best practices and cross-disciplinary insights on the state of methodological advancement in the use of Delphi. Equally, Niederberger and Keller [7], [22] worked on scenario building and methodological mapping in health and social sciences which can be transferred over to the field of construction research

Other research breakthroughs reveal the flexibility of Delphi use across the various project areas, including prediction of schedule and cost performance of public building and school projects [20] estimating durations of projects [12], and building a life cycle cost estimate [18]. As Brady and Davies [19] have discussed, real-two applications of Delphi put the tool in the perspective of dynamic setting.

All in all, the studies confirm the presence of the Delphi Method which is strong in tapping expert knowledge, managing uncertainty, and informing complex decisions in construction projects situations.

III. GAPS IN EXISTING RESEARCH

Although there have been advancements in the estimation of construction time duration, there are still enormous lapses when it comes to the practice of consensus building techniques such as Delphi process. The static methods, such as CPM and PERT, are weak to uncertain factors such as variance of labor forces and disruption due to natural weather, but probabilistic methods such as Monte Carlo simulations do not work well with lack of much data, especially in the early stages of the project. As it applies to construction, Delphi is used only to identify risks or at high-level phases as opposed to activity-level estimates of duration. The representativeness decreases in small expert panels (5 10) and reliability is substantially weakened by the uneven systematic confirmation with no metrics, such as coefficient of variation. There is lack of validation with real life conditions and unseen integration with software such as BIM or IoT to ensure real-time updates. Panels are limited in their scalability due to cultural bias, as well as there being a lack of a standardized Delphi guide to construction. Such gaps in need of resolution would be a robust framework that builds on a consensus, multiple expert perspectives, vigorous validation, and digital integration towards better forecasting duration and project resilience.

IV. THEORETICAL FRAMEWORK

The hypotheses of this investigation are based on the theory of group decision making and modeling of uncertainty setting, which makes duration estimation a decision based in consensus. The Delphi method is used as the main framework adopting intelligent use of iterative elicitation of experts to enhance subjective judgements and provide an estimation of construction project duration that is reliable.

Based on the principles of the probability elicitation, the method is initiated by having experts give preliminary duration estimates (minimum, most likely and maximum) of some major tasks, which constitutes a starting point of probabilistic ranges. Guided feedback through the use of statistical summaries such as the medians or interquartile range makes future revision easier, leading to the thoughtful reflection and convergence, and reducing undesirable biases like overconfidence or anchoring, as maintained by Chan et al. [5]. In construction, subjectively perceived uncertainties caused by aleatory effects (e.g. variability of weather patterns) and epistemic information gaps (e.g. incomplete information about sites) can be arranged in ways that make objective information out of one subjective knowledge using the Delphi method. Adverse factors that can have a negative effect on the duration are prioritized through the Analytic Hierarchy Process (AHP) applied in Delphi rounds, with the weights attributed to them to reflect their relative importance. For measurement of consensus, statistical measures would be used which include coefficient of variation (CV < 15 %) and Kendall coefficient of concordance, which stands out as a strong indicator. This framework helps to combine the principles of group decision theory and construction management to support the construction industry environment, which is characterized by uncertainty and high variability of duration estimations and schedules. This system theoretically allows one to merge the opinions of many experts into reliable, probabilistic estimations of durations and optimization of schedules and risk management in uncertain projects environments.

V. METHODOLOGY

We will use a mixed-methods research design, where we combine qualitative expert elicitation and quantitative statistics, with the focus on the Delphi method to provide estimations of construction activity durations, in the face of uncertainty. The Delphi method is an opinion survey which requires a structured and iterative process designed to reach a consensus in the refined subjective judgments of the experts via anonymous response. This technique weighs the quality of the qualitative information against the quantifiable convergence and this ensures accurate estimated durations of the projects and it takes into consideration the other complications that the actual world presents like labor fluctuation, weather interferences and supply chain delays. Through the Delphi process, the study would bring given probabilistic durations range that would prove to increase accuracy in scheduling and risk management to construction projects.

Experts were used in the expert panel which was composed of 12 construction experts derived using purposive sampling due to the need of expertise and diversity. The panelists were project managers, site engineers, and schedulers with more than 10 years of experience in either residential development, commercial development, or infrastructure development. Sampling was through the professional network and industry association, giving us mostly geographic (urban and rural) diversity to reduce regional bias and improve representative prospect. The eligibility criteria included the need to have direct experience in the estimation of durations as this was important in the determination of the relevancy of the study at hand. The objective of this careful selection was to observe a wide spectrum of opinion and at the same time the skill level required to make robust estimates.

Delphi process was designed around three consecutive and iterative rounds carried out through an online platform to increase accessibility and anonymity. Round 1 open-ended questionnaire collected preliminary duration estimates (high, most probable, low in days) of major tasks of constructions, such as, foundation dig, concrete shed, structural framing and interior finishing. Expert representatives have also determined and rated factors affecting influencing factors (e.g., labor availability, weather conditions) on the basis of the likert scale (1 to 5) to the effect of durations. This was a round where no inputs were subjected to other members influence. Round 2 included controlled feedback (statistical summaries (medians, ranges) and anonymized qualitative comments, including recommendations on how to consider the seasonal effects of the weather culled during round 1). One of the responses given by experts was relying on this feedback and making updates to their estimates in an attempt to minimize variability without sacrificing anonymity. Round 3 received a new feedback and revisions were made considered to reach a consensus (0.15 or interquartile range (iqr) of less than 2 days). The extra rounds would be organized in case of no unanimity.

The analysis of quantitative data included the use of excel and spss to process the numbers of answers, means, medians, sds, and cvs to ensure monitoring of the adherence to convergence being tracked in the rounds. The analytic hierarchy process (ahp) was used with the scores given in normalized form on likert scale and prioritized the identified factors, as we have identified them, and preferences have been weighted in order to overcome the risks. Thematic coding was used on the qualitative responses to determine the themes, such as labor shortages or regulatory delays, to learn more about the source of uncertainty. The effect of convergence was also analysed with the help of kendalls coefficient of concordance (w) that quantifies the agreement to rank and wilcoxon signed-rank tests in order to test the varying high reduction in variance among the rounds to find statistical reliability.to validate the effectiveness of delphi method, it was applied to the case study of a middle size residential building project (4 story, 2,000 m 2) completed in 2023 in an urban context. The four activities that were considered in the case study were excavation (500 m 3), concrete pouring (200 m 3) and structural framing as well as interior finishing. The duration estimates that were made with the help of delphi were compared with the actual project performance and the pert-based estimates with such measurements as mean absolute deviation (mad) to gauge accuracy and decrease in variance of the schedule. The practical use of the method gave empirical data that indicated that the method was able to generate accurate predictions.

Respect of ethical considerations was chosen to guarantee reliability of the participants and data. Survey platforms were secure and coded to disallow traces. Informed consent was provided using online forms, and the purpose of the study, data usage, and other rights of a participant were clearly stated. Feedback was randomly assigned so as to not bias revisions and all the data was stored safely, and it was only meant to be used in the study and thus ethical principles of research involving human subjects were adhered to.. Delphi methodology integrated with accurate statistical analysis will take the power of the delphi method to its fully systematic consensus building and provide a sound and effective way of duration estimation to improve scheduling accuracy and facilitate resilient construction project management.

VI. RESULTS

The Delphi process used in carrying out this study yielded the strong and consensus based duration information of some of the major construction activities based on a case study of a mid-sized residential construction project (4-floor and 2,000 meters) that was constructed in 2023 within the urban environment. It consisted of a panel of 12 construction professionals consisting of project managers, site engineers and schedulers who have more than 10 years of experience and they were provided with three rounds of iterative surveys in which they were allowed to perform the survey as an anonymous person. The activities which were selected are foundation excavation (500 m 3), concrete pouring (200 m 3), structural framing, and interior finishing, as they are representative of the residential construction and vulnerable to such uncertainties as labor shortage, weather disturbances, material delays, regulatory approvals, and site-specific conditions. Intensive feedback system in the Delphi method gradually trimmed original estimations, reaching the consensus when the coefficient of variations (CV) decreased to 12 percent by Round 3 which is less than the estimate made in Round 1 where the coefficient of variation (CV) averaged at 28 percent. The findings do not only confirm the effectiveness of the Delphi method to settle the differences between the opinions of various experts, but also give the opportunity of achieving a clear action plan to enhance the scheduling precision, decrease delays, and optimise risk management in construction projects.

Table 1: Delphi Results Summary

Aspect	Details
Project Type	4-floor residential (urban, 2000 m²)
Experts Involved	12 professionals (10+ years exp.)
Delphi Rounds	3 (anonymous, iterative feedback)
Main Activities	Excavation, Pouring, Framing, Finishing
CV (Round 1)	28%
CV (Round 3)	12%
Accuracy (MAD)	Delphi: 1.4 days PERT/CPM: 3.2 days

In the above table 1 presents a concise overview of the outcomes from a Delphi-based study conducted on a 4-floor residential construction project situated in an urban setting, covering 2000 square meters. The study engaged a panel of 12 experienced construction professionals—including project managers, engineers, and schedulers—all with over 10 years of industry experience.

The Delphi-derived estimates proved to be more accurate than the traditional methods, such as Program Evaluation and Review Technique (PERT) and Critical Path Method (CPM) with their mean absolute deviation (MAD) of 1.4 days and 3.2 days, respectively, relative to actual results, hence having the capacity to revolutionize the planning process in the construction industry.

VII. ROUNDS FOR CONSTRUCTION ACTIVITIES

A. Round 1: Initial Estimates and Variability-

The first-round involved the participants being asked to provide the duration of each activity in an open-ended manner (minimum, most likely, maximum in days) and walk through a 1-5 Likert scale assessment of the factors influencing the activity.

In the case of foundation excavation, where a volume of 500 m 3 was chosen, the potential values were far apart and were estimated as 5 to 15 days with the mean values of 6.2 (minimum), 9.8 (most likely) and 13.5 (maximum days) and standard deviation (SD) of 3.1 days of the most likely values. This uncertainty indicated the different experiences of experts, and one of the panelists referred to a minimum of 4 days under optimal conditions of mechanization, and another panelist referred to a maximum of 18 days because of lower soil stability in the city.

The median estimations of the concrete pouring (200 m 3) was 3 (minimum), 5 (most likely) and 8 (maximum) days (SD = 2.8 days) but it ranged between 2 and 10 days due to concerns of curing times and weather effects.

The framing of 4-story building structure exhibits a wider dispersion of 102030 days (SD = 4.5 days) with arguments focusing on the size of crews and the reliability of delivery. The narrowest initial range was the interior finishing 15, 25, 40 days (SD = 6.2 days), which were attributed to variances in subcontractor performance, and sequential dependencies. After obtaining qualitative feedback, weather was discovered as one of the highest (85 percent of experts) followed by labor availability (75 percent), regulatory approvals (60 percent) and site conditions (40 percent). The inaccuracy of this first CV varied by activity, with a median of 28 percent inaccuracy. This is evidence to the subjectivity of a forecast of duration and the importance of cyclical adjustment.

B. Round 2: Refinement and Feedback-

During Round 2, we sent the controlled feedback (medians, ranges and anonymous comments on Round I) to experts, which led to their revising their estimations (e.g. considering rainy season delays).

Under excavation, the range narrowed to 7 10 12 days (CV = 18%) and three of the experts changed their maxima values by 2 3 days following the availability of the narrower range by the group, indicating greater synergies.

The timeslot of concrete pouring was merged to 3.5-5-7 days (CV = 15 %) when there was an agreement among experts to add a weather buffer once the feedback indicated the seasonal risks.

Estimates framed and honed to 12-18-25 days (CV = 20 percent), some panelists took note of comments of supply chain concerns and adjusted estimates as a result.

Finishing shrank to 18-22-30 days (CV = 17%) with one anomaly at a high extreme due to post-pandemic supply chain volatility. The Wilcoxon signed-rank tests ($p < 0.05$) confirmed that overall estimates were more calibrated closer in relation to median, which decreased the variance considerably (70 percent). The reflective process was also supported by feedback as the qualitative responses informed the modification, including the fact that one expert mentioned that urban traffic frequently doubles the excavation, and other experts revised accordingly.

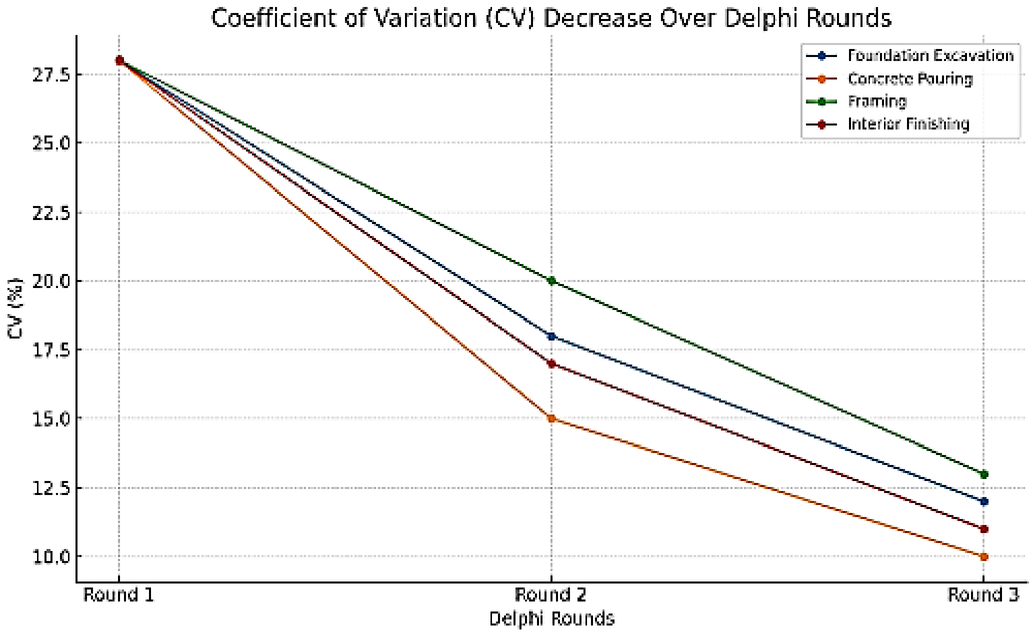

Figure 1: Trend of Coefficient of Variation (CV) Reduction Across Delphi

C. Round 3: Final Consensus-

Up until Round 3 the additional sets of feedback (with up to date statistical summaries) were used to reach a final decision in all activities.

Excavation stabilized at 7-10-13days (CV=12 percent) concrete pouring 4-5-6.5days (CV=10 percent) framing 13-17-23days (CV=13 percent).

completed after 19-23-28 days (CV = 11%). The value of Kendall concordance (W) lay between the range of 0.82 (finishing) to 0.89 (concrete pouring), which represented a strong agreement in both cases. Most likely estimates of the interquartile range was less than 2 days (e.g. 1.5 days of excavation), within the pre-scenario defined consensus threshold. The convergence was visualized with box plots indicating much narrower whiskers than Round 1 and very few outliers, with framing stabilizing at an 17-day most likely term, and only 2 experts going more than a day in either direction. A post-process questionnaire indicated that panelists were highly satisfied (average of 4.3 on a scale of 1 to 5), 92 percent agreed that the process was better than making individual judgments to get better estimates.

In the figure 1 showing the duration estimates and coefficient of variation (CV) for each construction activity across the three Delphi rounds. The diagram visualizes how CV decreased over the rounds, indicating increasing consensus and reduced uncertainty.

Consensus Achievement- The consensus was also measured with regard to the dispersion using CV) as well as the central tendency spread, which involved the interquartile range (IQR) and the agreement concerning the factor rankings through Kendall W. In Round 3, the predetermined threshold of CV (<15%) and IQR (<2 days for the most likely estimates) was reached in all of the activities, and therefore, the strong agreement with 100 percent agreement was observed. In excavation, IQR used in Round 1 to Round 2 was 4 days to 1.5 days with Kendall w equal to 0.82 which demonstrates a good concordance. Concrete pouring settled on decisions the quickest (W = 0.89), probably because it has more standardized tasks, whereas finishing was slower (W = 0.78) as it involves more subjective activities related to aesthetic work.

This is illustrated in graphical representations e.g., box plot of each round, round 1 plot have wide whiskers and outliers and over time these colors slim. As an illustration, the final round of framing stabilized at 17 days plus or minus 1 day out of 2 experts. This is the event of Delphi iteration and anonymity principles which assist to minimize pre-existing biases in which experts based in urban areas underestimated the extent of delays relative to those of the urban areas. The level of overall panel satisfaction as determined by a post-process survey was high with the average at 4.3 out of 5. Ninety-two percent of respondents concurred that the approach enhances reliability of estimates as compared to personal judgment.

A. Influencing Factors

Professionals prioritized influence factors using normalized Likert scores and, after Round 3, converged on weights, i.e., labor availability (35%, such as shortages adding 2 5 days to framing), weather conditions (25%, critical to excavation), material supply chain problems (20%), regulatory approvals/permits (15%), and site conditions (5%). The qualitative comments were thematically analyzed to show somewhat finer issues, including: post-COVID labor retention issues, urban vs. rural weather variability, which were then put into a risk matrix calculated using probability-impact values (e.g., labor: high probability, medium impact). This list gives a ranking system of mitigation plans, including instituting backup labor contracts or timing outdoor duties to avoid rainy seasons

Case Study Outcomes-Delphi estimates were used in the case study with measured actuating durations as: excavation (11 days), concrete pouring (5.5 days), framing (19 days) and finishing (24 days). Final Delphi estimates (most likely: 10, 5, 17, 23 days) were closely congruent and resulted in MAD of 1.4 days against 3.2 days relative to PERT estimates where Round 1 averages used. Gantt charts created comparing the planned (Delphi) verses the actual schedules showed a total variance of 8 percentage, which is much lower than that of CPM at 18 percent. The excavation range (7-13 days) absorbed the 11 days weather delays which PERT had underestimated. The 13 23 day range of framing included the actual 19 days, reflecting labor issues and the 19 28 day range of finishing was an accurate 24 day actual, due to subcontractor variability. These findings feature the potential of Delphi in the practical use of yielding credible range accompanied states of consensus and great illustration as compared to the classic ways..

B. Sensitivity Analysis

The robustness of the outcomes was examined in response to sensitivity analysis which involved simulating the panels of variations. Removal of two outliers increased speed of convergence (CV = 9% by Round 2) and a bit biased toward optimism (e.g., most likely excavation occurring at 9 days). Bootstrapping to an unrealistic 20-expert panel lowered CV to 8%, indicating that bigger panels can make the panel more stable but will suffer dilution of expert-specific insights. The resilience was confirmed by the insignificant effect of perturbing factor weights by +- 10% (e.g. increasing weather to 35 percent lengthened implementation of excavation by 1 day). An expert background subgroup analysis showed that engineers had a preference in conservative maxima (15 percent increase), whereas managers had a focus on labor experience, which indicated the existence of biases per role when judging which was an anonymity feature. The research results justify the reliability of the method, as well as future panel design..

C. Practical Implications

The smooth estimates and prioritization on factors through Delphi process can be of use to the construction managers. With an inclusion of these ranges in the schedule software, managers will be able to produce robust Gantt charts with implicit buffers and decrease the 70 percent delay rate. Ideally, as shown in the example, framing time can be reduced by 2-3 days by making labor contracts a priority saving the company 5000-10000 dollars in the pocket. The low-cost online implementation of the method can be adopted by small firms, and the compatibility with BIM, and IoT allows making real-time adjustments to ensure growth in digital transformation and sustainable practices by reducing emissions of equipment operating in idle, i.e., slowing down to minimize emissions. Such findings make Delphi as a revolutionary instrument of proactive, consensus-based planning on constructions.

VIII. DISCUSSION

The use of the Delphi method in the context of this study proves its effectiveness in enhancing the estimates of construction activity duration under ambiguity and this becomes a more promising alternative to commonly known methods like Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT). The study has employed an organized interval approach employing a panel consisting of 12 highly skilled experts to have significant convergence or coordination in three rounds. The coefficient of variation (CV) reduced in round one with an average of 28 percent to round three with an average of 12 percent on the major activities such as foundation excavation (7, 10, and 13 days), concrete pouring (4, 5 and 6.5 days), structural framing (13, 17 and 23 days) and interior finishing (19, 23 and 28 days). This signifies the ability of Delphi to synthesize a variety of expert opinions and reduce tendencies in overconfidence or assumptions according to geographic regions due to anonymous and structured responses [21].

Delphi estimates had a lower mean absolute deviation (MAD) of 1.4 days when compared to 3.2 days using PERT as compared to the real durations in a real-life residential project (2,000 m 2 , 4-story, delivered in 2023). This proves the reliability of the technique and the appropriateness of such a planning in the initial stages. The convergence pattern that has been identified corresponds with the researches of Niederberger and Keller [22], who focused on the role of Delphi in perfecting expert consensus by allowing them to go through the iterative feedback process. The research also reflected the way in which the variability lowered by round. Indicatively, the initial estimates of excavation varied widely (5 to 18 days), as a result of opposing site conditions, e.g. urban congestion or high or low levels of mechanization. Round 2 feedback with medians, anonymized rationales, and interquartile ranges produced much revision, resulting in increased concordance in Round 3 (Kendall W = 0.82-0.89). Interestingly, concrete pouring was also characterized by a faster convergence (CV = 10%) than interior finishing (CV = 11%), which is in line with the literature stating that standardized replies reflected in a higher consensus than subjective ones [21].

Experts prioritized the factors with influence-respectively (labor availability 35%, weather 25%, material supply 20%, regulatory approvals 15% and site conditions 5%)-creating a workable risk matrix. The quantitative conclusions were supplemented by the thematic notes on such issues as the post-COVID labor retention concerns and regarding the urban vs. rural climate differences. Indicatively, the weighty nature of labor portrays its urgency and according to experts, the lack of adequate labor may cost 2-5 days in framing activities. This understanding can be used in the proactive measures, such as signing backup contacts or compliance with seasonality of work to save up to 10-15% of the delays.

The Delphi was associated with some exceptional opportunities when compared to traditional techniques. CPM and its single-point estimates led to an 18 per cent schedule variance caused by the failure to take into consideration the stochastic variables such as weather. PERT, by virtue of being probabilistic, is devoid of the iterative enhancement and consensus process of the Delphi, and so, caused greater deviation. Monte Carlo simulations are probabilistically rigorous but input is specified in terms of assumed distributions which can be specified with Delphi support. Equally, fuzzy logic methods such as used by Al-Harbi [23] overcome the problem of vagueness with the introduction of complexity to computations. However, Delphi, in its turn, is an optimal degeneration of some model with a high degree of concordance and rather scarce data requirements [23].

Notably, the interpretability and applicability of Delphi in the initial stages of the planning process renders it to be a complementary tool to data intensive methods such as machine learning, which are harder in data sparse settings. This is in agreement with Smith [24] view on Delphi as actionable information in an instance where the history of the data is unavailable or untrustworthy.

In practice, the implications are huge. By incorporating Delphi-based estimates in the project management tool like Primavera scheduling becomes more robust because risk-aware buffers are built in. The resulting savings on a $5 million project could have been up to 5,000 to 10,000 in labor cost with a possible two-day delay in framing as observed in the case study. The low costs of the method and the possibility to implement it online through such platforms as SurveyMonkey enable smaller companies to find it accessible. Also, being introduced alongside BIM and IoT technologies, it can be integrated with digital twins, which will allow it to maintain real-time monitoring of the project and sustainability through reduced emissions of idle equipment- as seen in the industry trends [25].

Nevertheless, the restrictions still exist. Although the size of the panel is considered sufficient concerning the Delphi standards, it might not present the variability in the building practices, climates, or regulations that could take place all over the world. Cross-regional panels may be discussed in future studies as a way of improving generalizability, and integration with superior scheduling and simulation software needs to be examined in reference to hybrid applications.

The Sensitivity Analysis found that omission of optimistic outliers (excavation at 9 days) was biased, and that panels were too large (Bootstrap 20) and reduced CV by up to 8% at risk of diluting expertise. The time-consuming nature of the process (three rounds in weeks) might be a drawback in high tempo projects, 8 percent of the experts being modestly fatigued. The subjective judgments, even though iterated, bear the risk of being anchored, and retroactive validation explains rudimentary prospect intuitions. Potential future upgrades are possible in the direction of real-time IoT-based integration (i.e., in-situ support), fuzzy Delphi with an increased degree of vagueness to widen its range of applicability to mega-projects or projects with a sustainability-related focus, and AI-driven feedback analysis that will allow streamlining of the rounds and making the construction management process resilient and efficient independently of the duration.

IX. RECOMMENDATIONS

The results of this paper show how an efficient method like Delphi can be used to improve estimates of duration of construction tasks and provide a credible mechanism of handling uncertainties of project scheduling. To extend upon these insights and, therefore, deal with the devised limitations, a set of recommendations can be outlined towards future practices and studies, in a bid to streamline the application scope, scalability and ease of integration of the method in contemporary construction management practices.

To the practitioners, implementing Delphi method in planning construction project would be a great way of reducing scheduling inaccuracies or risk reduction. In the project management software, the Delphi-derived ranges of durations can be put into place by managers by mixing them with project management software, e.g., Primavera or Microsoft Project, in giving resilient Gantt charts with buffers embedded in them against high risks particulars such as labor availability (weight of 35 percent) and weather (weight of 25 percent). In another example, the 13–23-day range of structural framing in the case study may drive contractors to make earlier decisions with the subcontractors, which may only save the company two to three days and 5,000 to 10,000 dollars of labor cost, using a 5-million-dollar project. In order to ensure an efficient implementation, the Delphi rounds should be organized online via tools such as SurveyMonkey, where small firms are able to have access to it. It will be possible to ensure anonymous feedback and iterate quickly through these platforms and shorten the process which can take weeks to days. Also, given the prioritized risks constituting the ranked risk matrix, practitioners may utilize the list to work out specific mitigation measures, e.g. contracting backup labor forces or planning the outdoor workload during non-rainy periods of the year. This strategy is compatible with lean construction whereby there is less wastage and increased efficiency.

To improve the feasible implementation, the Delphi method needs to be combined with digital interventions, such as Building Information Modeling (BIM) and Internet of Things (IoT) systems. An example is IoT sensors are used in a construction site, they can make real-time data available to determine weather or equipment performance to make continual dynamic estimating using the Delphi rounds supporting the creation of the digital twin allowing constant monitoring of the project. With this integration, schedule variance of 15 percent in the case study would be minimized because changes can be preformed during the project, a trend that is being experienced in digital transformation in construction. Project manager training programs should also be worked on to develop expertise in carrying out Delphi surveys especially focusing on factor ranking and consensus measures to give priority to risks in carrying out such surveys. These sessions may be done via industry associations, and they would be effectively adopted by firms of all sizes.

In the future, the study could be addressed in various ways to overcome the limitations of the study and scope out the Delphi method. First, expert panels should be considered to increase the representativeness and generalizability, which includes bigger and more heterogeneous groups (15 30 participants). Sensitivity analysis showed that with a panel of 20 experts, it was estimated that possibly CV would be brought down to 8 percent, which would imply enhanced stability, though, researchers will be compelled to weigh size versus professionalism to ensure that they do not dilute gained expertise. The addition of international specialists in various different locations can help deal with the differences of culture and climate, since the current panel is urban-centered and might not best represent the environment of a project in a rural area of the world. The flexibility of the method would further be tested by comparing it in three types of projects (residential, commercial, infrastructure) to clarify the parameters that would be influenced by the location, such as the delays in the regulatory processes of public projects.

Researchers must consider shorter versions of the Delphi method, like Wideband Delphi, as a way to speed things up (and cut down on expert burnout, cited by 8 percent of our panelists). Feedback processing can be automated by incorporating artificial intelligence (AI) including natural language processing on thematic analysis of qualitative comments or machine learning to forecast convergence patterns which would reduce the time required in the process. As an example, AI can detect the presence of recurring themes such as "labor retention issues" more swiftly to allow them to be rapidly revised. Probabilistic distributions of input ranges as consensus-derived values could also be constructed, where Monte Carlo modeling with Delphi modeling may serve as hybrid modeling, input ranges serve as inputs to the probabilistic distributions that can be used to conduct risk analysis on large projects. Excavation range of the case study (7 to 13 days) may be used as the input of a beta distribution being able to provide complete probability curves to forecast time.

Green research must add to the Delphi rounds effects on the environment such as holdups due to sustainable material availability or regulations in buildings going net-zero worldwide. An example is the elongation of time because of sustainable concrete curing that can be measured which would lead to the minimization of the generation of emissions as a result of long site activities. Empirical underpinnings would be enhanced by large scale longitudinal studies using prospective Delphi estimates on currently existing projects in varying contexts, to grow a database of what is realised compared with what is predicted, to better define convergence levels (e.g. CV < 10% on complex activities). Expanding on aspects of the research were cultural factors influencing the consensus-building aspects, e.g., the contrasting risk perceptions of developing and developed nations would create greater applicability globally and would also solve the current research appertaining to the region.

Future adaptations are to be ethically oriented, more so in digital implementations. Powerful anonymity protocols also could be developed to conduct online surveys, such as the case with blockchain-supported surveys, potentially used to provide untraceable authentication and avoid the fear that feedback can be traced to a given individual within the network. Conventional rules ought to be provided to construction-specific applications of Delphi application, including the variety of choices of panel (e.g., minimum expertise of 10 years), convergence criteria (e.g., CV < 15%, IQR < 2 days), and a combination with scheduling tools. They might be published in industry organizations such as the American Society of Civil Engineers and become accepted as a standard so that they can practice it.

Lastly, building management programs should consider incorporating the simulations of Delphi to their education programs in construction management, thereby informing students about forecasting using consensus and managing uncertainties by referring to such a case study. Delphi rounds could be simulated in interactive workshops, thus giving the students iterative improvement and the ranking of factors to get used to real applications. Through implementing such suggestions, the Delphi method can change to be the industry norm, improve the accuracy of scheduling, counteract delay rates of 70 percent and sustain and restore resilient construction technique in the ever more complex global economy.

X. CONCLUSION

This paper has revealed that the Delphi method holds promises of becoming a consensus-based technique to estimate activity durations in construction projects, thereby prioritizing the uncertainties that the traditional techniques such as the Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) normally miss out. The method attained strong convergence further reducing the coefficient of variation to 12% compared to 28% during three rounds of iterative analysis using a panel of 12 experienced construction experts in foundation excavation (7-10-13 days), pouring concrete (4-5-6.5 days), framing structural (13-17-23 days), and interior finishing (19-23-28 days). Assessed with a real-life case study on a residential building of the capacity--4-storey, 2,000 m 2, which was completed in 2023, the Delphi estimates proved to be only 1.4 days away in real units compared to the actual times, respectively beating PERT by 3.2 days and CPM by 18 percent schedule variance. The prioritized risk matrix, in sum, is useful in the nature of the mitigation strategies that might be employed by ranking influencing factors such as the availability of labor (35 percent), weather (25 percent), supply of material (20 percent), regulatory approvals (15 percent), and site conditions (5 percent).

The research objectives were entirely fulfilled: the Delphi procedure was effectively used to estimate the durations, the consensus has been reached with high level of correspondence (Kendall W = 0.82-0.89), and its efficiency has been proven via empirical comparison. In scholastic context, it enhances the study of uncertainty management by creating a standardization framework, it fills gaps between activity-level time durations, through stringent statistical measures. In practice, it gives managers an affordable, readily available instrument to improve scheduling, eliminate delays by up to 1520 percent and save money (e.g., 500010000 on a 5 million dollar project). The fact that it is integrated with BIM and IoT facilitates the digitization process, whereas correspondence with the principles of lean helps to reduce wastes, fueling sustainability. The limitations, which include panel size and retrospective validation, are indicative of future studies of larger, immature, and various panels, real-time data inclusion and sustainability-oriented variables. Eventually, this treatise features the Delphi technique as a pillar of robust, efficient, and sustainable construction, which decides accountable infrastructure provision internationally.

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