### AHP analysis tools and methodology

The AHP analysis requires specialized software capable of handling the comparative matrices and performing necessary calculations. However, limitations were encountered with commercially available AHP software. Due to the limitations of available commercial software including the high cost of full versions, while free or demo versions restricted the number of responses, typically to a maximum of five questionnaires, a custom Python code was developed to conduct the AHP analysis

This custom Python script code computes the priority vector using both aggregation methods at the priority level and the matrix level, with calculations performed via the Arithmetic Mean and Geometric Mean approaches. These dual approaches of calculating priority vectors enhance the reliability of the results, capturing detail preferences expressed by the participants. This tool systematically computes priority vectors through two aggregation methodologies:

* + 1. Priority-level aggregation: It averages the individual respondent priority vectors directly (again, using both arithmetic and geometric means) post-calculation of eigenvectors.
    2. Matrix-level aggregation: It averages the raw matrices (both arithmetic and geometric means) and then calculates the priority vector. This aggregation is averaging before computing priorities resulting in better capture of the overall judgment structure.

A critical component of AHP is verifying the internal consistency of the decision-makers’ judgments. To ascertain robustness and accuracy of the gathered information, a Python script was utilized to methodically calculate the maximum eigenvalue (λₘₐₓ), the Consistency Index (CI), and the Consistency Ratio (CR) for every response matrix. The tool enforces a strict threshold where any matrix with a CR above 0.1 is considered inconsistent and is subsequently excluded from the analysis. This process ensures that only coherent and reliable judgments contribute to the final aggregated weights.

By developing custom Python code, the research not only overcomes the logistical constraints of existing software but also enhances the analytical depth and accuracy of the findings. The code's ability to handle complex computations and large datasets efficiently demonstrates the power of utilizing programming solutions in academic research.

Moreover, the flexibility of Python as a programming language allows for future modifications and extensions of the analysis. Researchers can adapt the code to accommodate additional factors, alternative aggregation methods, or different consistency thresholds as new data becomes available or as the scope of the research evolves.

Furthermore, this methodology promotes transparency and reproducibility in research. By documenting and sharing the code other scholars can replicate the study, verify results, or apply the techniques to different contexts. This openness promotes a collaborative academic environment where knowledge is built cumulatively.

### Ranking of factors using AHP

The study employed the AHP to prioritize 3 primary categories of factors, which were previously selected from an initial set of 6 through RII analysis. While listing top 10 specific factors; environmental factors included only 1 factor “Unforeseen ground conditions”, so it was excluded as AHP analysis requires at least 2 comparable factors per category. Therefore, AHP has to be conducted on the remaining 9 specific critical factors distributed among 3 main critical factors that significantly impact cost overruns.

For the Analytic Hierarchy Process (AHP) analysis, data were collected from four distinct stakeholder groups: clients, consultants, contractors, and freelancers. Specifically, 15 sets of responses were obtained from each group, culminating in a total of 60 responses prepared in excel. To ensure a comprehensive assessment, a balanced sampling methodology was employed, guaranteeing sufficient representation of diverse opinions in the analysis of the key determinants contributing to cost overruns.

Figure 5 provides AHP Model Tree Diagram of critical factors under consideration.

**Figure 5.** AHP Model Tree Diagram

A diagram of a company structure

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