Uncertainty of Embodied Energy and Cost Estimates for Structural Systems

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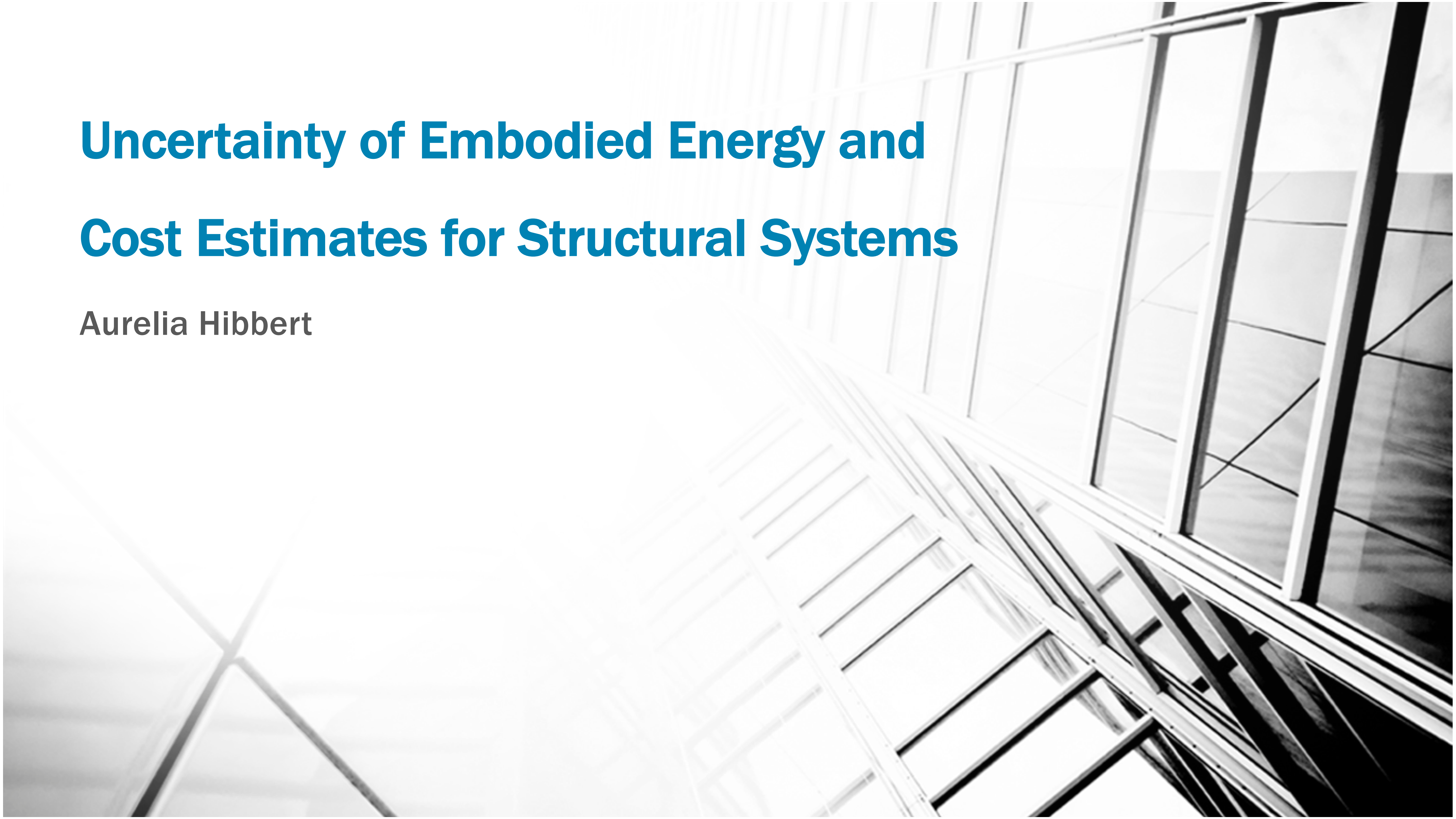


Research Questions

1. How can the change in project cost from estimate to execution be attributed to the three types of uncertainty (scenario, model and parameter) and are these uncertainty drivers shared by embodied energy estimates?

2. How does the inclusion of uncertainty analysis in design tools alter the outcome of decision making where both cost and embodied energy are analysed?

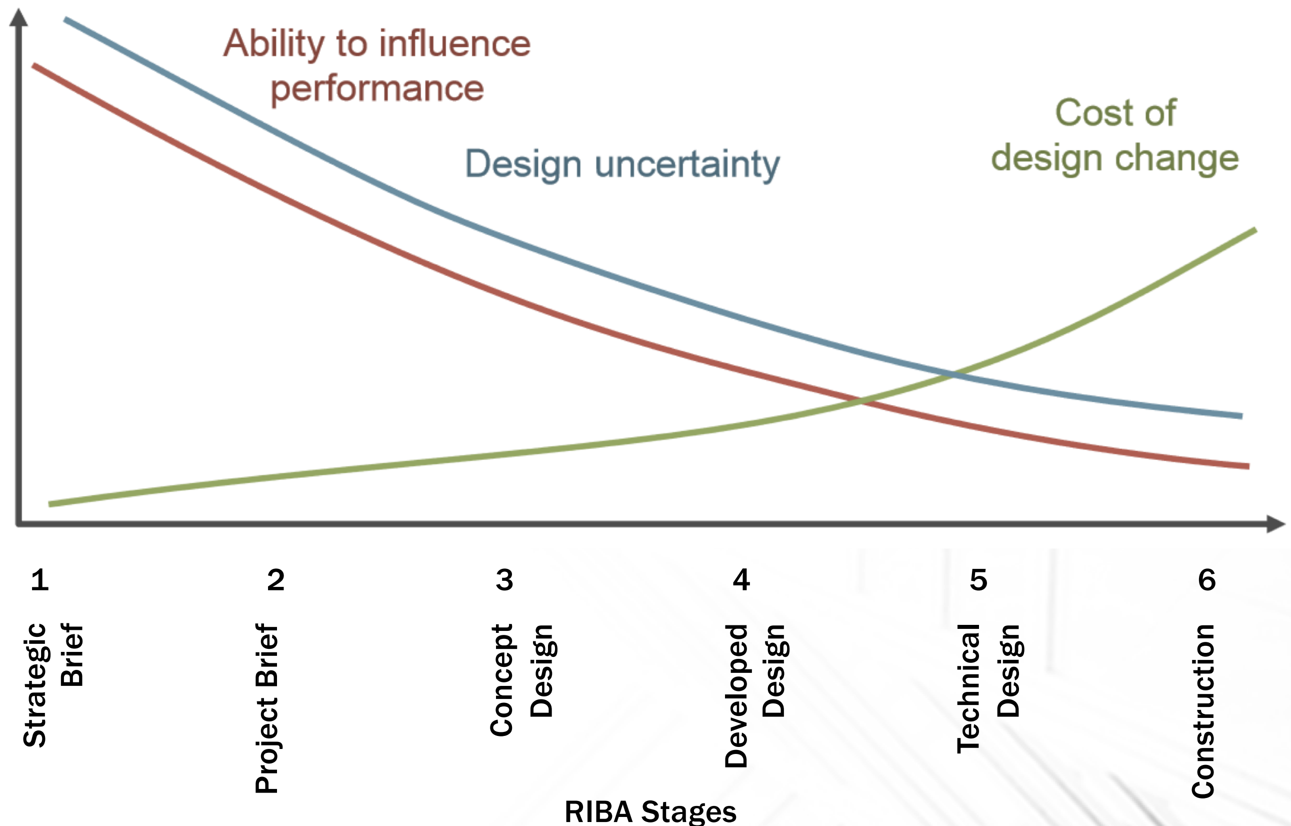
3. How does the exclusion of uncertainty in estimates affect the uptake of uncommon practices or products, which may otherwise have led to a better design either in terms of embodied energy or cost?

Motivation

- 36% of construction projects over-budget in UK, 2016
- Construction industry accounted for 23% of global emissions in 2009
- Embodied energy accounts for up to 50% of total life energy (Birgisdottir and Madsen, 2017)
- The structure can account for around 65% of the embodied energy (Cole and Kernan, 1996) and lasts whole life of building, unlike furnishings

Early Decision Making

- Large opportunity to influence performance (including embodied energy)
- Lack of detailed design information
- What if we can provide sufficiently certain data to drive well-informed early decisions?



Source: Hester, Gregory and Kirchain (2017)

Hypothesis – Estimates vs Predictions

$$C_T = \sum \left(C/q_m \times q_m \right) \tag{2}$$

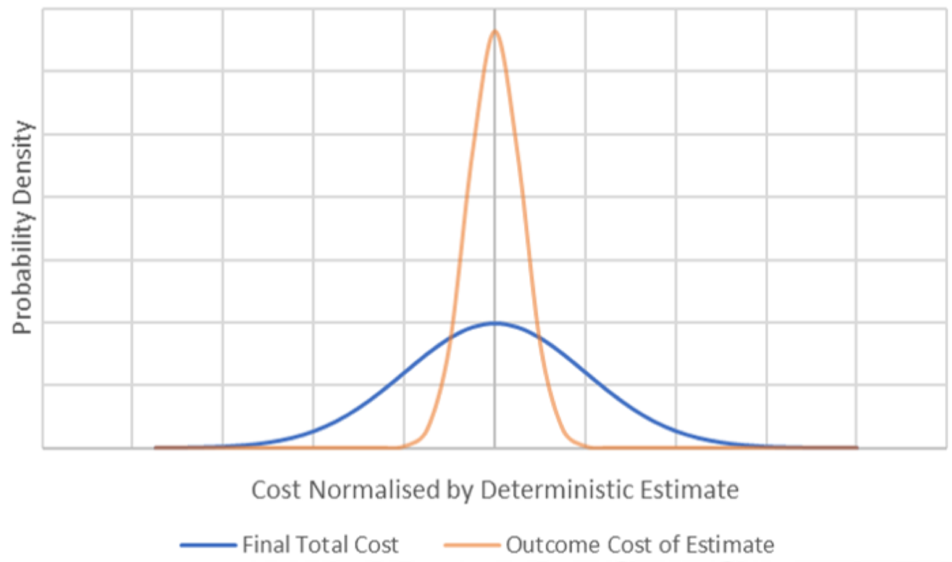
$$E_T = \sum \left(E/q_m \times q_m \right) \tag{3}$$

C_T - Total capital cost
E_T - Total embodied energy
q_m - quantity of material
C/q_m - the cost per unit of material
E/q_m - the embodied energy per unit of material

$$C_O = C_T \times s_m \tag{4}$$

$$E_O = E_T \times s_m \tag{5}$$

C_O - Final project cost
E_O - Final embodied energy
s_m - Effect of uncertainty drivers through project
C_T - QS cost estimate
E_T - Embodied energy estimate



Hypothesis – The ECM

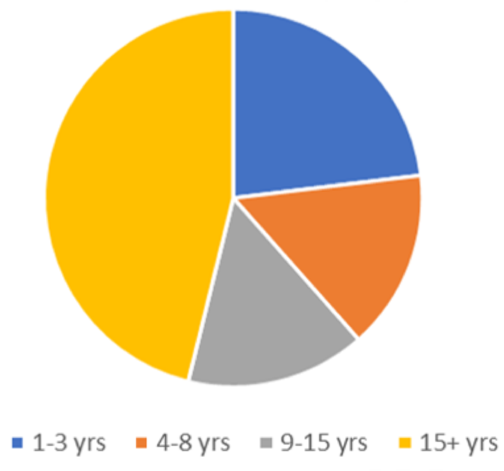
$$F = E + {}^{C}/_{\alpha}$$

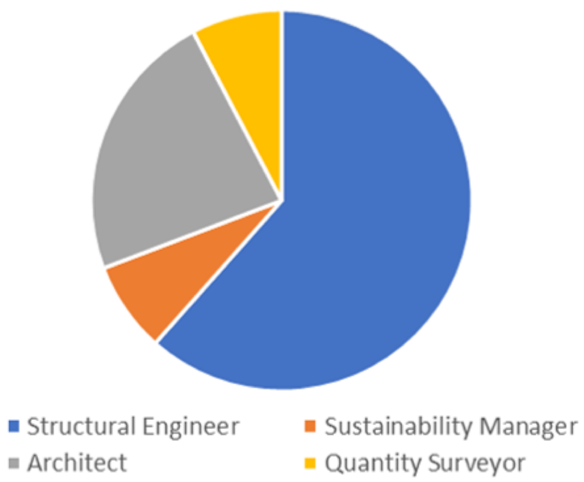
- Provides metric for data-driven comparison of design options
- Used in conjunction with its own guidelines to ensure low-energy is not achieved at the expense of the usability and comfort of the building
- Inclusion of uncertainty will affect the comparison of design options

Source: Mackay et al, Cambridge University (in preparation)

Data Collection

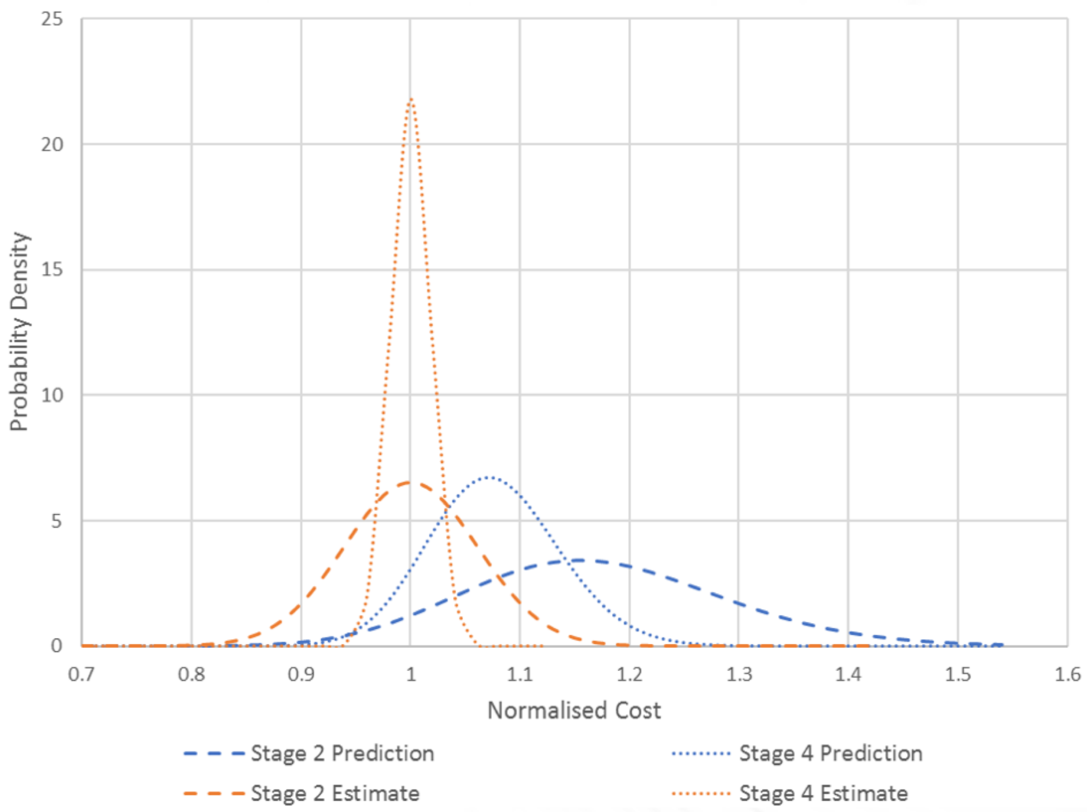
- Online Survey
  - 13 participants from construction industry
  - Should be extended for further validation
- Case Study
  - Cambridge University Civil Engineering Building
  - Existing ECM calculations
  - Example of innovative option





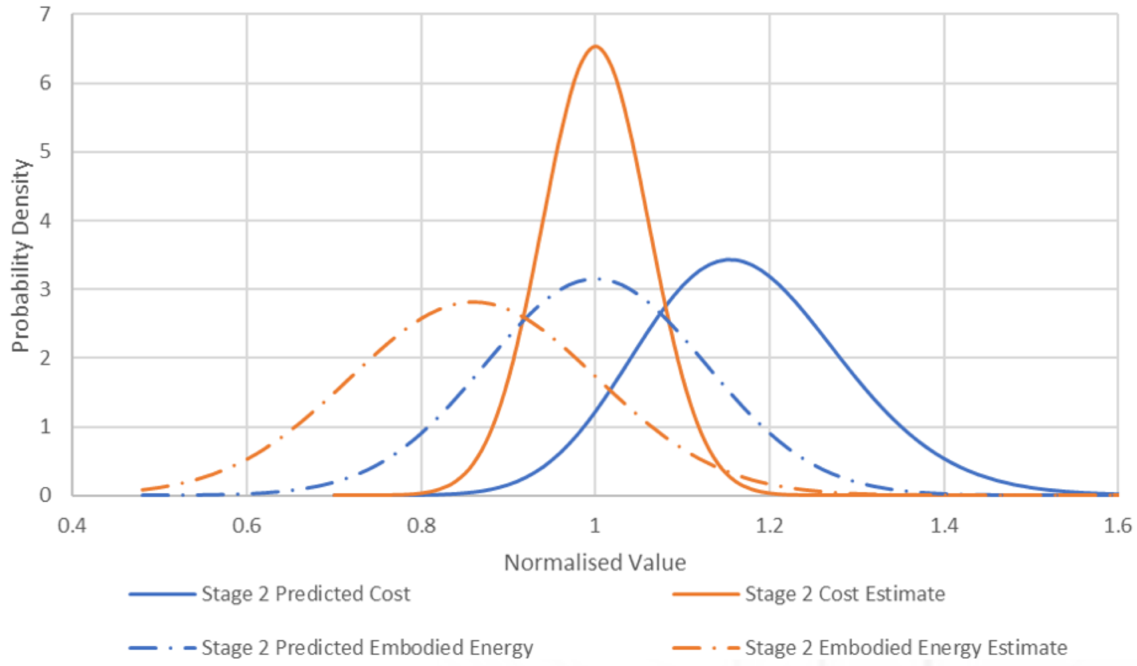
Analysis

- Hypothetical case asked for upper and lower bounds at RIBA Stages 2 and 4, as well as most likely final value
- Mean of each set assigned to 95th and 5th percentiles and mode
- Output lognormal distributions normalized around the QS estimate for comparison
- At each stage – transfer distribution for prediction from estimate found



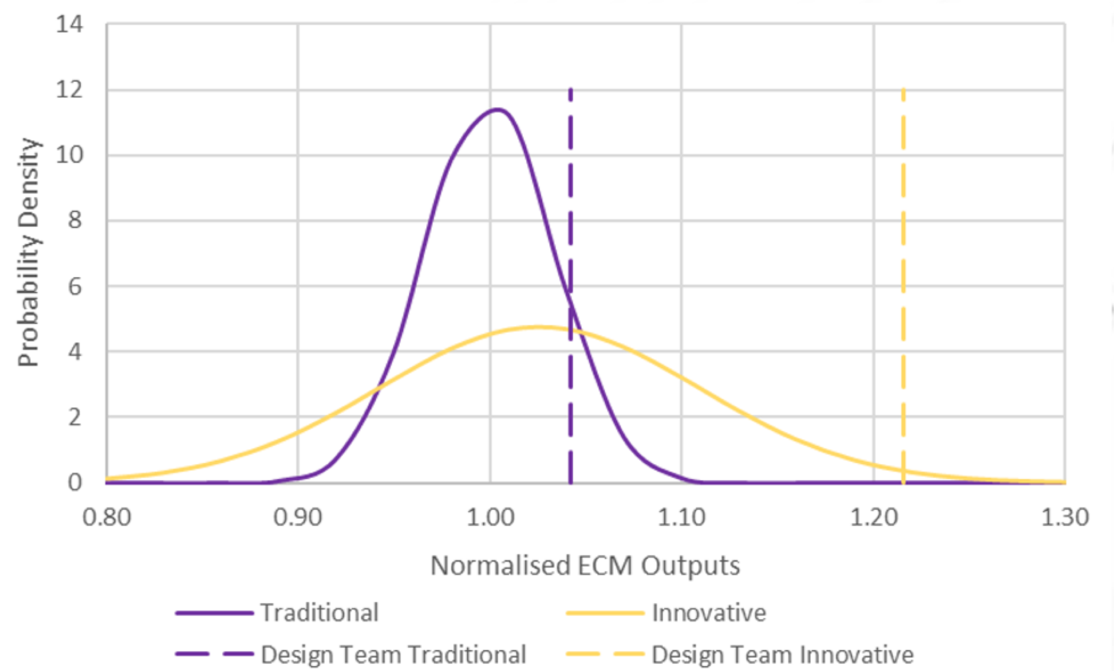
Analysis

- Key drivers of uncertainty:
  - Abnormals
  - Client changing scope
- Relate to changes in material quantities
- Transfer distribution accounts for these uncertainties



Analysis

- Included uncertainty in ECM calculations for Civil Engineering Building
- Uncertainty in innovative option higher than traditional option
- Values used by design team are not representative of how the options compare
- Convolution shows 39% chance that innovative option would perform better in ECM than traditional



Conclusions

- It is possible to use transfer distributions at any stage to calculate prediction from cost or embodied energy from estimate
- Inclusion of uncertainty shows variation in ECM outputs of up to 45% at RIBA Stage 2
- Inclusion of uncertainty allows probabilistic comparison of design options