Multi-Agent Large Language Model Framework for Code-Compliant Infrastructural Design

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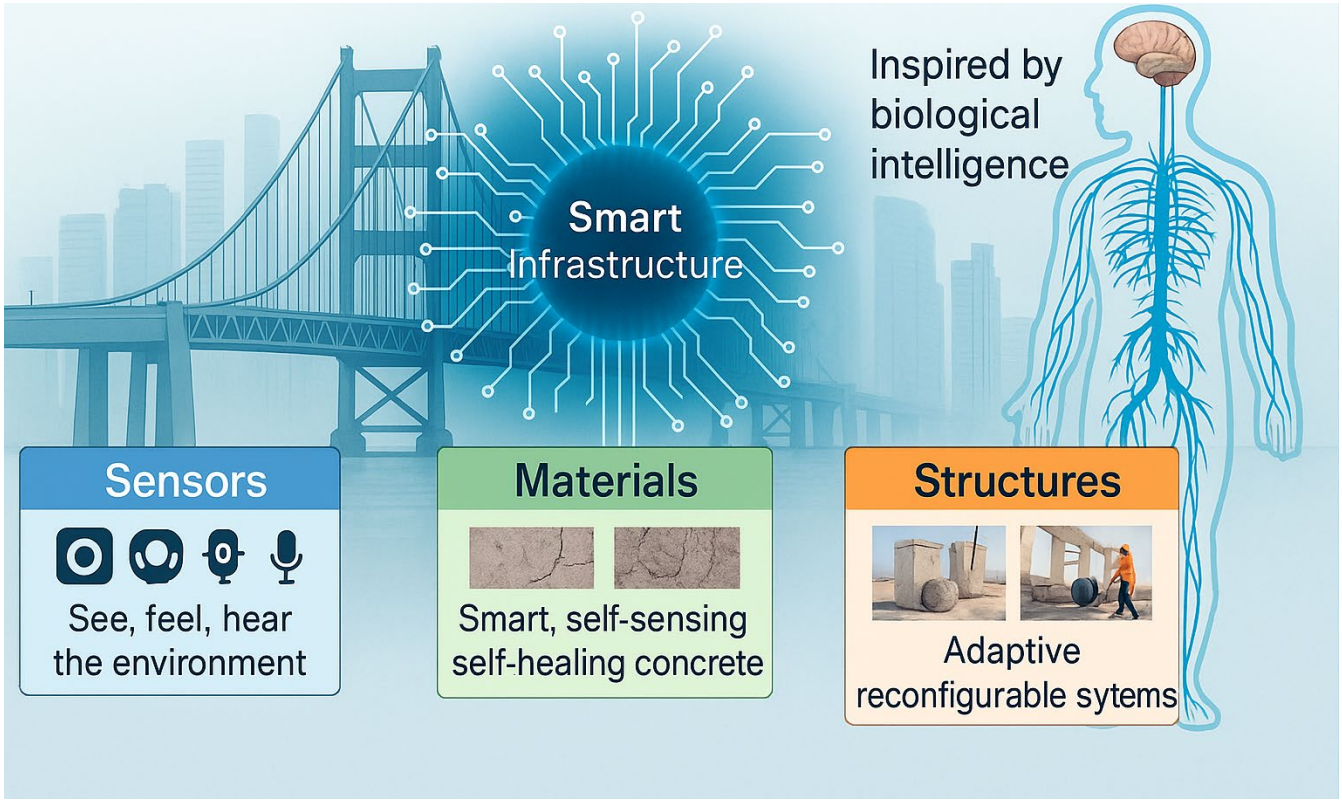
Smart Infrastructure Lab

- **Vision**
  - Intelligent infrastructure
  - Adaptive systems
  - Sustainable development
- **Mission**
  - AI in sensing
  - AI in structures
  - AI in material
- **Impact**
  - Safer communities
  - Greener environment
  - Smarter future



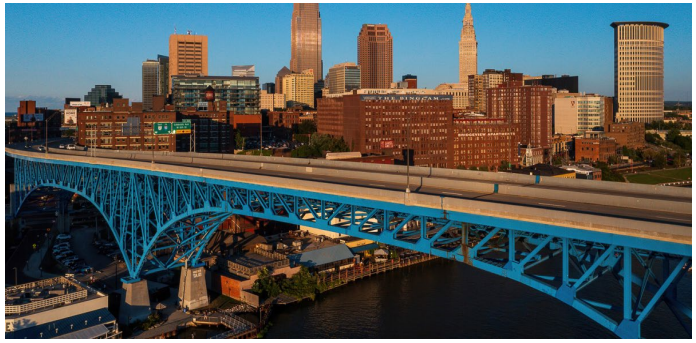
Outline

- Background
- Development of LLMs
- Proposed multi-agent LLM framework
- Case study on reinforced beam design
- Future outlook

Background

- **The new reality of infrastructural design.**

Complex structures


Multiple software tools

Revit

ETABS

SAP2000

SAP2000

AutoCAD

BIM 360

Excel

Engineering challenges

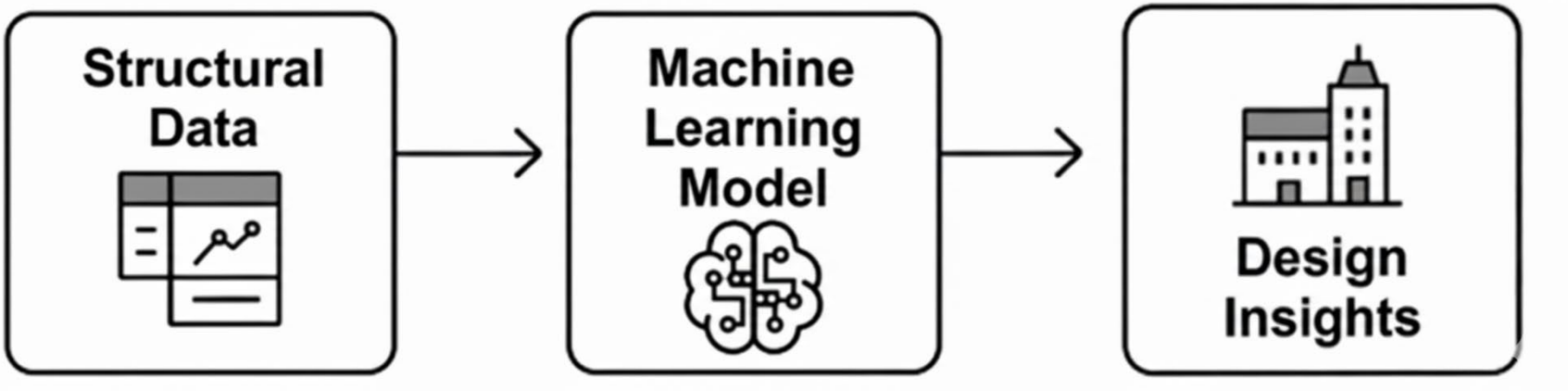
Coordination burden

Time pressure

Limited designs

Machine learning (ML)-aided structural design

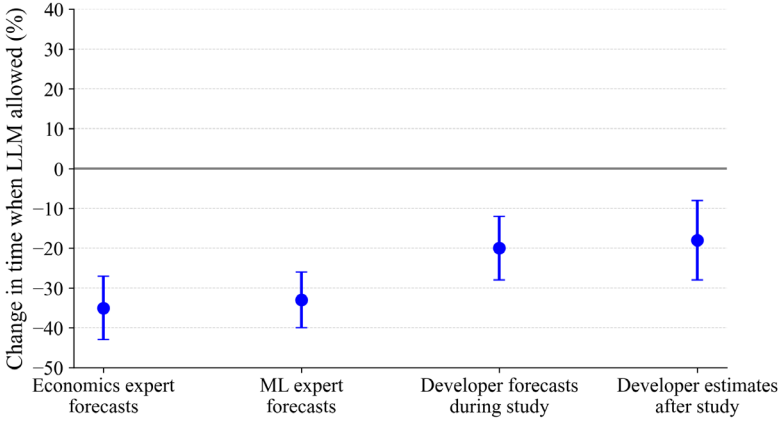
- ML models have been widely explored in structural tasks such as load prediction, member sizing, serviceability, etc.



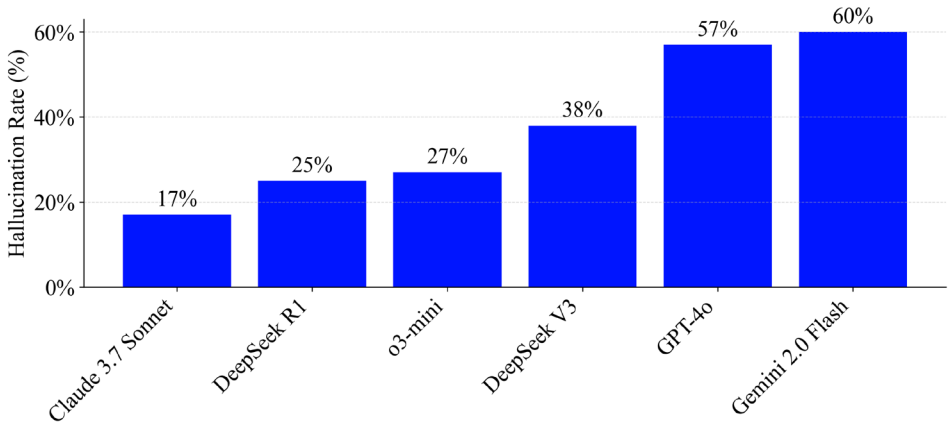
- ML models have yet to gain engineers' trust for safety-critical structural designs.

Large language models (LLMs)

- LLMs can interact with engineers in natural language
  - ➢Simple to use
  - ➢Easy to verify
  - ➢Efficient to deliver
- Limitations of current LLMs
  - ➢May hallucinate or produce misleading information
  - ➢Cannot directly operate engineering software or use design tools



Time efficiency boost with LLM

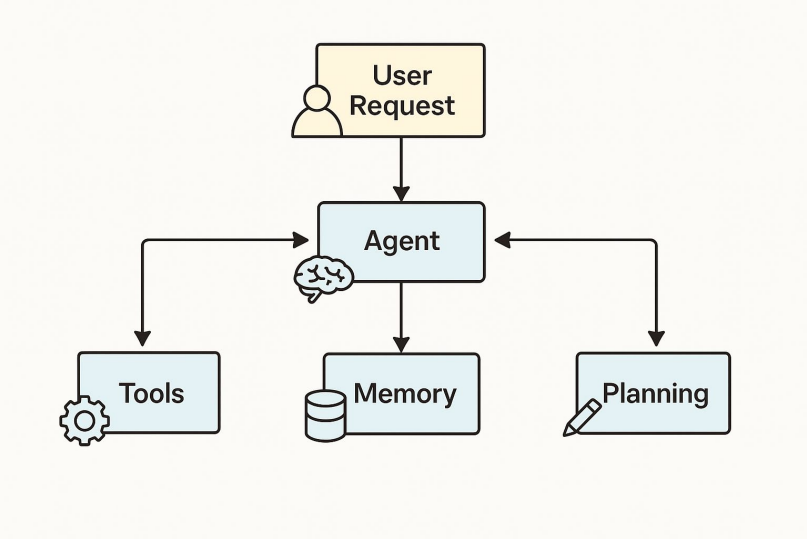


Hallucination rate of LLMs

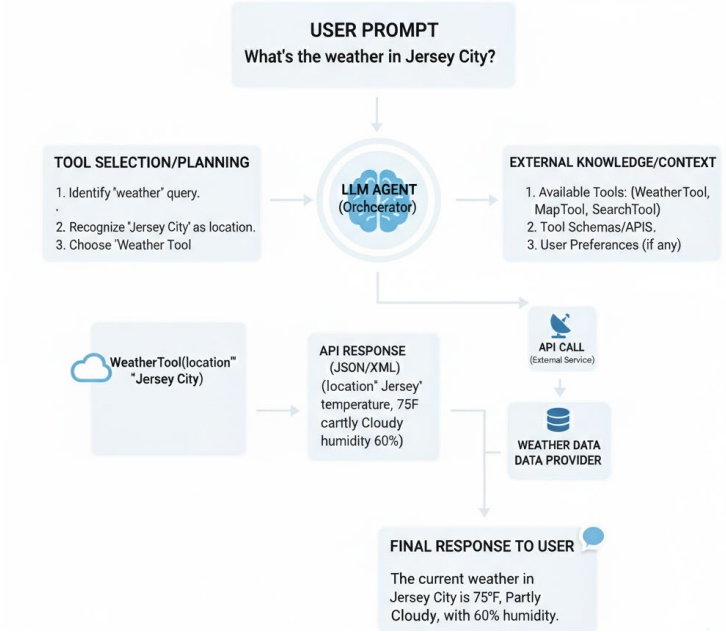
LLM agents

Designed to autonomously achieve goals by leveraging LLM.

- Planning: Breaks down the goal into steps.
- Tools: Uses external functions to take action.
- Memory: Learns from past interactions.



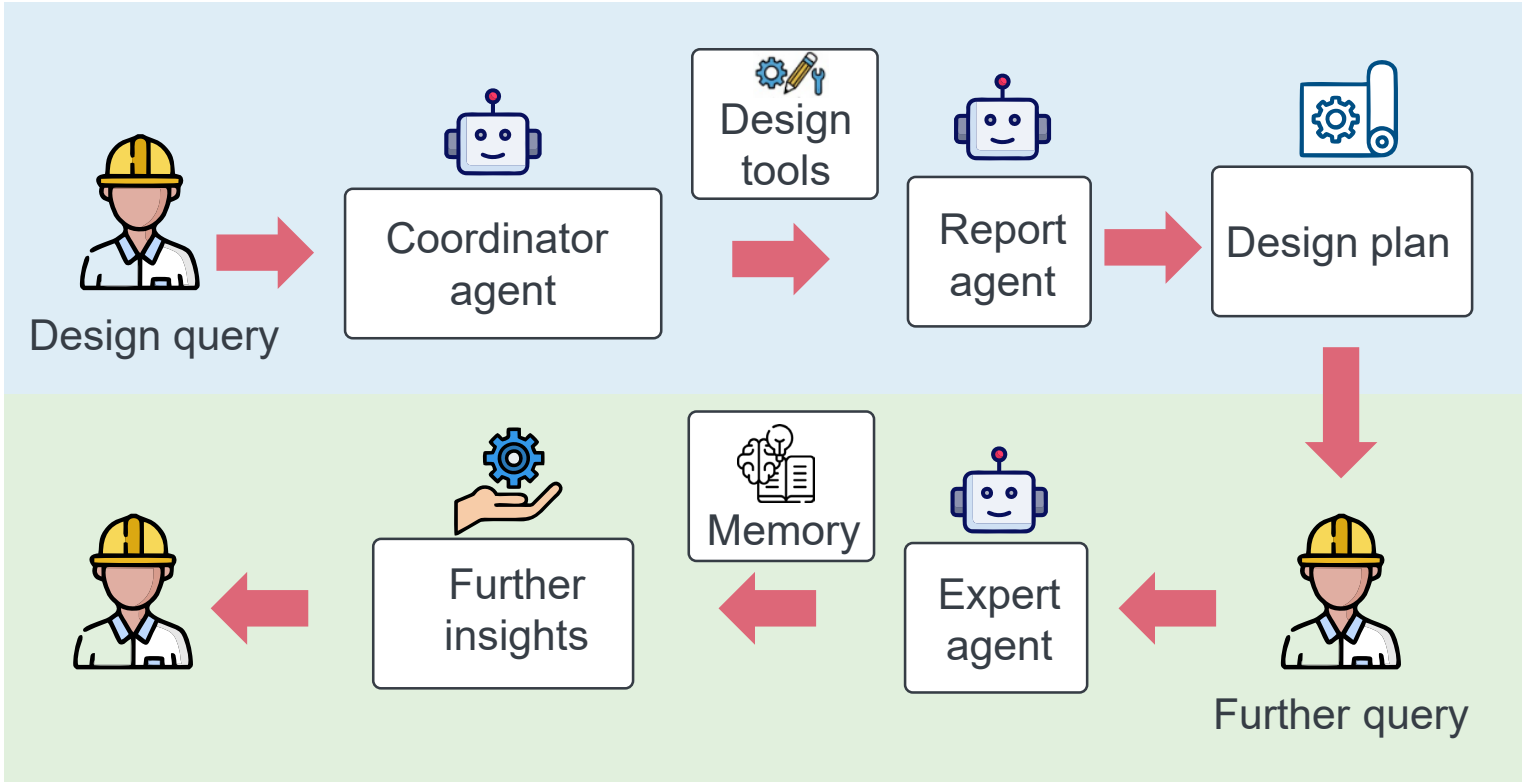
LLM agent architecture



Example

Our solution: multi-agent LLM framework

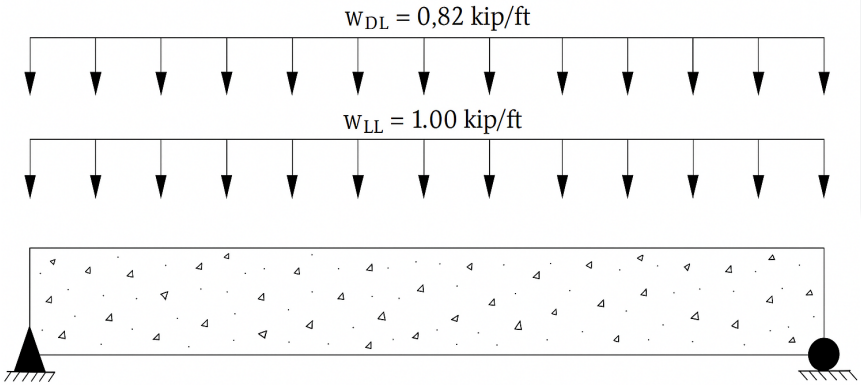
- Automates design through multiple LLM agents
- Ensures code compliance via design tools



Case study

Design a simply-supported reinforced concrete beam

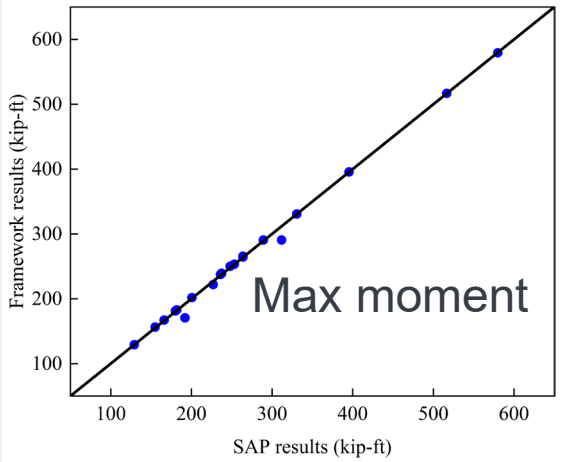
- Automated workflow
- High-fidelity results
- Efficiency gain
- High transparency

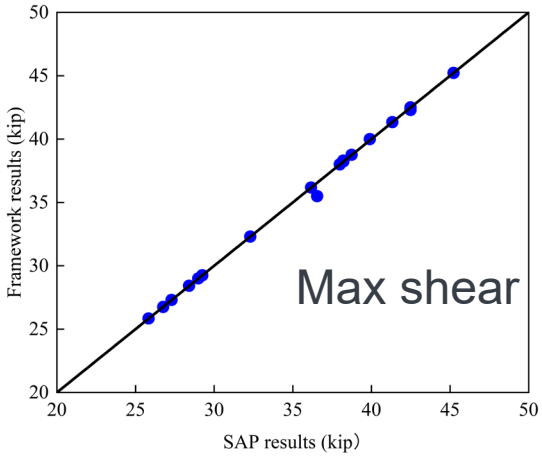


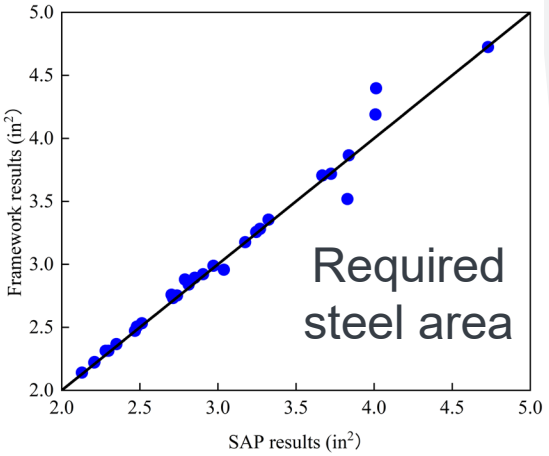
	Reference results	Framework results
Max moment	201.88 kip-ft	201.88 kip-ft
Max shear force	32.3 kips	32.3 kips
Required steel area	2.869 in^2	2.872 in^2
Shear capacity	41.79 kips	41.30 kips
Required time	60 min	5 min

Error analysis

- Validated against SAP2000 using 30 diverse beams.
- Achieved a 100% pass rate for code compliance and safety.
- Showed near-perfect correlation $R^2>0.98$.







Metric	Maximum moment	Maximum shear force	Required steel area
R^2	1.00	1.00	0.98
MAPE	1.12%	0.15%	1.51%
RMSE	5.69 kip-ft	0.20 kip	0.10 in²

$$R^2 = 1 - \frac{\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}{\sum_{i=1}^{n}(y_i - \bar{y}_i)^2}$$

$$MAPE = \frac{100\%}{n}\sum_{i=1}^{n}\left|\frac{y_i - \hat{y}_i}{y_i}\right|$$

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$$

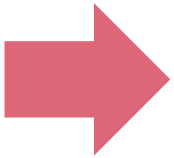
Interactive refinement

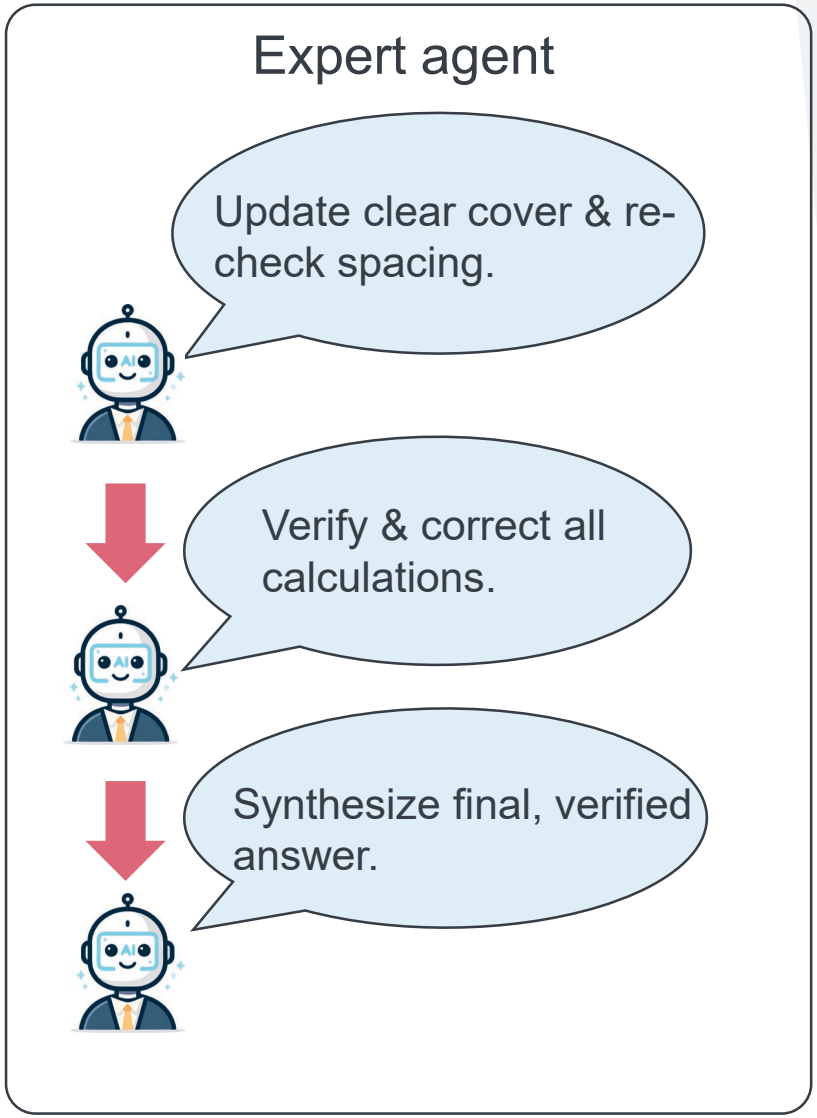
Further assistance

- ➢Exploring design alternatives
- ➢Clarifying complex concepts

If the environment is corrosive, does the current spacing between two rebars still satisfy the code compliance?

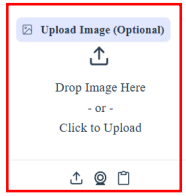
Further query



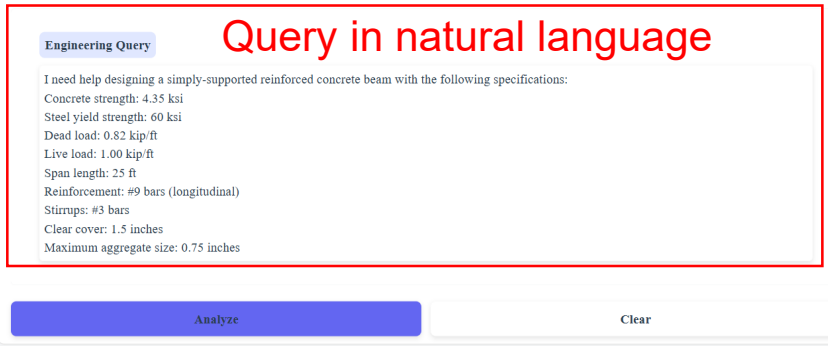


User interface

- Natural language input & output
  - ➢Accepts queries in plain English
  - ➢OCR-enabled for image uploads
  - ➢Detailed report output
  - ➢Further interaction
- Transparent workflow tracking

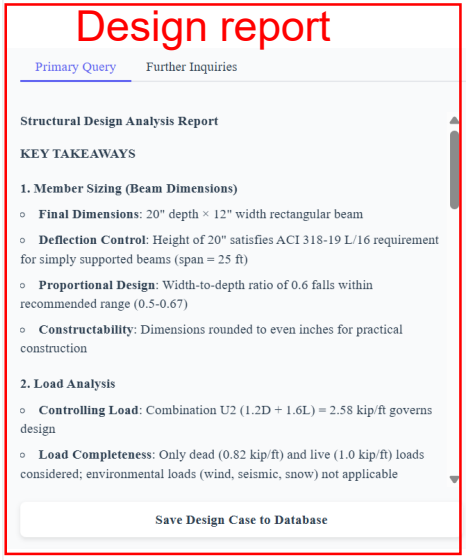


Upload image

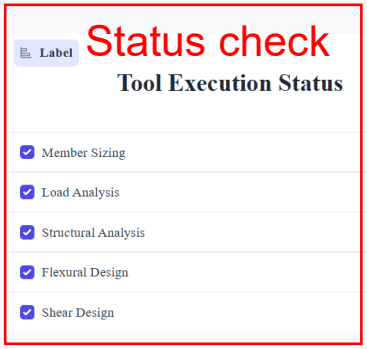


Query in natural language

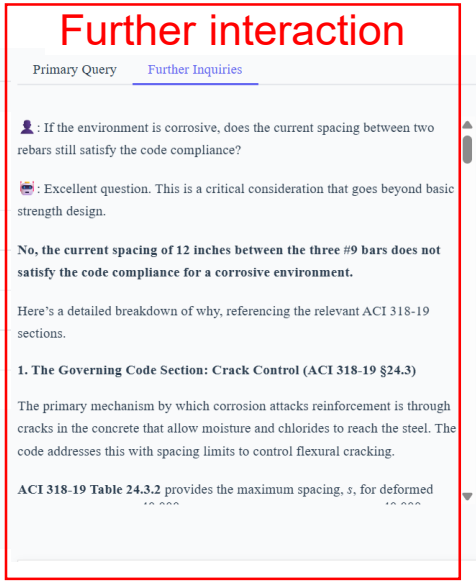
Design report



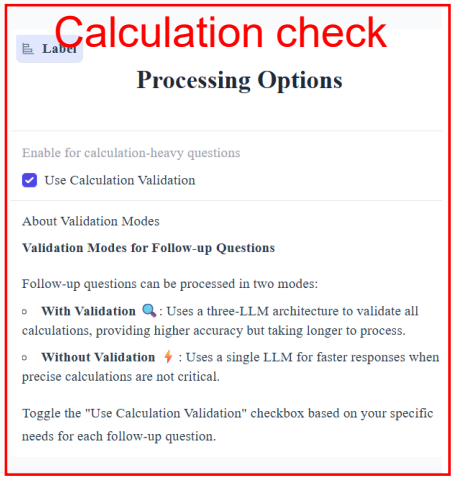
Status check



Further interaction



Calculation check



Limitations and outlook

Current limitations

- Scope: RC beams only.
- Computational latency.
- Lack of field study.

Future outlook & vision

- Expand to more structural elements.
- Improve computational efficiency.
- Integrate with industry-standard software.

Thank you for your attention!
Questions?