Stanford
School of Engineering &
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Earth. Climate. Society.

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Large Language Models Based In-Context Learning for Early Stage Building Life Cycle Assessment

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Agenda

1 Introduction

2 Methodology: building LCA dataset and methods

3 Results: LLM method comparative analysis

4 Conclusion

Building Design Space is Complex

Design variables:

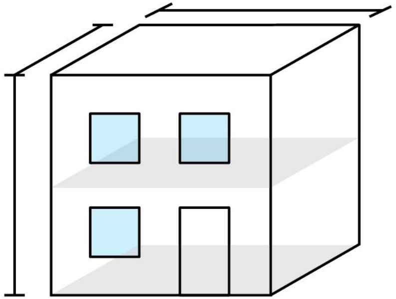
1) Number of buildings: 3 or 4
2) Orientation: 0-360°
3) Number of stories: 5-8
4) Footprint
5) Window-Wall-Ratio: 15-50%
6) Shading presence
7) Shading depth
8) Materials:
   Cladding (7), Substructure (2), Partition (5), Floor finish (8), Floor structure (12), Columns & beams (10), Windows (5), Wall structure (6), Wall finishes (2), Roof (10)
9) Dimensions:
   Cladding (4), Flooring surface (4), Ceiling (4), Wall finishes (4), Substructure (8)

Design space size: 5.73×10^{23}

Basbagill, J. P., & Stanford University Civil & Environmental Engineering Department. (2013). Integration of life cycle assessment and conceptual building design. https://purl.stanford.edu/vt683fq0708

Calculating Embodied Carbon in Buildings

Material amount
From Building 3D Model



x

Global Warming Potential
(GWP) per material
from LCI Database

kg CO_2e / unit of material

=

Embodied Carbon

kg CO_2e

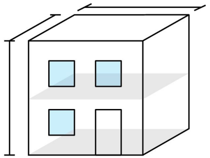
Assumptions

Buildings have thousands of parameters

Facilitating LCA Quantitation using LLMs - Fast and Recursive

Current Practice

Architect



Few design options

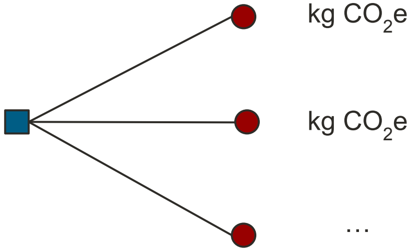
Engineer

Several days

→

LCA tool

(One Click LCA, Tally, LC3, etc.)



Linear data transmission

Research Goal

Parameters	
Area	m²
Width	m
...	...

Set of parameters

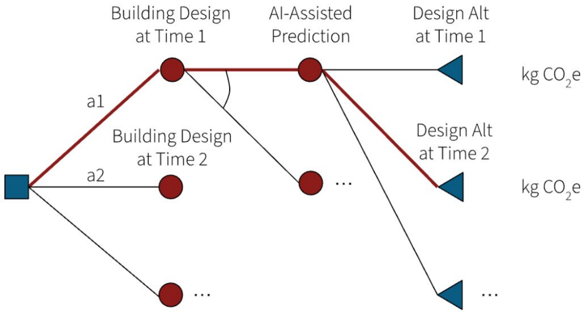
Architect

Several hours

→

LLM tool

(ChatGPT, Claude, etc.)



Non-linear and recursive process

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Building LCA Dataset from Carbon Leadership Forum (CLF)

- **292 buildings** contains **72 parameters** with carbon intensity
- 30 contributors across North America

- LLM Inputs: **49 parameters** excluding carbon data
  e.g. region, climate, building type, area, height, structural system, foundation, mass total

- LLM Outputs: **range of kg CO_2e/m^2** for each building
  - Comparison with **eci_a_to_c_cfa**: Embodied carbon intensity (Sum of the project's total GWP for life cycle stages A-C normalized by conditioned floor area (CFA) for new construction projects)

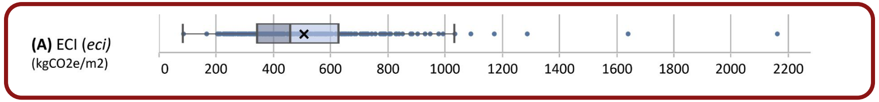
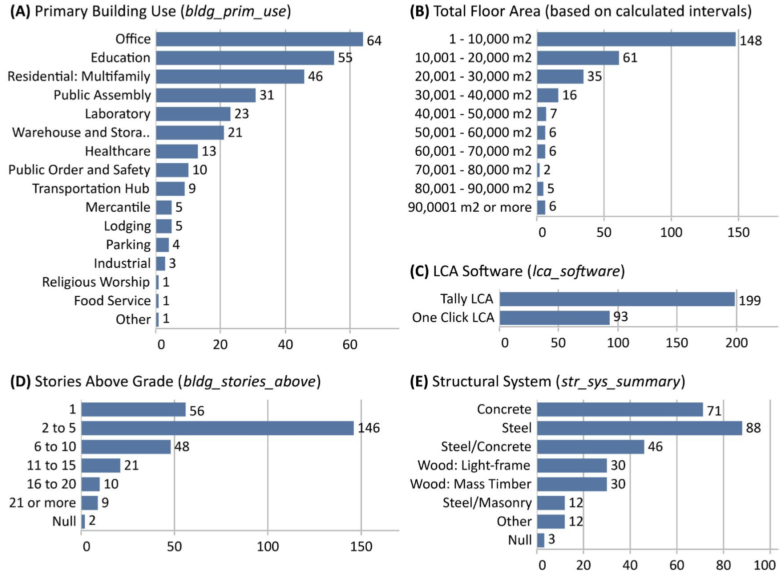


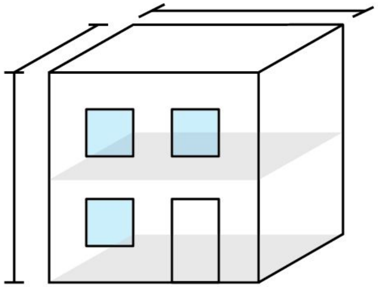
Diagram of the data preparation methods used to produce the data record.



Benke, B., Chafart, M., Shen, Y. et al. A Harmonized Dataset of High-Resolution Embodied Life Cycle Assessment Results for Buildings in North America. Sci Data 12, 1085 (2025). https://doi.org/10.1038/s41597-025-05216-0

Transitioning Manual LCA dataset to LLM Input

Human-curated Manual LCA dataset

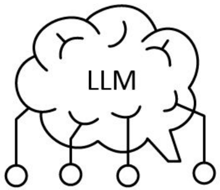


Total LCA
Kg CO_2 e

Building parameters as LLM inputs

Building Dataset

Parameters	
Area	m^2
Width	m
...	...



Kg CO_2 e

Limitations of manual LCA dataset

- Complex and manual
- Inconsistent
- Lack of data

Advantages of the LLM predictions

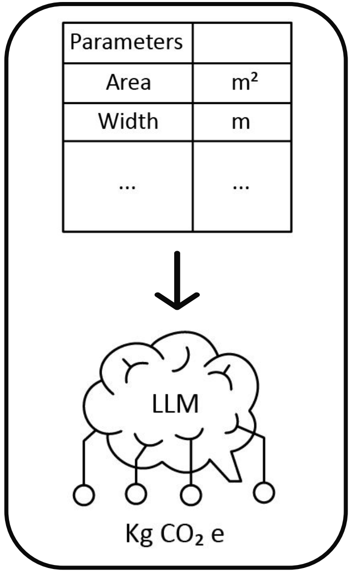
- Fast
- Simple inputs
- Automatic

In-context Learning Methods for LCA Prediction

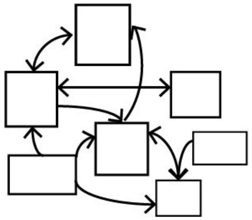
LLM Innate Knowledge

Domain Knowledge

Ontology-based Knowledge



5 journal papers and report related to building LCA



Building ontology:
Structured representation of building domain knowledge in each design step. Interconnections between building parameters and complexity are systematically captured.

Building LCA process documentation

Detailed Claude 3-7-sonnet API Prompt Structure

LLM Innate Knowledge	Domain Knowledge	Ontology-based Knowledge
(3)	(1) + (3)	(1) + (2) + (3)

(1) **These five journal papers (.pdf)** contain background information about early building LCA process.

(2) **This document (.txt)** contains a detailed practice guide on the life cycle assessment of buildings focused on implementation. Use this guideline for LCA estimation.

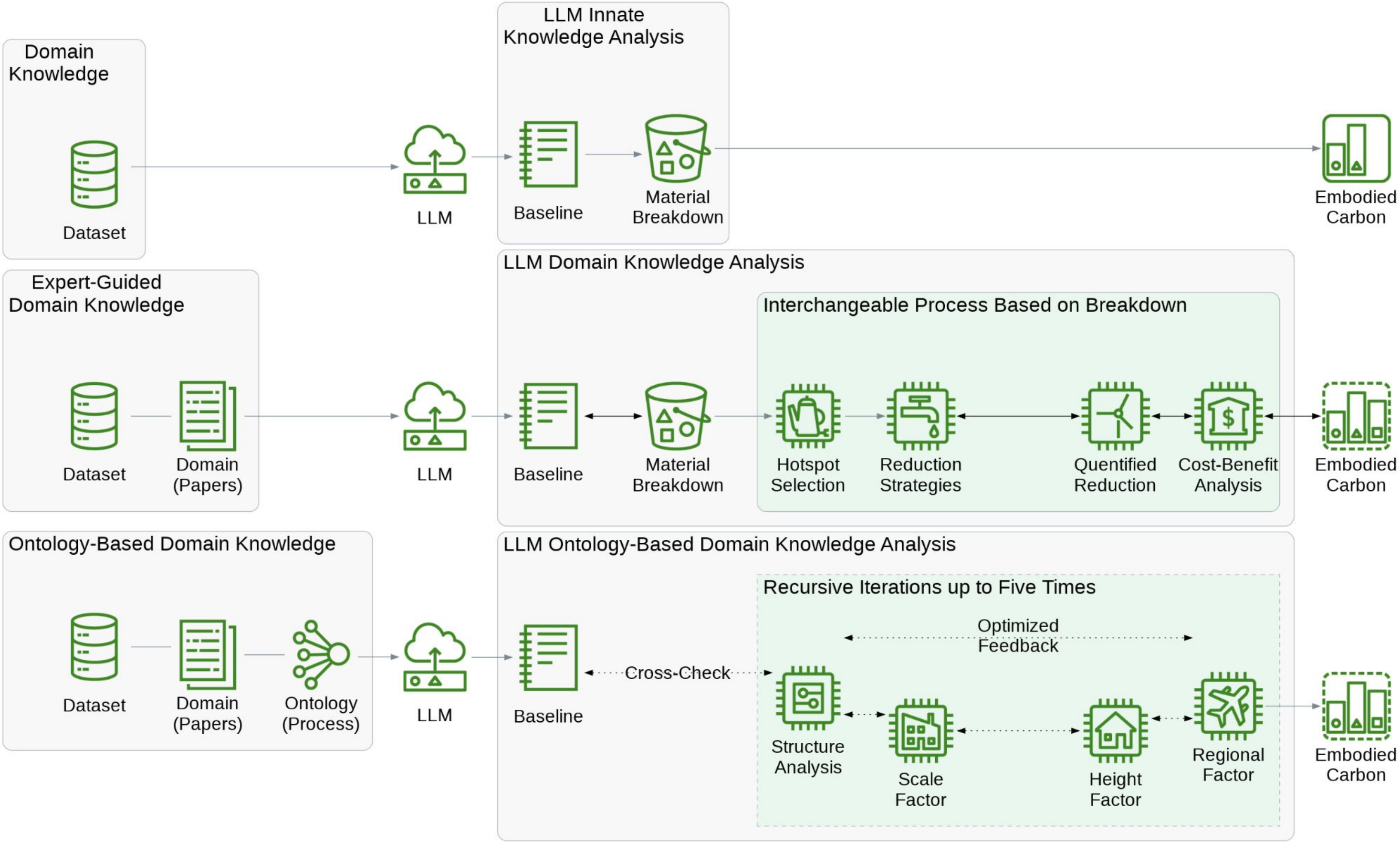
(3) Forget the information from previous sessions and calculate everything from the beginning. **data_glossary_LLM (.xlsx)** contains feature names and descriptions for the data. Reference the given feature information above. Estimate the embodied carbon value of (x) buildings **in the Excel file (.xlsx)**. Each row represents different building data. Provide each range for each data in units of $kgCO_2e/m^2$. For floor area, you need to use bldg_cfa. Update the ranges. If cfa is not provided, you can use bldg_renovated_cfa + bldg_renovated_gfa for renovated buildings. Include life cycle stages A-C. Show results in a table with the range with cfa. If it does not converge: Can you provide a plausible range for each building given the information in units of kg CO_2e/m^2?

Interactive LLM Sessions Reveal LCA Prediction Analysis

Innate Knowledge

Domain Knowledge

Ontology-Base Knowledge



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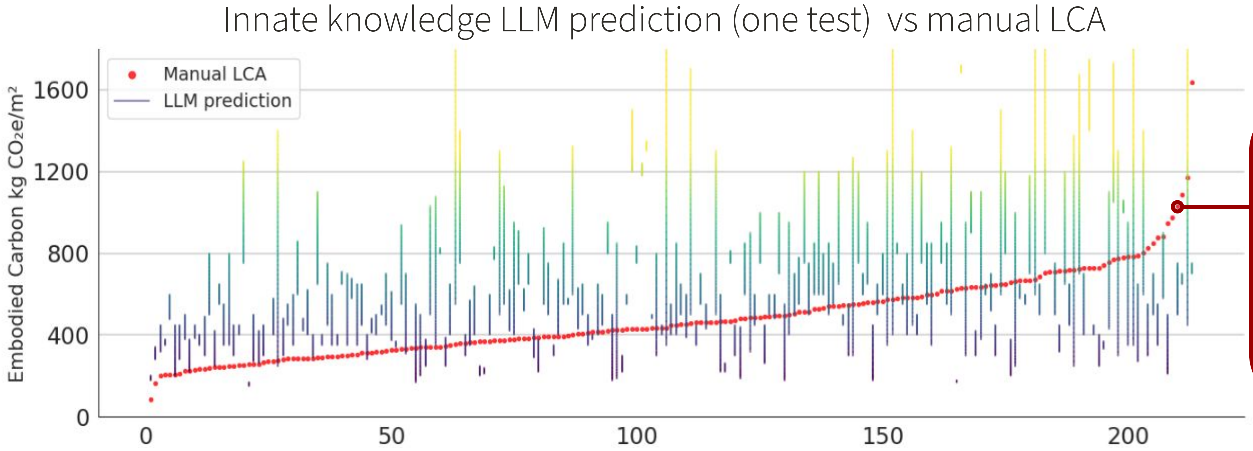
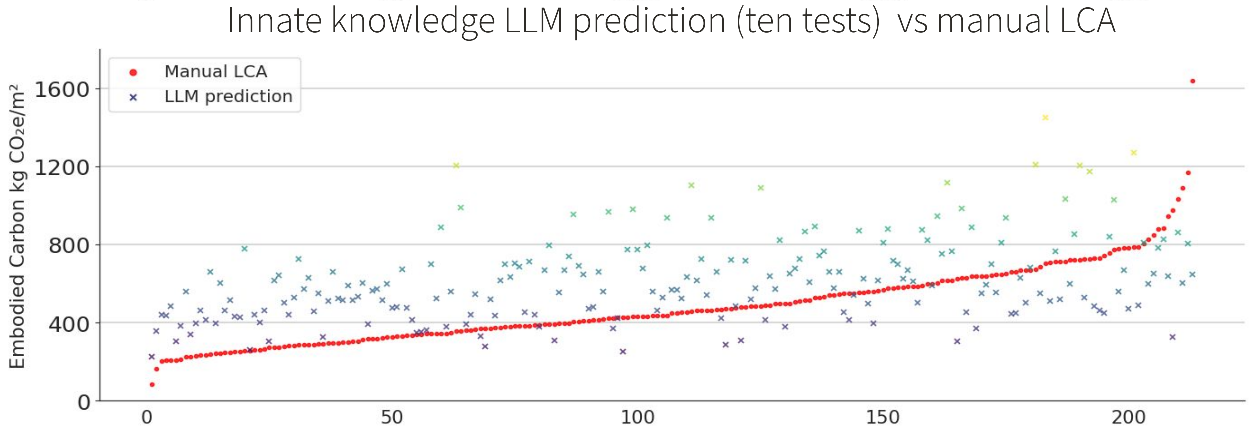
Comparing Manual LCA vs Innate Knowledge

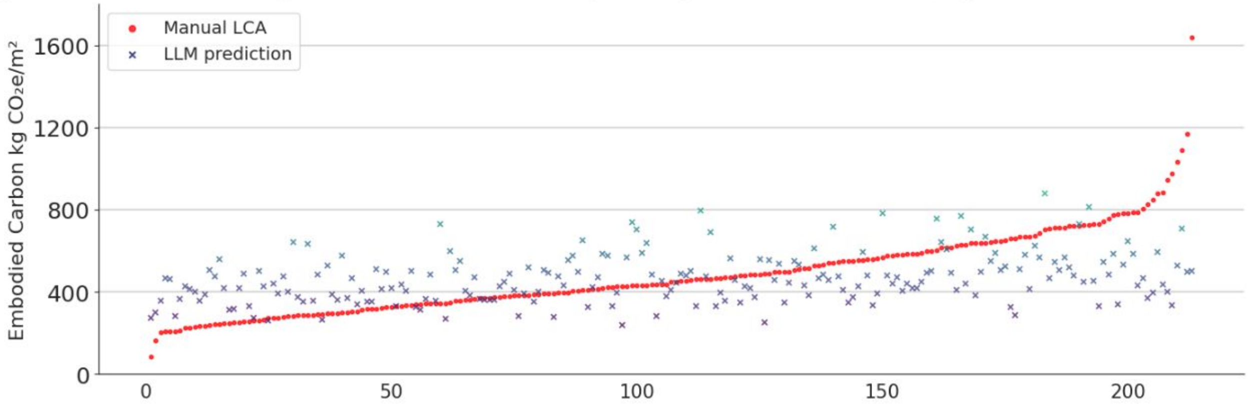


Building ID: **152**
Location: **WA**
Size: **4,350 ft^2**
Typology: **Education**
Stories: **2 to 5**
Structure: **Concrete**

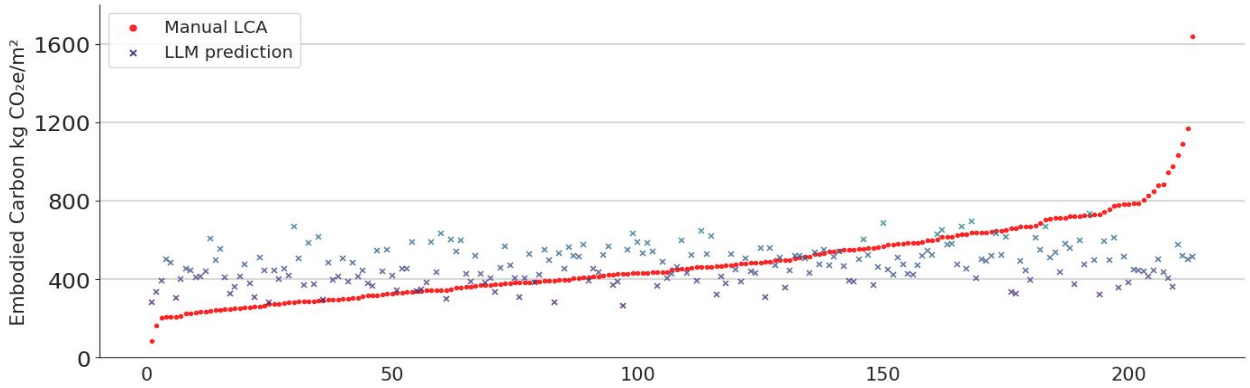


Comparing Domain vs Ontology-Based Knowledge

Domain knowledge LLM prediction (ten tests) vs manual LCA



Ontology-based domain knowledge LLM prediction (ten tests) vs manual LCA



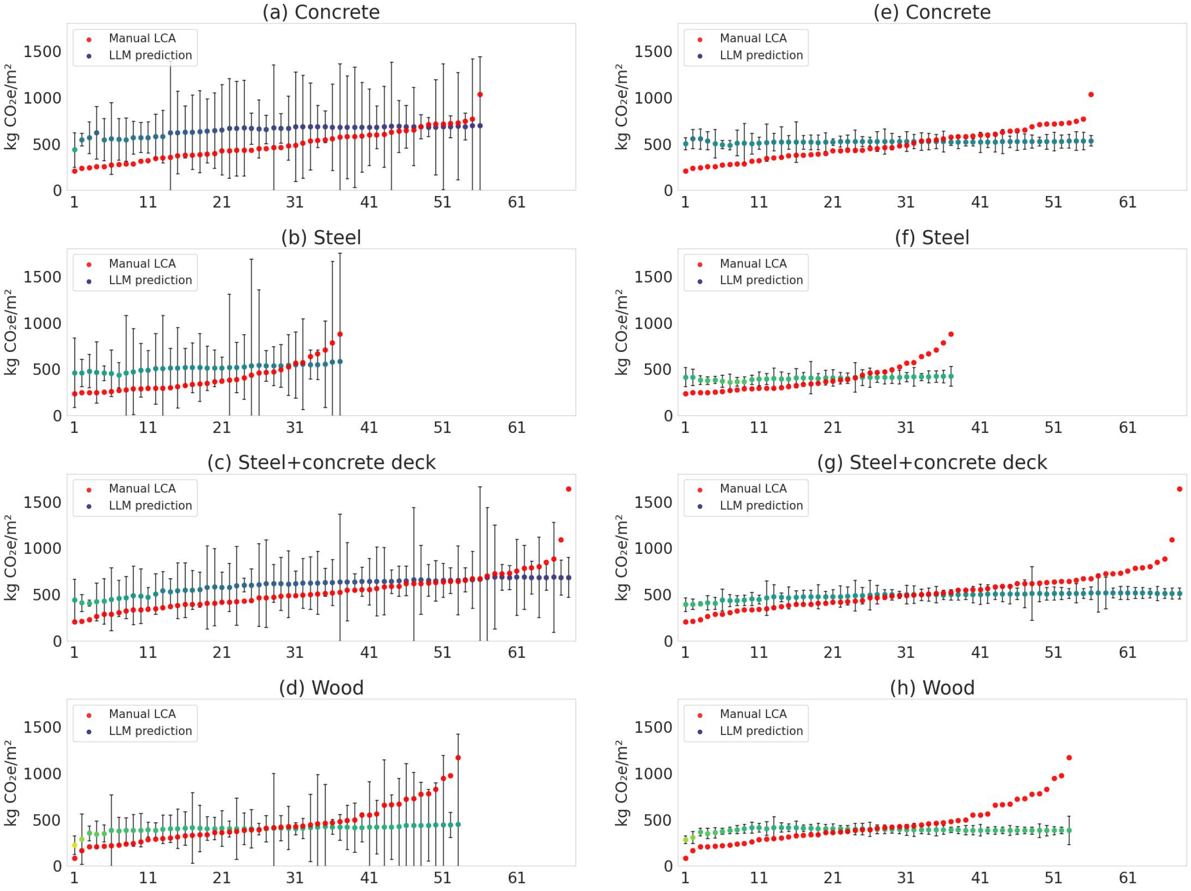
Error Reduction: Innate vs Ontology-Based

	Baseline manual	1. Innate	2. Domain	3. Ontology	Reduction (Innate vs Ontology)
RMSD*		392.4	244.3	230.9	**41%**
Distance		219.0	152.0	150.7	31%
Median	446.9	574.5	452.0	466.0	
Mean	482.5	613.3	464.4	471.8	
SD**		218.5	78.6	51.6	**76%**

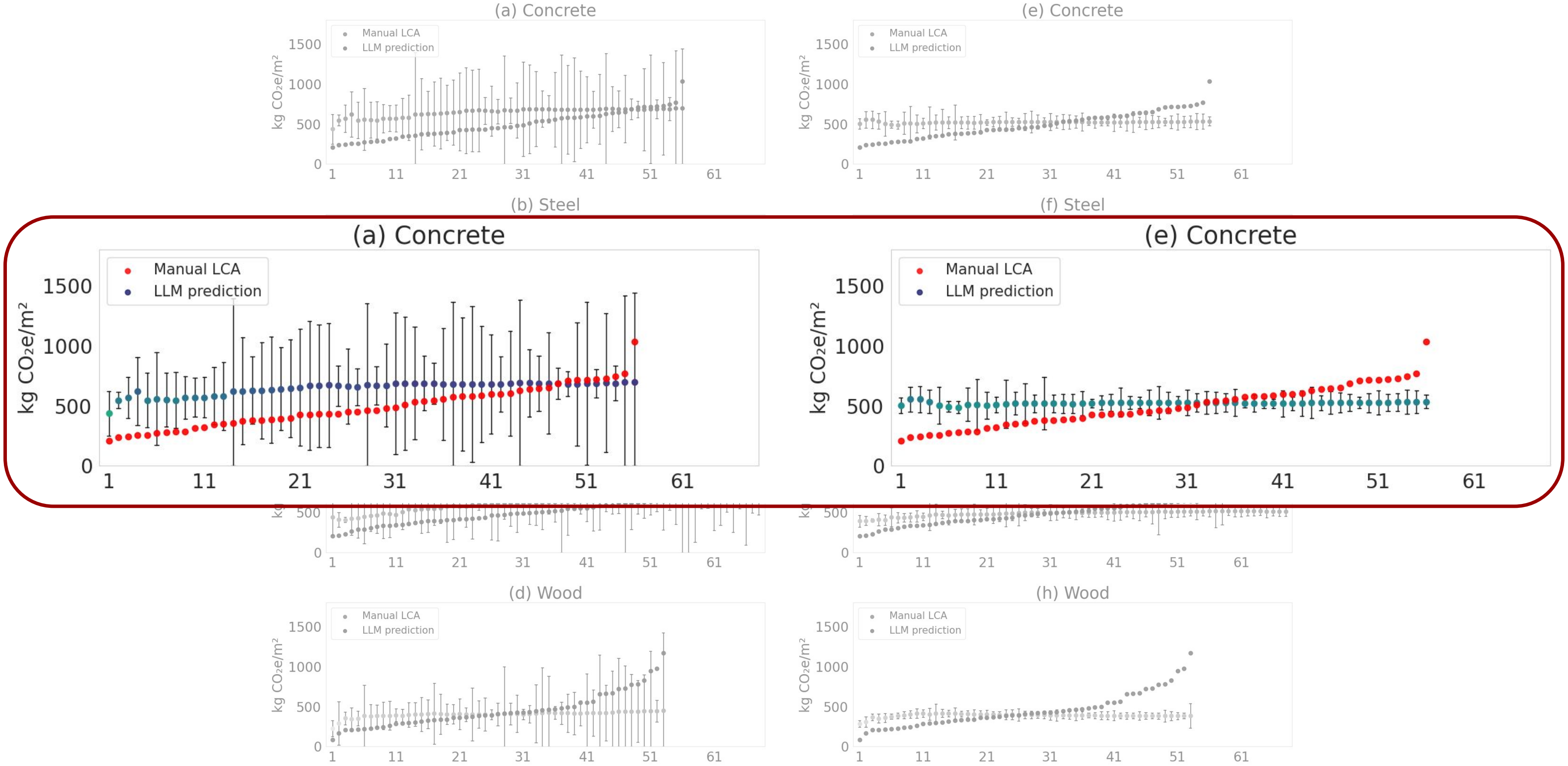
*Root Mean Square Error (RMSD)

**Standard deviation (SD)

Structural System Comparison: Innate vs Ontology-Based



Structural System Comparison: Innate vs Ontology-Based



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Conclusion

- The study evaluated three LLM methods for early building LCA, finding the **ontology-based approach** achieved **41% reduction in RMSE and 76% reduction in standard deviation** compared to using only innate knowledge.

- LLMs demonstrate **self-retrospective learning capabilities** where predictions gravitate toward mean values, resulting in underestimation of high carbon values and overestimation of low carbon values.

- The ontology-based approach transforms LLMs from simple pattern-matching to **iterative refinement through multiple feedback cycles**, enabling more accurate predictions when proper domain knowledge is provided.

- Future work will focus on developing **systematic human-LLM interaction frameworks** that integrate supervised learning, non-monotonic reasoning, and prompt engineering for practical industrial LCA applications, with potential extension to similar engineering problems like **clusters of buildings with similar features**.

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LinkedIn

Thank you!

Questions?

Paper

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