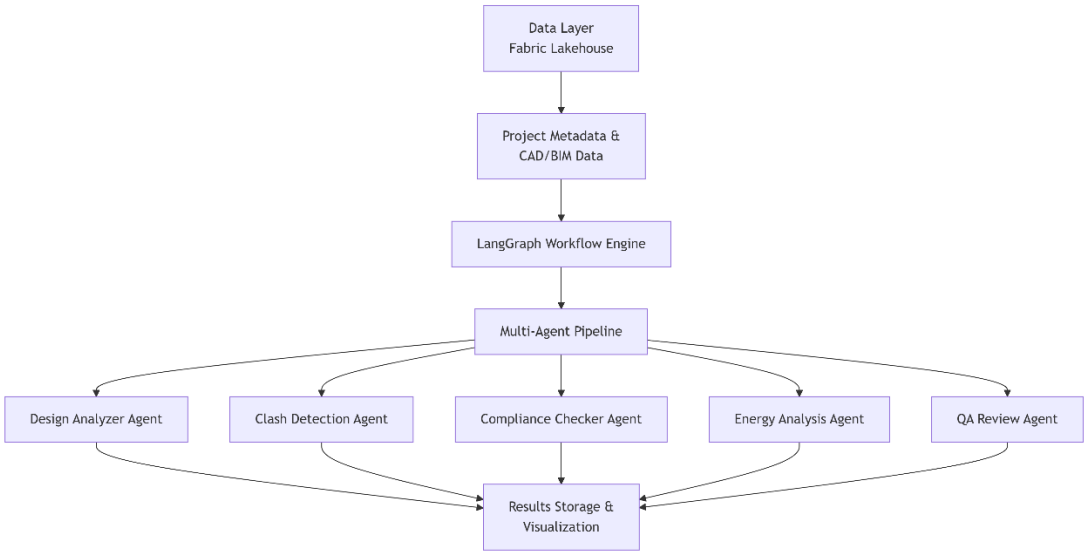
LangGraph Multi-Agent CAD/BIM Automation System- Technical Documentation

📋 System Overview

This system implements a **multi-agent workflow** using **LangGraph** and **LangChain** to automate CAD/BIM design analysis for Mechanical & Electrical (M&E) engineering projects. The system processes building design data through 5 specialized AI agents that perform sequential analysis and quality assessment.

📐 Architecture Diagram



🔧 Core Components

1. State Management (AgentState)

```
class AgentState(TypedDict):
    # Project Identification
    project_id: str
    project_name: str
    project_data: Dict[str, Any]
    design_intent: str

    # Agent Results (NEW - Proper state management)
    design_analyzer_result: Dict[str, Any]
    clash_detector_result: Dict[str, Any]
    compliance_checker_result: Dict[str, Any]
    energy_analyst_result: Dict[str, Any]
    qa_reviewer_result: Dict[str, Any]

    # Legacy Fields (Backward compatibility)
    design_analysis: Dict[str, Any]
    clash_analysis: Dict[str, Any]
    compliance_check: Dict[str, Any]
    energy_analysis: Dict[str, Any]
    qa_report: Dict[str, Any]

    # Workflow Tracking
    current_agent: str
    agent_progress: List[str]
    processing_times: Dict[str, float]
    errors: List[str]
    final_report: Dict[str, Any]
```

Significance:

- **TypedDict** ensures type safety and IDE support
- **Explicit state structure** prevents runtime errors
- **Dual field system** maintains backward compatibility while fixing state persistence issues
- **Comprehensive tracking** enables monitoring and debugging

2. Base Agent Class (MEAgent)

```
class MEAgent:
    def __init__(self, name: str, system_prompt: str, output_parser=None):
        self.name = name
        self.system_prompt = system_prompt
        self.llm = llm
        self.output_parser = output_parser
        self.result_key = f"{name.lower().replace(' ', '_')}_result"
```

Key Methods:

invoke() - Core Agent Execution

```
def invoke(self, state: AgentState)-> Dict[str, Any]:
    # Build prompt with project data and context
    prompt_content = self._build_prompt(state)
    messages = [
        SystemMessage(content=self.system_prompt),
        HumanMessage(content=prompt_content)
    ]

    # LLM API Call
    response = self.llm.invoke(messages)

    # Parse JSON response
    result = self._parse_response(response.content)

    # Return state updates
    return {
        self.result_key: result,  # Primary result storage
        f"{self.name.lower().split()[0]}_analysis": result,  # Legacy field
        "current_agent": self.name,
        "processing_times": {...},
        "agent_progress": [...]
    }
```

Significance:

- **Standardized interface** for all agents
- **Automatic state key generation** ensures consistency
- **Context-aware prompting** includes previous agent results
- **Robust error handling** prevents workflow failures

_parse_response() - JSON Response Handling

```
def _parse_response(self, response_text: str)-> Dict[str, Any]:
    # Multiple parsing strategies:
    # 1. Markdown code blocks (```json)
    # 2. Raw JSON extraction
    # 3. Fallback to text analysis
```

Significance:

- **Multiple fallback strategies** handle various LLM response formats
- **Error recovery** ensures workflow continues even with malformed responses
- **Flexible parsing** accommodates different LLM behaviors

3. Specialized Agent Classes

Each agent inherits from MEAgent with domain-specific system prompts:

Design Analyzer Agent

```
system_prompt = """You are a Senior M&E Design Engineer. Analyze CAD/BIM designs for:
```

- Design completeness and technical integrity
- Missing systems and documentation gaps
- Constructability and installation issues
- Technical risk assessment

Return JSON with: completeness_score, technical_risks, recommendations"""

Clash Detection Agent
system_prompt = """You are a BIM Coordination Specialist. Detect spatial clashes between M&E systems.
Identify coordination issues and provide resolution strategies.

Return JSON with: total_clashes, critical_clashes, clash_locations, resolution_strategies"""

Compliance Checker Agent
system_prompt = """You are a Singapore M&E Compliance Expert. Verify compliance with:
- BCA Green Mark 2021
- SS530 Energy Efficiency
- SS564 Plumbing Standards
- CP52 Electrical Installations

Return JSON with: compliance_score, violations_found, certification_impact"""

Energy Analysis Agent
system_prompt = """You are an Energy Efficiency Specialist. Analyze:
- Energy consumption optimization opportunities
- Green Mark certification potential
- Cost-saving opportunities
- Equipment efficiency assessment

Return JSON with: savings_potential, improvement_measures, payback_period_years"""

QA Review Agent
system_prompt = """You are a Quality Assurance Lead. Provide final quality assessment:
- Overall quality score (0-100)
- Critical issues identification
- Go/No-Go recommendation
- Executive summary for management

Return JSON with: overall_score, critical_issues, final_recommendation, executive_summary"""

LangGraph Workflow Engine
Workflow Construction
```
# Initialize State Graph
workflow = StateGraph(AgentState)

# Add Nodes (Agent Functions)
workflow.add_node("design_analyzer", design_analyzer_node)
workflow.add_node("clash_detector", clash_detector_node)
workflow.add_node("compliance_checker", compliance_checker_node)
workflow.add_node("energy_analyst", energy_analyst_node)
workflow.add_node("qa_reviewer", qa_reviewer_node)
workflow.add_node("finalizer", finalizer_node)

# Define Execution Flow
workflow.set_entry_point("design_analyzer")
workflow.add_edge("design_analyzer", "clash_detector")
workflow.add_edge("clash_detector", "compliance_checker")
workflow.add_edge("compliance_checker", "energy_analyst")
workflow.add_edge("energy_analyst", "qa_reviewer")
workflow.add_edge("qa_reviewer", "finalizer")
```

```
workflow.add_edge("finalizer", END)

# Compile Graph
app = workflow.compile()
```

LangGraph Significance:

- **Directed Acyclic Graph (DAG)** structure ensures proper execution order
- **State persistence** maintains data across agent executions
- **Compilation** optimizes execution and enables checkpointing
- **Visualization** capabilities for debugging and monitoring

Node Functions

Each node wraps an agent's invoke method and adds debugging:

```
def qa_reviewer_node(state: AgentState):
    result = qa_agent.invoke(state)
    print(f"  🗂️ QA Reviewer returning keys: {list(result.keys())}")
    if 'qa_reviewer_result' in result and result['qa_reviewer_result']:
        qa_data = result['qa_reviewer_result']
        if isinstance(qa_data, dict) and 'overall_score' in qa_data:
            print(f"  🎯 QA Reviewer has overall_score: {qa_data['overall_score']}")
    return result
```

Finalizer Node

Compiles all agent results into a comprehensive report:

```
def finalizer_node(state: AgentState):
    final_report = {
        "project_info": {...},
        "agent_analyses": {
            "design_analysis": state.get("design_analyzer_result", {}),
            "clash_analysis": state.get("clash_detector_result", {}),
            # ... other agents
        },
        "performance_metrics": {...}
    }
    return {"final_report": final_report}
```

📊 Data Flow & State Transitions

Initial State

```
initial_state = AgentState(
    project_id="WL-FABRIC-2024-001",
    project_name="Commercial Tower- Stone Lake",
    project_data={...},  # Loaded from Lakehouse
    design_intent="Certified Green Mark",
    # All result fields initialized as empty dicts
    design_analyzer_result={},
    clash_detector_result={},
    # ... other fields
)
```

State Evolution Through Workflow

1. **Design Analyzer Node**:
    - Input: initial_state
    - Output: design_analyzer_result populated
    - State: {..., "design_analyzer_result": {"completeness_score": 85, ...}}
2. **Clash Detector Node**:
    - Input: State from Design Analyzer
    - Output: clash_detector_result populated
    - State: {..., "clash_detector_result": {"total_clashes": 12, ...}}

3. **Compliance Checker Node**:
    - Input: State with design and clash results
    - Output: compliance_checker_result populated
    - **Context Building**: Previous agent results included in prompt
4. **Energy Analyst Node**:
    - Input: State with all previous results
    - Output: energy_analyst_result populated
5. **QA Reviewer Node**:
    - Input: Complete state with all technical analyses
    - Output: qa_reviewer_result with final assessment
    - Contains: overall_score, final_recommendation
6. **Finalizer Node**:
    - Input: Complete analyzed state
    - Output: Compiled final_report
    - Saves: All results to Lakehouse

💾 Data Integration Layer

Lakehouse Data Loading

```
def load_project_data_from_lakehouse(project_id=None):
    # Spark SQL queries to Fabric Lakehouse
    project_df = spark.sql("SELECT * FROM project_metadata")
    cad_df = spark.sql("SELECT * FROM cad_bim_data")

    # Merge and parse JSON fields
    merged_data = []
    for project in projects_pd.iterrows():
        # Complex data merging logic
        full_project_data = merge_project_cad_data(project, cad_data)
        merged_data.append(full_project_data)
```

Significance:

- **Unified data access** from Fabric Lakehouse
- **Automatic JSON parsing** for complex CAD/BIM data
- **Project-data correlation** ensures correct data relationships

Results Storage

```
def save_results_to_lakehouse(state: AgentState):
    for agent_name, results in agents_to_save:
        result_data = [{
            "project_id": state["project_id"],
            "analysis_timestamp": datetime.now().isoformat(),
            "agent_name": agent_name,
            "results_json": json.dumps(results),
            "processing_time": processing_time
        }]
        # Save to appropriate Lakehouse table
```

🎯 Key Design Patterns

1. Strategy Pattern - Agent Specialization

Each agent implements the same interface but with different expertise and prompts.

2. Chain of Responsibility - Sequential Processing

Agents process data in a specific order, each building on previous results.

3. Observer Pattern - State Monitoring

Debugging output monitors state changes at each step.

4. Template Method - Agent Execution

Base MEAgent class defines the execution template, specialized agents fill in details.

🔧 Configuration & Optimization

Cost Optimization

```
# Use cheaper model for testing
llm = ChatOpenAI(
   model="gpt-3.5-turbo",  # Instead of gpt-4
   temperature=0.1,       # Lower temperature for consistent results
   openai_api_key=OPENAI_API_KEY
)

# Process limited projects for testing
projects_to_process = projects_data[:1]  # Only first project
```

Performance Monitoring

- **Processing times** tracked per agent
- **Error collection** for failure analysis
- **Progress tracking** for workflow monitoring

🚀 Execution Flow in Detail

1. Data Preparation

- Load project metadata and CAD/BIM data from Lakehouse
- Merge and parse complex JSON structures
- Initialize LangGraph state with project context

2. Sequential Agent Execution

Design Analyzer → Clash Detector → Compliance Checker → Energy Analyst → QA Reviewer
Each agent:

- Receives current state with previous results
- Processes using domain-specific expertise
- Returns updated state with new analysis
- Maintains context for subsequent agents

3. Result Compilation & Storage

- Finalizer node aggregates all agent results
- Comprehensive report generation
- Persistent storage to Lakehouse tables
- Performance metrics collection

💡 Key Innovations

1. State Management Solution

Solved the critical issue of agent result persistence by:

- Explicit state field definitions in TypedDict
- Consistent key naming conventions (*_result)
- Dual-field system for backward compatibility

2. Robust JSON Parsing

Multiple fallback strategies handle various LLM response formats:

- Markdown code block extraction
- Raw JSON parsing
- Text analysis fallback

3. Context-Aware Agent Prompts

Each agent receives relevant context from previous analyses, enabling:

- Cumulative intelligence building
- Cross-agent dependency resolution
- Comprehensive final assessment

4. Production-Ready Architecture

- Error handling and recovery
- Performance monitoring
- Scalable data integration
- Cost-effective execution

This documentation provides a comprehensive understanding of the LangGraph multi-agent system's architecture, implementation details, and the significance of each component in creating a robust CAD/BIM automation workflow.

Our current implementation uses in-memory state management for simplicity in the demo. However, LangGraph provides enterprise-grade checkpointing with **SqliteSaver**, which we can easily integrate for production deployment. This would give us fault tolerance- if a workflow fails mid-execution, we can resume from the last checkpoint instead of starting over.

Outputs

```
CHECKING EXISTING DATA IN LAKEHOUSE
==================================================
Project Metadata: 5 records
CAD/BIM Data: 5 records
```

SAMPLE PROJECTS:

Table | New chart

Table view

	project_id	project_name	building_type	green_mark_target
1	WL-FABRIC-2024-004	Industrial Building - Jessica Bridge	Industrial Building	Certified
2	WL-FABRIC-2024-003	Mixed Development - Charles River	Mixed Development	Certified
3	WL-FABRIC-2024-001	Commercial Tower - Stone Lake	Commercial Tower	Certified
4	WL-FABRIC-2024-002	Commercial Tower - Stephen Circle	Commercial Tower	Silver
5	WL-FABRIC-2024-005	Residential Condo - Jamie Points	Residential Condo	Certified

```python
# Initialize the LLM with cost-effective model
llm = ChatOpenAI(
    model="gpt-3.5-turbo",  # Cost-effective for testing
    temperature=0.1,
    openai_api_key=OPENAI_API_KEY
)

class MEAgent:
    def __init__(self, name: str, system_prompt: str, output_parser=None):...

    def invoke(self, state: AgentState) -> Dict[str, Any]:...

    def _build_prompt(self, state: AgentState) -> str:...

    def _build_context(self, state: AgentState) -> Dict[str, Any]:...

    def _parse_response(self, response_text: str) -> Dict[str, Any]:...

# Define specialized agents
class DesignAnalyzerAgent(MEAgent):...

class ClashDetectionAgent(MEAgent):...

class ComplianceCheckerAgent(MEAgent):...

class EnergyAnalysisAgent(MEAgent):...

class QAReviewAgent(MEAgent):...

print("✅ LangGraph Multi-Agent System initialized!")
print("🤖 Available Agents: Design Analyzer, Clash Detector, Compliance Checker, Energy Analyst, QA Reviewer")
print(f"🔧 Using model: gpt-3.5-turbo (cost-effective)")
```

✓ - Command executed in 50 sec 246 ms by TAN JIA HUI, JOY on 11:10:10 AM, 10/27/25

```
🚀 INITIALIZING LANGGRAPH MULTI-AGENT SYSTEM...
✅ LangGraph Multi-Agent System initialized!
🤖 Available Agents: Design Analyzer, Clash Detector, Compliance Checker, Energy Analyst, QA Reviewer
🔧 Using model: gpt-3.5-turbo (cost-effective)
```

```python
def energy_analyst_node(state: AgentState):...

def qa_reviewer_node(state: AgentState):...

def finalizer_node(state: AgentState):...

# Build the graph
workflow = StateGraph(AgentState)

# Add nodes
workflow.add_node("design_analyzer", design_analyzer_node)
workflow.add_node("clash_detector", clash_detector_node)
workflow.add_node("compliance_checker", compliance_checker_node)
workflow.add_node("energy_analyst", energy_analyst_node)
workflow.add_node("qa_reviewer", qa_reviewer_node)
workflow.add_node("finalizer", finalizer_node)

# Define the flow
workflow.set_entry_point("design_analyzer")
workflow.add_edge("design_analyzer", "clash_detector")
workflow.add_edge("clash_detector", "compliance_checker")
workflow.add_edge("compliance_checker", "energy_analyst")
workflow.add_edge("energy_analyst", "qa_reviewer")
workflow.add_edge("qa_reviewer", "finalizer")
workflow.add_edge("finalizer", END)

# Compile the graph
app = workflow.compile()

print("✅ LangGraph Workflow Built Successfully!")
print("📋 Workflow Structure: Design → Clash → Compliance → Energy → QA → Final")
```

✓ - Command executed in 391 ms by TAN JIA HUI, JOY on 11:10:11 AM, 10/27/25

```
🏗️ BUILDING LANGGRAPH WORKFLOW...
✅ LangGraph Workflow Built Successfully!
📋 Workflow Structure: Design → Clash → Compliance → Energy → QA → Final

🎯 STARTING LANGGRAPH MULTI-AGENT WORKFLOW
======================================================================
This will:
1. 📊 Load project data from Lakehouse
2. 🤖 Run 5 specialized AI agents using LangGraph
3. 📝 Generate comprehensive analysis reports
4. 💾 Save all results back to Lakehouse
💰 COST-SAVING: Processing only 1 project with GPT-3.5-turbo
======================================================================
🚀 Executing LangGraph Multi-Agent workflow...
✅ Loaded 5 projects from Lakehouse
📋 Found 5 projects to analyze
💰 COST-SAVING: Processing only 1 project instead of 5

============================================================
🏢 PROCESSING PROJECT 1/1
📝 Name: Industrial Building - Jessica Bridge
🆔 ID: WL-FABRIC-2024-004
🎯 Target: Certified Green Mark
🏗️ Type: Industrial Building
📍 Location: Jurong East
```

```
🚀 STARTING LANGGRAPH WORKFLOW...
🔄 [Design Analyzer] Processing...
   ✅ Design Analyzer completed in 5.01s
   🗂️ Design Analyzer returning keys: ['design_analyzer_result', 'design_analysis', 'current_agent', 'processing_times', 'agent_progress']
🔄 [Clash Detector] Processing...
   ✅ Clash Detector completed in 3.69s
   🗂️ Clash Detector returning keys: ['clash_detector_result', 'clash_analysis', 'current_agent', 'processing_times', 'agent_progress']
🔄 [Compliance Checker] Processing...
   ✅ Compliance Checker completed in 4.45s
   🗂️ Compliance Checker returning keys: ['compliance_checker_result', 'compliance_analysis', 'current_agent', 'processing_times', 'agent_progress']
🔄 [Energy Analyst] Processing...
   ✅ Energy Analyst completed in 4.08s
   🗂️ Energy Analyst returning keys: ['energy_analyst_result', 'energy_analysis', 'current_agent', 'processing_times', 'agent_progress']
🔄 [QA Reviewer] Processing...
   ✅ QA Reviewer completed in 2.36s
   🗂️ QA Reviewer returning keys: ['qa_reviewer_result', 'qa_analysis', 'current_agent', 'processing_times', 'agent_progress']
   🎯 QA Reviewer has overall_score: 85
📊 [Finalizer] Compiling final report...
   🔍 Finalizer - All result fields:
   design_analyzer_result: <class 'dict'> - keys: ['completeness_score', 'technical_risks', 'recommendations']
   clash_detector_result: <class 'dict'> - keys: ['total_clashes', 'critical_clashes', 'clash_locations', 'resolution_strategies']
   compliance_checker_result: <class 'dict'> - keys: ['compliance_score', 'violations_found', 'certification_impact']
   energy_analyst_result: <class 'dict'> - keys: ['savings_potential', 'improvement_measures', 'payback_period_years']
   qa_reviewer_result: <class 'dict'> - keys: ['overall_score', 'critical_issues', 'final_recommendation', 'executive_summary']
      🎯 FOUND overall_score: 85
   ✅ Workflow completed in 19.58s
💾 All agent results saved to Lakehouse tables
🎯 FINAL SCORE: 85/100
✅ Recommendation: Go
⏱️ Total Time: 19.58s
🤖 Agents Completed: 5

======================================================================
🎉 LANGGRAPH WORKFLOW COMPLETED!
======================================================================
📈 Processed 1 project successfully!

🏢 Project 1: Industrial Building - Jessica Bridge
   📊 Quality Score: 85/100
   ✅ Recommendation: Go
   ⏱️ Processing Time: 19.58s

💰 COST SAVINGS ACHIEVED:
   - Used GPT-3.5-turbo instead of GPT-4 (≈10x cheaper)
   - Processed 1 project instead of 5 (5x cheaper)
   - Total cost reduction: ≈50x cheaper than full run

🎯 QA FINAL REPORTS SUMMARY:
```

Table | New chart

Table view

	project_id	quality_score	recommendation
1	WL-FABRIC-2024-004	85	Go
2	WL-FABRIC-2024-004	85	Go
3	WL-FABRIC-2024-004	79	APPROVED with conditions
4	WL-FABRIC-2024-005	78	PROCEED with improvements
5	WL-FABRIC-2024-003	88	PROCEED with improvements
6	WL-FABRIC-2024-001	82	REVIEW REQUIRED
7	WL-FABRIC-2024-002	89	REVIEW REQUIRED

```
🔄 LANGGRAPH WORKFLOW STRUCTURE:
Workflow: Design Analyzer → Clash Detector → Compliance Checker → Energy Analyst → QA Reviewer → Finalizer
✅ Graph-based workflow with proper state management and error handling

🎉 LANGGRAPH MULTI-AGENT SYSTEM IMPLEMENTATION COMPLETED!
```