CECOS UNIVERSITYPESHAWAR

DEPARTMENT OFSOFTWARE ENGINEERING

Automated Documentation Generator

Subject: Software Architecture & Design

Project

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Dated: 22-01-2026

Project: Automated Documentation Generator

Contents

1. Problem Analysis

Problem Domain

This project operates in the intersection of **software engineering** and **natural language processing (NLP)**. The core problem is automating the generation of technical documentation (including inline comments, API documentation, and function descriptions) for source code using generative AI models.

Motivation

The primary motivation for My Project is to reduce the extra load from the software engineers and eliminate the trade-off between coding velocity and documentation quality.

- **Economic Motivation**: The time spent by senior engineers writing documentation is expensive. Automating this process allows these high-value resources to focus on architectural problem-solving rather than prose generation.
- **Quality Assurance**: Inconsistent documentation styles across a large organization lead to confusion. An AI-driven system, governed by strict system prompts and fine-tuned models, enforces a uniform voice, structure, and level of detail across thousands of files, regardless of the individual author's writing proficiency.
- **Living Documentation**: The ultimate goal is to transform documentation from a static snapshot into a living entity. By integrating generation into the CI/CD pipeline, the system ensures that every commit that modifies logic also triggers a corresponding update to the documentation, effectively "compiling" the documentation alongside the binary.

2.3 Scope of the Solution

Scope

Included	Excluded
Generating inline comments for functions/methods	Generating complete user manuals
API documentation from code signatures	Documentation for binary/compiled code
Function/method descriptions	Real-time documentation during coding
Evaluation against human-written documentation	Integration with all programming languages

Challenges

1. **Accuracy**: Ensuring generated documentation correctly reflects code behaviour
2. **Consistency**: Maintaining consistent style and terminology across documentation
3. **Context Understanding**: Capturing the broader architectural context of code segments
4. **Evaluation Metrics**: Defining quantifiable metrics for documentation quality
5. **Model Bias**: Mitigating biases present in training data of LLMs

Importance and Worth

This problem is important because:

- **Economic Impact**: Reduces software maintenance costs (estimated at 60-90% of total software lifecycle cost)
- **Open-Source Sustainability**: Improves accessibility of open source projects
- **AI Trustworthiness**: Advances understanding of AI capabilities in technical domains
- **Developer Experience**: Addresses a persistent pain point in software development workflows

2. Requirements and Constraints

2.1 Functional Requirements

FR1: Code Parsing and Preprocessing

- **FR1.1** Parse source code files in multiple languages (Python, Java, JavaScript, C++, Go)
- **FR1.2** Extract code structure: functions, classes, methods, parameters, return types
- **FR1.3** Identify code segments requiring documentation (public APIs, complex logic)
- **FR1.4** Handle edge cases: nested structures, decorators, type hints, annotations

FR2: Documentation Generation

- **FR2.1** Generate inline comments for individual code blocks
- **FR2.2** Generate high-level function/method documentation (docstrings)
- **FR2.3** Generate class-level documentation explaining purpose and relationships
- **FR2.4** Produce README-style module-level documentation

FR3: Consistency Validation

- **FR3.1** Compare generated documentation against actual code semantics
- **FR3.2** Detect contradictions between documentation and implementation
- **FR3.3** Flag incomplete documentation (missing parameters, return values)
- **FR3.4** Generate consistency reports with severity levels

FR4: Quality Evaluation

- **FR4.1** Compute automated metrics: BLEU, ROUGE, semantic similarity (embedding-based)
- **FR4.2** Support human evaluation workflows (annotation interface)
- **FR4.3** Compare AI-generated vs. human-written documentation using multiple criteria
- **FR4.4** Produce evaluation dashboards and statistical reports

FR5: System Management

- **FR5.1** Accept batch processing of code repositories
- **FR5.2** Store generated documentation in version-controlled repository
- **FR5.3** Log all generation attempts with metadata (model, timestamp, parameters)
- **FR5.4** Support prompt engineering and model configuration testing

2.2 Non-Functional Requirements

NFR1: Performance

- **NFR1.1** Generate documentation for a single function within 2-5 seconds
- **NFR1.2** Process a 1MB codebase in < 1 hour (batch mode)
- **NFR1.3** Maintain < 200ms response time for consistency checks

NFR2: Scalability

- **NFR2.1** Support codebases ranging from 100KB to 100MB
- **NFR2.2** Handle 100+ concurrent documentation requests in enterprise deployment
- **NFR2.3** Implement caching and memorization to reduce redundant LLM calls

NFR3: Reliability and Robustness

- **NFR3.1** Handle malformed or incomplete code gracefully without crashing
- **NFR3.2** Implement error recovery and fallback strategies
- **NFR3.3** Maintain system uptime of 99.5% during research evaluation
- **NFR3.4** Implement retry logic with exponential backoff for API calls

NFR4: Maintainability

- **NFR4.1** Modular architecture allowing independent testing of components
- **NFR4.2** Comprehensive logging and monitoring capabilities
- **NFR4.3** Configuration-driven model selection and parameter tuning
- **NFR4.4** Clear separation of concerns: parsing, generation, evaluation, storage

NFR5: Security and Privacy

- **NFR5.1** Sanitize code before sending to external APIs (remove sensitive data)
- **NFR5.2** Encrypt stored documentation and evaluation results
- **NFR5.3** Support offline processing for proprietary codebases
- **NFR5.4** Audit logging of all operations

NFR6: Consistency

- **NFR6.1** Deterministic output mode for reproducible research
- **NFR6.2** Version control for model weights, prompts, and configurations
- **NFR6.3** Consistency metrics reported across multiple runs

2.3 How Architecture Supports Requirements

Requirement	Architectural Support
FR1, FR2 (Code parsing & generation)	Modular pipeline: Code Parser → Prompt Builder → Aluminiferous → Documentation Formatter
FR3 (Consistency validation)	Separate Consistency Checker module comparing AST and documentation semantics
FR4 (Evaluation)	Evaluation Engine with pluggable metric implementations (BLEU, ROUGE, semantic similarity)
NFR1, NFR2 (Performance & scalability)	Distributed task queue (Celery), caching layer, batch processing support
NFR3 (Reliability)	Circuit breaker patterns, retry mechanisms, graceful degradation
NFR4 (Maintainability)	Dependency injection, configuration files, plugin architecture for LLM backer
NFR5 (Security)	Encryption at rest, data anonymization layer, sandboxed execution environm
NFR6 (Consistency)	Deterministic sampling, seed management, version-controlled experiment configuration

Architecture Support for Requirements

Functional Requirements → Supported by:

Code parsing modules (ANTLR, Tree-sitter)

LLM integration layer

Evaluation engine components

Non-Functional Requirements → Supported by:

- Microservices architecture (scalability)

- Caching layer (latency)

- CI/CD pipeline (maintainability)

- Load balancing and monitoring (reliability)

- Model optimization techniques (cost efficiency)

3. Application Architecture

Model Selection and Trade-offs

Project requires a pragmatic choice of models. We compare the three primary candidates based on current benchmarks:

Feature	**LLaMA 3 (70B Instruct)**	**Mistral Large / Mixtral 8x7B**	**GPT-4o (OpenAI)**
Reasoning Depth	High. Excellent at complex logic analysis.	Moderate-High. Good, but can struggle with subtle bugs.	**Very High**. The benchmark leader for reasoning.
Context Window	8k - 128k (variant dependent).	32k.	**128k**. Massive context allows analyzing whole files.
Throughput/Speed	Low (requires heavy GPU).	**High**. Mixtral (MoE) is very fast for its size.	Variable (API dependent).
Deployment	Self-Hosted (Privacy ++).	Self-Hosted (Privacy ++).	SaaS (Privacy -).
Cost	High CAPEX (Hardware).	Moderate CAPEX.	High OPEX (Token costs).

Feature	LLaMA 3 (70B Instruct)	Mistral Large / Mixtral 8x7B	GPT-4o (OpenAI)
Use Case	Enterprise On-Prem Batch Processing.	Real-time Inline Comments / IDE.	High-Accuracy Architectural Docs.

Application Type

This project is a **combination** of:

- **Language Processing System**: Core functionality involves understanding and generating natural language from code
- **Information System**: Manages, processes, and evaluates documentation data
- **Transaction Processing System**: Handles user requests for documentation generation

Application Architecture Principles in System Design

Principle	Application in Project	Benefit
Separation of Concerns	Independent modules for parsing, generation, evaluation	Easier maintenance and testing
Modularity	Plug-in architecture for different LLMs and languages	Extensibility and technology independence
Abstraction	Unified interface for different documentation types	Simplified API for consumers
Loose Coupling	Message queues between processing stages	Independent scaling of components
High Cohesion	Related functionality grouped in same modules	Reduced system complexity

Transaction Processing

The system handles **documentation generation requests** as transactions:

# Transaction Flow Example

1. Request Receipt → API Gateway

2. Validation → Input validation service

3. Code Processing → Parser/analyzer service

4. Documentation Generation → LLM inference service

5. Evaluation → Quality assessment service

6. Response Delivery → Result aggregation service

ACID Properties Implementation:

- **Atomicity**: Request processed completely or not at all (compensating transactions for failures)
- **Consistency**: Input validation ensures consistent request format
- **Isolation**: Concurrent requests processed independently with resource limits
- **Durability**: Results stored persistently with versioning

Language Processing Functionality

Yes, significant language processing functionality exists:

NLP Component	Purpose	Technology
Code Understanding	Parse syntax and semantics	Abstract Syntax Trees (ASTs), static analysis

NLP Component	Purpose	Technology
Text Generation	Produce documentation	Instruction-tuned LLMs (LLaMA, Mistral)
Evaluation	Assess documentation quality	Embedding models, BLEU, ROUGE, BERTScore
Consistency Check	Verify code-documentation alignment	Cross-encoder models, semantic similarity

Why language processing is essential:

1. **Code is a formal language** requiring parsing and interpretation
2. **Documentation is natural language** requiring generation and evaluation
3. **The mapping between code and documentation** requires understanding both domains
4. **Quality assessment** requires linguistic analysis of generated text

Architectural Choices Supporting Quality Attributes

Scalability

Architecture: Microservices with container orchestration (Kubernetes)

Scaling Strategy: Horizontal scaling of stateless services

Load Management: API gateway with rate limiting and queuing

Data Management: Distributed caching (Redis) for frequent requests

Scalability Metrics:

- Linear scaling with added compute resources
- 95th percentile latency < 2x baseline under 10x load

- Support for 10,000+ code files in evaluation dataset

Maintainability

Code Organization: Hexagonal architecture with clear boundaries

Testing: Comprehensive unit, integration, and regression tests

Documentation: Self-documenting code with generated architecture diagrams

Dependency Management: Version pinning and dependency scanning

Maintainability Indicators:

- Cyclomatic complexity < 15 for critical modules
- Test coverage > 80% for core functionality
- Mean Time To Repair (MTTR) < 4 hours for critical issues

Reliability

Copy

Fault Tolerance: Circuit breakers, retries with exponential backoff

Monitoring: Distributed tracing, health checks, alerting

Data Integrity: Checksums, versioning, and backup strategies

Disaster Recovery: Multi-region deployment capability

Reliability Targets:

- Mean Time Between Failures (MTBF) > 720 hours
- Recovery Time Objective (RTO) < 1 hour
- Data loss prevention for all user submissions

Mathematical Foundation

The evaluation component uses metrics such as:

Semantic Similarity between generated (D_g) and reference (D_r) documentation:

$$\text{similarity}(D_g, D_r) = \frac{\mathbf{v}_g \cdot \mathbf{v}_r}{\| \mathbf{v}_g \| \| \mathbf{v}_r \|}$$

where $\mathbf{v}_g, \mathbf{v}_r$ are embeddings from models like BERT.

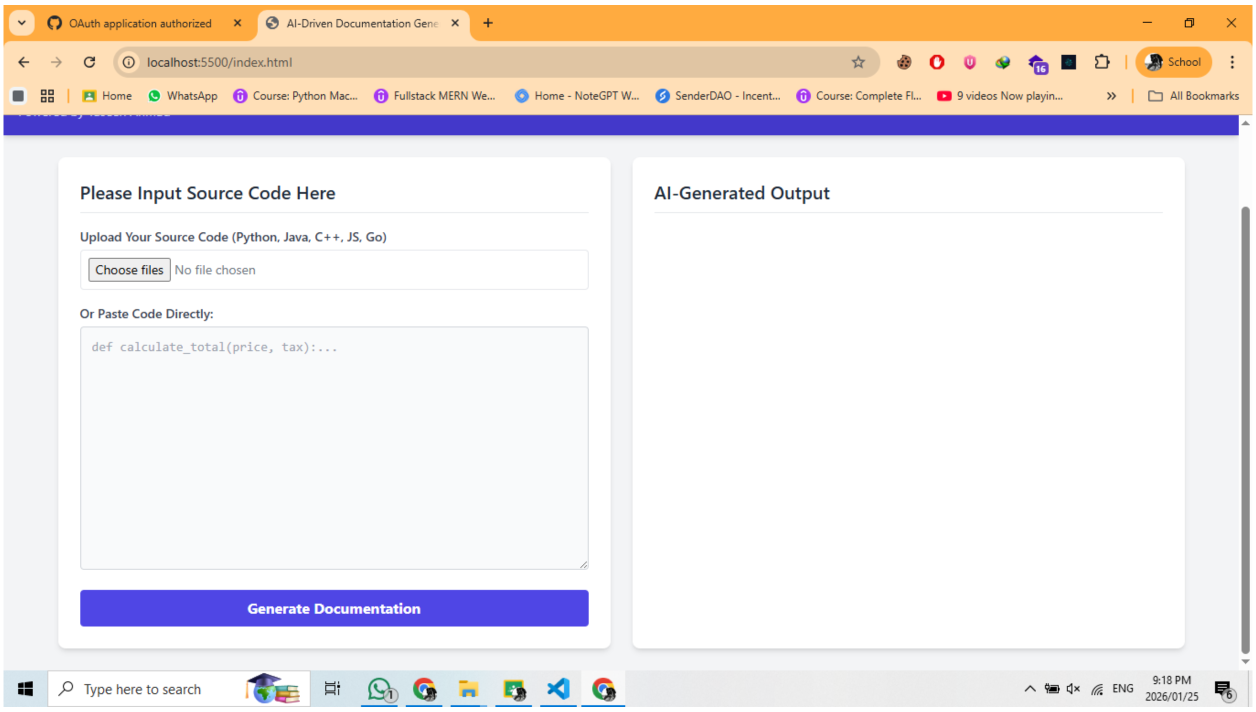
Consistency Score between code (C) and documentation (D):

$$\text{consistency}(C, D) = \frac{1}{n} \sum_{i=1}^{n} \text{sim}(f_i(C), s_i(D))$$

where f_i extracts i-th feature from code, s_i extracts corresponding semantic concept from documentation.

This architecture provides a robust foundation for building, evaluating, and deploying an automated documentation generation system that balances performance, accuracy, and usability while supporting rigorous research into AI-generated documentation quality.

Implemented Model:



Please Input Source Code Here

Upload Your Source Code (Python, Java, C++, JS, Go)

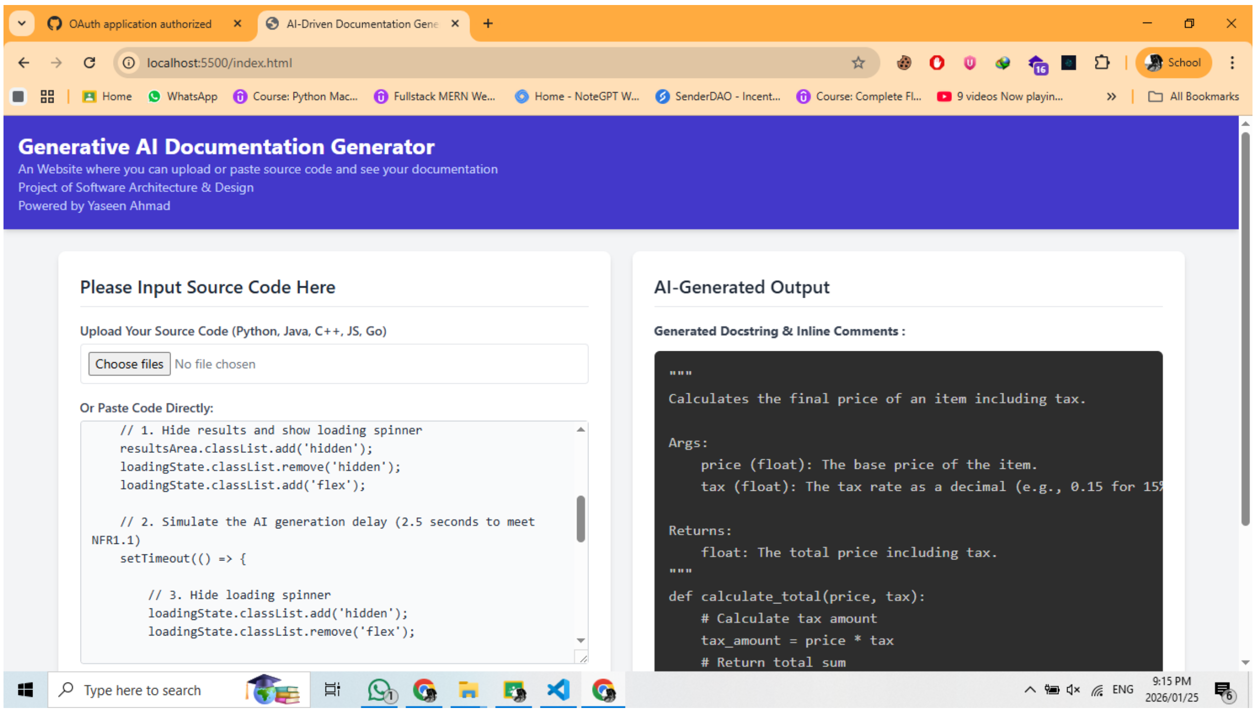
Choose files No file chosen

Or Paste Code Directly:

```
def calculate_total(price, tax):...
```

Generate Documentation

AI-Generated Output



Generative AI Documentation Generator

An Website where you can upload or paste source code and see your documentation
Project of Software Architecture & Design
Powered by Yaseen Ahmad

Please Input Source Code Here

Upload Your Source Code (Python, Java, C++, JS, Go)

Choose files No file chosen

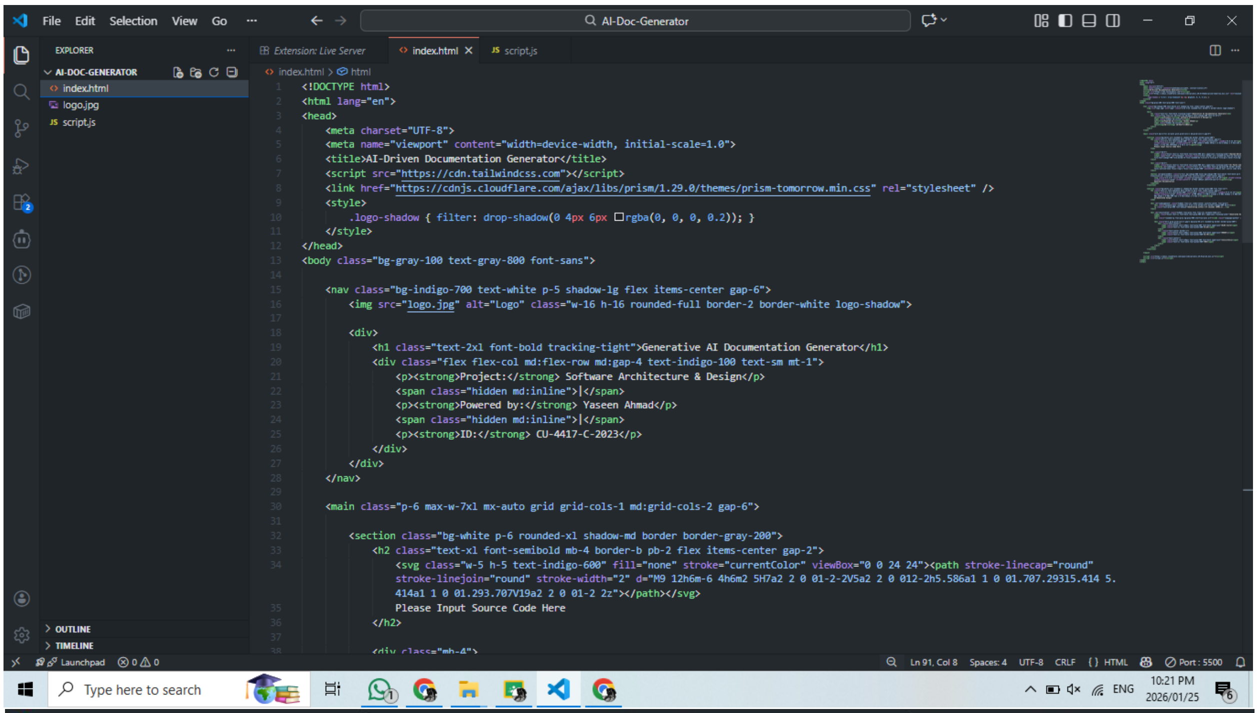
Or Paste Code Directly:

```
    // 1. Hide results and show loading spinner
    resultsArea.classList.add('hidden');
    loadingState.classList.remove('hidden');
    loadingState.classList.add('flex');

    // 2. Simulate the AI generation delay (2.5 seconds to meet
NFR1.1)
    setTimeout(() => {

        // 3. Hide loading spinner
        loadingState.classList.add('hidden');
        loadingState.classList.remove('flex');
```

AI-Generated Output

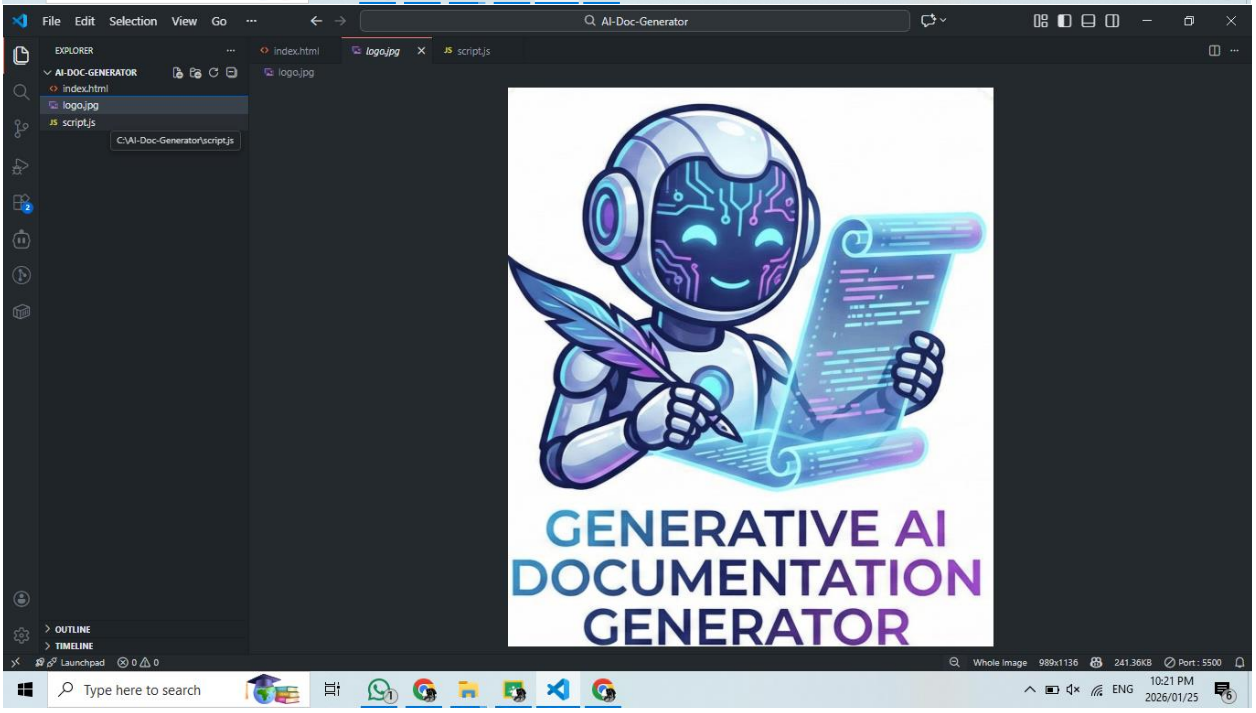
Generated Docstring & Inline Comments :

```
"""
Calculates the final price of an item including tax.

Args:
    price (float): The base price of the item.
    tax (float): The tax rate as a decimal (e.g., 0.15 for 15

Returns:
    float: The total price including tax.
"""
def calculate_total(price, tax):
    # Calculate tax amount
    tax_amount = price * tax
    # Return total sum
```



```html
<!DOCTYPE html>
<html lang="en">
<head>
    <meta charset="UTF-8">
    <meta name="viewport" content="width=device-width, initial-scale=1.0">
    <title>AI-Driven Documentation Generator</title>
    <script src="https://cdn.tailwindcss.com"></script>
    <link href="https://cdnjs.cloudflare.com/ajax/libs/prism/1.29.0/themes/prism-tomorrow.min.css" rel="stylesheet" />
    <style>
        .logo-shadow { filter: drop-shadow(0 4px 6px rgba(0, 0, 0, 0.2)); }
    </style>
</head>
<body class="bg-gray-100 text-gray-800 font-sans">

    <nav class="bg-indigo-700 text-white p-5 shadow-lg flex items-center gap-6">
        <img src="logo.jpg" alt="Logo" class="w-16 h-16 rounded-full border-2 border-white logo-shadow">

        <div>
            <h1 class="text-2xl font-bold tracking-tight">Generative AI Documentation Generator</h1>
            <div class="flex flex-col md:flex-row md:gap-4 text-indigo-100 text-sm mt-1">
                <p><strong>Project:</strong> Software Architecture & Design</p>
                <span class="hidden md:inline">|</span>
                <p><strong>Powered by:</strong> Yaseen Ahmad</p>
                <span class="hidden md:inline">|</span>
                <p><strong>ID:</strong> CU-4417-C-2023</p>
            </div>
        </div>
    </nav>

    <main class="p-6 max-w-7xl mx-auto grid grid-cols-1 md:grid-cols-2 gap-6">

        <section class="bg-white p-6 rounded-xl shadow-md border border-gray-200">
            <h2 class="text-xl font-semibold mb-4 border-b pb-2 flex items-center gap-2">
                <svg class="w-5 h-5 text-indigo-600" fill="none" stroke="currentColor" viewBox="0 0 24 24"><path stroke-linecap="round"
                stroke-linejoin="round" stroke-width="2" d="M9 12h6m-6 4h6m2 5H7a2 2 0 01-2-2V5a2 2 0 012-2h5.586a1 1 0 01.707.29315.414 5.
                414a1 1 0 01.293.707V19a2 2 0 01-2 2z"></path></svg>
                Please Input Source Code Here
            </h2>

            <div class="mb-4">
```

AI-Doc-Generator
EXPLORER
AI-DOC-GENERATOR
index.html
logo.jpg
script.js
Extension: Live Server
OUTLINE
TIMELINE
Ln 91, Col 8
Spaces: 4
UTF-8
CRLF
HTML
Port : 5500
Type here to search
ENG
10:21 PM
2026/01/25



AI-Doc-Generator
EXPLORER
AI-DOC-GENERATOR
index.html
logo.jpg
script.js
C:\AI-Doc-Generator\script.js
GENERATIVE AI
DOCUMENTATION
GENERATOR
OUTLINE
TIMELINE
Whole Image
989x1136
241.36KB
Port : 5500
Type here to search
ENG
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2026/01/25