AN AI-DRIVEN SAAS ECOSYSTEM FOR GEOFENCED CONSTRUCTION MANAGEMENT AND ARCHITECTURAL AUTOMATION

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ABSTRACT:

The Groundup is an AI-driven SaaS platform designed to streamline construction management and architectural planning through automation and real-time monitoring. The system enables users to generate intelligent 2D floor plans based on custom requirements such as building type, room configuration, and design constraints using advanced AI models.

To enhance visualization and decision-making, the platform provides an interactive 3D environment where users can explore and customize layouts, including structural elements and furniture placement. The application integrates geofencing techniques to ensure that construction updates, such as site images and progress reports, are verified based on location, thereby improving transparency and authenticity.

Groundup also supports real-time collaboration through a room-based system, allowing multiple stakeholders—such as homeowners, engineers, and architects—to communicate and share updates efficiently.

Built using modern technologies such as React, Three.js, Node.js, Firebase, and Google Gemini AI, the platform ensures scalability, responsiveness, and a seamless user experience.

KEYWORDS:

AI-driven Construction Management, Geofencing, Architectural Automation, SaaS Platform, 2D Floor Plan Generation, 3D Visualization, Real-time Collaboration, Firebase, Cloud Computing

1.INTRODUCTION

The increasing demand for precision and real-time oversight in construction and architectural workflows has led to a shift toward integrated digital ecosystems. Traditional construction management often relies on manual monitoring and fragmented communication, which can lead to site inefficiencies, boundary disputes, and delayed design iterations. This paper presents Groundup, an AI-driven SaaS ecosystem designed to automate construction management and enhance architectural workflows through geofencing and intelligent automation.

The system is developed using a modern full-stack architecture, utilizing React 19 for a high-performance frontend and Node.js with Express for the backend. It integrates Three.js to provide interactive 3D visualizations and an AI assistant powered by the Google Gemini API to generate structured 2D floor plans from natural language inputs. To ensure project integrity, the platform features a real-time collaborative chat environment with geotagged camera integration, allowing site engineers to verify inspections against precise geographic coordinates stored in Firebase.

Experimental results demonstrate that the proposed ecosystem significantly improves operational transparency and reduces the administrative workload associated with manual design and site tracking. By bridging the gap between conceptual architectural planning and physical site management, Groundup offers a scalable solution that enhances project accuracy and stakeholder engagement. This system represents a significant step forward in the digital transformation of the construction

industry, providing a unified platform for intelligent design and verified site execution.

2.PROBLEM STATEMENT

Despite the availability of modern CAD tools, the construction and design phase still suffers from several critical issues:

- Lack of Centralized Data Management: Designs and communication are scattered across emails and messaging apps.
- Inefficient Communication: Misalignment between owner requirements and engineer execution due to static visualization.
- Manual Site Tracking: No unified way to track site inspections or verify locations through geotagging.
- No Intelligent Guidance: Users struggle with initial layout ideas without professional architectural intervention.
- Limited Reporting: Difficulty in generating professional, data-driven design summaries for stakeholders.

3.EXISTING SYSTEM

The current landscape of construction management and architectural design is primarily characterized by fragmented, manual, or semi-digital workflows. In the traditional existing system, the transition from a client's conceptual vision to a concrete architectural plan involves a series of labour-intensive iterations. Architects typically utilize desktop-based CAD (Computer-Aided Design) software that lacks real-time collaborative capabilities. Consequently, design files and revisions are exchanged through disconnected communication channels such as emails and instant messaging apps. This decentralization often leads to version control issues, where stakeholders may inadvertently work with outdated blueprints, resulting in significant structural errors during the execution phase.

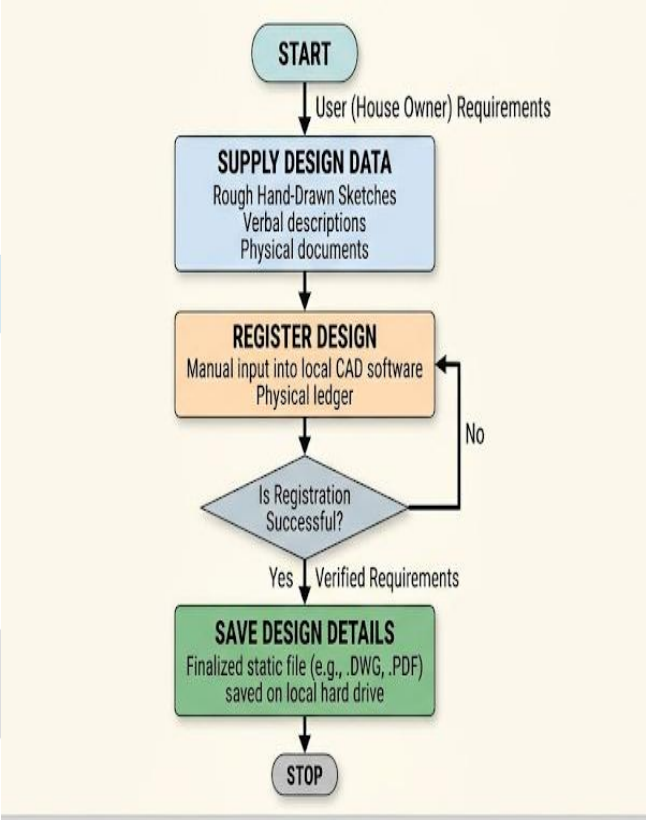

Fig 1: Block diagram of Existing system

4.WORKFLOW

The complete workflow can be summarized as follows:

1. Secure Role-Based User Authentication.
2. Input Land and Building Parameters.
3. AI Generates 2D Floor Plans.
4. Transform Plans into 3D Models.
5. Real-Time Material and Design Editing.
6. Place Building-Specific Virtual Furniture.
7. Collaborate via Geotagged Chat Rooms.
8. Export Professional PDF Design Reports.

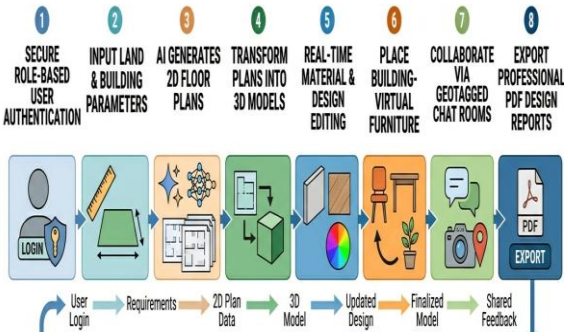

Fig 2: Workflow diagram

5.PROPOSED SYSTEM

The proposed system is a web-based platform that connects house owners and engineers through a centralized, AI-driven interface for architectural planning and visualization.

Main Users:

- **House Owners:** To envision, customize, and track their building designs.
- **Engineers/Architects:** To manage projects, generate technical plans, and conduct site inspections.

Core Functionalities:

- **AI-Driven Floor Plan Generation:** Converts natural language requirements into structured 2D architectural layouts using the Gemini API.
- **Real-Time 3D Visualization:** Transforms 2D plans into interactive 3D models using Three.js for immersive walkthroughs.
- **Dynamic Design Customization:** Enables real-time editing of materials (walls, floors) and building-specific furniture placement.
- **Collaborative Communication:** Features a room-based chat system with geotagged camera integration for synchronized site inspections.
- **Professional Report Exporting:** Generates comprehensive PDF design summaries including specifications and 3D snapshots.

6.SYSTEM ARCHITECTURE

The system follows a **client-server architecture**.

Components:

i) Frontend (Client)

- Built using React 19
- Handles 3D rendering (Three.js)

ii)Backend (Server)

- Built using Node.js/Express.js
- Manages APIs and business logic

iii) Database

- Firebase Firestore (NoSQL)
- Stores user data and designs

iv)AI Module

- Integrated through Gemini API
- Generates intelligent 2D floor plans
- Generate 3D view of the house.

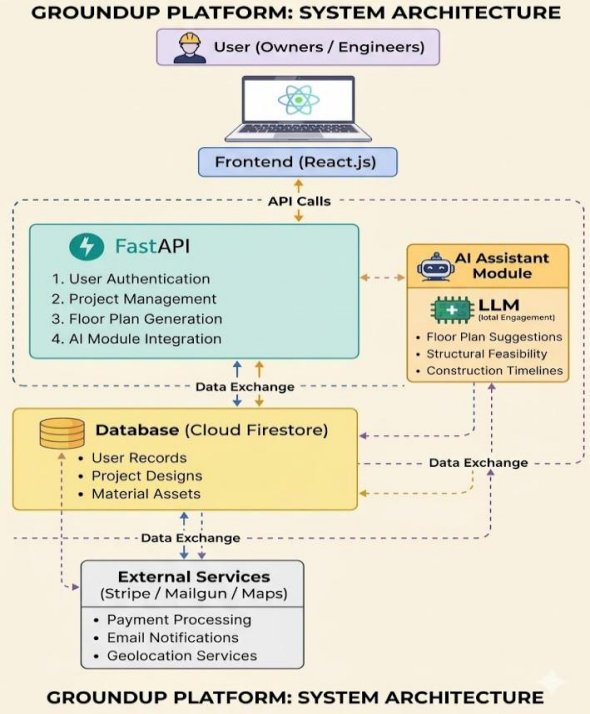

Fig 3: System Architecture

7.MODULE DESCRIPTION

7.1 Owner Module

The owner module provides features for individuals to envision and customize their architectural projects.

Features:

- Registration and login
- Input land measurements and requirements
- Generate and view AI floor plans
- Access 3D editor for customization
- Collaborate with engineers via chat

7.2 Engineer Module

The engineer module allows professionals to manage site technicalities and client requirements.

Features:

- Project dashboard management
- Review owner-generated 3D models
- Geotagged camera for site inspections
- Real-time chat with room codes
- Update project status and milestones
- Access site-specific structural data

7.3 AI Assistant Module

The AI assistant enhances the system by providing intelligent architectural suggestions using the Gemini API.

Features:

- Automated 2D floor plan generation
- Vastu compliance recommendations
- Optimized space utilization logic

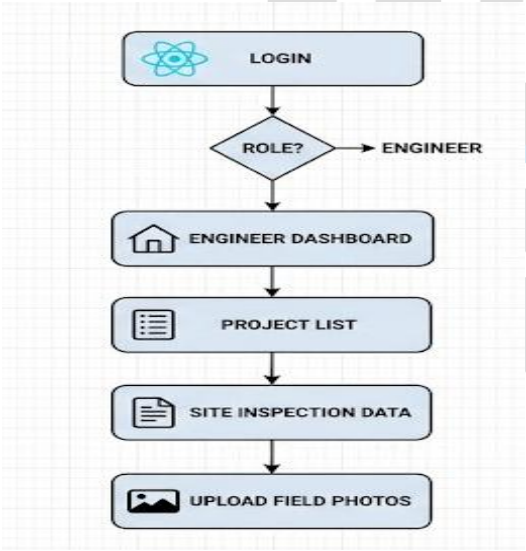

Fig 4: Engineer login modules

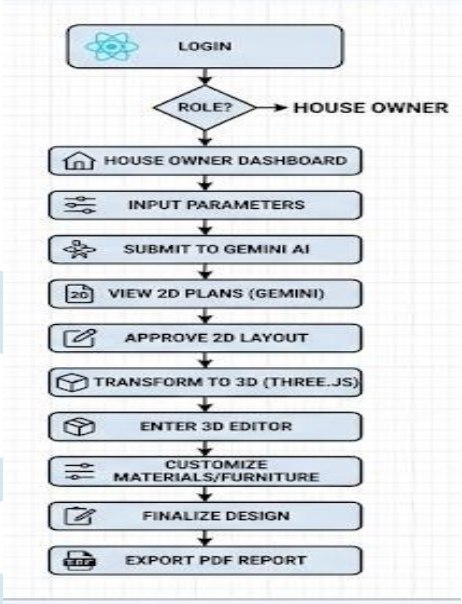

Fig 4: House Owner login modules

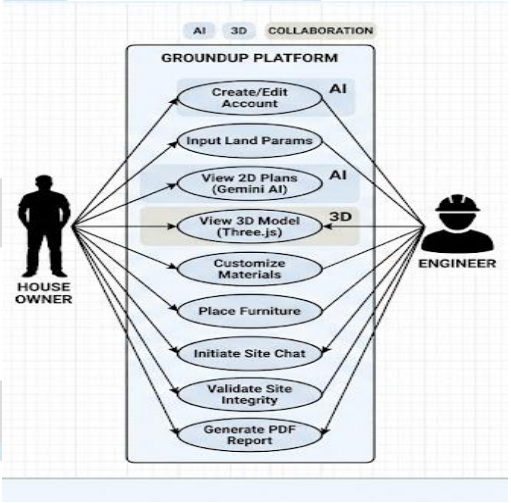

Fig 6: Use case diagrams

8.IMPLEMENTATION

8.1 Frontend Development

The frontend is developed using React 19 with Tailwind CSS for modern, utility-first styling. Features:

- Responsive 3D-integrated UI
- Component-based architecture
- Dynamic rendering via Three.js
- Real-time state management

8.2 Backend Development

The backend is developed using Node.js and Express.js, providing a scalable environment for architectural processing. Features:

- RESTful API endpoints
- Firebase Admin SDK integration
- Secure Gemini AI orchestration
- Real-time chat synchronization

8.3 Database Design

The system uses Firebase Firestore, a cloud-hosted NoSQL database. Collections:

- Users: Profiles for Owners and Engineers
- Projects: AI-generated 2D/3D layout data
- Messages: Room-based collaboration logs
- Reports: Metadata for exported PDF document

9. SYSTEM TESTING

System testing is a critical phase in the development of the Groundup platform to ensure reliability, performance, and accuracy of the architectural models. Various testing methodologies were applied to validate the AI generation and 3D rendering components.

The testing process was carried out in multiple stages, including unit testing, integration testing, and user acceptance testing, to ensure that each module functions correctly both individually and as part of the integrated system.

9.1 Unit Testing

Unit testing was performed on individual modules to verify functionality in isolation. Each component, such as the Gemini API parser, 3D coordinate mapping, and authentication, was tested independently. Examples:

- Login modules were tested with valid and invalid Google Auth tokens.
- Gemini API JSON outputs were validated for structural consistency.
- Three.js component rendering was tested with various land dimensions.

9.2 Integration Testing

Integration testing verified the interaction between the frontend, backend, and cloud services. The focus was on ensuring smooth communication between the AI engine and the 3D viewer. Key checks included:

- Data flow between React 19 and the Node.js backend.
- Synchronization between Firebase Firestore and the real-time chat module.
- Conversion accuracy when transforming 2D plan data into 3D extruded meshes.

9.3 User Acceptance Testing (UAT)

UAT evaluated the system from the perspective of both House Owners and Engineers in real-world architectural scenarios. Test cases included:

- Owner-driven land parameter input and plan generation.
- Engineer-driven site inspection and photo uploading.
- Real-time material customization in the 3D editor.
- Successful PDF report generation with accurate project metadata.

9.4 Performance Testing

Performance testing evaluated the system's ability to handle complex 3D rendering and AI processing. The system was tested for:

- FPS (Frames Per Second) stability during 3D model rotation and walkthroughs.
- Response time for AI-generated floor plans.
- Handling concurrent users in the collaborative chat rooms. Results showed smooth performance on both desktop and mobile browsers.

9.5 Security Testing

Security testing ensured that private project data and site inspection photos are protected. Key measures tested:

- Firebase Authentication for secure role-based access.
- Security Rules in Firestore to prevent unauthorized project viewing.

- Role-based access control (RBAC) separating Owner and Engineer functionalities.
- Secure handling of API keys for the Gemini AI module.

10.SECURITY MECHANISMS

The Groundup platform ensures robust data security through multiple layers of protection, specifically tailored for architectural data and collaborative communication.

Firebase Authentication:

Implements secure identity verification through Google OAuth and Email/Password providers. It manages session control and ensures that only authenticated users can access project dashboards.

Secure Data Encryption:

User project data and sensitive architectural parameters are protected using Firebase's built-in encryption standards. While the backend utilizes Node.js, sensitive configuration keys for the Gemini AI are managed via environment variables to prevent exposure.

Role-Based Access Control (RBAC): Access is strictly enforced through Firestore Security Rules. This restricts system functionalities based on user roles; for example, a House Owner can generate and edit designs, while an Engineer is restricted to site validation and inspection tools.

API Security & Middleware: Communication between the React frontend and the Express backend is secured to prevent unauthorized requests.

11.SYSTEM FEATURES

The Groundup platform provides a comprehensive set of features to streamline the architectural design and site inspection process. It offers centralized project management, allowing house owners and engineers to manage floor plans, 3D models, and site documentation efficiently. Real-time 3D visualization enables users to transform 2D layouts into immersive environments instantly for better spatial understanding.

The integration of an AI-powered design assistant (Gemini AI) enhances the user experience by providing automated floor plan generation, space optimization, and material suggestions tailored to user requirements. Furthermore, a collaborative dashboard presents key project insights and synchronized communication via geotagged chat, ensuring seamless coordination between owners and engineers within a user-friendly interface.

12.RESULTS AND DISCUSSION

The system was evaluated under various real-world scenarios, including **house owner registration**, **AI floor plan generation**, **3D model customization**, and **engineer-owner collaboration** via the geotagged chat.

The results demonstrate that the **Groundup** platform significantly reduces the manual workload and cost associated with early-stage architectural drafting by automating layout creation through the **Gemini AI**. It ensures faster visualization by instantly transforming 2D data into interactive **Three.js** 3D environments, improving overall efficiency in the design-to-validation phase.

Additionally, the **AI design assistant** contributes to better user engagement by providing intelligent spatial recommendations and Vastu-compliant suggestions. The system also enhances communication between homeowners and engineers through its synchronized inspection tools, making the entire construction planning process more streamlined, transparent, and effective.

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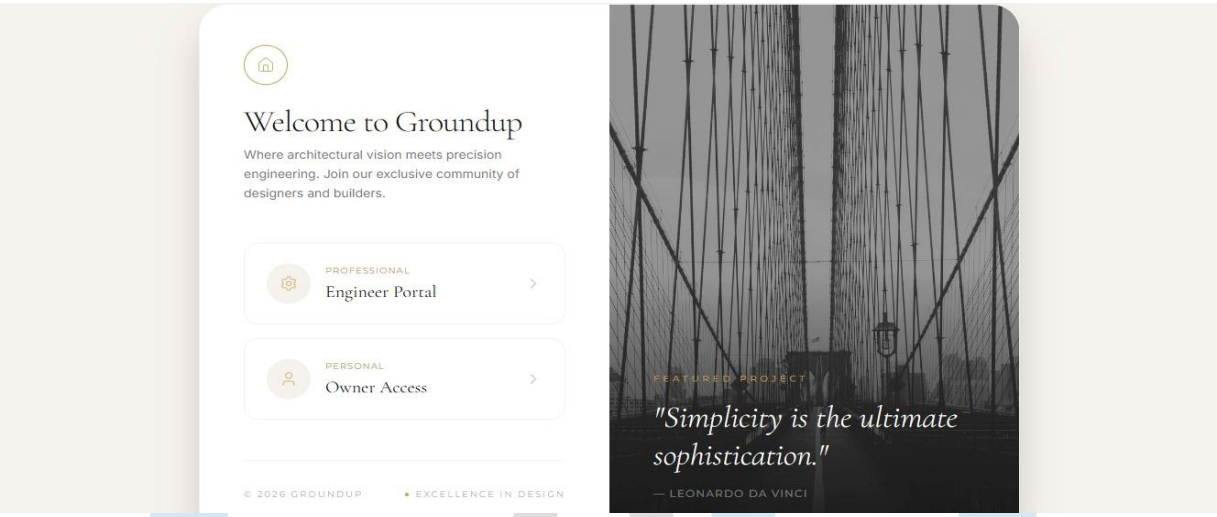
13. CONCLUSION

The **Groundup** platform successfully bridges the gap between conceptual house design and professional engineering validation. By leveraging **React 19** for a high-performance UI, **Three.js** for immersive 3D rendering, and **Gemini AI** for intelligent automation, the system provides an end-to-end solution for modern architectural planning.

The implementation of a centralized, cloud-based interface ensures that data is accessible and secure, while the collaborative features empower stakeholders to make informed decisions in real-time. Ultimately, the project

achieves its goal of making architectural design more accessible, efficient, and technologically advanced for the next generation of home building.



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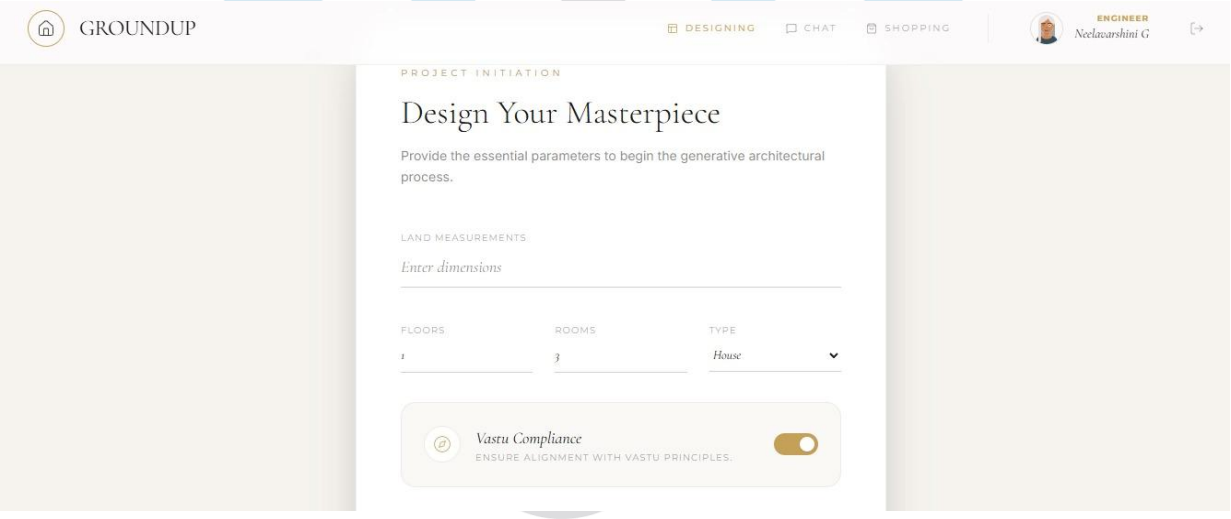

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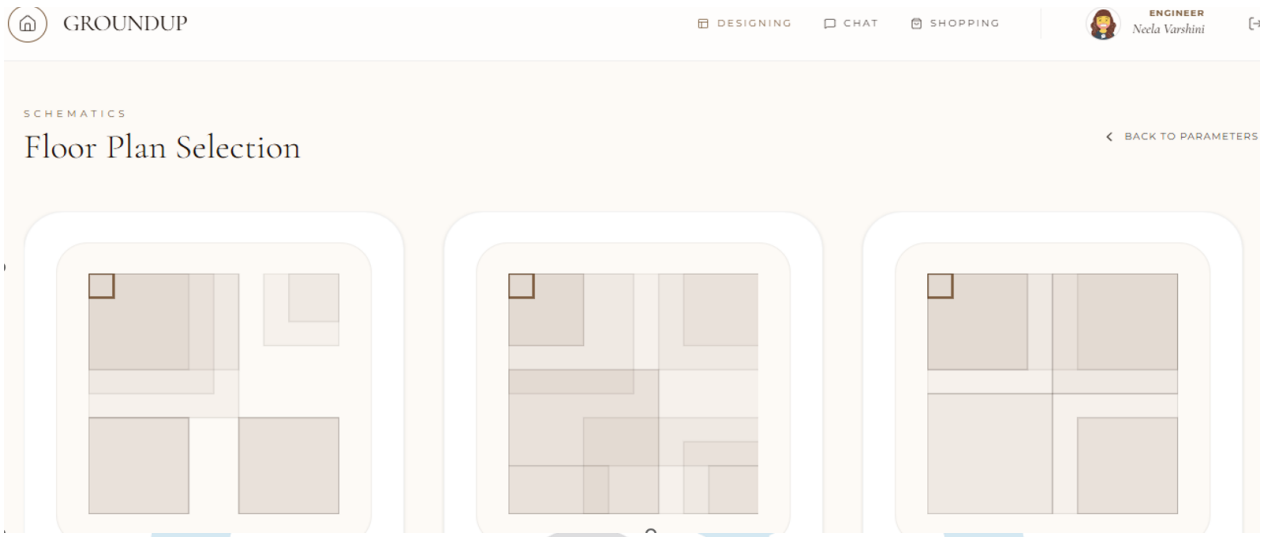

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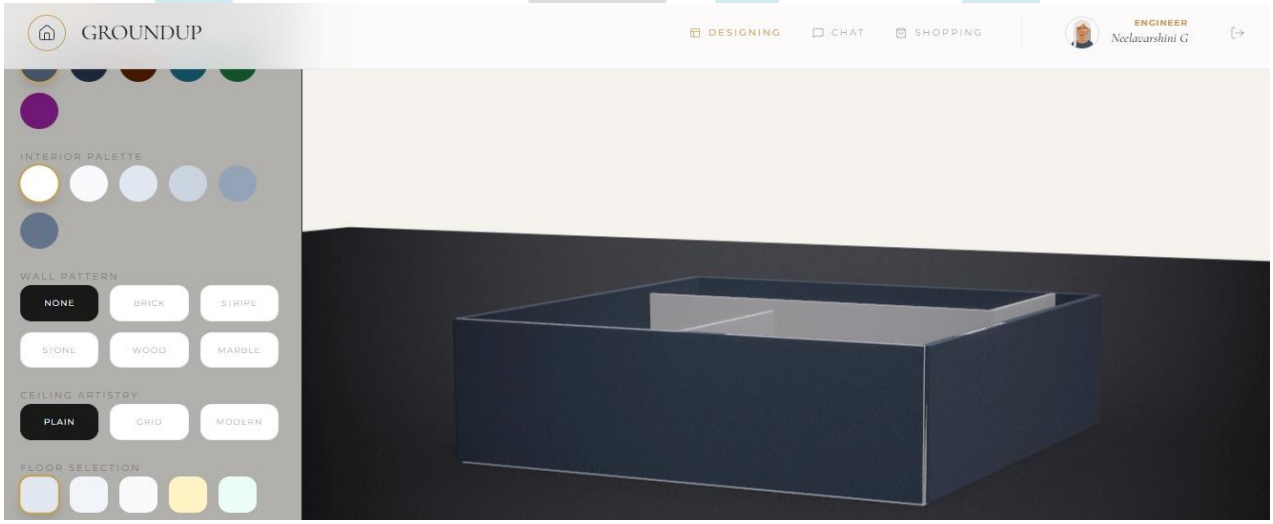

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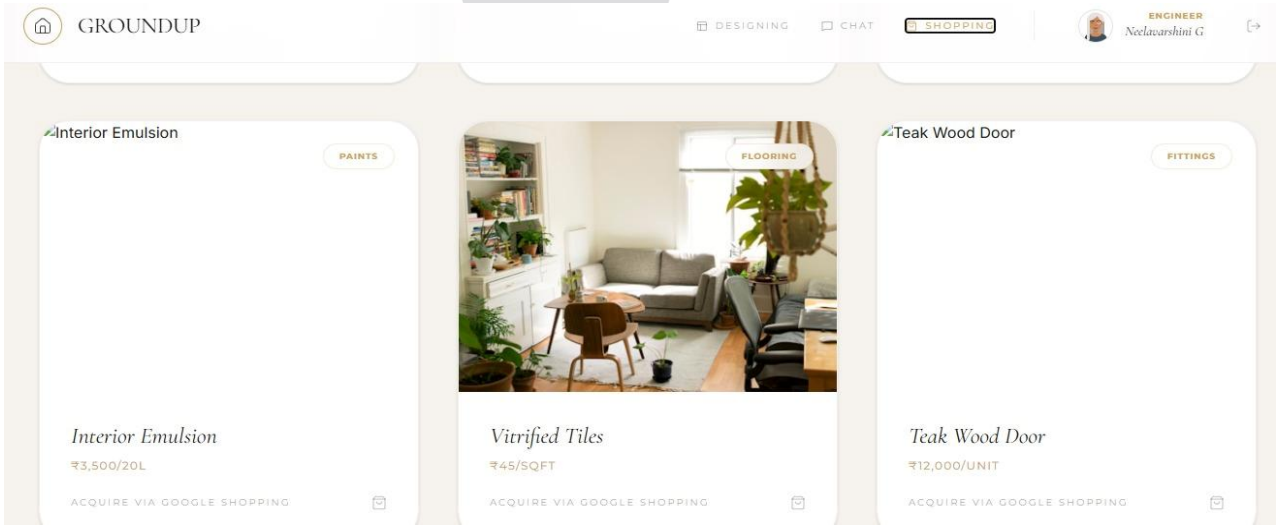

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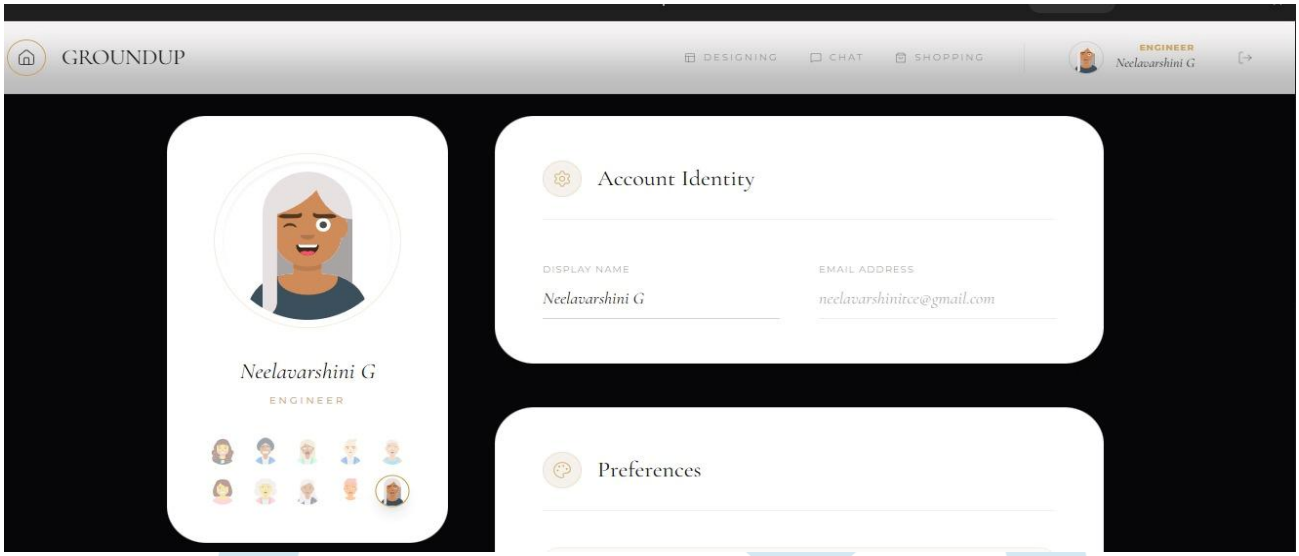

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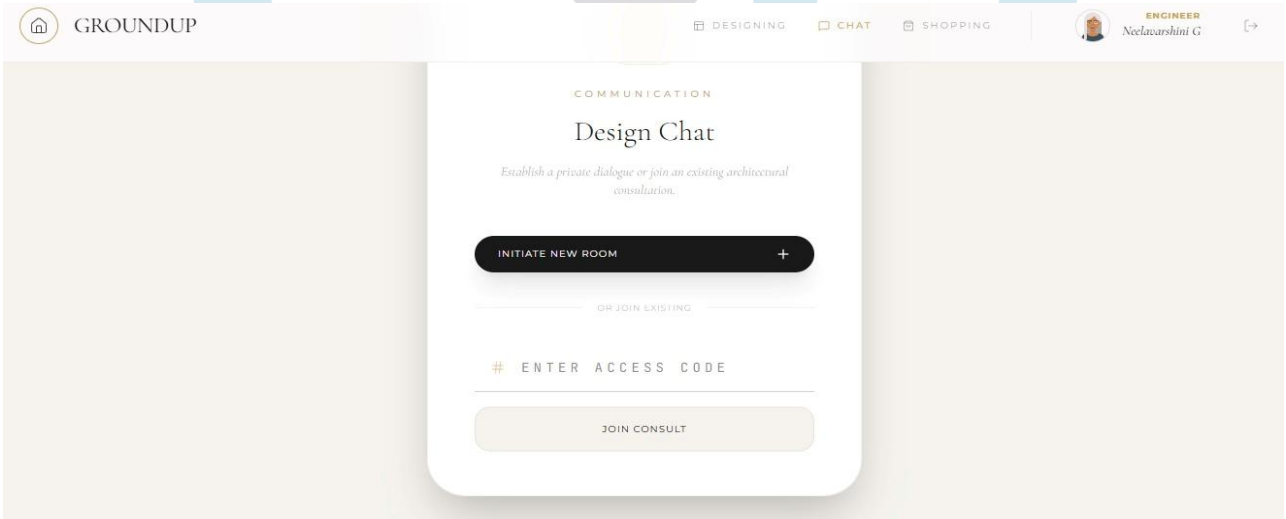

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