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AI-Integrated Self-Help Rural Housing and Livelihood Resilience System: A Bottom-Up Approach for Climate-Vulnerable Communities in Southwest Bangladesh

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ABSTRACT

This study investigates the conceptual potential of AI-driven generative design as an advanced design-policy tool for developing personalized, climate-resilient rural housing in the disaster-prone southwest region of Bangladesh. Centered on Nalian village in Dacope, Khulna, the research integrates field survey data, vernacular housing analysis, functional layout extraction, and climate-responsive design principles to propose a hypothetical digital resilience model for self-help housing adaptation. The model applies Graph Neural Network (GNN) and Convolutional Neural Network (CNN) principles for plan-generation logic, incorporates aerodynamic form considerations for cyclone-responsive three-dimensional massing, and establishes context-based material selection criteria. The academic contribution of this research is the integration of artificial intelligence, vernacular spatial knowledge, and community-based housing resilience within a unified conceptual framework. The study's originality is demonstrated by positioning AI not only as a form-generating tool but also as a decision-support mechanism that translates local needs, climatic risks, and construction practices into adaptable housing strategies. This research expands the scope of smart design policies by illustrating how digital design systems can facilitate participatory, scalable, and context-sensitive housing decision-making for climate-vulnerable communities. The findings indicate that integrating AI-assisted design with local knowledge can enhance access to resilient housing solutions, reinforce disaster preparedness strategies, and inform future policy frameworks for sustainable rural settlement planning in Bangladesh and similar global contexts.

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1. Introduction

1.1 Background and Context

Bangladesh faces significant climate-induced risks due to its low-lying deltaic geography, densely populated rural areas, and reliance on climate-sensitive livelihoods. The southwest coastal region, including Khulna, Satkhira, and settlements adjacent to the Sundarbans, is subject to recurring cyclones, storm surges, salinity intrusion, waterlogging, freshwater scarcity, and livelihood instability. These hazards directly impact rural housing, agriculture, drinking water access, food security, and income-generating activities, establishing climate resilience as a critical priority for settlement planning and design policy (World Bank, 2022; Ashrafuzzaman et al., 2022; Hassan et al., 2025; Hasan et al., 2025; Swarnokar et al., 2025).

Dacope Upazila in Khulna exemplifies one of the most vulnerable coastal environments, where salinity intrusion, irregular rainfall, cyclonic events, and land-use changes continually disrupt agriculture, fishing, and household livelihoods (Hasan et al., 2025; Swarnokar et al., 2025). Sutarkhali Union, including Nalian village, faces interconnected challenges, including food insecurity, income instability, limited access to freshwater, and elevated salinity exposure (Hassan et al., 2025). These circumstances demonstrate that housing resilience extends beyond structural considerations and must be conceptualized as part of a broader system encompassing livelihood security, water management, disaster preparedness, and community adaptation.

Prior research has highlighted rainwater harvesting, community-based water management, and climate-resilient livelihood strategies as key adaptation measures in coastal Bangladesh (Hajong et al., 2021; Shapna et al., 2024). Nevertheless, agricultural productivity and access to safe water remain limited by persistent salinity and inadequate infrastructure. Additionally, rural housing in disaster-prone areas is frequently constructed using informal or non-engineered methods, increasing vulnerability to cyclonic winds, storm surges, and flooding (Harun-Or-Rashid et al., 2022). While resilient housing prototypes and cyclone-responsive construction guidelines have been introduced, many interventions remain standardized and insufficiently tailored to the spatial, cultural, economic, and livelihood needs of individual households (Harun-Or-Rashid et al., 2022).

Participatory design and locally led adaptation approaches can enhance community resilience by integrating users' needs, vernacular knowledge, and everyday spatial practices into the design process (Rahman, 2023). However, architects, planners, and development practitioners frequently encounter challenges in translating diverse household requirements into customized, scalable, and technically robust housing solutions. Existing disaster-response and housing-delivery systems often lack continuous feedback mechanisms, which perpetuates unequal access to resilient design support and constrains long-term adaptation capacity (Sultana et al., 2022). This gap underscores the necessity for a design-policy framework that integrates local knowledge, technical expertise, digital tools, and user feedback into a more adaptive housing-support system.

Advancements in artificial intelligence and generative design have introduced new opportunities for data-driven architectural decision-making. AI-assisted design systems facilitate spatial organization, material selection, environmental assessment, and the generation of multiple design alternatives based on user-defined constraints (Hu et al., 2020; Albukhari, 2025). Specifically, graph-based and image-based learning methods, including Graph Neural Network (GNN) and Convolutional Neural Network (CNN) principles, offer conceptual frameworks for translating functional relationships, spatial adjacency, and visual design patterns into generative plan logic. Despite these advancements, most AI-based architectural research remains concentrated on urban, formal, or technologically advanced contexts, with limited focus on climate-vulnerable rural settlements, vernacular spatial systems, and self-help housing processes.

This study addresses the identified gap by proposing an AI-integrated self-help housing model tailored for climate-vulnerable rural communities in southwest coastal Bangladesh. The academic contribution lies in synthesizing artificial intelligence, vernacular housing analysis, community-based design, and climate-resilient settlement planning within a unified conceptual framework. The research demonstrates originality by positioning AI as a decision-support mechanism that translates household needs, local construction practices, climatic risks, and livelihood requirements into adaptable housing strategies. Within the context of smart design policy, the study introduces a digital resilience model that connects field-based knowledge with computational design logic to facilitate participatory, scalable, and context-sensitive housing decision-making. By centering on Nalian village in Dacope, Khulna, the research provides a locally grounded yet transferable framework for advancing rural housing adaptation in Bangladesh and similar climate-vulnerable regions.

1.2 Problem Statement and Research Gap

Rural communities in the southwest coastal region of Bangladesh are increasingly exposed to overlapping climate-induced risks, including cyclones, storm surges, salinity intrusion, waterlogging, freshwater scarcity, and livelihood instability. In Dacope Upazila, these stresses directly affect rural housing conditions, agricultural productivity, safe water access, public health, and household recovery capacity (Hassan et al., 2025; Hasan et al., 2025; Swarnokar et al., 2025). Although many studies have examined climate vulnerability, agricultural adaptation, water scarcity, and disaster management in coastal Bangladesh, rural housing is often addressed as a separate post-disaster reconstruction issue rather than as an integrated component of everyday livelihood resilience.

Existing research shows that localized adaptation practices, climate-resilient agriculture, rainwater harvesting, and disaster preparedness measures are already being practiced in coastal communities (Shapna et al., 2024; Swarnokar et al., 2025). Similarly, disaster-resilient housing studies in Dacope demonstrate that participatory design and the integration of local wisdom with scientific knowledge can improve community resilience (Rahman, 2023). However, these approaches remain limited in terms of scalability, personalization, and continuous professional support. Architects and technical professionals cannot physically design for every vulnerable rural household, while rural users often lack access to context-specific design guidance that responds to their land condition, functional needs, budget, material availability, and disaster exposure.

A further limitation is the predominantly top-down nature of many existing development and digital service delivery systems. Government agencies, NGOs, and development organizations often provide services, technologies, or housing support to rural users, but these systems frequently lack continuous feedback mechanisms through which users can report their experience, construction progress, changing needs, or design failures. Studies on disaster recovery in coastal Bangladesh show that access to relief and rehabilitation may also be shaped by gender, political connectedness, and local power relations, which can reproduce inequalities in post-disaster support systems (Sultana et al., 2022). Therefore, there is a need for a more transparent, adaptive, and bottom-up model that allows grassroots users to become active contributors to the design and resilience-building process.

At the technological level, recent advances in AI-assisted generative design show that spatial relationships and functional requirements can be encoded into computational systems for floorplan generation (Hu et al., 2020). However, such systems have mostly been developed for formal residential or urban contexts and are not directly applicable to climate-vulnerable rural settlements without extensive localization. Existing AI-based architectural tools generally do not incorporate vernacular housing practices, rural livelihood needs, local material constraints, cyclone-responsive form logic, salinity-related challenges, or real-time grassroots feedback. Moreover, realistic AI-generated rural housing design would require a large and carefully curated database of existing layouts, architect-suggested alternatives, material information, construction sequences, and user responses, which is currently unavailable.

The research gap therefore lies in the absence of an integrated framework that connects architects, grassroots communities, and AI technology for context-sensitive rural housing and livelihood resilience. Current studies address climate vulnerability, resilient housing, agriculture, water scarcity, digital platforms, and AI-based plan generation separately. However, there is limited research on how these domains can be combined into a single digital resilience model that can generate personalized housing options, provide step-by-step self-help construction guidance, support livelihood and disaster-management decisions, and improve continuously through user feedback. This study addresses that gap by proposing an AI-integrated self-help rural housing and livelihood resilience system for climate-vulnerable communities in southwest Bangladesh.

1.3 Objectives and Hypotheses

This study aims to create a framework for an AI-integrated self-help housing and livelihood system for climate-vulnerable communities in southwest coastal Bangladesh. It explores how architectural knowledge, local practices, environmental factors, and digital technology can be integrated through a bottom-up approach for context-sensitive housing and resilience planning.

The specific objectives of the study are as follows:

1. To document and analyze the existing housing conditions, homestead layouts, functional spatial practices, material use, and climate-related vulnerabilities of selected households in Nalian village, Sutarkhali Union, Dacope Upazila.
2. To identify vernacular housing patterns and local spatial logics, including the relationships between core houses, verandas, courtyards, kitchens, livestock shelters, storage areas, water sources, and livelihood spaces.
3. To develop a conceptual digital resilience model that connects architects, grassroots communities, and AI technology via a two-way feedback loop.
4. To propose a step-by-step AI-assisted housing design process, including plan generation, 3D form generation, and material assignment, based on local design practices, architect-suggested logics, simulation-informed studies, and material data.
5. To examine how a mobile app-based interface can deliver personalized housing solutions, self-help construction guidance, livelihood suggestions, and disaster preparedness.
6. To demonstrate how user feedback can refine the design database and improve housing and resilience solutions.
7. To assess the scalability of the proposed model for other rural and climate-vulnerable regions in Bangladesh.

The study proposes the following hypotheses:
H1: Local housing knowledge and vernacular practices can be translated into design databases for context-sensitive solutions.
H2: Architect-guided AI can generate personalized housing designs based on user requirements.
H3: An app-based digital platform can facilitate communication between architects and rural users.
H4: A feedback loop between users, architects, and AI technology can improve the adaptability of housing solutions.
H5: Integrating housing, livelihood, water, and disaster management in one digital resilience model can enhance rural climate resilience.

1.4 Significance of the Study

This study is significant because it proposes a conceptual pathway for extending architectural design support to rural communities through an AI-assisted digital system. In climate-vulnerable regions such as southwest coastal Bangladesh, rural households often rebuild, repair, or modify their homes with limited technical guidance, limited financial capacity, and increasing exposure to cyclones, flooding, salinity, and livelihood disruption. By proposing a system that connects architects, grassroots users, and AI technology, this research addresses the need for a more accessible, context-sensitive, and continuously improving design support mechanism.

The study contributes to architectural research by positioning rural housing as a dynamic design problem that combines spatial organization, climate responsiveness, local material use, livelihood functions, and disaster preparedness. Rather than treating rural houses only as shelter units, the proposed model considers them as part of a wider homestead and livelihood system. This is particularly important in coastal Bangladesh, where courtyards, verandas, kitchens, livestock shelters, storage spaces, water facilities, and livelihood-related activities are spatially interconnected.

The research also contributes to climate resilience studies by proposing a bottom-up digital resilience model. Existing rural development and disaster-management systems often work through top-down service delivery, where rural users receive support but do not always contribute to the continuous improvement of the system. In contrast, the proposed model emphasizes a two-way feedback loop, where rural users provide real-time feedback and usage data through the mobile app, and architects use that information to refine design databases, material logics, and future housing solutions. This creates a framework in which local experience becomes a continuous source of design knowledge.

The practical significance of the study lies in its potential to support self-help construction. The proposed app-based system can hypothetically provide rural users with personalized design options, step-by-step construction guidance, material lists, phased building strategies, repair suggestions, and disaster-preparedness instructions. It can also connect housing design with livelihood support, safe water facilities, and community communication. Although the AI system is not implemented in this study, the paper demonstrates how such a system may be structured in the future if adequate datasets, professional inputs, and technical tools become available.

2. Materials and Methods

2.1 Research Design and Methodological Approach

A conceptual design research approach was employed, supported by field-based spatial documentation, questionnaire surveys, architectural analysis, livelihood assessment, disaster-vulnerability observation, and simulation-informed design exploration. The study does not involve AI model development, coding, training, or computational testing. Instead, it proposes a conceptual digital resilience model to illustrate how AI could support climate-responsive rural housing, livelihood resilience, disaster preparedness, and user-centered design decision-making in future applications, provided that appropriate datasets, design logic, technical tools, and implementation capacity are available.

The methodology centers on three key actors: architects, rural users, and AI technology. Architects gather local knowledge through field surveys, spatial documentation, livelihood mapping, disaster-risk observation, and analysis of vernacular housing practices. These findings are translated into databases related to housing, materials, livelihoods, water management, and disaster response. In future implementations, these databases could support an AI-assisted system that generates personalized housing solutions based on user needs, including land area, functional requirements, family size, budget, local material availability, livelihood type, water access, cyclone vulnerability, flood risk, and salinity exposure.

Rural users are positioned as active participants rather than passive beneficiaries. The proposed local-language mobile interface would enable users to provide household information, livelihood requirements, material preferences, disaster concerns, and feedback on generated design options. The model incorporates a reward-based feedback mechanism, in which users may receive conceptual reward points for submitting feedback, updating household data, following disaster-preparedness guidance, selecting safer materials, maintaining water-management systems, and improving livelihood-supportive spaces. This reward system is intended to encourage continuous participation and to strengthen the feedback loop among users, architects, and the future AI-assisted design system.

This exploratory study combines local field evidence with architectural reasoning to demonstrate how AI could bridge the gap between professional expertise and rural self-help construction. The design outputs presented were manually prepared by the author and were not generated by a coded AI model. These outputs reflect field findings, vernacular spatial practices, livelihood needs, disaster-resilient design considerations, and climate-responsive architectural strategies. The study thus establishes a clear distinction between the current conceptual and manual design demonstration and the future potential for developing a fully functional AI-assisted application.

The methodological process comprised seven interrelated phases. The first phase involved field investigation of a selected homestead cluster in Nalian village, Sutarkhali Union, Dacope Upazila, Khulna. Activities included questionnaire surveys with household owners, photographic documentation, sketches of existing house forms and homestead layouts, drone-based imaging to identify land boundaries and spatial organization, and observation of local climate risks. The second phase focused on analyzing existing functional, livelihood, and vernacular practices, examining the relationships among core houses, verandas, courtyards, kitchens, livestock shelters, storage spaces, ponds, roads, water sources, farming areas, fishing-related spaces, and livelihood activities. The third phase translated field findings into design variables, such as land area, family size, room requirements, budget, material availability, livelihood type, water-management needs, cyclone risk, flood risk, salinity exposure, and emergency access.

The fourth phase entailed developing a conceptual AI-assisted housing and resilience workflow, including plan-generation logic, three-dimensional form-generation logic, material-assignment logic, livelihood-space allocation, and disaster-preparedness logic. The proposed system was structured to demonstrate how future AI technology could assist in generating personalized, climate-responsive, livelihood-sensitive, and disaster-resilient rural housing options. The fifth phase focused on designing a local-language mobile interface to ensure accessibility for rural users. This interface was conceptualized to support household data input, livelihood information, design-option review, disaster-preparedness guidance, and feedback submission. The sixth phase introduced a reward-based feedback mechanism to encourage user participation and continuous system refinement. The seventh phase involved the manual architectural demonstration of five user-based design solutions, illustrating how the proposed system could generate context-sensitive outputs with adequate data and technical implementation in the future. The methodological process of the study is summarized in Figure 1, which presents the conceptual digital resilience framework developed by the authors.

This methodological structure is appropriate for the study, as the research aims to develop a conceptual framework rather than test a completed technological product. It clarifies the design logic, data requirements, stakeholder relationships, livelihood integration, disaster-preparedness strategy, reward-based user engagement, and potential operational pathway of the proposed digital resilience model. Furthermore, it establishes the study's originality by positioning AI as a future decision-support mechanism that integrates professional architectural expertise, local knowledge, rural livelihoods, disaster resilience, and participatory feedback within a smart design-policy framework.

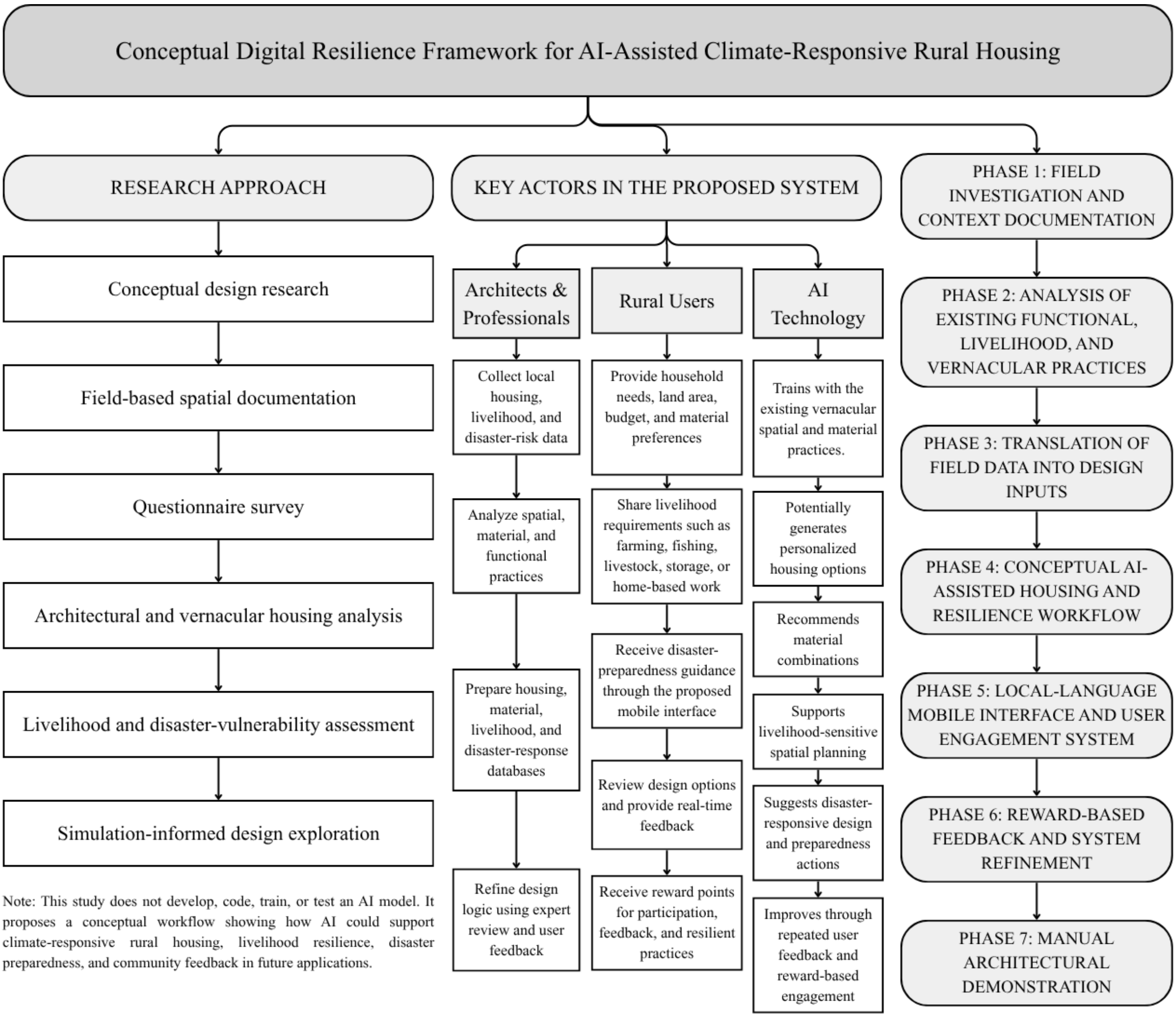


Figure 1. Methodological flow of the study showing the conceptual digital resilience framework. (Developed by the Authors)

2.2 Study Area and Case Selection

The study was conducted in Nalian village, Sutarkhali Union, Dacope Upazila, Khulna District (Figure 2). The area faces constant threats from cyclones, storm surges, salinity intrusion, flooding, and waterlogging because of its geographical position. The area faces significant challenges in housing, livelihood security, water access, and disaster resilience, which makes it ideal for investigating climate-resilient housing solutions.

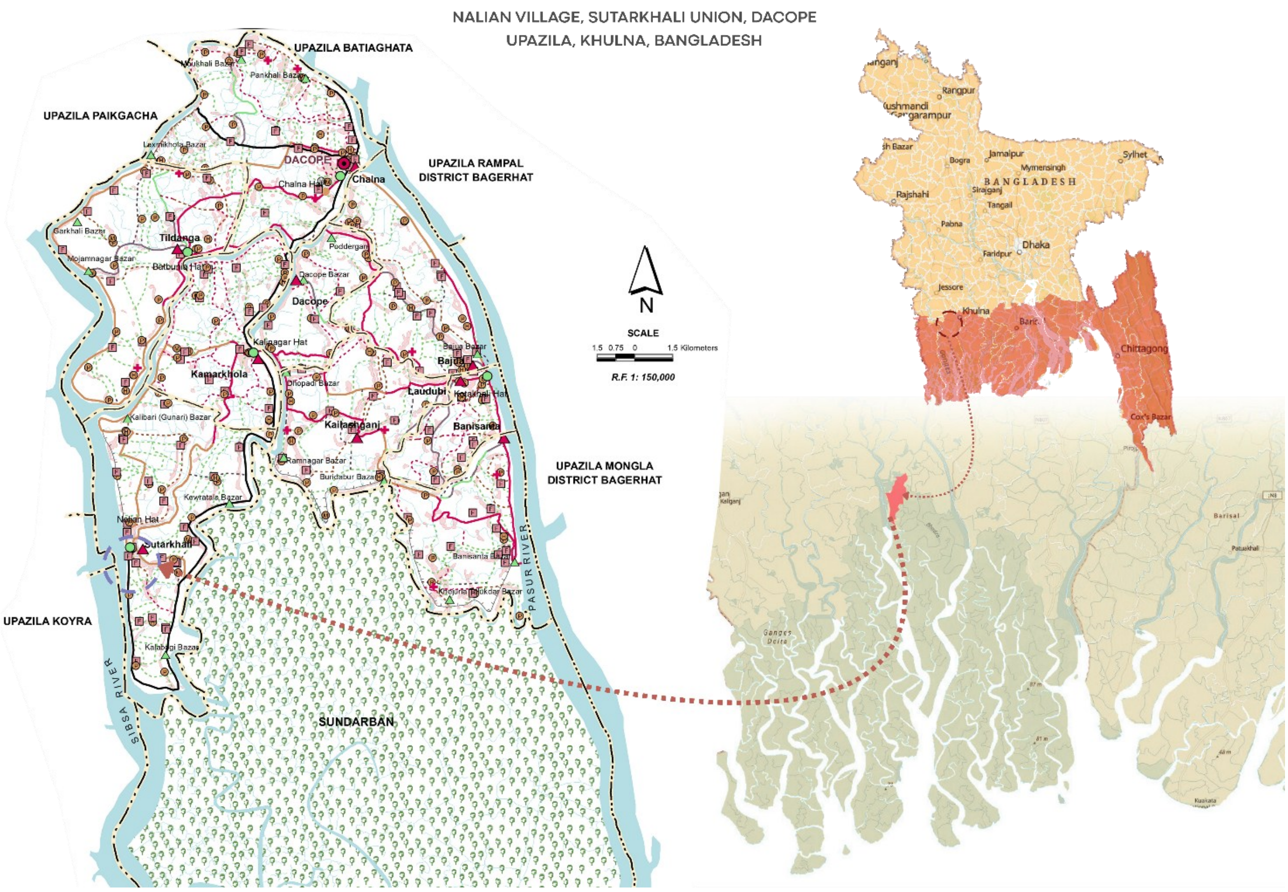


Figure 2. Map of the study area in Nalian village, Sutarkhali Union, Dacope Upazila, Khulna District (Developed by the Authors)

Five homesteads were selected based on housing diversity, proximity to the Shibsha River, and willingness to participate, offering insights for enhancing housing resilience in other coastal areas.

2.3 Field Survey and Primary Data Collection

Primary data were gathered through surveys, observations, and imaging to document housing, layouts, materials, and disaster resilience practices in Nalian. These data underpin the AI-assisted rural housing framework.

A questionnaire collected data on demographic information, housing preferences, resilience strategies, and livelihoods. Interviews provided insights into spatial practices and material preferences for the housing design database. Field observations along with sketches mapped homestead layouts and room positions. The use of materials like bamboo, mud, tin, and bricks was assessed for climate resilience. Photographs documented materials, vulnerabilities, and layouts, highlighting areas prone to cyclone damage. Drone images mapped homestead boundaries, geographical context, identified flood risks, and showed how homes are distributed in relation to hazards. All data were compiled into a design database, which is essential for developing the new AI-assisted resilience model database.

2.4 Conceptual Framework for AI-Assisted Housing Generation

2.4.1 Development and Implementation of the Conceptual Digital Resilience Model

The Digital Resilience Model, illustrated in Figure 3, integrates architectural design, local knowledge, and artificial intelligence to generate personalized housing solutions for rural communities. This model employs a feedback loop that connects architects, grassroots, and AI systems. Architects collect local knowledge through surveys and field observations, which is then used to develop a design database containing functional layouts and material specifications. The AI system processes user inputs such as land area, functional requirements, and budget to produce optimized designs with step-by-step guidance. The process is iterative, with AI-generated solutions presented to users via a mobile application, and user feedback incorporated to refine the system.

Figure 2 presents the sequential process for implementing the system in the field, with support from government bodies and agencies. These institutions will sponsor architects, AI engineers, software developers, and other professionals to collaborate on system development. Initial field surveys will collect local knowledge regarding housing practices, adaptation strategies, material usage, budget preferences, and vulnerabilities in existing housing designs. The collected data will inform the creation of a design database and three-dimensional forms to address climate-related vulnerabilities. Professionals will develop databases containing plans, three-dimensional models, and materials based on realistic, resilient designs. These designs will be tailored to site-specific requirements and will include detailed construction instructions. The application interface will integrate housing design with additional features for livelihood, water management, and disaster preparedness. It will support input in the local language and deliver accessible, user-oriented outputs. Non-governmental organizations or local bodies will train community members to use the system and will incentivize participation through rewards. User feedback will be incorporated into the system, enabling architects to refine designs and promote continuous improvement. This feedback loop will facilitate the ongoing evolution of the system, ensuring its relevance and adaptability, and fostering a dynamic, user-centered model that strengthens climate resilience in rural communities.

2.4.2 Conceptual Workflow for AI-Assisted Housing Generation

A conceptual AI framework is proposed to combine architectural knowledge, local practices, and environmental factors for generating climate-resilient housing. While generative AI design tools are not yet available, a possible three-step process for future development is outlined below.

The first step, plan generation, seeks to create contextually appropriate housing plans tailored to users' functional requirements. These plans are derived from vernacular layouts documented in a design database, which includes various functional configurations such as bedrooms, dining rooms, toilets, and storage, collected through field surveys in Nalian village. This process utilizes the Graph2Plan system, where the AI model retrieves and adapts plans based on land area, functional needs, and budget constraints (Hu et al., 2020). The system searches a database containing both vernacular and architect-designed plans, selects suitable designs, and refines them according to specific user preferences. Graph Neural Networks (GNNs) model spatial relationships between rooms, while Convolutional Neural Networks (CNNs) further refine the plans to ensure they fit within site boundaries and maintain vernacular integrity. This approach produces personalized housing plans that adhere to local architectural logic and climate-resilient principles. The second step is 3D form generation, in which architects initially approve and validate forms designed to withstand cyclone winds, flooding, and other environmental challenges. The final step is material selection, where the AI system matches materials from a local database according to cyclone resilience, salinity resistance, and cost-efficiency. Materials are chosen based on the user's budget, ensuring both durability and affordability while accounting for local market availability.

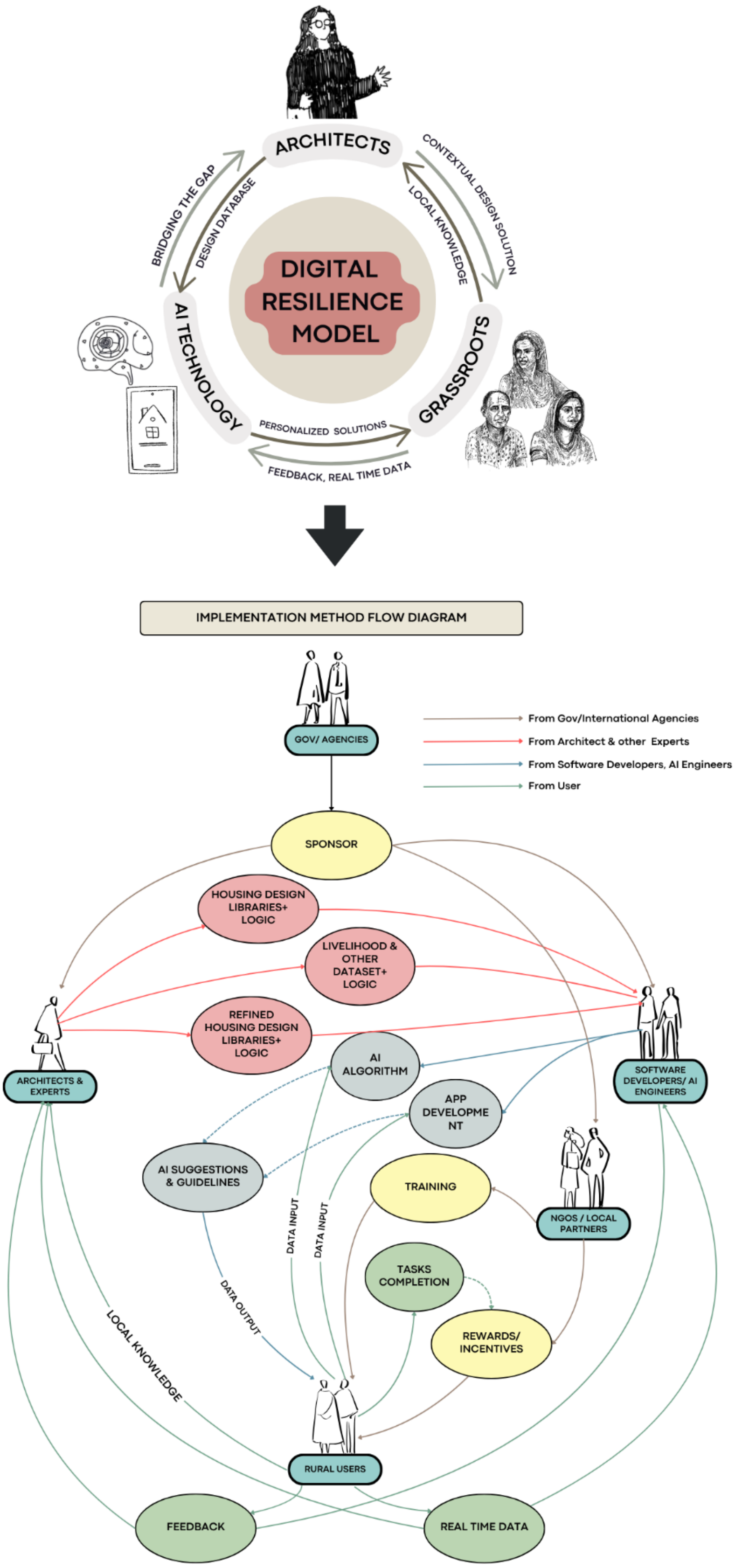


Figure 3. Digital Resilience Model and its Implementation Method Flow Diagram (Developed by the Authors)

2.4.3 Mobile Application Interface, User Journey, and Feedback Mechanism

The mobile application interface functions as the primary point of interaction between users and the AI-assisted housing generation system. After installation, users are required to create an account and provide essential data, including land area and specific functional requirements such as the number of rooms, kitchen, and storage spaces. Utilizing this information, the application generates personalized housing designs and enables users to select the most appropriate option. The application offers step-by-step construction instructions, supplemented by video tutorials and diagrams presented in the local language to ensure accessibility for users with diverse literacy levels. Users may adjust material selections to align with their budget, receiving real-time feedback regarding the impact of these changes on both functionality and structural resilience. A task-tracking system allows users to monitor their progress and earn rewards for completing activities such as house construction or livelihood-related tasks. Accumulated rewards may be redeemed for tools, healthcare services, and additional resources. The application incorporates a feedback mechanism that enables users to provide input on design elements, thereby refining the AI system and improving subsequent housing solutions. This iterative process increases the system's adaptability to local conditions.

2.5 Manual Development of Architectural Designs

Although the AI system remains conceptual and has not yet been implemented, this study presents manually developed housing designs for five users within the study area to illustrate the system's potential outputs. These designs are informed by data collected from field surveys and architectural analysis focused on disaster resilience and functional requirements. The manual designs exemplify how the AI system could, in principle, generate personalized housing solutions based on user inputs and context-specific data.

3. Results

3.1 Existing Homestead Conditions and Spatial Findings

Field observations provided essential data on demographic characteristics, livelihoods, land ownership, and household details, including construction materials and spatial organization for the five selected users (Table 1, Table 2). These data informed the creation of a design database for integration into the AI-assisted housing generation model. Functional layouts, which reflect vernacular practices and local living requirements, were then converted into Layout Graphs (Figure 4) for processing by a Graph Neural Network (GNN) during the plan generation phase.

Homesteads are generally organized around a central house containing bedrooms, dining areas, and multipurpose spaces. Verandas, which open onto a central courtyard, are used for storage, resting, and hosting guests. Separate toilet and tubewell areas ensure privacy and uphold cultural standards of cleanliness. Livestock shelters are located either adjacent to the house or in separate structures. Construction materials are primarily sourced locally, including mud, wood, bamboo, and golpata, selected for their affordability and availability near the Sundarbans. In recent years, more durable materials such as bricks, pre-cast concrete columns, and tin sheets have been introduced. However, tin sheets remain susceptible to wind damage, resulting in roof failures and, in some cases, fatalities from airborne debris.

Proximity to the Shibsha River exposes these homesteads to significant flood risks, prompting the elevation of homes on plinths up to four feet high. These plinths have been upgraded from mud to brick and cement to improve waterproofing. Nevertheless, saltwater intrusion and erosion continue to threaten housing, potable water, and agriculture. Adaptation measures include constructing temporary shelters during floods, although storm-resistant features such as tin-sheet overhang roofs often fail during cyclones. Most adaptations remain reactive, highlighting the absence of proactive, long-term design strategies for climate resilience.

Table 1: Database of the selected five users' demographic data, land ownership, and household details.

User No	Demographic Data						Land Ownership		Household Details				
	Owner's Name	Age	Sex	Occupation	Spouse	Family Members	Household	Agriculture land	House No	Toilet	Water Reservoir	Pond	Livestock
1	Mr. Sabdul Sardar	70	Male	Crab Catcher, Fisherman		6	Yes	No	3	2	2	1	Goat
2	Mrs. Saru Begum	45	Female	Fisherman	-	2	Yes	No	2	1	1	1	-
3	Mrs. Morjina	55	Female	Fisherman	-	2	Yes	No	2	1	1	1	Duck
4	Mr. Rezaul Gazi	44	Male	Crab Catcher, Fisherman, Farmer (Agriculture)	Tailor	8	Yes	Yes	5	1	2	1	Cow, Duck
5	Mrs. Firoza	27	Female	Tailor	Crab Catcher, Fisherman	4	Yes	No	2	1	1	1	-

Table 2: Database of the selected five users' homestead details of construction elements & materials.

	Homestead No.	Made By	Function	Plinth	Wall	Column	Beam	Roof	Rafter	Window
Household 01 Mr. Sabdul Sardar	**H1**	NGO	Bed + Dining	Mud	CGI Sheet	Pre-cast Concrete	Pre-cast Concrete	Cement Sheet	Wood	Wood
	H2	NGO	Bed	Mud	Cement Sheet, Golpata (Veranda)	Pre-cast Concrete	Pre-cast Concrete	Cement Sheet	Wood	Wood
	H3	Self	Kitchen + Goat shed	Mud	Golpata	Tree Trunk	Tree Trunk, Bamboo	Golpata, Bamboo purlin	Wood	Wood
	T1	NGO	Toilet	Brick-Cement	CGI Sheet	Pre-cast Concrete	Wood	Cement Sheet	Wood	-
	T2	NGO	Toilet	Brick-Cement	CGI Sheet	Pre-cast Concrete	Wood	Cement Sheet	Wood	-
Household 02 Mrs. Saru Begu	**H1**	NGO	Bed	Mud	Cement Sheet	Pre-cast Concrete	Pre-cast Concrete	Cement Sheet	Wood	Wood
	H2	Self	Kitchen + Storage	Mud	CGI Sheet	Tree Trunk, Bamboo	Tree Trunk, Bamboo	Golpata, Bamboo purlin	Wood	Wood, CGI Sheet
	T1	NGO	Toilet	Brick-Cement	CGI Sheet	Pre-cast Concrete	Wood	Cement Sheet	Wood	-
Househ old 03	**H1**	NGO	Bed	Brick-Cement Mud (Veranda)	Cement Sheet CGI Sheet (Veranda)	Pre-cast Concrete	Concrete post	Cement Sheet	Wood	Wood

	H2	Self	Kitchen + Storage	Mud	Golpata	Tree Trunk, Bamboo	Tree Trunk, Bamboo	Golpata, Bamboo purlin	Wood	-
	T1	NGO	Toilet	Brick-Cement	CGI Sheet	Pre-cast Concrete	Wood	Cement Sheet	Wood	-
Household 04 Mr. Rezaul Gazi	**H1**	Self	Bed	Brick-Cement	CGI Sheet	Pre-cast Concrete	Pre-cast Concrete	Cement Sheet	Wood	Wood
	H2	Self	Kitchen + Storage	Mud	CGI Sheet, Golpata	Pre-cast Concrete	Pre-cast Concrete	Cement Sheet	Wood	Wood
	H3	NGO	Bed	Mud	CGI Sheet, Golpata	Pre-cast Concrete	Pre-cast Concrete	Cement Sheet	Wood	Wood
	H4	Self	Bed	Mud	Golpata	Tree Trunk	Tree Trunk, Bamboo	Golpata, Bamboo purlin	Bamboo	-
	H5	NGO	Cow shed	Mud	Top wall Golpata	Pre-cast Concrete, Tree Trunk	Wood plank Tree Trunk, Bamboo	Cement Sheet	Wood	-
	T1	NGO	Toilet	Brick-Cement	CGI Sheet	Pre-cast Concrete	Wood	Cement Sheet	Wood	-
Household 05 Mrs. Firoza	**H1**	NGO	Bed	Mud	Cement Sheet	Pre-cast Concrete	Pre-cast Concrete	Cement Sheet	Wood	Wood
	H2	NGO	Kitchen + Storage	Mud	Cement Sheet	Pre-cast Concrete	Pre-cast Concrete	Cement Sheet	Wood	-
	T1	NGO	Toilet	Brick-Cement	CGI Sheet	Pre-cast Concrete	Wood	Cement Sheet	Wood	-

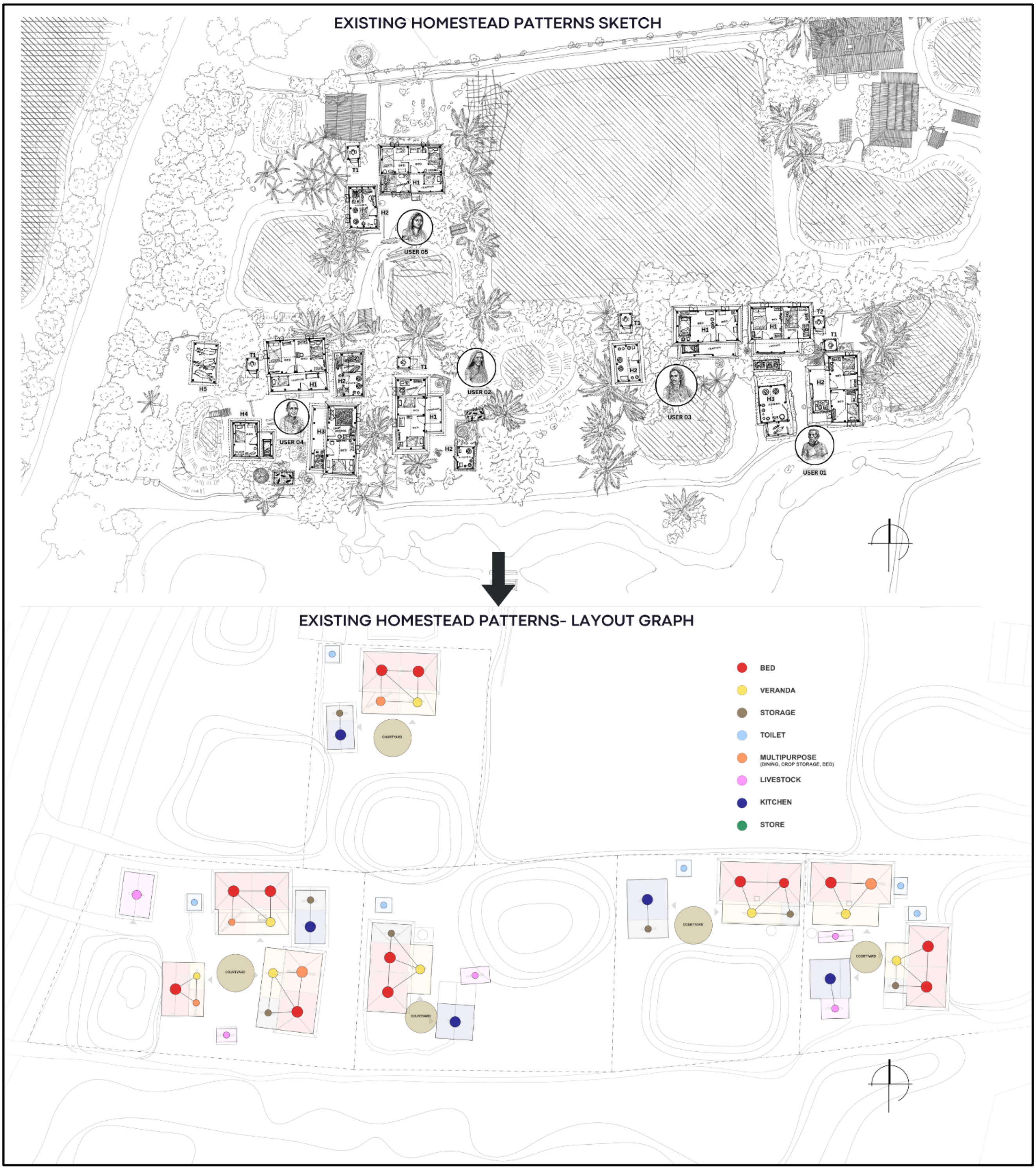


Figure 4. Transformation of existing homestead functional layouts into Layout Graphs. (Developed by the Authors)

3.3 AI-Assisted Housing Generation Workflow Result

The AI-assisted housing generation process employs a three-step pipeline to produce context-sensitive, climate-resilient housing solutions. This pipeline consists of plan generation, 3D form generation, and material assignment. Each stage builds upon the previous one, utilizing data from the design database, user inputs, and architectural logic to develop tailored housing solutions. The following sections detail the specific results of each stage.

3.3.1 Plan Generation Output Logic

The Plan Generation step is the initial stage of the AI-assisted housing generation workflow. This stage begins with user inputs, including land area, boundary, and functional requirements such as the number of bedrooms, storage space, and veranda. These inputs are used to search the design database, which contains both vernacular and architecturally improved housing layouts. The AI system matches user inputs to the most suitable plans in the database and adjusts layouts to specific preferences, including room adjacency and spatial flow.

The Plan Generation process uses Graph Neural Networks (GNNs) to optimize functional layouts by encoding spatial relationships among rooms and their adjacencies within boundary constraints. The system evaluates multiple design options and selects the most optimal layouts for user consideration. Subsequently, the Convolutional Neural Network (CNN) process refines these layouts by incorporating natural factors such as ventilation, lighting, and climatic conditions. Figure 3 presents the workflow of the CNN and GNN models for plan generation, illustrating how they process user input to produce optimized, context-sensitive housing designs.

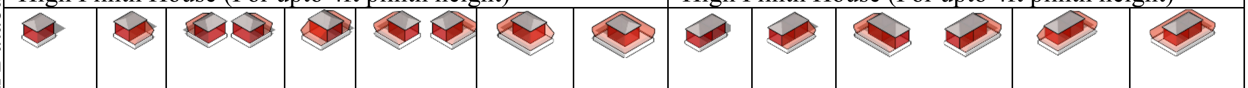
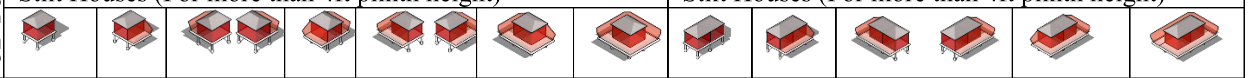
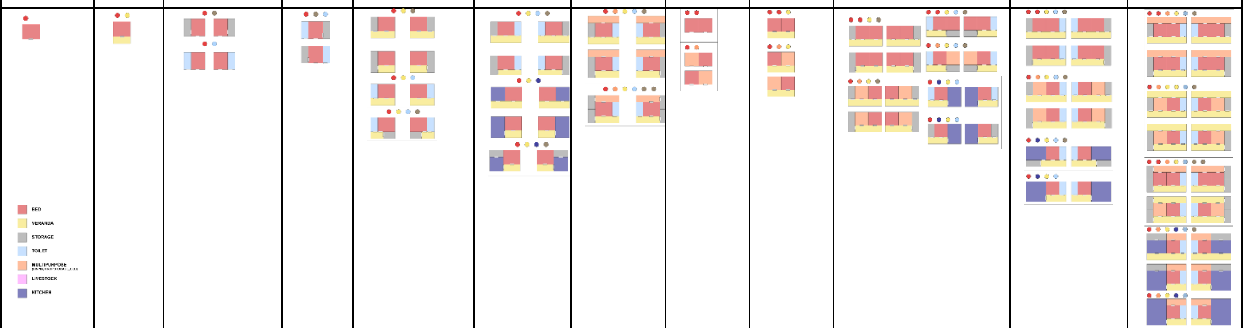
3.3.2 3D Form Generation Output Logic

At this stage, the system selects the appropriate 3D form for the housing design from a pre-existing 3D form and plan database, as shown in Table 3, developed by architects. This stage integrates the plan database with the associated 3D forms, automatically selecting the optimal form according to the housing plan.

Rhino Flow RT is used for wind simulations to identify the most aerodynamic 3D forms. The wind simulation results, presented in Table 4, demonstrate improvements in roof shapes that reduce wind resistance and prevent uplift.

For this study, two types of 3D forms were generated- the high plinth house and the stilted house. The selection between these forms is based on analysis of the user's geographical location and flood risk assessment. In flood-prone areas, the system selects the stilted house design, which elevates the living space above floodwaters. In areas with lower flood risk, the system selects the high plinth design, which raises the house above ground level to protect against waterlogging and seasonal flooding. This selection process ensures that housing designs are appropriate for local environmental conditions and maintain cyclone resilience.

Table 3: Database of 3D Forms and Plan Layouts.

	1 Room Core House	**2 Room Core House**
3D Form Database	High Plinth House (For upto 4ft plinth height)	High Plinth House (For upto 4ft plinth height)
		
	Stilt Houses (For more than 4ft plinth height)	Stilt Houses (For more than 4ft plinth height)
		
Plan Database (Layout Grap		
	Services (Kitchen, Livestock)	**Shops**
3	Regular Plinth Height	High Plinth Shops (For upto 4ft plinth height)

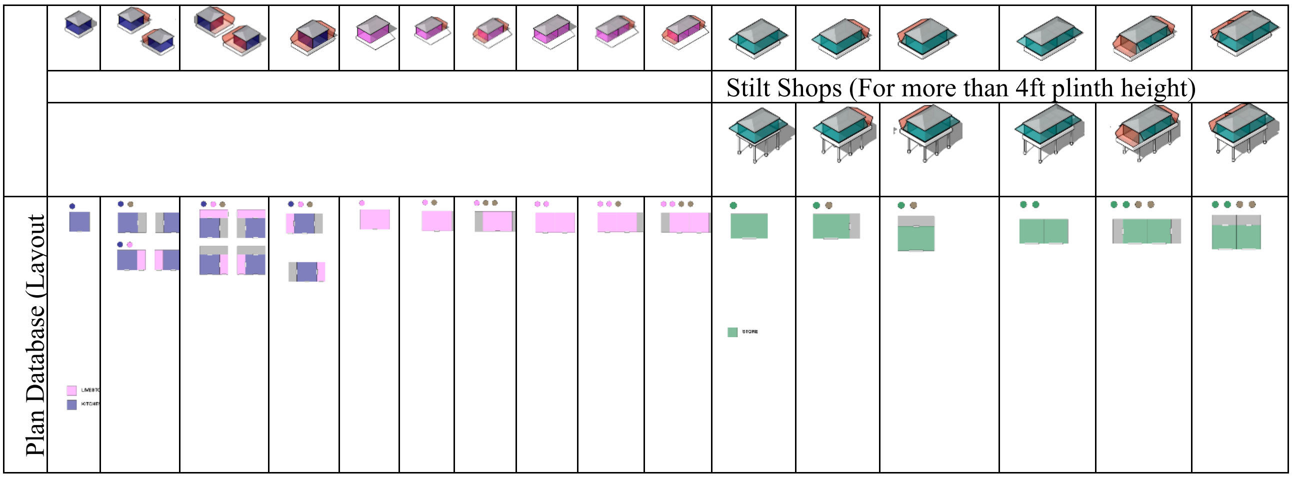


Table 4: Comparison of Wind Simulation Results for Existing and Proposed House Form in Rhino Flow-Rt.

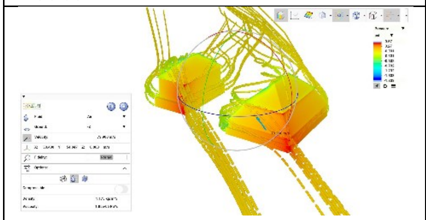
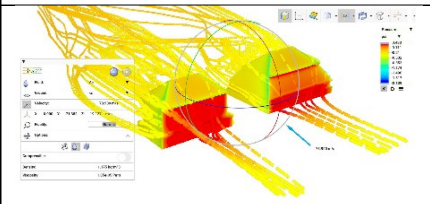
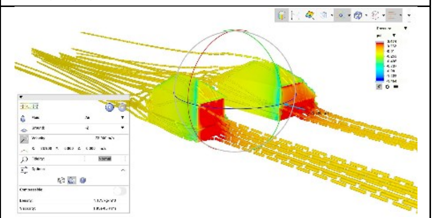
Wind Pressure at the corner of the house	**Wind Pressure on the Longer Facade**	**Wind Pressure on the Shorter Facade**
 Left: Existing House Form, Right: Proposed House Form	 Left: Existing House Form, Right: Proposed House Form	 Left: Existing House Form, Right: Proposed House Form

Figure 5 presents the flow diagram for the AI-assisted housing design process. The diagram outlines the sequence of user inputs, such as land area, functional requirements, and budget, which are utilized to retrieve and adjust plans from the backend database. These plans are then matched with suitable 3D forms according to the user's specific needs and environmental factors, including flood risks. The structural type of the 3D forms, either frame structure or load-bearing structure, is determined based on the selected plan and 3D form. If the form includes any exposed straight wall of the core house, a load-bearing structure is selected to resist cyclone winds; otherwise, a frame structure is chosen to facilitate easy dismantling of the entire house if necessary. The selected forms then proceed to the material assignment stage for further design development.

3.3.3 Material Assignment Output Logic

The third step in the AI-assisted housing generation workflow is material assignment. During this phase, the system selects suitable materials from a local material database based on the housing design structure type (Figure 6). The database contains locally available materials, including traditional options such as mud, bamboo, brick, and wood, as well as industrial materials such as corrugated or flat tin sheets, precast concrete column beams, metal bracings, and cement sheets. Each material is assigned a resilience rating from 1 to 10, indicating its resistance to wind and water damage. Local market prices are periodically updated in the database.

The material selection process further considers the building elements such as the foundation, walls, beams, and roof, and their positions according to the structure type. The AI system then automatically selects appropriate materials for each element, taking into account the structure type and climatic conditions. This targeted assignment ensures that each component is optimized for environmental factors and the resources available in the region.

The final output is a comprehensive 3D visualization model of the house, which displays the assigned materials within the selected 3D form. This approach ensures that the resulting design is structurally sound, resilient, practical, affordable, and tailored to local needs, thereby making it suitable for implementation by the intended users.

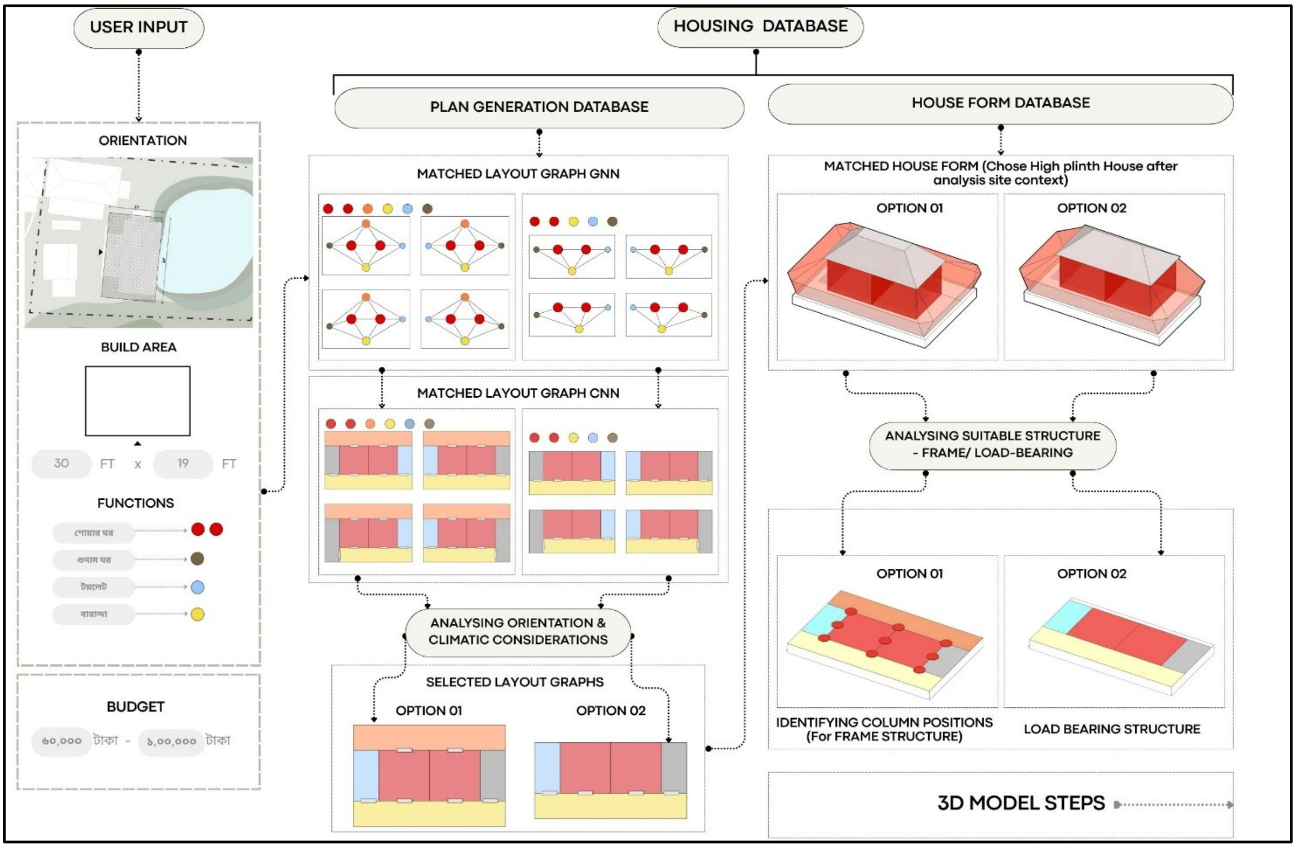


Figure 5. Flow diagram illustrating the user input process, backend plan retrieval and adjustment from the database, and the selection of 3D forms assigned to the plans for subsequent material assignment. (Developed by Authors)

3.4 Mobile App Interface and User Experience Flow

The mobile app provides a user-friendly platform for rural households to interact with the AI-assisted housing system. It guides users through selecting, customizing, and building housing designs, even for those with limited technological expertise. Upon launching the app, users create an account and provide personal details to generate a personalized profile. The main dashboard includes five sections: House, Livelihood, Disaster Management, Water, and Contact for easy navigation.

In the House section, users can choose to build a new house or repair an existing one, providing inputs like land area, functional needs, and budget. The AI system generates personalized design options with step-by-step instructions and 3D visualizations. Users can also adjust materials based on budget and local availability, with alternative options provided if necessary.

The Material Assignment feature helps users select resilient materials, ensuring affordability without compromising quality. Once final designs and materials are selected, users receive a step-by-step construction guide (Figure 7), along with video tutorials, ensuring clarity for easy self-construction.

In addition to the step-by-step guidelines, users receive a comprehensive material list that includes all required building elements and pricing details based on local market rates. The application also enables users to contact local sellers directly, thereby streamlining the purchasing process. The Contact page of the application presents users with a directory of local builders available to assist with construction. This feature ensures access to professional support when required, while preserving users' autonomy in managing the construction process.

The application incorporates a feedback system that enables users to evaluate their designs according to functionality, usability, and aesthetic criteria. This feedback is transmitted to architects, facilitating refinement of AI-generated designs and enhancement of subsequent versions.

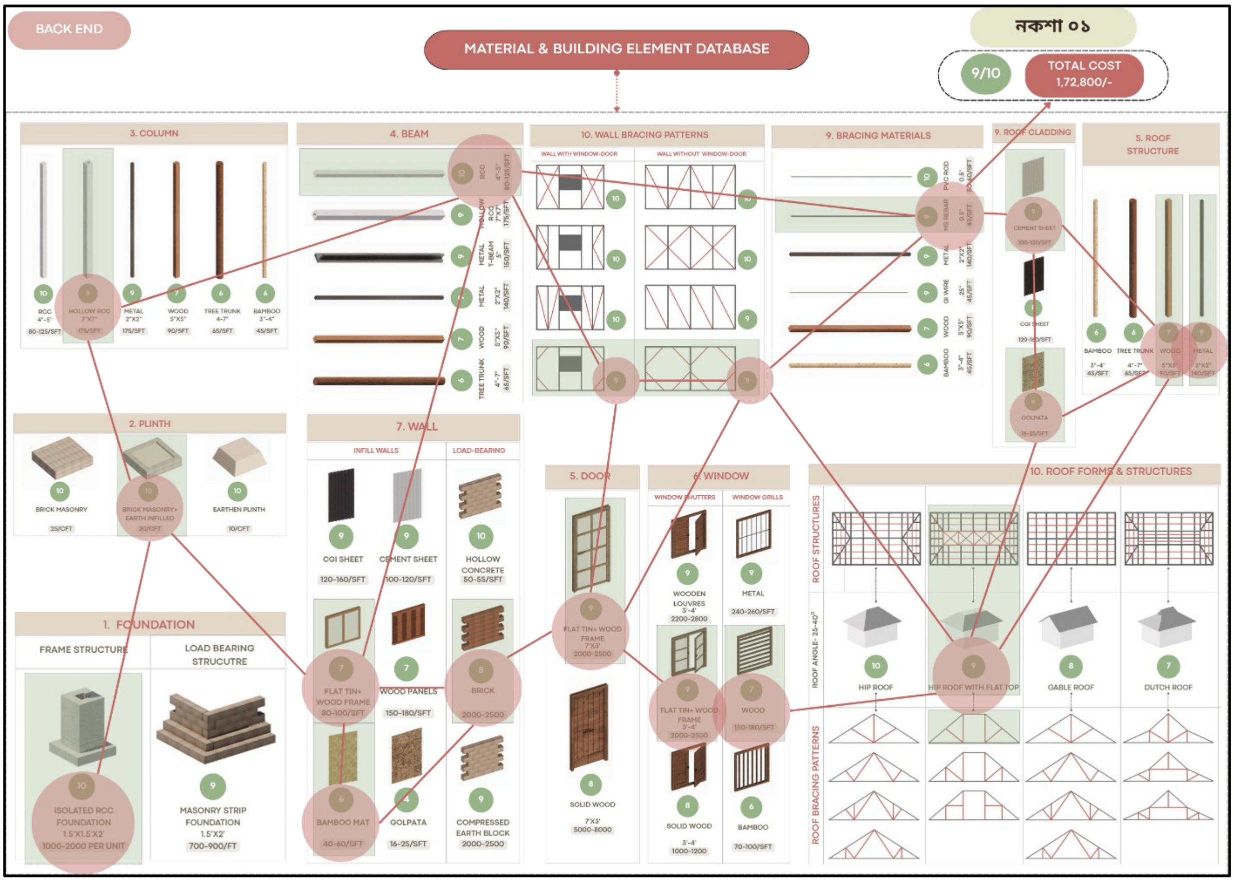


Figure 6. Material selection process based on user budget and resilience ratings, ensuring an optimal choice for the housing design. (Developed by Authors)

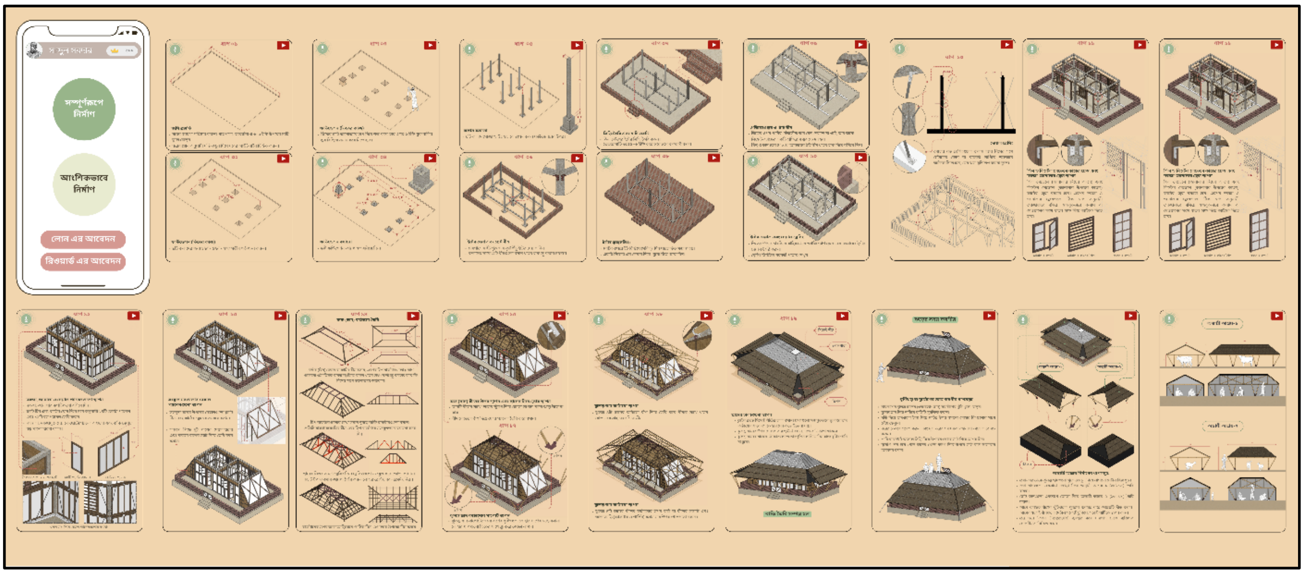


Figure 7. Step-by-step construction guideline for users, demonstrating the house building process with dimensions and instructions in the local language. (Developed by Authors)

Figure 8 presents the functional framework of the housing section within the AI application. After construction is completed, experts visit the site to assess the finished house and grant rewards based on task completion.

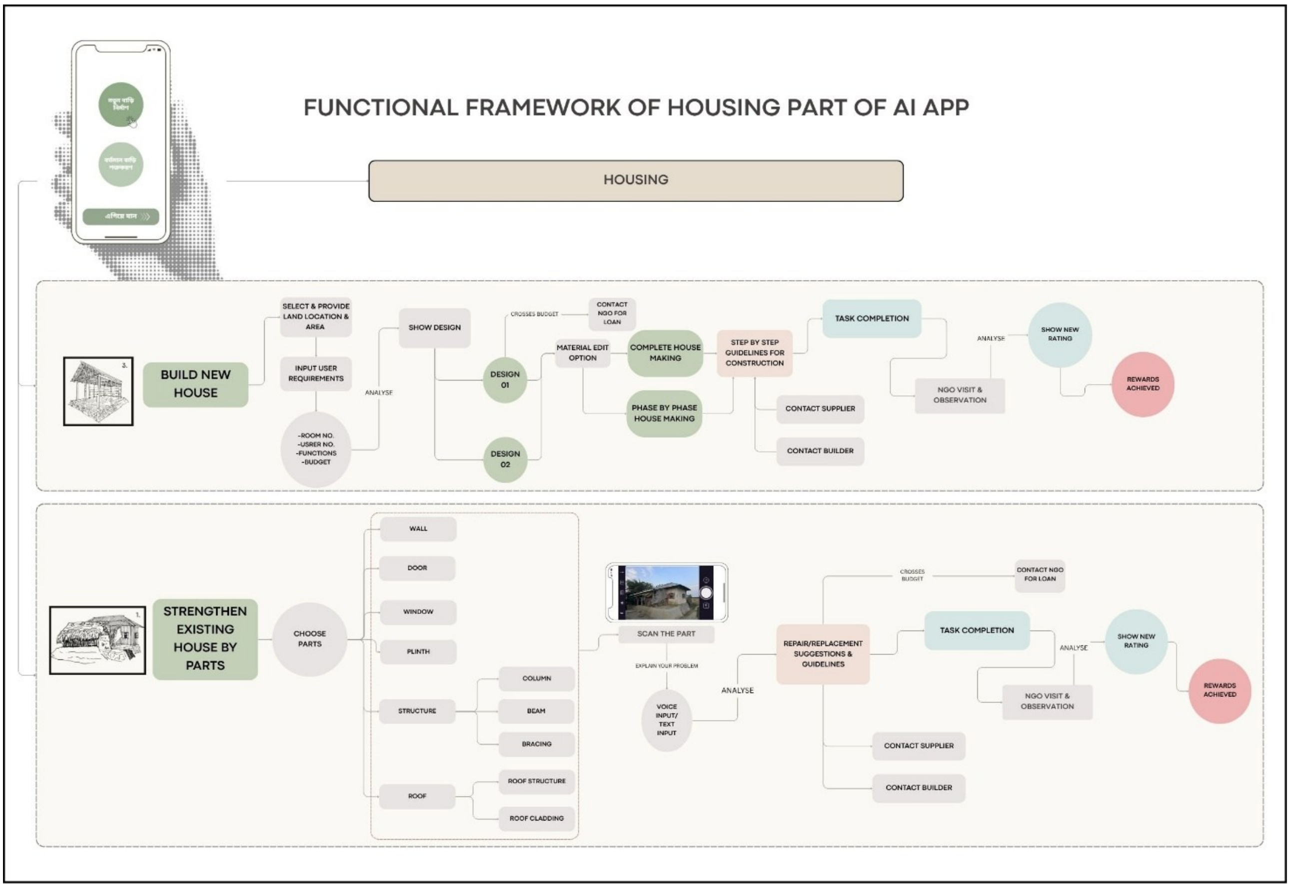


Figure 8. Functional Framework of Housing Part of AI App. (Developed by Authors)

The Livelihood section (Figure 9) is intended to support users in improving their economic circumstances by presenting region-specific livelihood options, such as farming, fishing, crabbing, livestock rearing, and day labor for Nalian village. The application offers guidance on improving agricultural practices and increasing productivity, providing step-by-step instructions on selecting saline-resistant crops, managing water, and undertaking seasonal activities. By incorporating disaster-resilient agricultural methods, the application assists users in safeguarding their livelihoods against environmental hazards. The Contact section provides users with essential local contacts, including fishermen, crabbers, day laborers, and other relevant stakeholders. This section serves as a communication hub, facilitating direct interaction with local stakeholders and organizations that can offer material resources, construction labor, technical assistance, and livelihood support.

The Disaster Management section is integral to enhancing community resilience against cyclones, floods, and other natural disasters. The application provides early warning alerts, offering up to a seven-day forecast of potential disasters specific to each user's location. It recommends evacuation plans, supplies emergency contact information, and assists users in identifying secure shelter locations during storms. When homes are at risk of damage, the application advises contacting core house users for shelter. Additionally, it guides the creation of temporary shelter options by dismantling designed houses and outlines essential preparations to protect households.

The Water section focuses on water management by offering tools and recommendations to enhance water storage, rainwater harvesting, and filtration systems. The application allows users to apply for water-related incentives, such as water tanks, rainwater-harvesting pipes, and filters, thereby increasing access to safe water for domestic use.

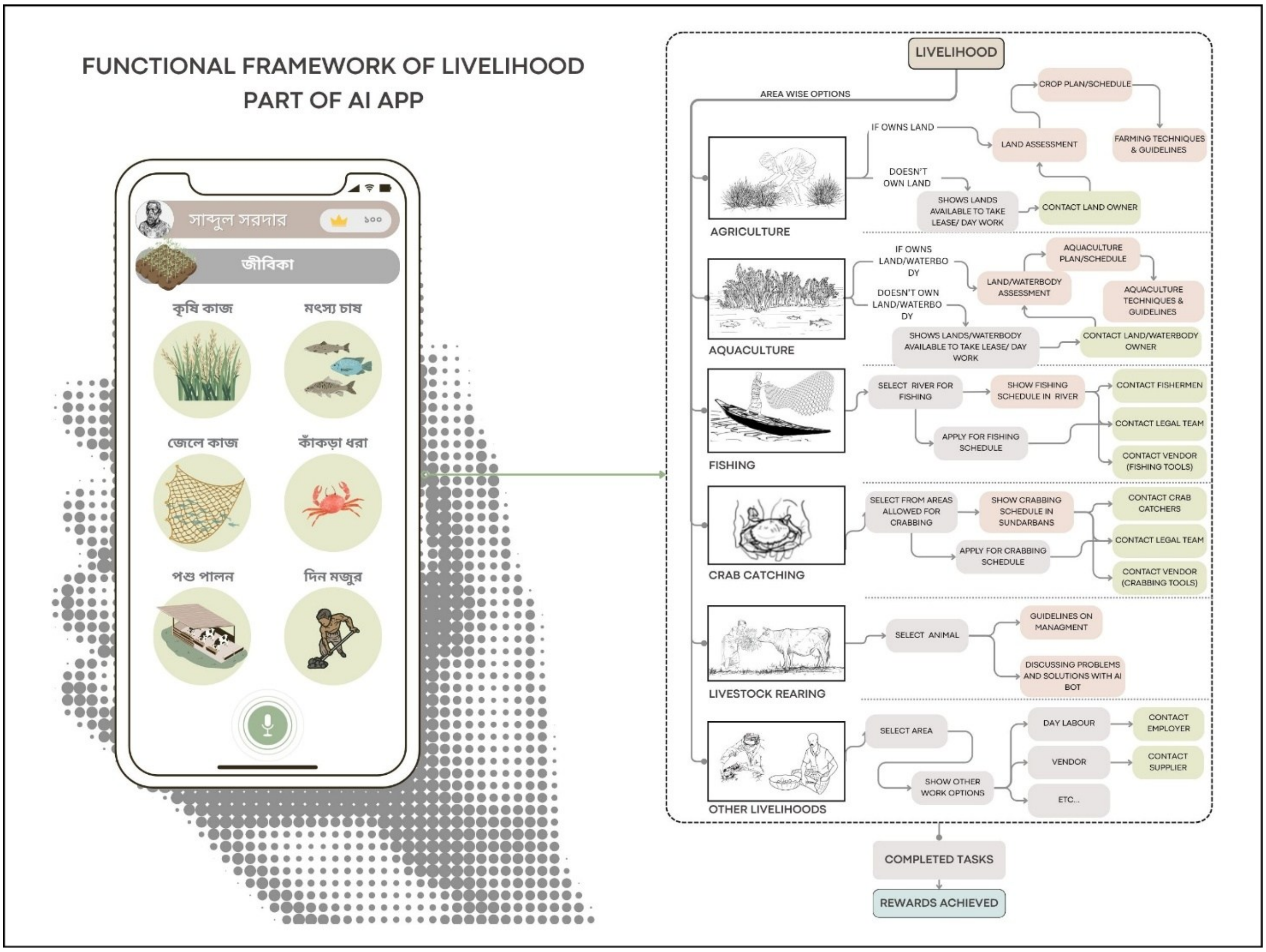


Figure 9. Functional Framework of Livelihood Part of AI App. (Developed by Authors)

3.5 Demonstration of House Design Solutions for Five Users

The following subsections present the manually created conceptual AI-generated housing design solutions for five selected users from the Nalian village cluster (Table 5). These designs were generated based on their specific functional requirements, land area, and budget constraints. Each design demonstrates how the AI system could generate personalized solutions by leveraging the design database, material database, and wind-simulation results.

In all of these houses, cyclone resilience is achieved through an aerodynamic roof shape, informed by wind simulation results. The low overhang roofs can be closed during storms to minimize wind exposure, thereby reducing wind uplift and protecting the core house's structural integrity. These roofs are also designed to be dismantled during emergencies, enabling the creation of temporary shelters for the family or livestock.

3.5.1 House 1: User 1 – Sabdul Sardar

User 1, Sabdul Sardar, required a two-room core house with additional storage, a toilet, and two verandas. The house, measuring 29'10" x 19', includes one bedroom and a multipurpose room that serves as a dining or living area in the core house. Two verandas on either side enhance ventilation, provide functional spaces for rest or storage, and act as protective buffers against cyclone damage. Toilet and storage are placed on both sides.

A raised plinth mitigates flood risk by providing protection from inundation. The isolated reinforced cement concrete (RCC) foundation and brick masonry plinth ensure a durable base. The house is designed as a frame structure, allowing for complete dismantling and relocation if necessary after a disaster. Materials include precast concrete columns and beams, flat tin with wooden-framed infill walls, and cement-sheet cladding for the core house roof. The metal roof structure and wall bracing enhance structural integrity, while golpata and bamboo are used for the overhang roofs to provide natural cooling and cost-effectiveness.

3.5.2 House 2: User 2 – Saru Begum

User 2, Saru Begum, required a one-room core house with a large kitchen and dining area, an additional toilet, and two verandas. The house measures 29'10" x 19'.

The one-room core house serves as both a bedroom and a living space, designed for multifunctionality. The additional kitchen/dining area provides ample space for daily activities, while the two verandas offer extra space for storage or livelihood use. These verandas also act as protective buffers against strong winds during a cyclone.

Like House 1, House 2 is a frame structure, allowing the entire house to be dismantled for relocation. The material selection for House 2 mirrors that of House 1, with a focus on resilience and affordability. Both House 1 and 2 have attic space under the core house roof, which is generally used as storage space, that can be converted to shelter space during disaster events.

3.5.3 House 3: User 3 – Mrs. Morjina

User 3, Mrs. Morjina, required a service house designed to accommodate a kitchen and a small livestock shelter. The key requirements were to allow easy access to both the kitchen and the livestock, while ensuring serviceability and cyclone resilience.

The house, measuring 23’4” x 10’6”, includes a kitchen area that is directly connected to a small livestock shelter, specifically designed for goat rearing. The house also features tilted walls with low overhang roofs on the left and right sides. These roofs serve a dual purpose: they allow smoke to be removed from the kitchen and create space for feeding livestock. During cyclones, these overhang roofs can be closed to protect the structure from wind damage, enhancing the house's cyclone resilience.

The materials selected for this house include brick masonry, with precast concrete columns and beams for structural stability. The roof is made of cement sheets, and the internal infill wall is constructed from bamboo mat & wooden frame, which provides flexibility to modify the interior spaces as needed. The overhang roofs are made of golpata, supported by bamboo.

3.5.4 House 4: User 4 – Mr. Rezaul Gazi

User 4, Mr. Rezaul Gazi, required a livestock house designed to accommodate cows. The house was intended as a large, open space for livestock, with easy external access for feeding and maintained cyclone resilience.

Similar in size and materials to House 3 (23’4” x 10’6”), this house is specifically designed to house cows. The structure consists of a large, open interior space, where cows stand on both ends of the house. Food is provided through outside openings on the left and right sides, allowing for easy feeding. The design incorporates tilted walls and low overhang roofs on both sides, similar to House 3. These roofs help with ventilation by removing odor from the interior, and also provide a means to protect the cows during cyclone events. The materials used are identical to those in House 3.

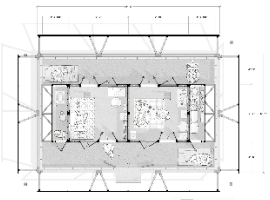
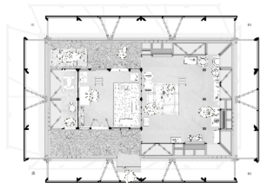
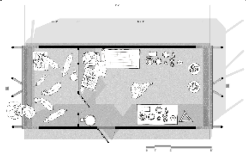
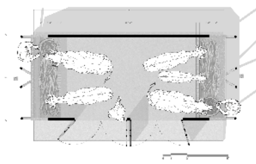
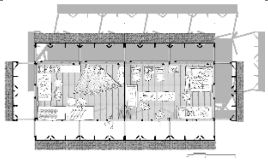
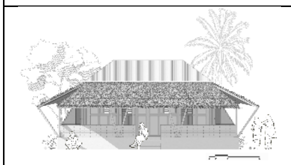
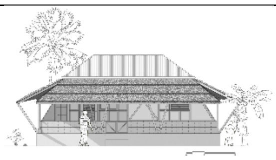
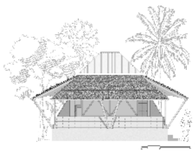
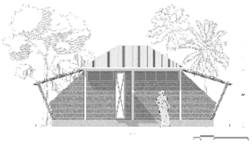
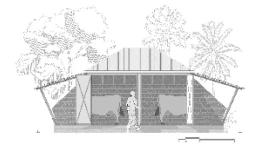
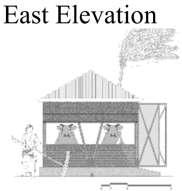
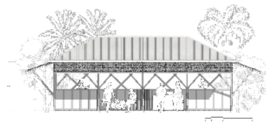
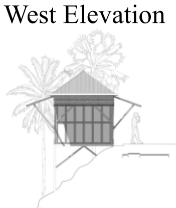
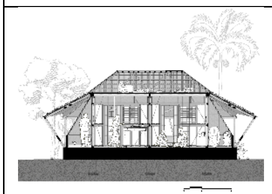
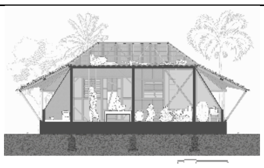
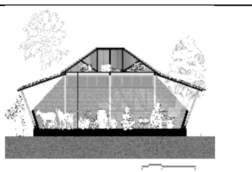
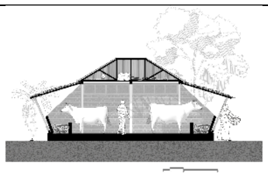
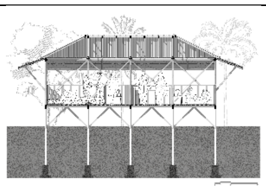
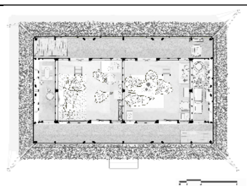
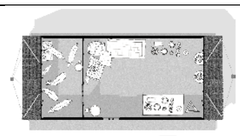
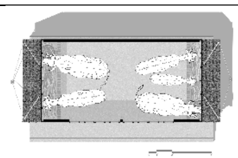
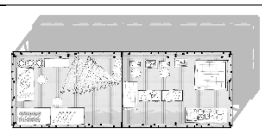
3.5.5 House 5: User 5 – Mrs. Firoza (Shop)

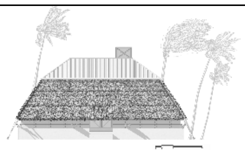
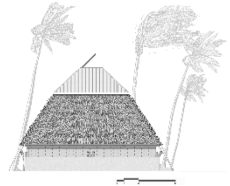
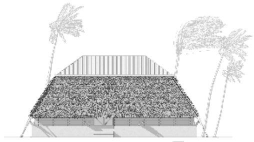
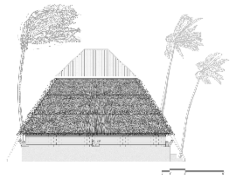
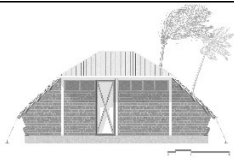
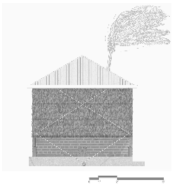
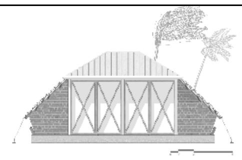
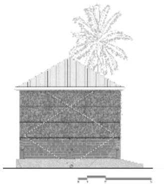
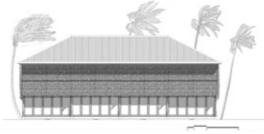
User 5, Mrs. Firoza, required a stilted shop for her business. The design needed to accommodate two shops: one for renting and the other for selling goods.

The shop, measuring 30' x 10', is built on stilts to align with the polder height, providing elevated protection against flooding. The shop’s half-open walls offer adequate ventilation while maintaining visibility for customers. The cyclone resilience of the shop is ensured through low overhang roofs, which can be closed during cyclones to protect the inside from wind damage. The stilted foundation is reinforced with bracings, ensuring additional structural strength to withstand strong winds and other disaster-related stresses.

The materials chosen for the construction of this shop include pre-cast concrete columns for the stilted foundation, ensuring durability and flood protection. The bamboo flooring offers an affordable, sustainable option while maintaining flexibility. The half walls are made from a combination of flat tin and wooden-framed infill, the main roof is made from cement sheets, while the low overhang roofs are constructed with golpata cladding and bamboo structures, allowing for easy dismantling during disaster events for temporary shelter.

Table 5: Designs of Five Homesteads

	HOUSE 01	**HOUSE 02**	**HOUSE 03**	**HOUSE 04**	**HOUSE 05**
Users	 **USER 01** **Mr. Sabdul Sardar**	 **USER 02** **Mrs. Saru Begum**	 **USER 03** **Mrs. Morjina**	 **USER 04** **Mr. Rezaul Gazi**	 **USER 05** **Mrs. Firoza**
Function	2 room Core House, Additional: Storage, Toilet, Veranda	1 room Core House, Additional: Kitchen, Toilet, Veranda	Service: Kitchen, Livestock (Goat)	Service: Livestock (Cow)	Roadside Shop: 2 rooms
Regular Times	 Plan at 6’9”	 Plan at 6’9”	 Plan at 6’9”	 Plan at 6’9”	 Plan at 17’
	 West Elevation  North Elevation	 North Elevation  East Elevation	 East Elevation  South Elevation	 East Elevation  South Elevation	 West Elevation  South Elevation
	 Section	 Section	 Section	 Section	 Section
Cyclone Times	 Plan at 6’9”	 Plan at 6’9”	 Plan at 6’9”	 Plan at 6’9”	 Plan at 17’

	 West Elevation  North Elevation	 North Elevation  East Elevation	 East Elevation  South Elevation	 East Elevation  South Elevation	 West Elevation  South Elevation
Perspective Visualization					

4. Discussion

4.1 Interpretation of Key Findings

This conceptual study demonstrates the potential of an AI-assisted, architect-supervised, and locally informed design framework to support climate-responsive self-help housing in rural communities. The primary finding is that rural housing resilience can be enhanced when architectural expertise, vernacular spatial practices, household-specific needs, livelihood requirements, and disaster-risk information are integrated within a unified digital resilience model. Instead of viewing housing as an isolated physical structure, the proposed framework situates rural housing within a broader adaptive system linked to livelihood security, water management, disaster preparedness, and user participation.

The significance of this study is its contribution to smart design-policy approaches for climate-vulnerable rural settlements. Existing rural housing interventions are frequently standardized, top-down, or limited to structural improvements. In contrast, the proposed approach offers a more flexible decision-support pathway, enabling architects to collect field-based knowledge and translate it into design, material, livelihood, and disaster-response databases. In future applications, these databases could facilitate AI-assisted generation of personalized housing options based on land size, family structure, budget, material availability, livelihood practices, water access, salinity exposure, cyclone risk, and flood vulnerability. Thus, the study connects design intelligence to community-based adaptation and offers a potential approach to making professional housing guidance more accessible to rural users.

The findings indicate that vernacular housing practices continue to serve as valuable sources of design knowledge. Elements such as courtyard use, veranda-based transition spaces, homestead clustering, livelihood-supportive outdoor areas, local material practices, and water-related spatial arrangements offer practical design cues for climate-responsive rural housing. Integrating these local practices with AI-assisted design logic enables the proposed model to generate housing solutions that are technically advanced, culturally familiar, functionally relevant, and accessible to users. This approach reinforces the study's originality by positioning AI as a decision-support tool that mediates between professional expertise and rural self-help construction, rather than replacing architects or local knowledge.

The study also underscores the importance of a feedback-based system. The proposed mobile interface enables rural users to review design options, submit household information, communicate livelihood needs, and provide input on cost, layout, materials, comfort, and usability. A reward-based feedback mechanism is conceptually introduced to encourage participation, allowing users to earn points for submitting feedback, updating household data, following disaster-preparedness guidance, maintaining water-management systems, or selecting safer construction options. This feedback structure is significant because it transforms rural users from passive recipients of design solutions into active participants in the design and adaptation process.

The disaster-preparedness component further enhances the value of the proposed model. Climate-responsive design decisions, including improved roof forms, stronger wall systems, raised plinths, safer material selection, emergency access, water-storage planning, and cyclone-aware spatial organization, can reduce vulnerability when incorporated into household-level housing decisions. Simulation-informed design exploration indicates that roof shape, wall orientation, and built-form configuration influence wind response and cyclone resilience. While this study does not include full computational testing or AI model validation, it demonstrates how future AI-assisted systems could integrate disaster-risk criteria into housing-generation logic. Reliability of the findings should be understood as analytical rather than statistical. Since the study is based on a selected rural context in Nalian village, the specific design outputs cannot be directly applied to all rural settlements without modification. However, the methodological framework can be transferred to other climate-vulnerable rural regions if local data are collected and the design variables are adjusted according to the specific context. The proposed process field documentation, vernacular analysis, livelihood mapping, disaster-risk identification, design-variable formulation, AI-assisted workflow development, user-interface design, and feedback-based refinement can be adapted for other coastal, flood-prone, cyclone-prone, or resource-constrained communities in Bangladesh and similar global contexts.

In summary, this study provides a conceptual roadmap for integrating AI, local knowledge, architectural expertise, livelihood planning, water management, disaster preparedness, and participatory feedback into a unified rural housing support system. The primary contribution is the formulation of a smart design-policy framework that clarifies how such a system could be structured, the data it would require, the ways rural users could participate, and the role of architects in guiding context-sensitive housing adaptation. This framework is relevant for future research, policy development, and community-based implementation of climate-resilient rural housing.

4.2 Comparison with Previous Studies

The findings of this study are consistent with existing research that underscores the vulnerability of rural housing in coastal Bangladesh and the necessity for climate-resilient housing solutions. Vernacular design strategies in cyclone-prone regions, such as the use of local materials and courtyard-centered layouts, have demonstrated improved disaster resilience (Hajong et al., 2021; Sultana et al., 2022). The present study corroborates these conclusions while also identifying the limitations of materials such as corrugated tin sheets, which remain vulnerable to wind damage.

In contrast to previous studies that primarily address improvements to existing housing or post-disaster relief, this research introduces an AI-assisted framework for personalized housing design. This approach transitions from top-down interventions to a bottom-up, user-centered methodology, tailoring housing solutions to local climate conditions, available materials, cultural practices, and specific user needs. Although AI-based architectural research has predominantly concentrated on urban environments (Hu et al., 2020), the present study conceptually broadens its application to enhance rural housing resilience.

The establishment of a feedback loop among architects, grassroots users, and AI systems constitutes a significant innovation of this study. Previous research on digital platforms in Bangladesh has mainly emphasized sector-specific applications, such as agriculture-related mobile applications and user-value integration in digital services (Shams et al., 2021; Shams et al., 2023). In contrast, this study integrates housing design, livelihood support, water management, disaster preparedness, and user feedback within a unified adaptive platform. The incorporation of local knowledge into AI-supported decision-making is also consistent with participatory approaches to AI design, where stakeholder involvement is considered important for developing context-sensitive and socially responsive systems (Hossain and Ahmed, 2021; Delgado et al., 2023). Therefore, the proposed model advances a more comprehensive strategy for disaster-resilient rural housing by enabling design solutions to evolve through iterative feedback from architects, rural users, and future AI-assisted systems.

5. Conclusion

5.1 Summary of Key Findings

This study introduces a conceptual AI-integrated digital resilience model for climate-responsive self-help housing in rural coastal Bangladesh. The research is structured around five hypotheses: the translation of local housing knowledge into design databases, the potential of architect-guided AI for personalized housing generation, the use of an app-based platform for architect-user communication, the significance of feedback loops, and the integration of housing, livelihood, water, and disaster management within a unified resilience framework. The findings conceptually support these hypotheses, while emphasizing that the study does not present a developed, trained, or tested functional AI system.

Regarding **H1**, the study shows that local housing knowledge and vernacular practices can be translated into structured design information. Field documentation from Nalian village demonstrated that rural housing is shaped by courtyard use, veranda spaces, homestead clustering, kitchen placement, livestock areas, storage needs, ponds, roads, water access, and livelihood activities. These elements can be converted into design variables, spatial adjacency logic, material information, livelihood requirements, and disaster-risk criteria. This supports the idea that vernacular housing knowledge can serve as the basis for a context-sensitive design database.

Regarding **H2**, the study conceptually illustrates how architect-guided AI could generate personalized housing designs based on user requirements. The five manually prepared housing design demonstrations reveal how variations in household needs, land conditions, budgets, materials, livelihood practices, and climate risks result in distinct spatial and architectural responses. While these designs were not produced by an AI model, they exemplify the design logic that could be incorporated into an AI-assisted workflow under architectural supervision. This finding supports the hypothesis that AI can serve as a decision-support tool for personalized rural housing, contingent upon the development of adequate datasets, design rules, and technical systems.

Regarding **H3**, the proposed local-language mobile application demonstrates how a digital platform could facilitate communication between architects and rural users. The app concept allows users to provide household data, select housing needs, identify livelihood requirements, submit material preferences, receive design guidance, access disaster-preparedness information, and give feedback. This finding supports the hypothesis that an app-based platform can reduce the communication gap between professional architects and rural self-help housing users.

Regarding **H4**, the study highlights the importance of a feedback loop between users, architects, and AI technology. The proposed system allows rural users to review design options and provide responses on cost, layout, material suitability, comfort, usability, livelihood needs, and disaster preparedness. Architects can then interpret this feedback and refine the design logic, while a future AI system could improve through repeated data input and user responses. The reward-based feedback mechanism further strengthens this process by encouraging users to participate continuously. This supports the hypothesis that feedback loops can improve the adaptability and responsiveness of rural housing solutions.

Regarding **H5**, the study finds that housing resilience in climate-vulnerable rural areas cannot be addressed through shelter design alone. In the study context, housing is closely linked with livelihood security, water access, salinity exposure, disaster preparedness, livestock management, storage, farming, fishing, and household-level adaptation. Therefore, the proposed digital resilience model integrates housing, livelihoods, water, and disaster management into a single conceptual framework. This supports the hypothesis that a broader integrated model can contribute to rural climate resilience more effectively than isolated housing interventions.

The academic contribution of this study is the integration of AI-assisted design, vernacular spatial knowledge, participatory design, self-help housing, livelihood resilience, water management, and disaster preparedness within a unified conceptual framework. While existing literature on AI in architecture predominantly addresses formal, urban, or technologically advanced contexts, research on rural, climate-vulnerable, self-help housing environments remains limited. This study addresses this gap by positioning AI as a prospective decision-support mechanism that connects architects, rural users, local construction practices, and climate adaptation needs, rather than solely as a form-generation tool. Furthermore, it advances the smart design-policy discourse by proposing a framework that enables digital tools to facilitate scalable, accessible, and context-sensitive housing decision-making for vulnerable communities.

In summary, the study finds that an AI-integrated digital resilience model has significant conceptual potential to support climate-responsive rural housing adaptation in southwest coastal Bangladesh and in comparable climate-vulnerable regions. Nevertheless, these findings are exploratory and necessitate further technical development, empirical testing, and field validation before the proposed model can be implemented as a functional design-support system.

5.3 Strengths and Limitations of the Study

A primary strength of this study is its integrated research approach. Rather than addressing rural housing solely as a physical construction issue, the study considers it as part of a broader climate encompassing livelihood, water, disaster preparedness, user participation, and digital decision support. This comprehensive perspective is particularly relevant for coastal Bangladesh, where household vulnerability arises from factors such as salinity, soil instability, scarcity, unstable income, cyclone exposure, and limited access to professional design guidance, in addition to weak construction.

Another notable strength is the field-based grounding of the conceptual model. Employing questionnaire surveys, photographic documentation, sketches, drone imagery, and homestead layout enabled the identification of actual spatial practices and household needs. This approach ensured that the proposed framework was developed as a locally informed architectural and design-policy proposal, rather than as a purely technological concept.

The study further introduces an original actor-based structure by integrating architects, rural users, and prospective AI technology within a single feedback-driven system. Architects serve as data collectors, knowledge translators, and design supervisors, while rural users actively contribute requirements and feedback. AI technology is envisioned as a future decision-support tool capable of generating, filtering, and refining housing options. The incorporation of livelihood input, disaster-preparedness guidance, local-language interaction, and reward-based feedback enhances the model's relevance for community-based implementation.

Despite these strengths, the study presents several limitations. First, the research is based on a specific homestead cluster in Nalian village, Sutarkhali Union, Dacope, Khulna, which limits the statistical generalizability of the findings to all rural communities in Bangladesh or other countries. The generalizability of the study is therefore analytical rather than universal. Adaptation of the framework to other locations would require collecting local data and adjusting design variables to reflect specific climatic, cultural, economic, material, and social conditions.

Second, the study presents a conceptual framework rather than a fully developed technological product. No AI model was coded, trained, or computationally tested. The five design outputs were manually prepared to illustrate the potential operation of a future AI-assisted system. Consequently, the actual accuracy, efficiency, usability, and scalability of the proposed AI workflow remain unverified.

Third, the proposed mobile application and feedback system were not tested with actual results; the study cannot confirm that it includes interaction with the app, comprehension of design outputs, or the long-term effectiveness of the reward-based feedback mechanism. Factors such as smartphone

access, internet connectivity, digital literacy, trust in technology, and user motivation require further investigation.
Fourth, the disaster-resilience and material-selection components are conceptual and informed by simulations. While the study suggests that roof form, wall configuration, raised plinths, material selection, water-management strategies, and spatial organization can enhance resilience, comprehensive structural testing, wind-performance validation, flood-risk simulation, construction-cost analysis, and long-term durability assessment were beyond the scope of this research.
Finally, the successful implementation of the proposed model would necessitate interdisciplinary collaboration among architects, AI developers, local communities, NGOs, government agencies, disaster management authorities, and funding organizations. In the absence of technical infrastructure, institutional support, training, and community-level facilitation, large-scale application of the proposed framework may be challenging.

5.4 Recommendations for Future Research

Future research should focus first on developing a functional prototype of the proposed AI-assisted housing design system. This would require a larger and more diverse dataset containing rural house layouts, user requirements, livelihood patterns, material information, disaster-risk profiles, construction costs, water-management conditions, and climate-responsive design criteria. Such a dataset would be necessary to test whether the conceptual design logic proposed in this study can be translated into a working AI-assisted platform.
Second, the framework should be tested across multiple rural and coastal regions of Bangladesh, including cyclone-prone, flood-prone, salinity-affected, and riverbank-erosion-prone settlements. Comparative studies would help determine how the model can be adapted to different ecological, cultural, material, and socioeconomic contexts. This would also strengthen the generalisability of the research beyond Nalian village.
Third, future studies should conduct real-time user testing of the proposed mobile interface. Rural households should be involved in evaluating the interface's clarity, the usefulness of generated design options, the practicality of the construction guidance, the accessibility of local-language communication, and the effectiveness of the reward-based feedback system. This is necessary to understand whether the proposed platform can function in real self-help housing contexts.
Fourth, the disaster-resilience performance of the proposed design outputs should be validated through structural analysis, wind simulation, flood-risk modeling, material testing, cost-benefit analysis, and prototype construction. Long-term monitoring of built examples would also be important to assess durability, thermal comfort, maintenance, user satisfaction, and performance during extreme weather events.
Fifth, future research should examine the institutional and economic feasibility of implementing the model at scale. This includes exploring partnerships with government housing programs, NGOs, microfinance institutions, local builders, disaster-management agencies, and community organizations. Research should also investigate training models for improving digital literacy among rural users and technical capacity among local construction workers.
Finally, future work should transform the present conceptual framework into a technically developed, field-tested, and policy-supported AI-assisted design platform. This would address the major limitation of the current study and provide a clear direction for advancing smart design-policy tools for climate-responsive rural housing, livelihood resilience, water management, and disaster preparedness.

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The author(s) report no conflicts of interest.

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The data that support the findings of this study are available from the corresponding author, L.Y.L., upon reasonable request.

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Not applicable.

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