Sync the Silos, Drill the Depths: A Digital Platform to Streamline Early Phase Resilience Research in Architectural Design

Yongqin Zhao

A thesis
Submitted in partial fulfillment of the
Requirement for the degree of
Master of Science in Architecture

University of Washington
2025

Committee:
Narjes Abbasabadi
Heather Burpee

Program Authorized to Offer Degree:
Architecture

© Copyright 2025

Yongqin Zhao

University of Washington

Abstract

Sync the Silos, Drill the Depths: A Digital Platform to Streamline Early Phase Resilience Research in Architectural Design

Yongqin Zhao

Chair of the Supervisory Committee:
Narjes Abbasabadi
Department of Architecture

Resilience to extreme weather and natural disasters is vital in healthcare architecture, protecting lives, budgets, and operations for clients, users, and designers alike, from the societal scale down to the individual site. Despite the availability of many resources, the integration of resilience in current design practice remains limited. In response, this research explores how the project team can more effectively utilize available resources to thoughtfully and strategically be best informed in the resilience design research process.

Based on a review of current literature, resources, and a detailed survey and in-depth workshops, this study proposes an essential workflow that addresses the limitations of several existing frameworks. The tasks within the essential workflow are designed precisely for use cases at the early design phase. Then, based on the essential workflow, a web-based platform is developed, providing architectural design teams with a more accessible and friendly approach to streamline the resilience design research workflow: identifying the specific concern, assessing risk and vulnerability, and navigating resilience-related resources.

This study delivers the first lightweight, task-oriented workflow that unifies dispersed resilience data, tools, and precedents within a single, designer-friendly platform. By mapping resources directly to early-phase tasks, the platform provides project teams and the broader resilience community with an accessible hub for rapid, structured inquiry. Methodologically, the work introduces a Retrieval-Augmented Generation (RAG) approach tailored to AEC design tasks, demonstrating how bespoke, in-house AI applications can streamline niche workflows and open a new direction for building-design technology.

Table of Contents

List of Figures

List of Tables

Table of Acronyms

Acronym	Full Name / Meaning
AEC	Architecture, Engineering, and Construction
AIA	American Institute of Architects
API	Application Programming Interface
ASCE	American Society of Civil Engineers
ASHE	American Society for Healthcare Engineering
BCA	Benefit–Cost Analysis
BCR	Benefit-Cost Ratio
BIM	Building Information Modeling
BRIC	Building Resilient Infrastructure & Communities
CAD	Computer-Aided Design
CBA	Choosing-by-Advantages
CDC	Centers for Disease Control and Prevention
CSS	Cascading Style Sheets (web styling language)
DOCX	Microsoft Word Open XML Document format
DOGAMI	Oregon Department of Geological and Mineral Industries
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
HHS	U.S. Department of Health and Human Services
HTML	HyperText Markup Language
HTTP	HyperText Transfer Protocol
IFC	Industry Foundation Classes
JSON	JavaScript Object Notation
LLM	Large Language Model
MEP	Mechanical, Electrical, and Plumbing (building systems)
nDCG	Normalized Discounted Cumulative Gain (ranking quality metric)
NIBS	National Institute of Building Sciences
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
OEM	Oregon Emergency Management

PDF	Portable Document Format
POE	Post-Occupancy Evaluation
RAG	Retrieval-Augmented Generation
RFP	Request for Proposal
ROI	Return on Investment
UI	User Interface
UX	User Experience
USGS	United States Geological Survey
WA	Washington State (U.S. postal abbreviation)

Acknowledgements

I am grateful to the many individuals and organizations whose support, expertise, and encouragement made this thesis possible, developed alongside the ARC Fellowship at ZGF.

My deepest appreciation goes to my thesis committee at the University of Washington. Dr. Narjes Abbasabadi, my committee chair, safeguarded the overall direction of this work and continually challenged me to ground each idea in rigorous scholarly practice. Professor Heather Burpee shared domain knowledge and critical feedback that sharpened my methodology and helped crystallize the broader vision.

This thesis would not have taken its present form without the mentorship of Dr. Flavia Grey, my firm advisor at ZGF. Flavia's candid feedback, practical insight, and unwavering encouragement allowed me to translate speculative ideas into actionable strategies. I also extend heartfelt thanks to my colleagues at ZGF—Sarah Crochet, Marty Brennen, Tim Myers, Jonah Hawk, Dane Stokes, Chuou Zhang for their advice and technical expertise, and to many more ZGFers whose collective support sustained this work. I am likewise grateful to ZGF's senior leadership, especially Todd Stine, whose vision helped launch the ARC Fellowship and champion interdisciplinary research within the firm.

I am equally thankful to Dr. Karen T.H. Chen, my ARC faculty advisor, whose thoughtful perspectives bridged academic inquiry and professional practice. I also thank the ARC Fellowship leadership—Dean Renée Cheng for launching the program, and Teri Randall and Prof. Carrie Sturts Dossick for their coordination, resources, and feedback.

To the design teams and professionals who participated in interviews and surveys: your real-world insights enriched the project immeasurably and grounded the research in practice.

Finally, I owe an immeasurable debt to my parents, whose sacrifices and steadfast belief laid the foundation for this journey. To my wider family and friends, thank you for the patience, encouragement, and good humor that kept me grounded through late nights and long weekends.

Throughout the research and writing process, I utilized tools such as Grammarly for English phrasing and grammar checks, and ChatGPT (GPT-4, O1) as on-demand tutors and background learning on web-development patterns and open-source libraries. All AI suggestions were critically assessed and incorporated only when they advanced the project's objectives and were fully understood by the author.

Portions of the platform's proof-of-concept code were drafted and refined through iterative prompts with GitHub Copilot (VS Code extension, May 2025) and ChatGPT (GPT-4o, O1, O3, Jan–May 2025). Every AI-assisted snippet was manually reviewed, refactored, and tested locally to verify functionality, security, and license compatibility. I retain full responsibility for the accuracy and integrity of all content.

I also acknowledge the global open-source community and developer forums whose libraries, best practices, and troubleshooting guidance made rapid experimentation possible.

Any errors or omissions that remain are entirely my own.

Chapter 1. Introduction

1.1 Research Background

1.1.1 Resilience in Architecture Design

Resilience in the built environment has attracted increasing attention from both industry and academia as a critical factor in enabling buildings to withstand hazards, particularly those related to climate change and natural disasters. Scientifically, resilience is defined as the capacity of social, economic, and environmental systems to absorb disturbances while maintaining essential functions (*AR5 Synthesis Report*, n.d.). According to the American Institute of Architects (AIA), resilience in the built environment can be manifested in five dimensions: health, social, infrastructure, environmental, and economic resilience (Shams et al., n.d.). From a temporal perspective, resilience refers to a building's ability to prepare for, withstand (through structural durability and spatial flexibility), and recover from natural hazards (Di Pilla, 2021). In this research, resilience is understood both temporally and across different building systems, as the capacity of a building, encompassing its infrastructure, structure, and operations, to anticipate, endure, and recover from disruptive events.

Although resilience remains an abstract concept, it can be operationalized using various indicator metrics. For instance, the "4R" framework provides a method for evaluating resilience through building-specific indicators (Di Pilla, 2021).

Indicator	**Definition**
Robustness	"The ability to keep critical operation running during a crisis."
Resourcefulness	"The ability of being effectively prepared to respond and manage a crisis."
Rapid recovery	"The ability of restoring normal performance quickly after disruption."
Redundancy	"The ability of providing on backup systems when primaries fail."

Table 1.1: Indicator of Building Resilience (Di Pilla, 2021)

The United States has witnessed a growing frequency of "billion-dollar" disasters, accompanied by escalating financial losses and fatalities (NOAA National Centers for Environmental Information (NCEI), 2025). However, evidence suggests that investment in hazard-resilient design yields long-term economic returns. For instance, in June 2001, Tropical Storm Allison struck Houston, delivering over 40 inches of rain. The resulting floods caused widespread basement inundation, power outages across the Texas Medical Center (TMC), and the closure of nine hospitals (*FEDERAL Help Offered for Storm Damage at Texas Hospitals*, n.d.). The total damage to hospitals, medical schools, and research laboratories was estimated at approximately USD 2 billion, with hundreds of patients urgently evacuated (*When Hurricane Harvey Hit, the Texas Medical Center Stood Ready | BuildingGreen*, n.d.).

In response, TMC and its member institutions made significant investments to upgrade buildings and infrastructure. For example, Memorial Hermann Hospital enhanced its underground generators, switchgear, and other critical systems. The effectiveness of these upgrades was demonstrated during Hurricane Harvey in 2017. Despite receiving a continental-record 51 inches of rain over five days, all but one TMC facility remained fully operational for both existing and incoming patients (Galehouse, 2017). More broadly, the National Institute of Building Sciences (NIBS) estimates that the benefit-cost ratio (BCR) for natural hazard mitigation ranges from 3:1 to 7:1, affirming the economic and functional benefits of investing in resilient and future-proof buildings (Federal Emergency Management Agency, 2018).

Building resilience has multifaceted impacts, social, environmental, and economic. Socially, resilient buildings help maintain essential functions, safeguard public health, and facilitate faster community recovery (Brambilla et al., 2021; *Rebuilding a More Resilient Nepal*, n.d.). Environmentally, they reduce dependence on external resources such as energy (Bianchi, 2023; Gil-Ozoudeh et al., 2023). Economically, resilient features lower lifecycle costs by minimizing repair and maintenance needs, thereby enhancing the longevity and value of properties (Bianchi, 2023; Di Pilla, 2021).

Stakeholders in the context of building resilience include owners and managers, users and occupants, as well as surrounding communities. For property owners and managers, resilient buildings offer cost savings, reduced operational downtime (Berke et al., 2021), and improved marketability (Dong et al., 2021). For users, occupants, and communities, such buildings ensure continued access to essential services even during crises (Bianchi, 2023).

	Owner/Management	**User/Occupant & Community**
Society/ Operation	Avoid facility closures and revenue loss	Uninterrupted emergency, ICU, and transplant care; Maintains an essential life-saving shelter
Environment/ Health	Resilience upgrades (e.g., elevated equipment, sealed flood doors) often cut long-term energy and pump-out demand, aligning with low-carbon facility goals.	A less disturbed indoor environment for vulnerable patients and staff
Property/ Economic Assets	High BCR ratio; Lower future lifecycle cost	Cuts taxpayer-funded recovery bills

Table 1.2: Benefit of Resilience Healthcare Facility

1.1.2 Resource for Design Resilience

Resilience matters, not only for patients, staff, and facility owners, but also for the broader communities that rely on healthcare infrastructure during and after crises. Nevertheless, a quick pulse-check using Google Trends reveals that "resilience" still lags behind more established concepts such as "sustainability" and "green building" in terms of public and academic attention. The gap, however, is narrowing: search interest in resilience has more than doubled over the past five years, and the volume of peer-reviewed publications has increased at a comparable rate. This growing momentum indicates that the architectural and design professions increasingly recognize resilience as a fundamental element of future-proof design.

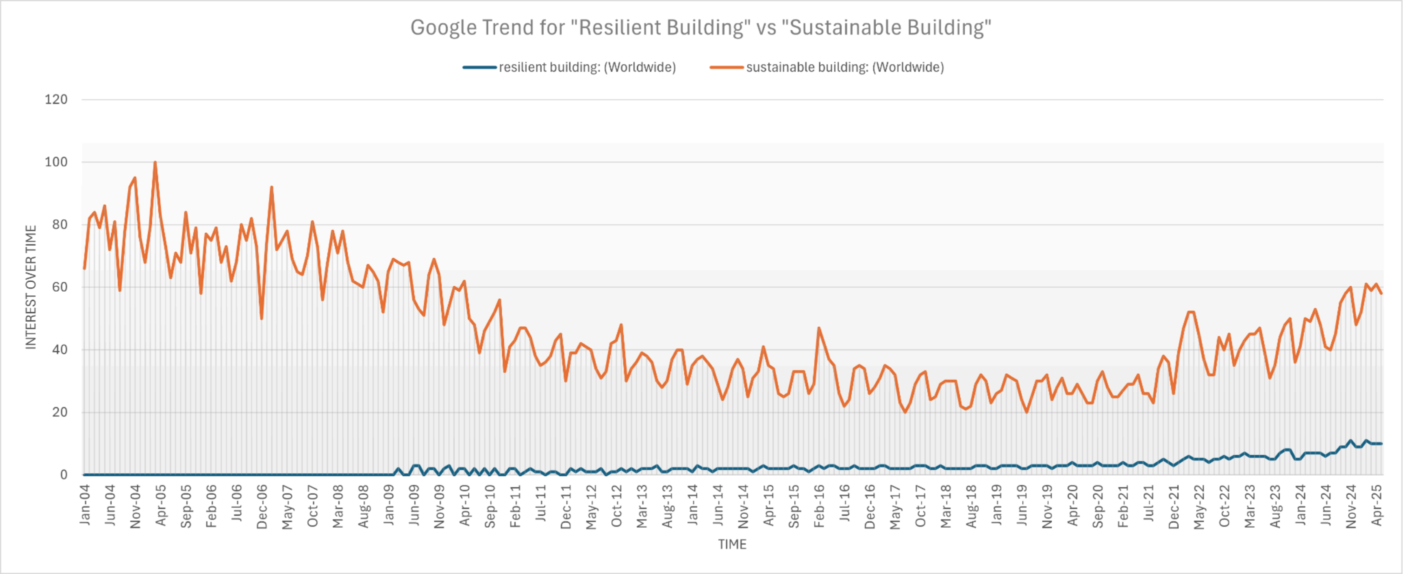


Figure 1.1: Search Trend for "Resilient Building" and "Sustainable Building", accessed June 10, 2025. Source: Google.

A wealth of resources now exists to support resilience planning in healthcare design. Reputable organizations such as the American Institute of Architects (AIA) and the Federal Emergency Management Agency (FEMA) offer open-access toolkits, data repositories, and analytical frameworks to facilitate resilience-focused research and design. These tools can serve as foundational starting points for design teams embarking on resilience initiatives.

However, despite the abundance of resources, design professionals continue to highlight difficulties in effectively navigating and integrating them. The current research process often lacks a clear structure, resulting in significant time lost toggling between fragmented resources and isolated tasks.

To address this inefficiency, a hierarchical framework that organizes available resources, tasks, and procedural steps is essential. A structured, phase-oriented workflow could significantly enhance resource navigation, improve the integration of data sources, and streamline the transition between tasks. Ideally, such a workflow should:

- Enable rapid access to authoritative data without a time-consuming "treasure hunt";
- Link relevant data directly to specific design phases and tasks; and
- Seamlessly connect discrete tasks, such as hazard assessment and precedent analysis, into a smooth, cohesive process.

1.2 Research Question and Objective

Resilience is essential for both society and the stakeholders who use or live in proximity to buildings, and it should be an integral part of architectural design. Architects, as key agents in the built environment, are responsible for incorporating resilience into their design strategies. However, project teams often face substantial challenges during the design process when attempting to implement resilient design principles.

This research addresses the following key questions:

- What are the current resources and challenges encountered by project teams in implementing resilient design across different design phases?
- What approaches are currently used in resilience design research?
- How can a systematic tool be developed to support project teams through the most essential steps of the resilience research workflow?

In response to these questions, this study aims to develop a digital platform that offers project teams a more accessible and user-friendly means of streamlining the resilience research process. Specifically, the platform:

- Provides a guided, easy-to-adopt workflow with embedded access to essential data;
- Facilitates efficient navigation of resources, including precedents, strategies, tools, support, etc..
- Delivers a guide for new projects, integrating a precedent library, resource navigation modules, and existing tools into an interactive, unified platform.

1.3 Research Scope

Healthcare is a foundational component of societal wellbeing, and its critical role underscores the necessity for continuous operation and heightened resilience against natural hazards. During such events, healthcare facilities must go beyond protecting in-house patients and staff; they are also expected to accommodate an immediate post-disaster surge, including injured civilians, evacuees from nursing homes, and neighboring residents seeking shelter.

Among the various types of healthcare infrastructure, hospitals are of particular interest in this study due to their scale, complexity, and indispensable function. Hospitals usually combine a wide range of services, including emergency departments, operating rooms, intensive care units, inpatient wards, laboratories, pharmacies, imaging suites, and more within one facility or campus. In contrast, outpatient clinics offer limited services on a smaller scale. The magnitude and interdependence of systems housed in hospitals necessitate an even higher standard of operational continuity. Consequently, hospitals have become proving grounds for advanced resilience strategies, and the insights gained from their design and operation can inform resilience measures across other healthcare and building typologies.

Natural hazards are among the leading causes of hospital evacuations (Mace & Sharma, 2020), and the critical nature of hospitals has been increasingly acknowledged in building codes and regulations (Scott et al., 2023). Focusing on hazard-induced disruptions not only addresses an urgent life-safety concern but also offers a replicable framework for protecting other high-risk buildings facing intensifying climate threats.

This study targets the earliest stages of the design process, specifically the pre-design phase and even the Request for Proposal (RFP) stage, where defining the project scope offers a high-leverage opportunity to shape both budgetary allocations and performance expectations. Survey and workshop findings indicate that resilience-related considerations are most effectively introduced during this initial phase. By providing project teams with rapid risk narratives and an integrated resource library at this juncture, the research aims to close communication gaps and embed resilience thinking before critical design decisions are finalized.

The intended audience encompasses all design professionals. By equipping every member of the project team, regardless of their level of experience, with accessible and actionable resilience tools, this approach democratizes expertise and fosters a shared understanding of resilience across disciplines.

With this research scope, hospitals and other mission-critical facilities are better positioned to integrate resilience from the very outset of project development, thereby enhancing their capacity to deliver robust, future-ready infrastructure.

Typology:	Hospital
Hazard	Nature Hazard
Design Phase:	Very early phase (Pre-Design/Request for Proposal)
Platform User:	Architecture Design Team (regardless of their experience level and role)

Table 1.3: Research Scope

1.4 Research Framework

The Research Framework is discussed in the following chapters:

Chapter 2, Related Work: This chapter establishes the analytical foundation by examining the discourse of resilience across research and practice. It outlines existing resources and types of precedents. It analyzes several real-world case studies across various design phases to understand how resilience is currently implemented and how resources and precedents are utilized.

Chapter 3, Methodology: This chapter integrates the literature findings from Chapter 2 with a real-world survey and workshop to establish a parallel yet aligned direction for developing a workflow. Section 3.1 introduces the comprehensive seven-step workflow, synthesized from the literature and practice review in Chapter 2, and used as a discussion “playground” during later user sessions. Section 3.2 outlines our mixed-methods data collection design, which combines a cross-firm survey with a series of semi-structured workshops. Section 3.3 refines the comprehensive model into an essential early-phase workflow, focused on hazard identification, risk assessment, and resource navigation, based on the empirical insights gathered. Section 3.4 documents data sources and preliminary constraints, and Section 3.5 clarifies the scope of the prototype by outlining what the platform is and is not.

Chapter 4, Resilience Research Platform: This chapter translates the essential workflow into a functional platform, presenting the technical design and implementation of the proposed digital platform. It begins with an overview of the selected technologies to contextualize development choices, and proceeds to explain the software architecture at both conceptual and implementation levels. The chapter details how the platform operationalizes the streamlined workflow and supports user interaction with resilience resources.

Chapter 5, Result and Discussion: This chapter summarizes user feedback on the platform and reflects on the broader contributions of this research to both the resilience design field and the domain of design technology. It also discusses limitations encountered during the research and offers directions for future development and refinement of the platform.

Chapter 2. Related Work

2.1 Current Literature Discussion of Resilience

A review of current literature was conducted to investigate recent advancements and applications of resilience in architectural design, particularly to assess its potential integration into a structured workflow for design teams. As of December 2024, no academic research has yet proposed a comprehensive, standardized methodology or workflow for conducting resilience research throughout the design process. Nevertheless, several studies touch on elements that could inform such a workflow. The aim of this literature overview is not to provide an exhaustive state-of-the-art review, but rather to clarify: (1) the target audiences and intended beneficiaries of resilience research; (2) the functional characteristics of successful deliverables in their original contexts; and (3) the potential for adapting these deliverables to support resilience-oriented workflows in the early conceptual and pre-design phases of healthcare projects.

2.1.1 Literature Discussion: Topic, Deliverables, Audience

Resilience in the built environment is addressed across multiple scales, including urban, community, and building levels. At the building scale, resilience research in various typologies generally focuses on these themes: structural robustness against hazards (Bianchi, 2023; *Rebuilding a More Resilient Nepal*, n.d.), environmental adaptability and energy efficiency (Forgaci, 2020; Gil-Ozoudeh et al., 2023), and flexibility and continuity of operations for maintaining functionality during emergencies (Brambilla et al., 2021) and occupants' comfort (Dong et al., 2021). Key deliverables include assessment scorecards (Berke et al., 2021) and assessment framework (Bianchi, 2023), and guidelines for incorporating adaptable systems in building design (Dong et al., 2021).

In the context of healthcare, resilience emerges as a critical priority due to the imperative for facilities to remain operational during and after emergencies. The literature on healthcare resilience addresses the demand for resilience in both structure and operation. Given the unpredictable nature of health crises, adaptability and flexibility in healthcare spaces, such as modular layouts and reconfigurable systems, would enable healthcare facilities to manage varying patient loads and operational needs (Brambilla et al., 2021; Pilanawithana et al., 2022). Healthcare facilities must protect both physical infrastructure and occupant safety (De Genaro Chiroli et al., 2023; *Rebuilding a More Resilient Nepal*, n.d.), as well as prepare for a broad range of hazards (Brambilla et al., 2021). This range of literature is targeted towards healthcare facility managers, architects, healthcare professionals, and emergency planners, with the deliverables from adaptable frameworks for emergency planning (Brambilla et al., 2021), guidelines for infection control and surge capacity (Pilanawithana et al., 2022).

Resilience research in architecture and the built environment is increasingly recognized for its relevance to a diverse set of stakeholders. Key beneficiaries across various resilience studies include: the architecture and engineering team, the building owner and management, and the healthcare emergency response team. Architecture and engineering professionals are the primary users of resilience guidelines, scorecards, and assessment tools, which aim to inform design choices that enhance a building's ability to withstand hazards. The project team can use resilience insights to guide material selection, structural design, and energy efficiency. Building owners and managers could benefit from frameworks that highlight lifecycle benefits, such as reduced maintenance costs and prolonged functionality during disruptions. And the healthcare emergency response team can learn from how adaptable spaces can be implemented to maintain functionality.

Topic	**Example**
Resilience Assessment and Evaluation	Scorecards, performance metrics, multi-dimensional indicators.
Urban and Regional Planning & Policy for Resilience	Policy integration, spatial planning, zoning.
Public Health and Critical Infrastructure Resilience	Public health, essential services, critical infrastructure.
Data-Driven and Technological Approaches to Resilience	Big Data, simulations, digital modeling.
Sustainable Building and Green Infrastructure	Climate adaptation.
Community and Stakeholder Engagement	Participatory modeling, human-centered approaches.
Disaster Recovery	Long-term resilience planning and Post-Disaster Development

Table 2.1 : Popular Topics in Literature Discussion

The effectiveness of resilience tools and deliverables lies in specific features that cater to the needs of their intended audiences. For a resilience workflow focused on healthcare architecture, incorporating these features could create an adaptable and user-friendly tool. Real-time hazard data, flexible design modules, and visual dashboards would enable architecture teams to assess resilience and respond to varied healthcare demands comprehensively. Notable features that make these deliverables valuable within their original research contexts include: Data-Driven and Contextualized Assessments, Multi-Hazard and Flexible Design Strategies, Visual and Scenario-Based Frameworks. Resilience deliverables incorporating real-time or predictive data can make assessments relevant and actionable, like the utilization of geospatial data, IoT sensors, and predictive modeling in creating dynamic resilience assessments(Forgaci, 2020). Data-rich approaches enable tailored solutions for specific environments and user needs, like using occupant behavior data to help predict resilience outcomes under varying conditions (Dong et al., 2021). Several studies use scenario-based tools or scorecards to visualize resilience and map potential outcomes. In a participatory scenario, visualizations can involve stakeholders in scenario-based resilience planning. These visual tools clarify complex resilience challenges and improve stakeholder engagement, making resilience assessments more accessible and impactful.

2.1.2 Summary

The current literature on resilience primarily concentrates on conceptualizing resilience frameworks, developing metrics for assessment, or enhancing specific components within the broader resilience process. However, from the practitioner's perspective, a recurring question emerges: *How can this research be applied to everyday project workflows?*

While research on the comprehensive workflow is lacking, several key features offer valuable transferable elements. These include: data integration, multi-hazard adaptability, visual assessments, and stakeholder engagement, which provide valuable insights for workflow design. Additionally, the modular assessment phases and precedent-sharing practices identified across studies can be directly adapted to healthcare architecture.

Specifically, four designable features emerge as especially relevant to a future workflow for healthcare architecture: Modular Assessment Phases, Stakeholder Collaboration, Precedent Directory, and Visual Tools. Several studies recommend phase-based approaches that could inform the structure of a resilience workflow. Iterative resilience assessments at different design stages are used to refine building robustness and adaptability (Bianchi, 2023). Resilience studies emphasize stakeholder engagement to ensure that resilience measures align with the needs of diverse groups (Drăgoicea et al., 2020; Verweij et al., 2020).

Incorporating these features can help transform complex resilience strategies into a structured, user-friendly workflow. This would allow architecture teams to integrate resilience from the earliest stages of healthcare projects, providing a practical, accessible bridge between advanced academic research and real-world application.

2.2 Current Resilience Research in Design Practice

2.2.1 Resource & Organization

In architectural practice, resilience-focused design inquiries invariably begin with the collection and review of foundational background material that informs all downstream decisions. Once these resources are established, the design team can apply its architectural expertise with greater confidence and precision. To facilitate this process, a well-structured taxonomy of common resource types is essential, one that traces how each resource informs specific design tasks and phases throughout the project lifecycle.

The current resources are framed by three guiding questions that practitioners frequently encounter during the design process: 1) for “what/where is this, what is the consequence”, design team would like to identity potential hazards and understand their risks across different building system; 2) for “what action should I do in what/where”, design team would like to explore available design strategies and interventions appropriate to the identified hazards, and assess their contextual performance; and 3) for “how to make it affordable/feasible”, design team would need access to financial and technical support mechanisms to ensure that proposed solutions are viable for implementation. Accordingly, resources are first grouped into six categories: **data, tool, case study, strategy, funding,** and **consultant**.

- Data: raw data collected from reliable sensors or surveys and maintained by reliable sources;
- Tool: desktop or web‑based software that either transforms data into actionable insight or enables data modeling and assessment;
- Case study: a rigorously document explaining how a completed project implemented a resilience measure, including its context, process, and outcome;
- Strategy library: a well-outlined and indexed collection of design strategies;
- Funding: organizations that offer financial support projects implementing resilient design strategies and achieving resilient goals;
- Consultant: external organisations with specialised expertise; architecture firms may partner with them to supplement in‑house capabilities.

With such a wealth of resources available, the next challenge is to structure the research and design workflow, aligning resources with the phases and roles. This raises a fourth guiding question: 4) “how to start and coordinate”, which involves another type of resource: toolkit.

- Toolkit: a curated framework that maps the deployment of the above resources across project phases, outlining key tasks, deliverables, and responsible parties.

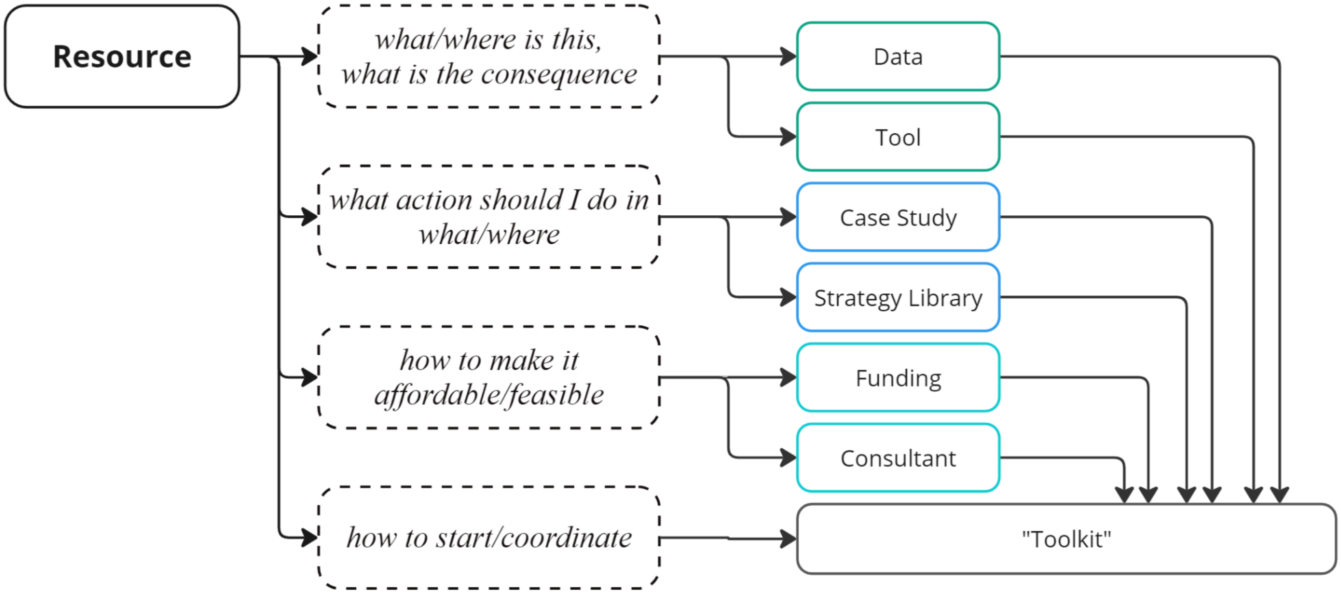


Figure 2.1 : Seven Types of Resources

In practice, typical resilience research begins with **data**, such as hazard maps, climate projections, or environmental health indicators, often sourced from organizations like FEMA, NOAA, etc. These are analyzed using **tools** that estimate risk exposure and system vulnerabilities for specific types and locations.

Once the design team has clarified the relevant hazards and their likely impacts, attention shifts to identifying appropriate **strategies** and **precedents**. Here, case studies provide evidence of how peer projects have addressed similar challenges, while strategy libraries translate those precedents into discrete design moves that can be combined, adapted, and tailored to current conditions. Additionally, case studies would offer feasibility within a real-world context, and the form of a “library” would improve search efficiency.

Feasibility and affordability are also critical concerns. Teams often explore external **funding opportunities**, including resilience grants or tax incentives, to offset implementation costs. They may also partner with **consultants** whose expertise in engineering, public health, or community engagement can reduce trial-and-error expenses and improve design effectiveness.

The complexity of coordinating these resources across design phases leads to the need for structured **toolkits**. These toolkits, usually originating from government agencies or industry associations, provide a roadmap for aligning tasks, milestones, and responsibilities with relevant resources.

For these resources to be valid inputs in design decision-making, they must be credible and authoritative. Typically, each resource is created, published, and maintained by a recognized entity such as a government agency, professional society, or research institution. Table 2.3 summarizes key types of organizations and the resources they typically offer:

- Governmental Agency: FEMA, CDC, NOAA, USGS, HHS, etc.
- industry association: AIA, ASCE, ASHE, etc.

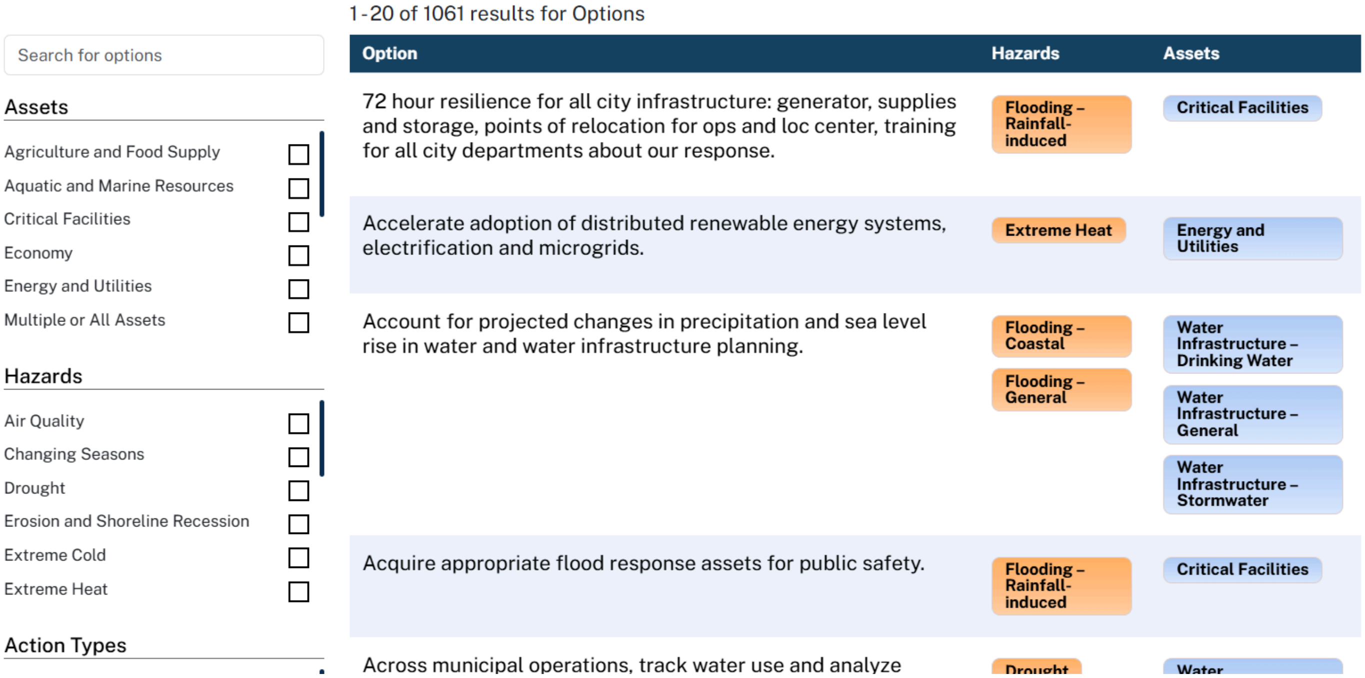
	FEMA Federal Emergency Management Agency	**NOAA** National Oceanic and Atmospheric Administration	**USGS** United States Geographical Survey	**AIA** The American Institute of Architects	**ASCE** The American Society of Civil Engineers
Data & Tool	Resilience Analysis & Planning Tool (RAPT); HAZUS; National Risk Index; National Flood Hazard Layer (NFHL);	Climate Data Online (CDO); NCEI Storm Events DB; Sea Level Rise Viewer; Climate Explorer;	National Seismic Hazard Maps; National Water Information System (NWIS); Landslide Inventories;	Resilience Design Toolkit;	Infrastructure Report Card datasets; ASCE Hazard Tool; Infrastructure Resilience Division;
Case Study & Strategy	Mitigation Best Practices Portfolio; Building Science Disaster Support; Building Science Resource Library; Risk Mapping, Assessment and Planning (Risk MAP);	Climate Resilience Toolkit case studies; Climate Resilience Toolkit Option Database;	—	Disaster Assistance Handbook case studies; Resilient Project Process Guide;	Failure Case Studies database; ASCE/SEI 7 & related standards library
Funding & Consultant	Building Resilient Infrastructure & Communities (BRIC); Hazard Mitigation Grant Program (HMGP); Flood Mitigation Assistance (FMA) competitive grants	National Coastal Resilience Fund; Climate Adaptation Partnerships (previously RISA);	Cooperative Matching Funds (joint project studies with states/tribes)	—	—

Table 2.2 : A Non-Exhaustive List of Key Organizations and Resources

2.2.1.1 NOAA Climate Resilience Toolkit – Options Database

Among publicly available resources, the Options Database in NOAA's Climate Resilience Toolkit can be a *model* strategy library. This database serves as a quick-start catalogue of over 1,000 adaptation strategies compiled from 62 local, state, and regional resilience plans (*All Options Embed*, n.d.; *Options Database | U.S. Climate Resilience Toolkit*, n.d.). Its purpose is to lower the research burden during early scoping phases by surfacing a diverse range of strategies, from community hubs and distributed microgrids to managed retreat and coastal buffer zones, that might otherwise remain hidden in local planning documents. In this database, an "option" is an umbrella term encompassing objectives, strategies, and actions that range from policies and programs to infrastructure projects and emerging technologies.

The interface is an interactive sheet that lets users filter entries by hazard, asset class, action type, and more. For example, practitioners can quickly retrieve nature-based flood-mitigation ideas targeting critical facilities. Each option lists its associated hazard, asset, and action taxonomy and provides a link to the originating plan for deeper inquiry. However, crucial contextual metadata, such as project scale, sector, audience, and implementation maturity, are not provided within the sheet itself.



1-20 of 1061 results for Options

Search for options

Assets

- Agriculture and Food Supply ☐
- Aquatic and Marine Resources ☐
- Critical Facilities ☐
- Economy ☐
- Energy and Utilities ☐
- Multiple or All Assets ☐

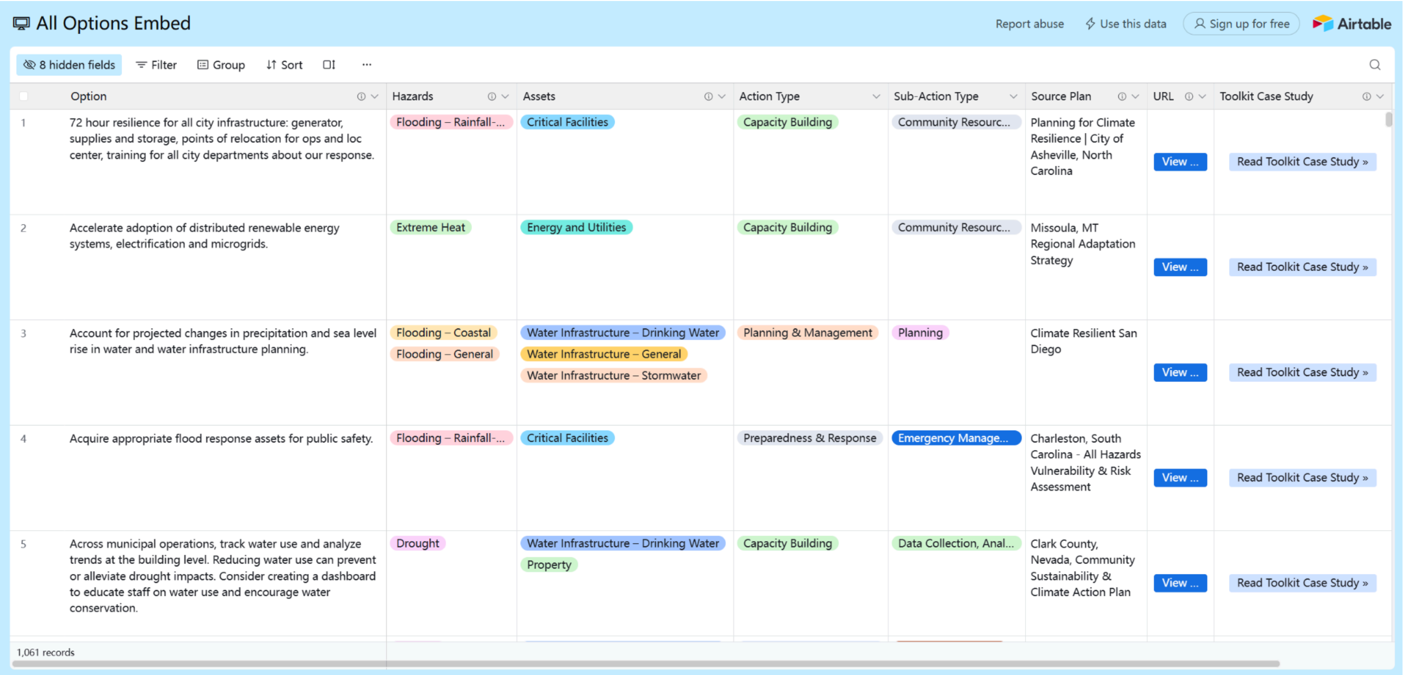
Hazards

- Air Quality ☐
- Changing Seasons ☐
- Drought ☐
- Erosion and Shoreline Recession ☐
- Extreme Cold ☐
- Extreme Heat ☐

Action Types

Option	Hazards	Assets
72 hour resilience for all city infrastructure: generator, supplies and storage, points of relocation for ops and loc center, training for all city departments about our response.	Flooding – Rainfall-induced	Critical Facilities
Accelerate adoption of distributed renewable energy systems, electrification and microgrids.	Extreme Heat	Energy and Utilities
Account for projected changes in precipitation and sea level rise in water and water infrastructure planning.	Flooding – Coastal Flooding – General	Water Infrastructure – Drinking Water Water Infrastructure – General Water Infrastructure – Stormwater
Acquire appropriate flood response assets for public safety.	Flooding – Rainfall-induced	Critical Facilities
Across municipal operations, track water use and analyze	Drought	Water

Figure 2.2 : Screenshot from the Option Database Hosted in NOAA's webpage, accessed June 09, 2025 (*Options Database | U.S. Climate Resilience Toolkit*, n.d.)



	Option	Hazards	Assets	Action Type	Sub-Action Type	Source Plan	URL	Toolkit Case Study
1	72 hour resilience for all city infrastructure: generator, supplies and storage, points of relocation for ops and loc center, training for all city departments about our response.	Flooding – Rainfall-...	Critical Facilities	Capacity Building	Community Resourc...	Planning for Climate Resilience | City of Asheville, North Carolina	View ...	Read Toolkit Case Study »
2	Accelerate adoption of distributed renewable energy systems, electrification and microgrids.	Extreme Heat	Energy and Utilities	Capacity Building	Community Resourc...	Missoula, MT Regional Adaptation Strategy	View ...	Read Toolkit Case Study »
3	Account for projected changes in precipitation and sea level rise in water and water infrastructure planning.	Flooding – Coastal Flooding – General	Water Infrastructure – Drinking Water Water Infrastructure – General Water Infrastructure – Stormwater	Planning & Management	Planning	Climate Resilient San Diego	View ...	Read Toolkit Case Study »
4	Acquire appropriate flood response assets for public safety.	Flooding – Rainfall-...	Critical Facilities	Preparedness & Response	Emergency Manage...	Charleston, South Carolina - All Hazards Vulnerability & Risk Assessment	View ...	Read Toolkit Case Study »
5	Across municipal operations, track water use and analyze trends at the building level. Reducing water use can prevent or alleviate drought impacts. Consider creating a dashboard to educate staff on water use and encourage water conservation.	Drought	Water Infrastructure – Drinking Water Property	Capacity Building	Data Collection, Anal...	Clark County, Nevada, Community Sustainability & Climate Action Plan	View ...	Read Toolkit Case Study »

Figure 2.3 : Screenshot from the Full view of Option Database with All columns Hosted in Airtable, accessed June 09, 2025 (*All Options Embed*, n.d.)

Regarding the content of this database, the options are sourced from urban to regional scale planning, but not from actual building-scale design. Thus, the database's convenience comes with three substantive trade-offs:

- Missing context: Beyond hazard, asset, and action type, the sheet omits key descriptors, including scale (building, district, region), decision phase, cost magnitude, stakeholder audience, and level of maturity. Users must consult the source documents for these details.
- Predominantly plan-level, qualitative content: While the database is rich in high-level ideas, it offers limited guidance once a design team moves into schematic modelling or engineering documentation.
- Limited support for building-scale design: The majority of records focus on district-level planning, land-use, public-health programs, or regional infrastructure. Consequently, design teams seeking building-specific strategies, especially for healthcare, may find limited applicability.

2.2.2 Current Research on workflow

2.2.2.1 US Climate Resilience Toolkit and Sustainable and Climate-Resilient Health Care Facilities Toolkit

The U.S. Climate Resilience Toolkit is a publicly available web-based platform that aggregates climate datasets, tools, case studies, and funding opportunities into a single interface, designed for use by communities and sectors seeking to address climate risk (*Home | U.S. Climate Resilience Toolkit*, n.d.). At the core of this resource is a six-step "Steps to Resilience" framework, which guides users from data interpretation through adaptation planning. Its interactive website allows users to browse and filter content based on sector and hazard type, helping surface localized climate impacts (e.g., flood, wildfire, sea-level rise) alongside relevant response strategies.

As a one-stop shop, first-time practitioners can quickly get high-level background knowledge, and the toolkit excels at the front end of adaptation work: it quickly surfaces hazard trends (heat, flood, wildfire, sea-level rise), overlays social-vulnerability indices, and suggests high-level options that communities have used elsewhere. However, the toolkit stops at identifying high-level knowledge (hazard, possible action); for more in-depth tasks, users must switch to other platforms or consult external sources.

The Sustainable and Climate-Resilient Health Care Facilities Toolkit ("Sustainable and Climate-Resilient Health Care Facilities Toolkit," n.d.) adapts the Climate Resilience Toolkit's step-wise workflow to healthcare, aiming to keep facilities safe, functional, and compliant under extreme weather. Designed for facility administrators, engineers, and emergency planners, it introduces five healthcare-specific focus areas (e.g., land use, building infrastructure, operations) and links climate risks to functional continuity in medical settings. It offers a straightforward checklist to link physical hardening to clinical continuity. Similar to the Climate Resilience Toolkit, it offers a list of resources at each step, but also stops short of offering design-phase deliverables.

While being a good starting point for understanding context and potential options, these two toolkits are not designed with the architecture design team in mind, and fail to provide in-depth knowledge for design use cases. Their value lies in speed and breadth; they reduce the time of preliminary research, but teams must be familiar with the various resources they offer, or even switch between sources.

2.2.2.2 AIA-HKS Resilience Design Toolkit

The AIA–HKS **Resilience Design Toolkit** is a practitioner-focused playbook that guides architects through a rigorously evidence-based sequence, weaving resilience considerations into every stage, from project pursuit to post-occupancy. Synthesising methodologies from FEMA, NOAA, and peer toolkits, and aligning with performance frameworks such as REDi, RELi, and the AIA Framework for Design Excellence, it translates disparate standards into a cohesive, designer-friendly language (Shams et al., n.d.). The Toolkit's five-stage process deliberately extends the earlier Resilient Buildings Planning Worksheet. Work now begins as early as Define Scope and Build Team, then runs through hazard identification, cost-benefit analysis (BCA + CBA), and closes with a Post-Occupancy Evaluation (POE) loop. This breadth lets a design team pick up resilience considerations at early stages.

One of its contributions is promoting quantified approaches, like Benefit–Cost Analysis and Choosing-by-Advantages, elevating resilience to a financially defensible requirement. Another contribution is translating high-level resilience theory into a step-by-step guide anchored in the typical project phases.

The toolkit is intentionally positioned as a "starting template." Its example questions, workshop agendas, and adaptable frameworks give new teams a ready-made scaffold for resilience discussions. Yet this breadth can overwhelm smaller or resource-constrained groups: without careful tailoring, activities such as charrettes, extensive data collection, and economic modeling may prove impractical for tight schedules or limited budgets.

2.2.2.3 Summary

	Example 1: US Climate Resilience Toolkit	**Example 2: Sustainable and Climate-Resilient Health Care Facilities Toolkit**	**Example 3: AIA-HKS Resilience Design Toolkit**
Targeted Audience	Everyone concerned about resilience; but mostly Local governments, planners, at any sector, any scale	Healthcare Facility administrators, emergency-preparedness teams,	Architecture Design Team, Owners, Engineers
Workflow	Start -> Identify Hazard -> Assess Risk -> Investigate Options -> Prioritize -> Implement	Same as US Climate Resilience Toolkit	Define Scope -> Build Team Identify Hazard -> Integrate Design -> Evaluate
Domain-Specific Perspective	Multi-sector, general	5 facility-specific “Elements” (e.g., Land-Use & Building Design)	Integration with architecture certification and popular tools
How Design Team can use it	Site-specific inputs (location, historical events, building systems) drive the risk matrix		Can start from anywhere.
Strengths	Intuitive interface; fast orientation for newcomers	Healthcare specificity for facility teams.	General enough for all typologies and context; Integrate well with existing knowledge, some designers might already quite familiar.
Limitations	Lacks detailed design guidance at fine granularity, especially for implementing the concept; Not enough for a design team to use for a full design lifecycle	Not for design team	Static PDF templates; Resource and knowledge intensive, might require user’s experience level
If there could be an improved version	Could benefit from deeper design-phase integration	—	“Lite” version for even junior designer or client with limited prior resilience knowledge

Table 2.3 : Summary of Three Toolkits’ Workflow

2.2.3 Practice Examples

Having identified the key categories of resilience resources, this section examines how these resources are applied in real-world architectural practice. The aim is to identify patterns in resource use across different project phases and infer generalizable workflows that can inform future resilience research and implementation in design processes.

2.2.3.1 Resilience Worksheet (Risk & Vulnerability Assessment)

One illustrative example is the publicly available Resilient Buildings Planning Worksheet (City of Vancouver, 2023),. This tool has been utilized in early-phase risk assessments for several projects within the architecture firm ZGF. The worksheet offers a four-step, qualitative assessment workflow that guides users from initial hazard identification to the selection of resilience strategies.

The worksheet offers both design teams and clients a lifecycle perspective on building performance under risk, supporting informed decision-making and early-phase discussions around resilience. Rather than prescribing fixed strategies, the final step provides a structured platform for exploring customized responses appropriate to each project's constraints and opportunities.

Despite its strengths in framing a clear and logical process, from hazard identification to actionable strategies, the worksheet has limitations. First, it assumes that users possess sufficient background knowledge to research and interpret the implications of each identified hazard. While it supports a comprehensive analysis, the burden of hazard-specific research falls heavily on the project team.

Step	**Main Actions**	**Key Inputs**	**Outputs (Auto/Manual)**	**Data Flow**
Step 1: Exposure	Choose "Yes / No / Maybe" for each of hazards;	Site location, environmental data, historical events	List of hazards that a building might be exposed to	Only rows marked Yes are pulled into into Steps 2–4
Step 2: Impact	Score Consequence 1-5 for nine building systems (structure, MEP, operations, etc.)	Hazard list from Step 1	Consequence score per hazard-system;	Multiplied by Likelihood in Step 3 to calculate risk
Step 3: Likelihood & Risk	Assign Likelihood 1-5 to each hazard; Record rationale	Historical statistics, expert judgment	Risk score (Consequence * Likelihood); Overall risk rating & conditional formatting	Risks ≥ 10 are highlighted and forwarded to Step 4
Step 4: Strategies	Review Medium/High-risk items; Select a response (Existing / Planned / Not Feasible) and explain	Risk (≥ 10) from Step 3	Strategy list	—

Table 2.4 : Four Steps of the Resilient Buildings Planning Worksheet (City of Vancouver, 2023).

Second, the format, a dense Microsoft Excel spreadsheet, poses usability challenges. While spreadsheet-based tools are familiar to many professionals, the volume and complexity of embedded information can slow onboarding, particularly for users with limited data analysis experience. Compared to modern, web-based platforms, the worksheet lacks visual clarity, interactive features, and intuitive navigation, which may hinder broader adoption, especially among less data-centric stakeholders.

Nonetheless, this example demonstrates a foundation structure for resilience assessment at the pre-design stage. It also emphasizes the necessity of tools that balance analytical capability with accessibility and usability, which is an imperative that informs the development of the workflow and platform proposed in this research.

2.2.3.2 A Hospital Design with Resilience for Tsunami

The second case study concerns a ZGF-designed hospital project, Columbia Memorial Hospital, located in Oregon, positioned within the Cascadia Subduction Zone's XL tsunami inundation area. Both the existing facility, constructed entirely of wood, and a planned 180,000 ft² expansion are situated in the Cascadia Subduction Zone's XL inundation area, a high-risk seismic and tsunami zone. The existing structure lacks foundational integrity sufficient to withstand major earthquakes or tsunamis, rendering it likely non-operational during emergencies. Therefore, the expansion's structure, critical infrastructure, and designated evacuation areas were required to be carefully designed for resilience against these primary hazards.

The project's research process broadly followed the previously introduced four guiding questions, although the progression was in reality non-linear and iterative. Significant external support, particularly in funding and partnerships, played a crucial role in enabling advanced resilience strategies.

1. Early Outreach: The project team reached out to the University of Washington for detailed, site-specific tsunami modelling at an early master planning stage. Oregon Emergency Management (OEM) was also engaged early on to help identify grant funding sources for feasibility studies and to enhance connections with state geological resources, such as the Oregon Department of Geological and Mineral Industries (DOGAMI).
2. Site-Scale Tsunami Simulation: OEM secured FEMA funding for the University of Washington to conduct detailed inundation modeling.
3. Design Iteration: The design was refined to raise critical functions above inundation depth, integrate vertical-evacuation roof decks, and specify a hybrid concrete-steel podium.
4. BRIC Grant: A collaborative application by OEM, Clatsop County, and the project team secured additional funding through FEMA's Building Resilient Infrastructure & Communities (BRIC) program for resiliency scope premiums (*Building Resilient Infrastructure and Communities | FEMA.Gov*, 2025).
5. Design Implementation: The project team could implement some advanced, tsunami-resilient design features that would otherwise be cost-prohibitive.

While this case follows the theoretical guiding questions, the real-world process involved iterative loops between the project team, university, Clatsop County, OEM, FEMA, and funding timelines, illustrating that resilience implementation in practice is often far more complex and fragmented than linear frameworks suggest. Nevertheless, the project exemplifies an ideal scenario: strong client involvement, generous funding, and access to external consultants. These favorable conditions, however, may not be replicable in resource-constrained projects.

In this consideration, the workflow in this example can still be adapted and improved for la ater project:

- **Resource Portability:** How can resources and strategies from this project be shared with others? Resources used in different types of tasks should be catalogued in a searchable repository so that other coastal hospitals can reuse them rather than commissioning bespoke studies.
- **Workflow Modularity**: Break each overarching step into smaller, actionable steps, so new teams can very quickly pick up relevant portions without adopting the full framework. This modularity would enhance accessibility and facilitate incremental adoption.

2.3 Research Gap and Opportunities.

Source	**Gap**
Literature Discussion	Emphasis on improving isolated tasks (advanced modelling, metrics) rather than making results accessible to non-experts
Workflows & Toolkits	Existing frameworks are broad but remain **conceptual** and require considerable onboarding time
Scattered Resource	Rich data and precedents are **scattered and lacking** quick navigation
Practice Example 1: Resilience Worksheet	Usability barriers: Valuable content but heavy manual effort
Practice Example 2: Hospital Project	Demonstrate success only under ideal, resource-rich conditions; Workflows are project-specific

Table 2.5 : Related Work Summary

Current literature on resilience in the built environment largely concentrates on enhancing the performance of individual tasks, such as improving simulation accuracy, refining assessment metrics, or optimizing building responses to hazards. While these advancements are valuable, they tend to remain within the domain of technical experts, rather than being translated into accessible tools for everyday design teams.

Simultaneously, academic discussions have largely revolved around clarifying definitions and theoretical principles of resilience or developing high-fidelity tools for advanced performance analysis. There is a noticeable gap in research that addresses how to integrate these advancements into a structured, early-phase workflow that is practical and usable for the design team.

While resilience research benefits from abundant resources, including hazard data, case studies, and strategic toolkits, many of these materials are fragmented, hard to navigate, or disconnected from the early design process. Consequently, no current solution interweaves the most essential resources into a single, guided, early-phase workflow that a design team can open on day one of a project.

Moreover, existing practice resources oscillate between content-rich but labor-intensive tools and resource-heavy flagship projects, underscoring the need for a lightweight, easily adoptable workflow that delivers depth without requiring either spreadsheet stamina or extraordinary funding.

Opportunities implied by these gaps converge on three action points:

1. Deliver an accessible workflow that packages familiar, low-threshold tasks into a coherent path designers can follow on day one.
2. Integrate dispersed resources, hazard data, precedents, and strategy libraries, behind a unified navigation layer, eliminating the need for manual scavenging or extensive onboarding.
3. Provide lightweight, modular tools that automate data pulls and scale in depth: easy enough for small teams to adopt, yet extensible enough to incorporate lessons from flagship, resource-rich projects.

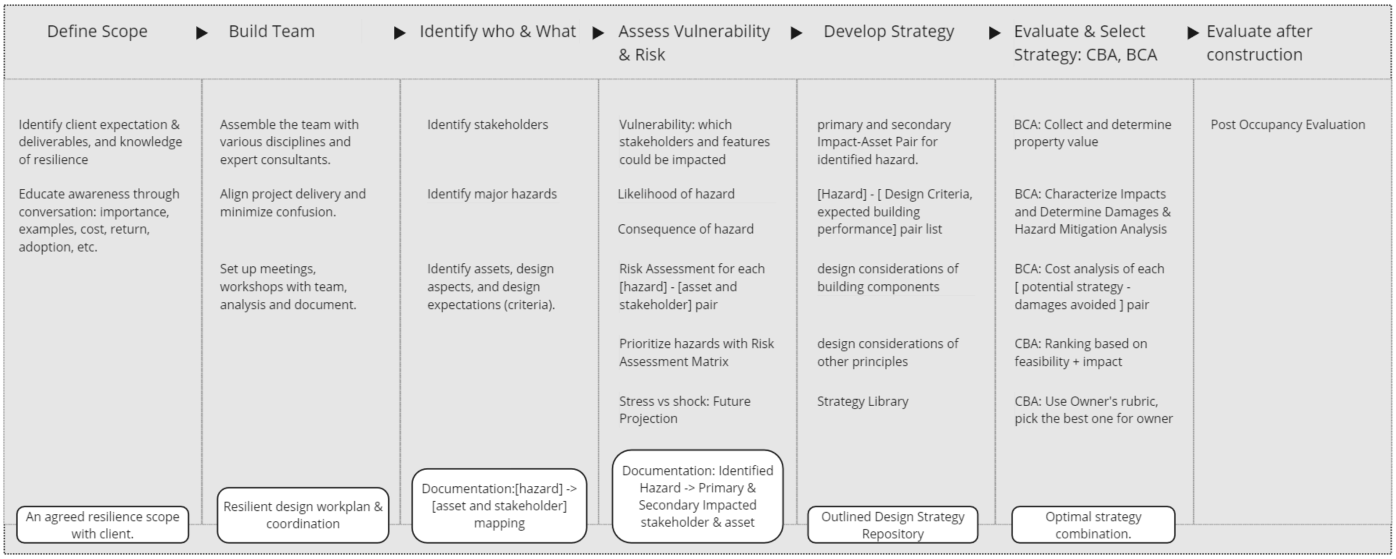
Chapter 3. Methodology

3.1 Method Overview: A Comprehensive Workflow

The three toolkits reviewed in Section 2.2.2 each occupy distinct positions along the spectrum of resilience research support. The U.S. Climate Resilience Toolkit is a broad, multi-sector portal for datasets, tools, and high-level adaptation guidance. The Sustainable and Climate-Resilient Health Care Facilities Toolkit tightens the focus to healthcare infrastructure, offering discipline-specific resources. The AIA–HKS Resilience Design Toolkit moves further toward architectural practice, offering a process-oriented structure that maps resilience integration onto familiar design tasks and project phases.

While these toolkits are individually valuable, the transition between them and the coordination of tasks across resources still impose significant overhead for design teams. They help teams understand "what is relevant" and "what might need to be considered," but they fall short in answering a more pressing, practical question: How can a design team, especially one with limited prior knowledge and time, efficiently navigate and operationalize these tasks and resources?

Building upon insights from the workflow structures reviewed in Section 2.2.2 and the practice examples in Section 2.2.3 , three critical questions emerge: 1) what is a bigger picture of the workflow in the context of comprehensive design phases; and 2) can key milestones and deliverables be defined and standardized within each phase; and additionally, 3) within each step, how can tasks be broken down into guided, clearly structured components to support usability and quick adoption? With these questions in mind, a comprehensive version of resilience design workflow is developed with more clearly staged tasks, and with most possible tasks to accomplish within each step.



Define Scope	▶ Build Team	▶ Identify who & What	▶ Assess Vulnerability & Risk	▶ Develop Strategy	▶ Evaluate & Select Strategy: CBA, BCA	▶ Evaluate after construction
Identify client expectation & deliverables, and knowledge of resilience	Assemble the team with various disciplines and expert consultants.	Identify stakeholders	Vulnerability: which stakeholders and features could be impacted	primary and secondary Impact-Asset Pair for identified hazard.	BCA: Collect and determine property value	Post Occupancy Evaluation
Educate awareness through conversation: importance, examples, cost, return, adoption, etc.	Align project delivery and minimize confusion.	Identify major hazards	Likelihood of hazard Consequence of hazard	[Hazard] - [Design Criteria, expected building performance] pair list	BCA: Characterize Impacts and Determine Damages & Hazard Mitigation Analysis	
	Set up meetings, workshops with team, analysis and document.	Identify assets, design aspects, and design expectations (criteria).	Risk Assessment for each [hazard] - [asset and stakeholder] pair	design considerations of building components	BCA: Cost analysis of each [potential strategy - damages avoided] pair	
			Prioritize hazards with Risk Assessment Matrix	design considerations of other principles	CBA: Ranking based on feasibility + impact	
			Stress vs shock: Future Projection	Strategy Library	CBA: Use Owner's rubric, pick the best one for owner	
An agreed resilience scope with client.	Resilient design workplan & coordination	Documentation:[hazard] -> [asset and stakeholder] mapping	Documentation: Identified Hazard -> Primary & Secondary Impacted stakeholder & asset	Outlined Design Strategy Repository	Optimal strategy combination.	

Figure 3.1 : Proposed Seven-Step Comprehensive Workflow

Once the horizontally phased and vertically detailed workflow was finalised, it was deployed as a discussion "playground" in the survey and workshop sessions (Section 3.2), allowing practitioners from a wide range of firms and project contexts to map their own experience onto each step. Their collective feedback both validated the framework and supplied the broader practice-based perspective needed to situate the workflow within today's resilience landscape.

3.2 Survey and Workshop

3.2.1 Survey

To obtain a panoramic view of how resilience research is currently practiced, an online questionnaire was distributed across six architecture and design firms that are part of the University of Washington's Applied Research Consortium (ARC): ZGF Architects, DLR Group, 7 Directions Architects/Planners, Mithun, Schemata Workshop, and Glumac. The objective of the survey was threefold: (1) to assess participants' resilience-related knowledge, experience, and exposure to typical hazards; (2) to identify barriers encountered at different design phases; and (3) to gather insights into what types of tools, resources, or guidance would help bridge existing practice gaps.

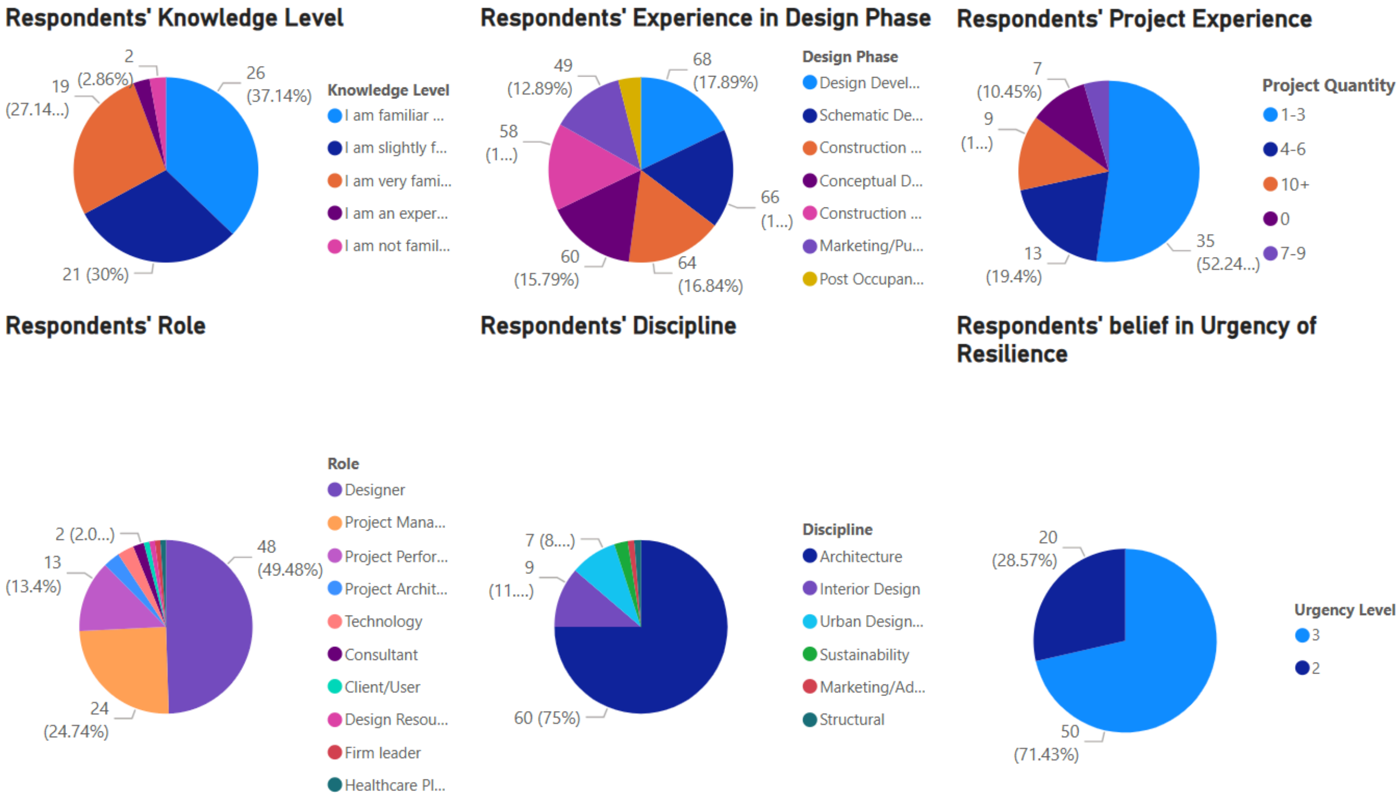
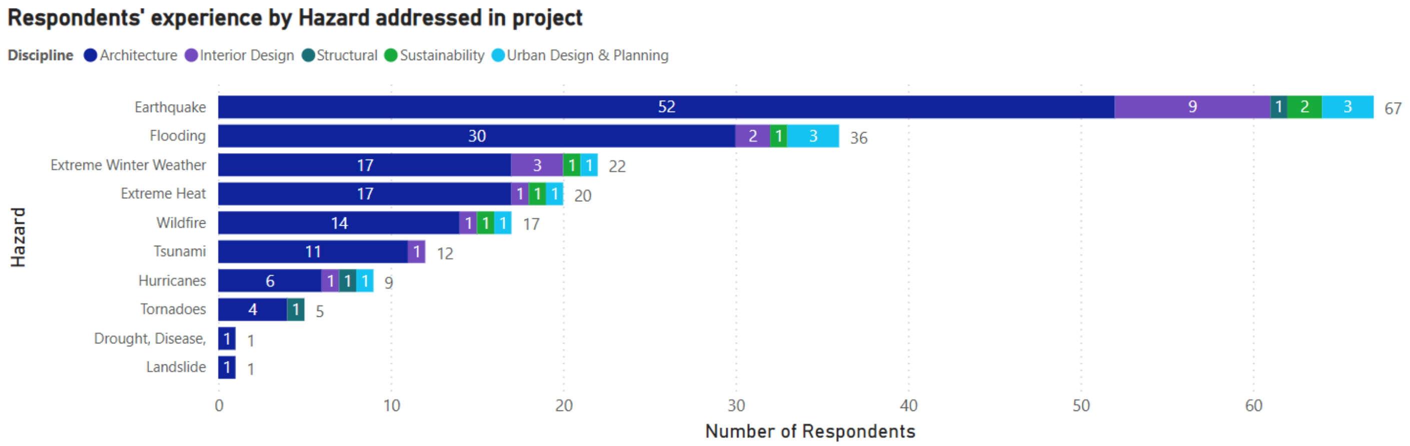


Figure 3.2 : ZGF Respondents' Background

The survey was divided into three sections: (1) Respondent Background: firm affiliation, discipline (e.g., architecture, interiors, urban design), professional role, experience with building types, and phases of involvement; (2) Resilience Practice: self-assessed knowledge level, number of resilience-focused projects, types of hazards addressed, perceived urgency, key obstacles encountered, and phases most impacted by gaps in support.; and (3) Open Sharing: open-ended questions inviting stories, suggestions, and willingness to participate in follow-up discussions or workshops.

The survey combined closed-ended questions with Likert-scale assessments to enable quantifiable analysis, supplemented by open-ended prompts to capture qualitative insights. The full list of questions is attached as Appendix A. A total of 115 valid responses were collected, with 71 responses from ZGF (approximately 62%) and 44 from partner firms. Within ZGF, 17% of respondents had participated in more than ten resilience-related projects. Respondents from partner firms reflected greater disciplinary diversity and, in general, self-rated higher in resilience knowledge and experience. Most participants identified as architects, interior designers, or urban designers, serving in roles such as designers, project managers, and performance consultants.

While acknowledging potential sampling bias, ZGF's internal promotion of the survey likely increased participation rates, responses from other firms may be viewed as self-selecting for those already engaged in or interested in resilience, thus representing a highly relevant perspective group. The inclusion of both ZGF and non-ZGF firms allows for comparative insights, with ZGF results serving as the primary focus due to the larger sample size, and partner firms' data offering a valuable reference for broader implications.



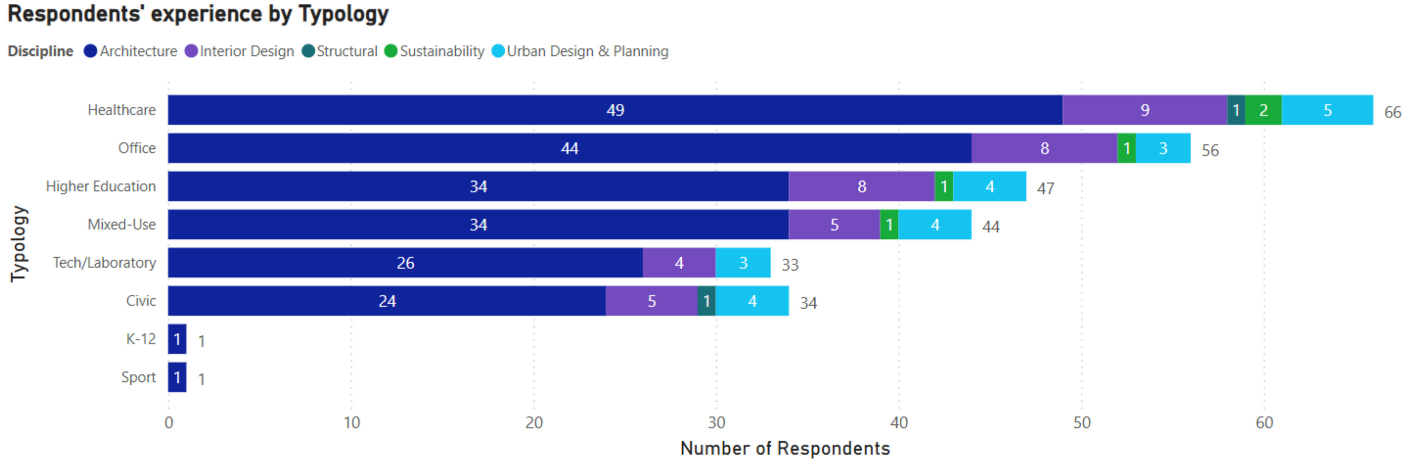


Figure 3.3 : ZGF Respondents' Experience

Healthcare facilities surfaced as the most representative project type, followed by office, higher-education, and mixed-use buildings. Respondents emphasized that hospitals must remain operational during crises, making them prime testbeds for comprehensive resilience strategies. Across all firms, the four most common hazards were earthquake, flood, extreme heat, and extreme winter weather. These hazards span project types and phases, underscoring the need for multi-hazard design.

Participants were asked to select from six designated barriers to implementing resilience strategies; three barriers were most frequently cited, especially during the pre-design through schematic design phases:

- Alignment with owners/contractors on the level of resilience, its necessity, scope, and cost.
- Lack of supporting resources—data, tools, consultants, and references.
- Difficulty in hazard and risk assessment for specific projects.

Respondents also noted hurdles in cost–benefit communication, fragmented resources, and insufficient mentorship or structured processes. While AEC professionals, especially architects, recognize the urgency of integrating resilience into design, they often lack the effective tools, cohesive resources, and compelling narratives needed to communicate the value of resilience to clients and persuade them to implement corresponding strategies. Respondents called for intuitive risk-communication tools, centralized resource indexes, and clear methods for quantification to close this gap between intent and implementation.

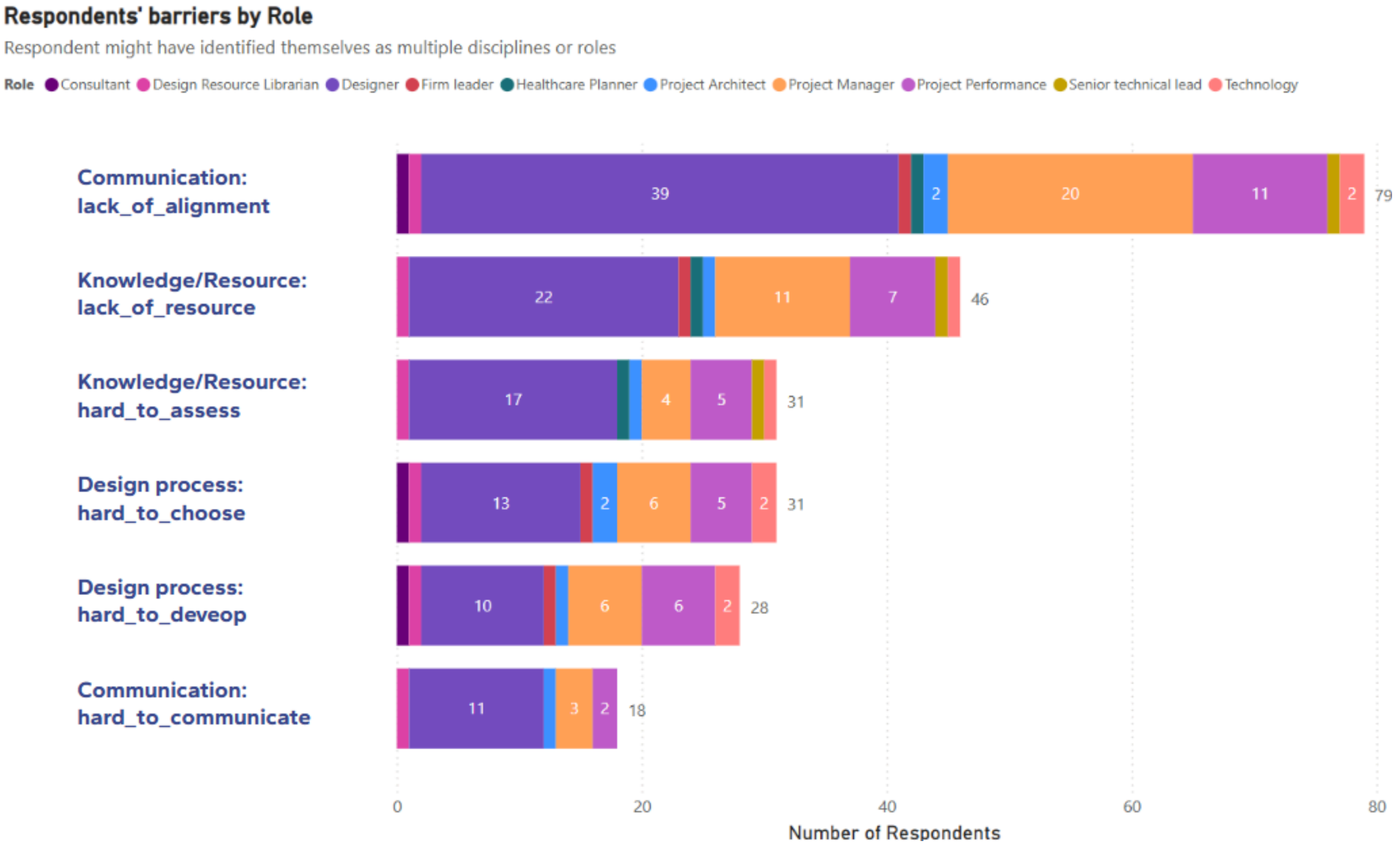


Figure 3.4 : All Respondents' Barrier

An effective solution must therefore fuse three capabilities: an intuitive pathway for risk assessment, seamless access to authoritative data and precedents, and straightforward mechanisms for communicating necessity with real-world examples.

The result from the survey also helps narrow down the scope of this research. The scoping exercise ultimately concentrates on healthcare facilities, as this building type spans the full spectrum of high-frequency hazards, engages the broadest range of disciplines and roles, and provides lessons readily transferable to other mission-critical buildings. Based on the survey results, earthquakes, floods, and extreme heat are identified as the most urgent and ubiquitous risks across U.S. climate zones and therefore form the core hazard set.

Furthermore, attention is strategically directed at the **early project stages**, from pre-design through schematic design, where the survey revealed the most significant pain points. At this phase, timely delivery of **risk data, strategy options, and cost justification** can avert costly late-stage revisions and significantly enhance client buy-in. The intended audience is the entire design team, regardless of their prior exposure to resilience, most would need accessible tools for hazard identification, strategy selection, and persuasive client communication at project kick-off.

	to Client	**to Team**
Barrier	Clients are “scared” of complicated resilience knowledge Clients want to see how resilience actually helps financially.	Hard-to-navigate resources (especially no one set this up!) Hazard identification & risk assessment Resilience precedents
What is ideal	Organize material by: typology/geographic zone/design system Hazard-specific generic solutions (collection of strategy) Show the concrete examples, both successful and unsuccessful Curated standards, guidelines, code excerpts	
Opportunity	A single, easy-to-navigate hub for resilience resources, especially for early-phase decisions and client persuasion. Solutions must combine user-friendly risk assessment, integrated authoritative data/precedents, and clear quantified communication material. A well-structured, guided workflow	

Table 3.1 : Survey Summary

3.2.2 Workshop

While the survey identified headline barriers, further granularity became essential, specifically, to identify *which tasks within which design phases* require the most immediate attention and *what types of support* design teams actually need. Three semi-structured workshops were conducted at ZGF, each lasting about one hour and involving 4–6 participants (15 total) who had expressed interest in the survey. The aim was to drill down into phase-specific pain points and discuss actionable support mechanisms.

The survey is designed with these 2 objectives: 1) Pinpoint the design phase(s) that need the most attention (Where); 2) Identify approaches and tools that can effectively assist the design team (How). Starting from these objectives, the workshop, mainly a semi-structured discussion, is developed into 4 parts.

- Part 1: Introduction and Workflow Review – reflections on the existing resilience workflow and notable good/bad experiences at each step.
- Part 2: Resource – participants' experience with resilience resource, current challenges in locating information and examples of reliable sources
- Part 3: Precedent & Strategy – participants' experience with precedent and strategy, how they translate prior knowledge into actionable design moves.
- Part 4: Task Prioritisation – which tasks most urgently need improvement and what form of support is preferred.

Workshop discussions converged on three design steps that demand the greatest improvement.

- Initial Scoping emerged as the top priority: participants stressed that early, high-level hazard framing, presented in digestible language and backed by clear graphics, precedent case studies, and funding insights, helps owners understand why resilience matters and agree on time, cost, and consultant requirements from Day One, and prevents costly re-work later
- Risk Assessment ranked second, with designers noting that projects often lack a systematic method and that agreement on scope and assumptions is essential; without it, only the most obvious threats receive attention.
- Develop Strategy was third, highlighting the need for a tiered library that offers concise executive summaries with links to deeper technical guidance, all delivered in a simple, approachable, and maintainable format.

Across these phases, participants consistently identified four categories of support needed to facilitate resilience integration:

- Rapid communication tools capable of producing client-ready materials;
- A centralized, searchable resource hub organized by context;
- Curated lists of funding opportunities and cost-benefit guidance to support implementation feasibility;
- A minimal workflow with baseline resources, designed to rapidly equip teams for informed early-stage dialogue with clients and consultants. "Too many resources" can be a problem.

3.2.3 Summary

The survey and subsequent workshop form a two-step, progressively finer inquiry into resilience practice. The survey provided a wide-angle snapshot across multiple firms, revealing systemic barriers and guiding the study's scope. The workshop then zoomed in within ZGF to validate those findings, assign phase-level priorities, and outline detailed support mechanisms.

- **What – Key Barriers:** Early-phase communication gaps with owners, fragmented or inaccessible resources, and unstructured hazard assessment practices remain the primary hurdles. These barriers hinder both the justification and implementation of resilience measures.
- **Where – Critical Phases.** The decisive moment is the *Define Scope* stage, where alignment on time, cost, and performance goals sets the project's trajectory. Systematic *Risk Assessment* is the next linchpin, ensuring that all relevant hazards, and not just the obvious ones, are considered in the design. Finally, *Develop Strategy* benefits from a structured, tiered knowledge base to translate analysis into actionable design moves. Notably, the key steps are highly aligned with what we learn from the practice examples.
- **How – Support Pathways.** Both datasets converge on four intervention themes:
    - Rapid, compelling risk-communication tools for owner engagement.
    - A centralized, context-tagged resource hub that unifies data, case studies, and guidance.
    - Funding or ROI modules that pair cost–benefit logic with real-world success stories.
    - A minimal workflow with baseline resources that elevate internal capacity and embed resilience thinking as early as the RFP or pre-design stage.

Together, the survey's breadth and the workshop's depth map a clear route forward: resilience strategies must be integrated early, at the point of scope definition and risk framing, through content that is layered, easily navigable, and communicative.

3.3 An Essential Workflow

The comprehensive workflow presented in Section 3.1, synthesized from leading toolkits and practical experience, provides design teams with a clear, step-by-step roadmap for resilience research. By packaging each phase with well-defined tasks, it replaces open-ended exploration with a structured starting point. However, during the workshop sessions, where the workflow was used as a "playground" for participants to identify pain points, several limitations became apparent. In very early design phases, not every step is equally urgent, and the full seven-step sequence can feel cumbersome to teams with limited time, experience, or specialised resources.

The results from the survey and workshop unveil where (which steps and tasks) and how (what the workflow should offer) the design team would love to improve. A simplified yet focused version of the previous comprehensive workflow is tailored for this feedback. This version concentrates on the tasks most critical to early-phase project development, especially for teams with limited time, experience, or access to specialized resources. The essential workflow emphasizes three key steps:

- Identifying hazard: What hazard would happen on this site;
- Assessing risk: how the hazard(s) would impact each system of the building project, and at what level of risk;
- Navigating resource: browse a selected range of resources, most importantly, case study and strategy collection, so that they can later be used for strategy development;

Because these steps rely primarily on publicly available or firm-agnostic data, the essential workflow can be adopted quickly across different project types and geographic contexts. In contrast to many existing toolkits, which aim for exhaustive coverage of tasks and resources and thus risk overwhelming small teams, this pared-down sequence is purpose-built for rapid, targeted research. It provides designers with a clear entry point, immediate access to the most pertinent information, and the flexibility to scale into deeper analysis only when time and scope permit.

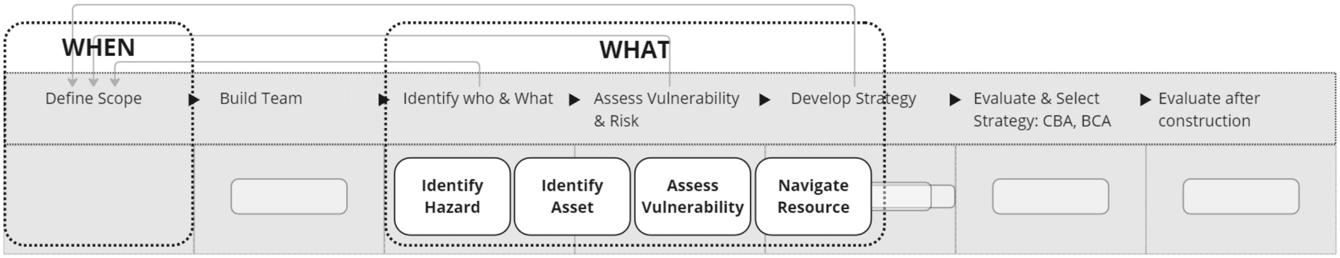


Figure 3.5 : The Essential Workflow- Trimmed from the Comprehensive workflow

Tasks should be designed to be "resource-dependent" and also offer the flexibility for project context. Within the 3 essential steps, these questions is developed to respond to the :

1. What is the hazard that might be happening on this site?
2. How would this hazard impact my building and occupants?
3. What project has a similar context?
4. What are some strategies for this context and hazard?
5. How do I compare these results?
6. What are some other resources?

To structure the essential workflow, each input factor was evaluated against two key criteria: Frequency, which refers to how many of the core questions the factor can answer, and Usage Pattern, which indicates the typical way a design team interacts with that factor (Search, Consult, Exhaust, or Compliance).

Factor	Q1	Q2	Q3	Q4	Q5	Q6	Total Freq	Dominant Pattern	Additional Comment
Site Context & Hazard	●	●	●	●	–	●	5	Search	Critical starting point for all assessments
Precedent & Strategy Library	–	–	●	●	●	–	3	Search	Mentioned in the survey and workshop
Consultant / Gov Agency	–	–	–	–	–	●	1	Consult	Existing tools like "Procore Network"
Certification & Funding	–	–	–	–	–	●	1	Consult + Compliance ＋ Funding	Not task-specific in early phases
Building & Local Code	●	●	–	–	–	–	2	Compliance	Existing tools like "UpCodes"
Essential Asset List	–	●	–	–	–	–	1	Exhaust (list all)	Too project-specific, not "reusable" for more projects

Table 3.2 : Selecting Factors for Questions

By mapping each factor to the question set and tallying its hits, an initial priority ranking is obtained.

Site Context & Hazard emerged as the top priority. It addresses almost all core questions and acts as the workflow's "ignition key": without a clear understanding of the site's primary hazards, subsequent vulnerability assessments and strategy discussions stall. Practically, the factor is accessed through Search (or can be automatically pulled from NOAA/FEMA APIs), backed by authoritative data. The second most valuable factor is the Precedent & Strategy Library, it directly answers all designers related to navigating resources, providing design teams with rapid exposure to relevant case studies and strategic options.

Other factors, such as consultants, funding databases, and local codes, are excluded from this lean workflow because they either replicate existing tools, entail higher implementation costs, or offer limited generalizability across project types. In the spirit of a minimum viable workflow, they are currently ignored.

With the core factors defined, the next step involves structuring the parameters required to execute the workflow. These parameters represent the specific data fields needed to answer the core questions in each task.

		Parameters	Source	Example	Source	Question
Core Factors in the workflow	**Site Context & Hazard**	**Location**	User specify	Seattle, WA	User	Q1
		Historic Hazard (type, frequency)	FEMA API	–	Q1	Q2, Q3, Q4, Q6
		Other Context : Typology, Project constraint, scale, etc.	User specify	Hospital; 200,000 sf	User	Q2, Q3, Q4, Q6
	Precedent & Strategy Library	**Case study**	Workflow Embedded + User upload	–	User + Demo	Q3, Q5
		Strategy	Workflow Embedded + User upload	–	User + Demo	Q4, Q5
Supportive Factor	**Building System List**	–	Workflow Embedded	–	User + Demo	Q2
"Other resource"	**Any types of resource**	–	Workflow Embedded + User upload	–	User + Demo	Q6

Table 3.3 : Parameters for Workflow's Core Questions

3.4 Data Collection

The primary obstacle encountered during data collection was the scarcity of publicly available, high-quality case studies and strategy records that are narrowly focused on healthcare resilience. Most open-access information is fragmentary, buried in unstructured reports or conference slide decks, and therefore ill-suited to direct query or comparison. Faced with this barrier, the research could proceed in one of two directions. The first was to invest heavily in curating an expert-grade, healthcare-specific knowledge base, an ambitious goal but one unlikely to be completed within the project timeline. The second was to leverage readily available resilience datasets that, while not exclusive to healthcare, share a schema compatible with the Option Database (All Options Embed, n.d.), and thus provide an immediate foundation for search and retrieval.

Category	Dataset / File	Size	Key Fields (if table file)	Original URL	License / Availability	Question
Case-Study Library	fema-case-study.csv	1,255 records	Title, Hazard, Location, Description, URL	https://www.fema.gov/emergency-managers/practitioners/case-study-library	Public domain / CC0	Q3, Q5
Hazard Guidance	fema-publication.csv	441 records	Title & PubNo, Year, Description, Hazard, URL	https://www.fema.gov/emergency-managers/risk-management/building-science/publications	Public domain / CC0	Q6
Strategy Library	All Options Embed.csv	1,061 records	Option, Hazard, Asset, Action, Description, URL	https://toolkit.climate.gov/option	Public domain / CC0	Q4, Q5
Other Resource (Funding)	Building Code Funding Opportunities.pdf	4 pages	Funding source, eligibility, application notes	https://www.fema.gov/emergency-managers/risk-management/building-science/building-code-funding-opportunities	FEMA open PDF	Q6
Other Resource (Healthcare Speciality)	CR4HC_1_All_Multiple Hazards.pdf (one chapter of the original 373-page pdf)	38 pages	Healthcare-specific steps, tools, resource links	https://toolkit.climate.gov/topic/health-care	NOAA open PDF	Q6
Hazard	FEMA Disaster Declarations API	68,193 records	Hazard, State, County, BeginDate, EndDate	https://www.fema.gov/openfema-data-page/disaster-declarations-summaries-v2	Public domain / CC0	Q1–Q4, Q6
Systems Checklist	City of Vancouver Building Resilience Planning Worksheet	–	System name, function, resilience target, redundancy level	https://vancouver.ca/files/cov/resilient-buildings-planning-worksheet.xlsx	Municipal open data	Q2

Table 3.4 : Data Used as Demo for Building the Platform

Given the time and resource constraints, the second path was chosen. Although these public datasets lack the depth and clinical specificity of a bespoke collection, they serve as effective placeholders for validating the platform's search and recommendation engine. All demo datasets were drawn from authoritative sources cited in Section 2.2.1, FEMA, NOAA, and other government portals, and are both freely accessible and carry no material licensing barriers to commercial use by licensing restrictions. With the data gap acknowledged and a surrogate corpus in hand, the project can advance to the next phase: constructing and refining the tool itself.

3.5 What This Platform Is and Is Not

This research positions the proposed platform as an open, expandable toolkit for supporting early-phase resilience exploration in architectural design. Its primary aim is to demonstrate that, even using imperfect but schema-compatible public datasets, design teams can rapidly transition from hazard identification to precedent exploration and initial strategy formation. As such, the core focus of this research lies in the design of the workflow, processing of structured data, and creation of a usable, intuitive interface, one that demonstrates how disparate information streams can be normalized, queried, and meaningfully compared within a unified platform.

This platform is not intended to function as a comprehensive or expert-curated knowledge base. Nor does it seek to replace detailed resilience modeling, code compliance workflows, or the professional judgment of licensed experts. The current data layer serves as a proxy, enabling proof-of-concept validation; richer, practice-specific content will only emerge if and when the design community or design firms contribute high-quality case studies, strategies, and metrics.

Because the platform remains open and collaborative, users play a pivotal role. They are responsible for validating the accuracy, relevance, and intellectual property status of any material they upload. In short, the tool supplies the structure and search intelligence, but the user must provide and curate the knowledge that gives the structure lasting value.

Chapter 4. Resilience Research Platform

4.1 Technology Background

4.1.1 AEC Data and Knowledge

Architectural data encompasses a broad and diverse range of formats and sources. Beyond fundamental documents such as building codes, zoning, and municipal master plans, design teams also rely heavily on site-specific geographic data (e.g., GIS hazard overlays), legacy project documentation (e.g., narratives, drawing sets, detail sheets, and photographic archives), manufacturer-issued material data sheets, granular BIM element schedules, and historical CAD/IFC files that encode previous coordination decisions. Many of these data types are crucial in the very early stages of a project, when designers must quickly frame regulatory constraints, precedents, and site risks before beginning any substantive design work.

While the majority of this information remains text-heavy, the containers that store this knowledge are highly fragmented: GIS data is typically accessed via web-based map viewers; code databases exist as large, keyword-searchable online libraries; BIM data is often buried within proprietary filters; and decades-old CAD files usually require manual review due to cryptic file naming conventions. This "unconnected" retrieval process imposes a significant overhead, particularly for junior designers, who must piece together critical information from disparate locations and file formats before any modeling can begin.

Typical Information	Dominant Current Retrieval Method	Useful in Very-early-phase?	Chosen for this platform?
Site Hazard & GIS	Government websites; GIS viewer	Yes	Yes
Historical project Knowledge (including case study, strategy collection)	Manual folder search; asking senior staff	Yes	Yes
Codes & regulations	Paper codes; keyword search in online code library	Yes	–
Material data	Manufacturer PDFs; BIM object portals	–	–
BIM/CAD/IFC	Native design-software browsers or filename search followed by manual visual review	–	–

Table 4.1 : Data and Knowledge in a Typical Architecture Design Process

4.1.2 Information Retrieval and Retrieval-Augmented Generation.

Retrieval-Augmented Generation (RAG) is an Large Language Model (LLM) application framework that fuses two components: (1) a vector search engine that encodes both a static corpus (e.g., documents) and the incoming user query into dense embeddings and returns the most semantically similar chunks; and (2) a LLM that turns the retrieved evidence into a nature language response. In a typical "naïve" RAG pipeline, everything is in memory: it builds a simple embedding index over the user's files, finds the *k* most similar chunks for every new query, and passes them to the LLM to draft a single-shot answer directly from those chunks. This recipe was introduced in 2020 (Lewis et al., 2021) and has been popularised through open-source tutorials and libraries. While deceptively simple, naïve RAG already mitigates hallucinations by forcing the model to ground its response in retrieved passages (Shi et al., 2023).

In the AEC domain, RAG application, usually from niche players, are beginning to emerge: Knowledge Architecture's "Advanced Employee Search" mines intranet documents with semantic embeddings for tasks like search for consultant (*Introducing Advanced Employee Search*, 2025), and Linc AI markets a generative knowledge base for construction teams that surfaces cited answers across drawings, specs, and historic marketing documents (Linc AI, n.d.).

4.1.3 Web Development

The chief benefit of a web application is that it runs directly from the browser, with no local installation needed. Because it relies on open standards (HTML, CSS, JavaScript), the HTTP protocol, and cloud hosting, any device with a modern browser can reach the latest version instantly. From the user's perspective, there is no concern about compatibility, version control, or manual updates. Developers, in turn, can iterate quickly and deploy new features without worrying about what's installed on each user's machine.

A modern web application typically follows a two-layer framework, and the data communication within these layers, every time you click or tap, is like a three-stop journey:

- The client/frontend: It runs in the user's browser. It would: render the interface, capture user action and input data, process lightweight operations (e.g., animations, local caching), and communicate with the backend when more complex data or logic is required. After the server responds, the frontend would update the display accordingly.
- The server/backend: It processes requests from the frontend, interacts with databases, runs algorithms, and sends back the results. It handles core functions like API calls, security validation, and data aggregation.

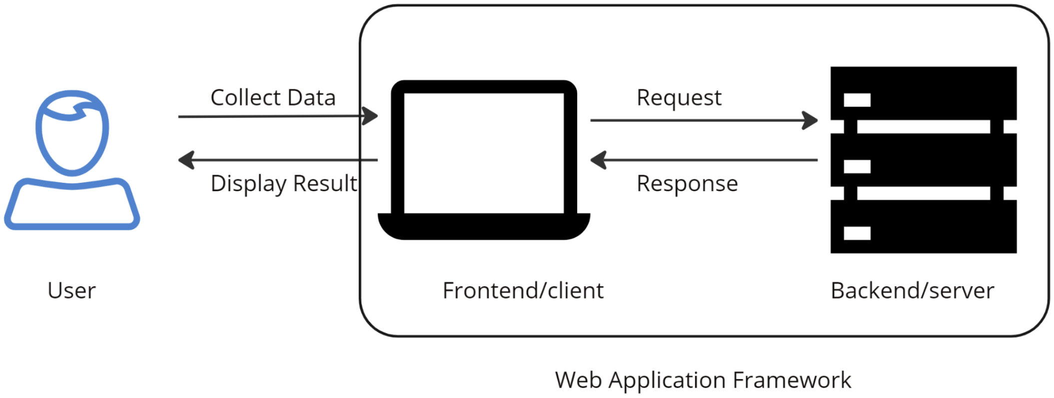


Figure 4.1 : Modern Web Application Framework

Because the browser only downloads lightweight front-end code, users always run the latest version without installing anything. Meanwhile, the heavy-lifting part, data storage and complex algorithms, remains in the backend, where it can scale, update, and stay protected. And when using services provided by another party, API, an application-programming interface that returns machine-readable JSON through simple web URLs, would be used. The clear separation and communication between these layers ensure a smooth user experience, allowing teams to swap technologies under the hood without affecting what users see on-screen.

To streamline development, teams often rely on well-established **technology ecosystems** rather than starting from scratch: frameworks, libraries, and cloud services that handle the routine plumbing so teams can focus on features. Every language has its own ecosystem; in our case, we stay in the JavaScript family, so the same language runs everywhere. On the front end, React provides pre-built components and a tidy way to manage changing screens. On the back end, Node.js lets developers write server logic, connect to databases, and expose secure APIs without wrestling with low-level networking code (*Node.Js — Run JavaScript Everywhere*, n.d.). And on the frontend, React.js could help with dynamic features and also support component library-like Material UI (*Material UI*, n.d.; *React*, n.d.).

4.2 From Workflow to Platform: Essential Functionality and Component

Based on the essential workflow developed in Chapter 3 and the typical user questions identified at each step, this section outlines the core functional components necessary for translating the workflow into a usable, browser-based platform. Each component represents a high-level encapsulation of multiple lower-level functions, spanning both frontend and backend operations. Here is a list of 6 core components:

1. Hazard Finder: Retrieves and visualizes hazard records from FEMA based on the user-specified location. Users would select hazards most relevant to their site for further analysis.
2. Risk Assessor: Guides users through evaluating the impact of selected hazards on relevant building systems and subsystems, including assessing future likelihood and prioritizing high-risk scenarios.
3. File Curator: Enables users to upload structured files (e.g., tables, PDFs), parse and save content, and interact with it via a chatbot-style interface.
4. Context Composer: Helps users define project-specific parameters such as location, building typology, scale, regional setting, and other contextual fields in a structured format.
5. Query & Answer: Supports semantic search within uploaded documents. Accepts natural language questions, retrieves relevant text segments, and optionally summarizes the findings.
6. Knowledge Explorer: Visualize retrieved results from " Query & Answer" by mapping semantically connected results, especially from structured files, based on shared context. This feature helps users discover related strategies or precedents.

Component and Step	Input from User	Other Input data	What this Component would do	Key Technology
Step 1: Hazard Finder	location	FEMA API	Fetch all hazard records from FEMA with the user's input location, render and display to the user, and record hazards selected by the user	FEMA api, Recharts, Express.js
Step 2: Risk Assessor	building system-subsystem,	User-selected hazards (from previous step)	Guide the user through the process of assessing the impact of the hazard on the related building system-subsystem, assessing the likelihood of the hazard happening in the future, and selecting prioritized risks to consider in later steps	React, MaterialUI
Step 3 + File Management: File Curator	File (table file or pdf)		Handle file uploading and parsing, provide a chatbot-like window for the user to quickly talk with a file	**Backend:** Multer, OpenAI, LangChain, etc. **Frontend:** React, MaterialUI, React-force-graph-3d, etc.
Step 3: Context Composer	Project context (text)	–	Define project context in a more structured way, including location, typology, scale, geography region, and other customized fields.	
Step 3: Query & Answer	Question in natural language	Retrieved Chunks from previous Query (if asked to perform summarization)	Perform semantic search with the user's message within a specific range of files, render and display retrieved results; also support summarization of retrieved results	
Step 3: Knowledge Explorer	–	Retrieved Chunks from previous Query	Visualize the retrieved result from " Query & Answer" by connecting results with the same context, only support the result from the table file	

Table 4.2 : Data and Knowledge in a Typical Architecture Design Process

4.3 Implementation

4.3.1 Step 1: Identify Hazard: Hazard Data through FEMA API

To retrieve credible and authoritative hazard data, this platform utilizes the Federal Emergency Management Agency (FEMA), the U.S. agency responsible for maintaining nationwide disaster records. Instead of manually downloading large, static datasets, the platform connects directly to FEMA's OpenFEMA API, enabling real-time access to historical hazard data in machine-readable JSON format. For example, the endpoint delivers up to 5,000 disaster-declaration summaries for Washington State in a single request:

https://www.fema.gov/api/open/v2/DisasterDeclarationsSummaries?$filter=state%20eq%20%27WA%27&$top=5000&$format=json		
Broken-down request		What it means
Path	https://www.fema.gov/api/open/v2/DisasterDeclarationsSummaries	Routes the request to the 'DisasterDeclarationsSummaries' dataset via OpenFEMA (the agency's public, no-auth, OData-style API) version 2
Query parameter: **filter**	$filter=state%20eq%20%27WA	Filters rows so only records whose state field equals 'WA' are returned.
Query parameter: **top**	$top=5000	Limits the response to the first 5000 rows after filtering.
Query parameter: **format**	format=json	Tells the server to send back JSON instead of CSV or XML.

Table 4.3 : FEMA API Request Example

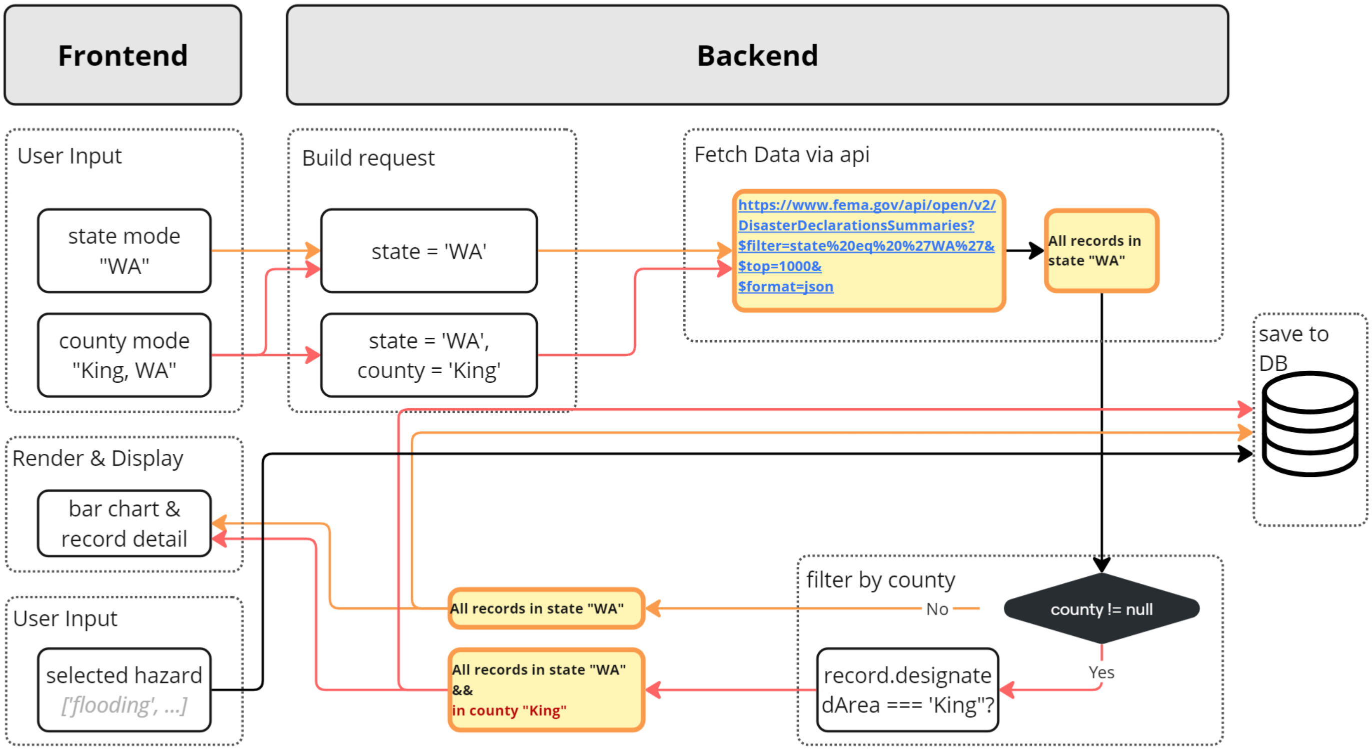
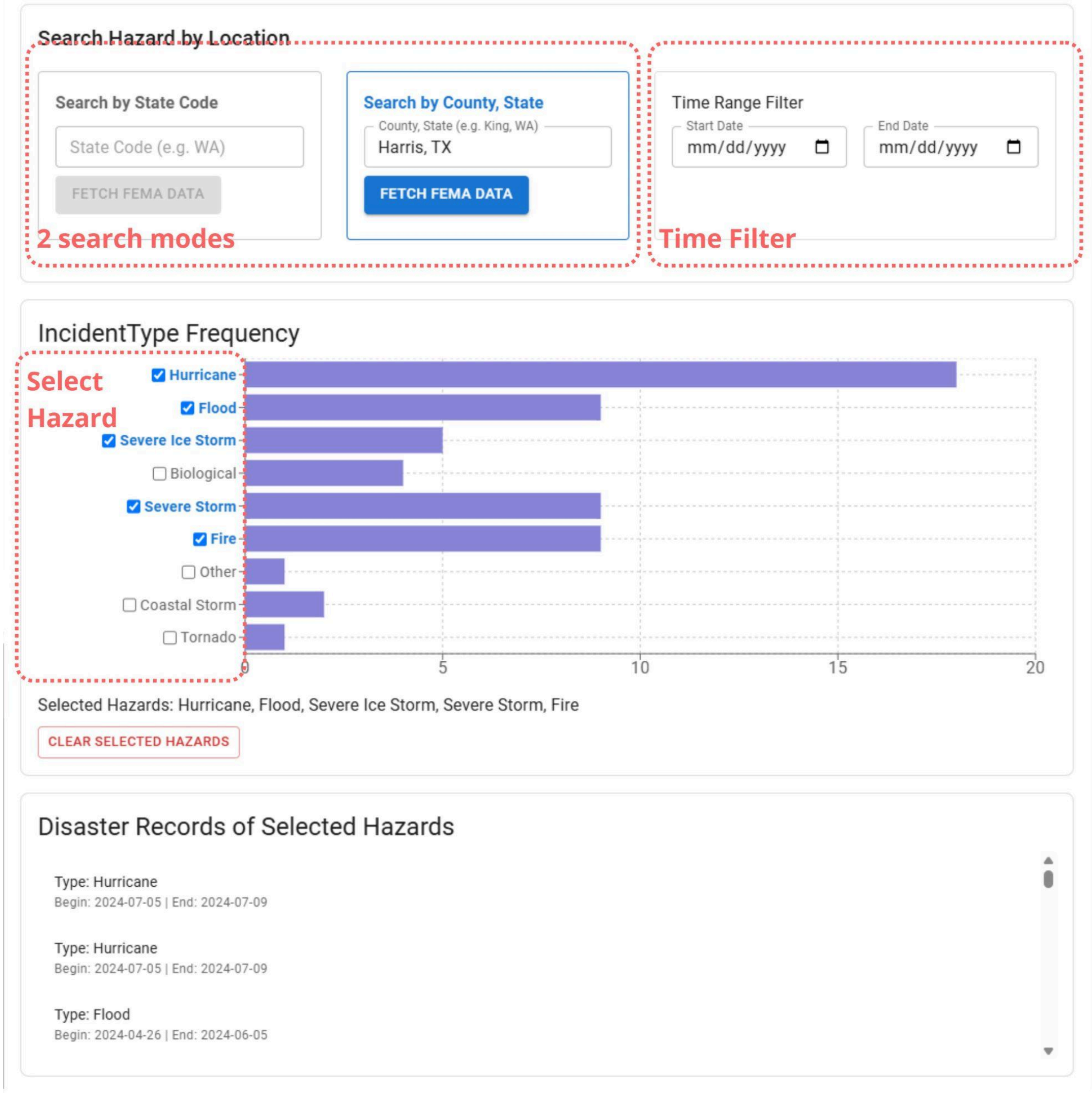


Figure 4.2 : Two Search Modes and Output

The platform offers two query modes, providing users with flexibility. In state mode, the user inputs a two-letter abbreviation, such as "WA," and the request is sent to OpenFEMA. Every record returned for that state is then saved. In county mode, the user adds a county name ("King, WA"); the same state-level response is retrieved, but the platform then filters the list to keep only rows whose "designatedArea" field matches the chosen county. Either way, the retrieved dataset is stored on the backend, forming the hazard base for downstream tasks. Figure 4.3 illustrates this flow from user input to filtered dataset.

Once the data from FEMA arrives and is stored in the backend, the front-end bar chart then visualizes the number of declarations by hazard type. Users can click on individual bars to select which hazards are relevant to their project; these selections are stored server-side for subsequent risk assessment steps.



Search Hazard by Location

Search by State Code

State Code (e.g. WA)

Search by County, State

County, State (e.g. King, WA): Harris, TX

Time Range Filter

Start Date: mm/dd/yyyy

End Date: mm/dd/yyyy

IncidentType Frequency

☑ Hurricane
☑ Flood
☑ Severe Ice Storm
☐ Biological
☑ Severe Storm
☑ Fire
☐ Other
☐ Coastal Storm
☐ Tornado

Selected Hazards: Hurricane, Flood, Severe Ice Storm, Severe Storm, Fire

Disaster Records of Selected Hazards

Type: Hurricane
Begin: 2024-07-05 | End: 2024-07-09

Type: Hurricane
Begin: 2024-07-05 | End: 2024-07-09

Type: Flood
Begin: 2024-04-26 | End: 2024-06-05

Figure 4.3 : Interface of Step One

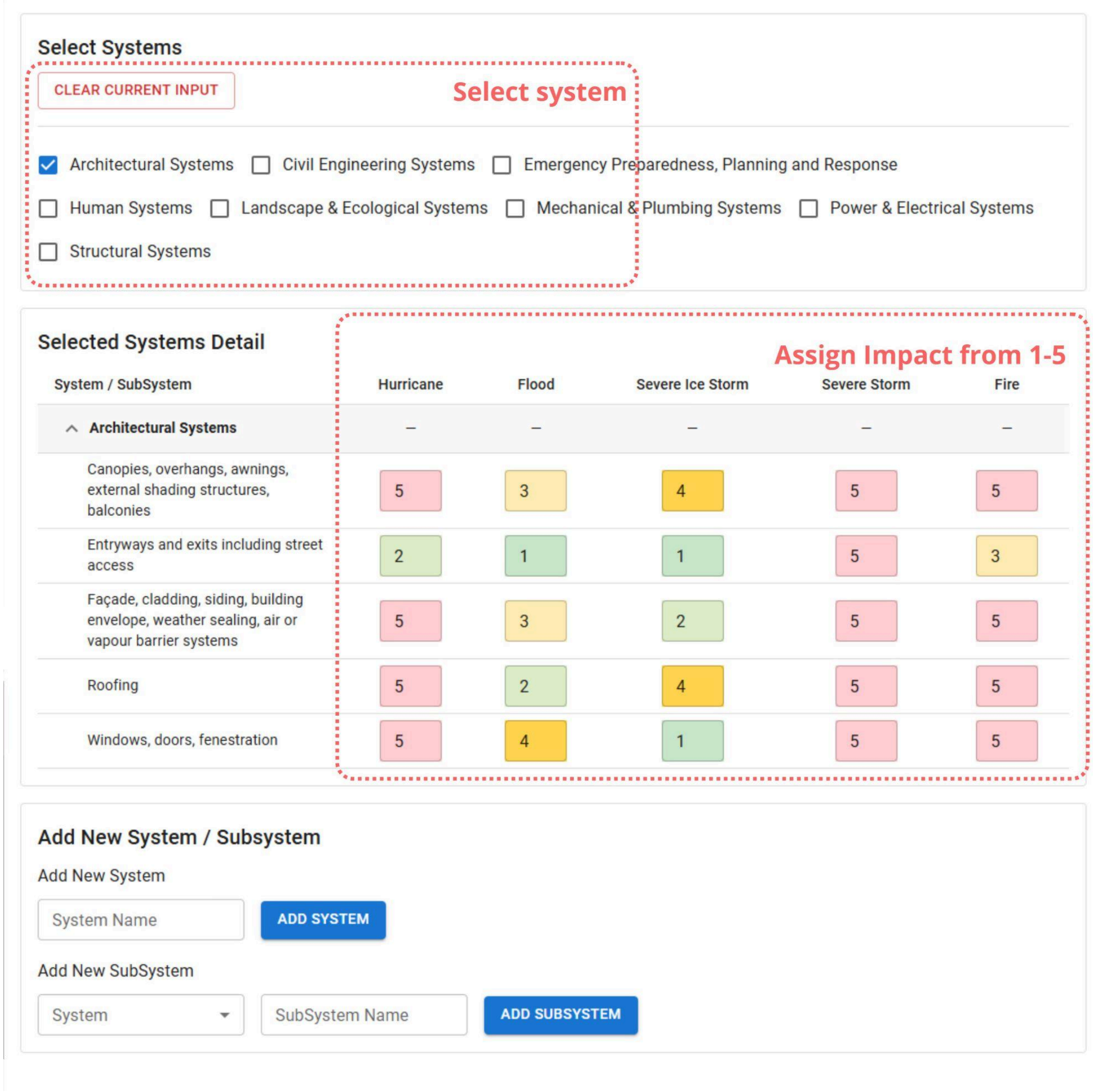
4.3.2 Step 2: Assess Risk

Building on the Building Resilience Planning Worksheet reviewed earlier (City of Vancouver, 2023), Step 2 of the platform divides the overall risk-assessment task into three sequential subtasks:

1. Assess the impact of each hazard on every building system and subsystem
2. Estimate the likelihood that those hazards will occur within the building's service life
3. Combine impact and likelihood to identify prioritized hazard–system pairs

4.3.2.1 Assess Impact of Hazard on Building System-Subsystem

Mirroring the Building Resilience Planning Worksheet (City of Vancouver, 2023), each selected hazard is displayed alongside a predefined list of building systems (architectural, structure, envelope, MEP, etc.). The user would assign an impact score from 1 (low) to 5 (high) wherever a meaningful effect exists. Default systems and subsystems are pre-loaded, but users may add custom systems or subsystems to reflect project realities. All scores are stored server-side for later calculations. Note that this process requires the user's architectural knowledge, and the quality of this step depends on the practitioner's own expertise and project-specific insights.



☑ Architectural Systems ☐ Civil Engineering Systems ☐ Emergency Preparedness, Planning and Response
☐ Human Systems ☐ Landscape & Ecological Systems ☐ Mechanical & Plumbing Systems ☐ Power & Electrical Systems
☐ Structural Systems

System / SubSystem	Hurricane	Flood	Severe Ice Storm	Severe Storm	Fire
Architectural Systems	–	–	–	–	–
Canopies, overhangs, awnings, external shading structures, balconies	5	3	4	5	5
Entryways and exits including street access	2	1	1	5	3
Façade, cladding, siding, building envelope, weather sealing, air or vapour barrier systems	5	3	2	5	5
Roofing	5	2	4	5	5
Windows, doors, fenestration	5	4	1	5	5

Figure 4.4 : Interface of Step Two-Task One, Impact Assessment

4.3.2.2 Estimate Likelihood of Hazard

In the second task, the platform converts the raw FEMA records from Step 1 into an intuitive representation of how frequently each selected hazard has occurred in the past. A bar chart appears for every hazard: the horizontal axis shows calendar years (with a toggle to switch aggregation by decade or year), and the vertical axis counts the events logged in each period. A quick glance indicates whether a threat is commonplace, episodic, or virtually absent.

Hazard Frequency

Aggregation: ● By Year ○ By Decade

Focus Hazards: ☐ Hurricane ☐ Flood ☐ Severe Ice Storm ☐ Severe Storm ☐ Fire

Switch Aggregation Mode

Displayed Hazard Record

Hazard Frequency

Aggregation: ○ By Year ● By Decade

Focus Hazards: ☐ Hurricane ☐ Flood ☐ Severe Ice Storm ☐ Severe Storm ☐ Fire

Figure 4.5 : Interface of Step Two-Task Two, Likelihood Assessment

With all hazards' records being rendered across the timeline, the user would assign a likelihood score (1–5) representing their judgment of how likely the hazard is to recur within the project's service life. This would also be saved on the server and used in future steps.

4.3.2.3 Select Prioritized Risk

Finally, with the hazard’s impact on building subsystems and hazard likelihood estimated, the user would then go to the last subtask: prioritize risk. Impact and likelihood are overlaid to display a colour-coded matrix of all hazard–system combinations. This matrix enables the user to visually compare different hazard–system combinations, facilitating quick prioritization.

Impact score (1-5)

Hover to see detail

Hazard: Severe Ice Storm
System: Architectural Systems
SubSystem: Canopies, overhangs, awnings, external shading structures, balconies
Likelihood: 3
Impact: 4
Score: 12

if many risks have identical impact and likelihood, they would be slightly shuffled to avoid visually overlap

Hazard Likelihood (1-5)

Sort by Hazard, System, or RiskScore

Risk Score Desc

Select	Hazard	System	SubSystem	Impact	Likelihood	RiskScore
☑	Hurricane	Architectural Systems	Canopies, overhangs, awnings, external shading structures, balconies	5	5	**25**
☑	Hurricane	Architectural Systems	Windows, doors, fenestration	5	5	**25**
☑	Hurricane	Architectural Systems	Roofing	5	5	**25**
☑	Hurricane	Architectural Systems	Façade, cladding, siding, building envelope, weather sealing, air or vapour barrier systems	5	5	**25**
☑	Severe Storm	Architectural Systems	Windows, doors, fenestration	5	3	**15**
☑	Severe Storm	Architectural Systems	Canopies, overhangs, awnings, external shading structures, balconies	5	3	**15**
☑	Severe Storm	Architectural Systems	Entryways and exits including street access	5	3	**15**
☑	Severe Storm	Architectural Systems	Façade, cladding, siding, building envelope, weather sealing, air or vapour barrier systems	5	3	**15**
☑	Severe Storm	Architectural Systems	Roofing	5	3	**15**
☑	Flood	Architectural Systems	Windows, doors, fenestration	4	3	**12**

Selected risk will be visible in next step

Figure 4.6 : Interface of Step Two-Task Three, Prioritized Risk

To support decision-making, a sortable table is also provided. Users select the hazard–system pairs they plan to address, which are then stored server-side and passed to **Step 3** for strategy matching and resource navigation. It is suggested that any pair whose composite risk score exceeds 10 should be considered, according to the Building Resilience Planning Worksheet (City of Vancouver, 2023).

$$Risk = \underset{0 \text{ or } 1}{Exposure} * \underset{1 \text{ to } 5}{Consequence} * \underset{1 \text{ to } 5}{Likelihood}$$

4.3.3 File Management

The File Management page serves as the platform's intake and triage desk, and would typically be maintained by a project team member or a resilience champion from the user's organization. Users upload documents, categorize each by docType (e.g., Case Study, Strategy, or Other Resource), assign it to a specific workspace, and define semantic labels for tabular files. This labeling step allows the system to recognize and index key data fields (e.g., *Hazard Type*, *System*, *Cost*) across files with varied column headings. This is an implementation of the "tweaked" RAG based on the original RAG framework (Lewis et al., 2021), and the enriched tags of the table file would be helpful in step 3, enabling multi-file coherence during retrieval and comparison.

A built-in "Quick Chat" panel allows users to interact with uploaded files using natural language. With conversation memory enabled, users can ask follow-up questions without restating context. This feature facilitates immediate fact-checking and helps validate content relevance.

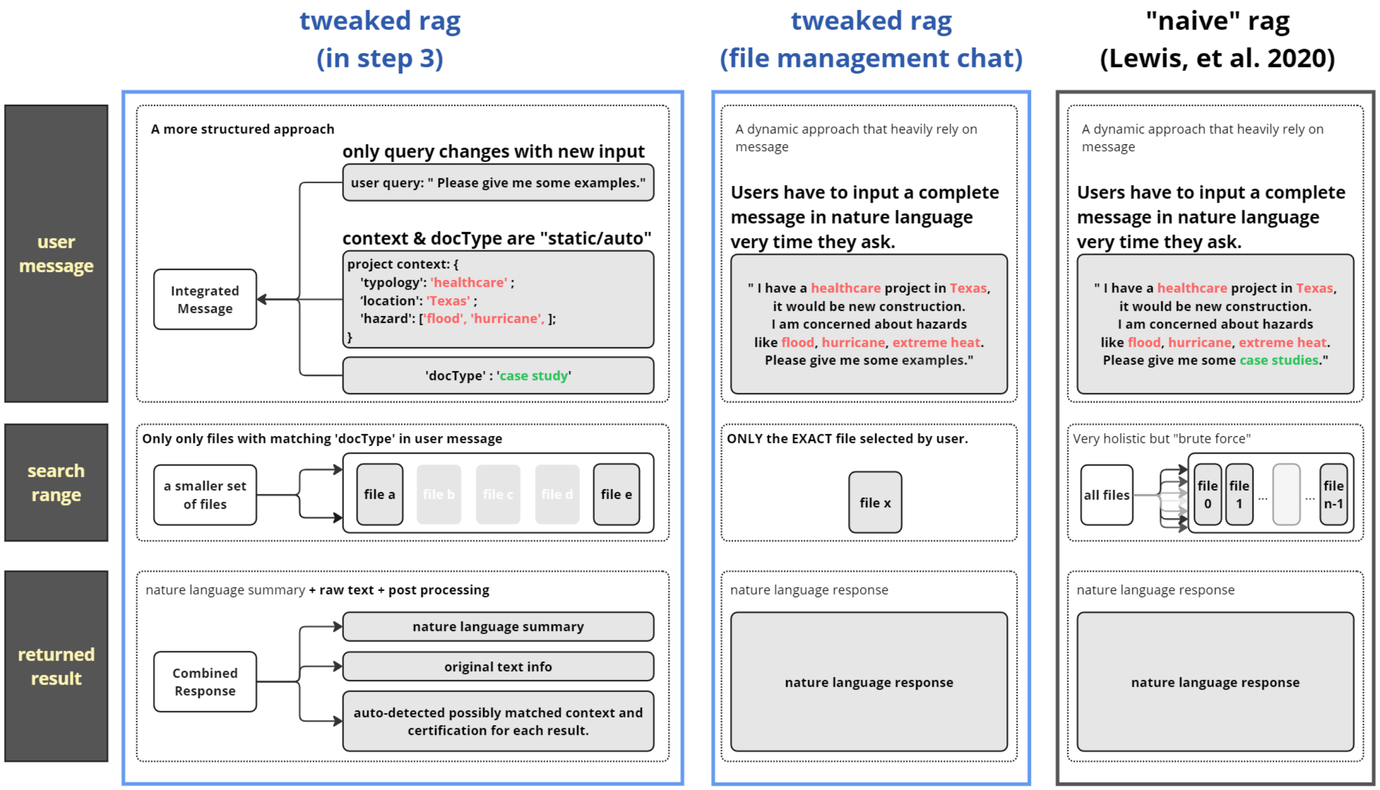


Figure 4.7 : RAG Implementation in This Platform VS the Original "Naive" RAG

Due to the absence of a fully curated resilience library for healthcare building design, the prototype includes a set of publicly open resilience-related datasets. Although these files may lack complete hazard taxonomies or performance metrics, their structure mimics the expected schema of future private-sector contributions. The full list of data used can be found in Table 3.3, except for the hazard data and system checklist (used in step 1 and step 2). A "Load All Demo Files" button would pull this data from the server, allowing users to search and compare.

4.3.4 Step 3: Retrieval Augmented Generation

Unlike the original “naive RAG,” which treats all documents equally and expects the user to re-enter context with each query, the Step 3 implementation introduces a “just enough” structure to make the workflow feel purpose-built for design teams. RAG in this platform is tweaked and adjusted for design’s search of information in these aspects: vector store construction (Section 4.3.3), user message formulation (Section 4.3.4.1), and retrieved result presentation (Section 4.3.4.4).

Specifically, the tweaked RAG framework in Step 3 trims the search space before retrieval by filtering on docType. It also re-uses a cached project context so users never re-state basic facts. Each returned result would contain the original information from the related file, and is enriched with a one-sentence LLM summary, explicit file-and-page provenance, plus automatic code-reference highlights. The results are then elevated beyond a flat list through a graph view that reveals hidden relationships (build graph function) and a tiered summarisation pass that distils both per-file and whole-set insights (summarize function). Together, these refinements deliver faster, cleaner and far more interpretable answers than the brute-force approach.

4.3.4.1 Construction of User’s Message

In “Naive” RAG, users submit free-form queries without contextual grounding, which leads to redundancy and degraded performance over time. Users are often forced to retype basic project parameters in every question, and the retrieval engine must scan all available chunks, resulting in slower response times and less focused results. To address this, RAG in step 3 would build the user’s message from three lightweight parts that isolate what is *static,* what can be *automatically* detected*, and* what is *dynamic*.

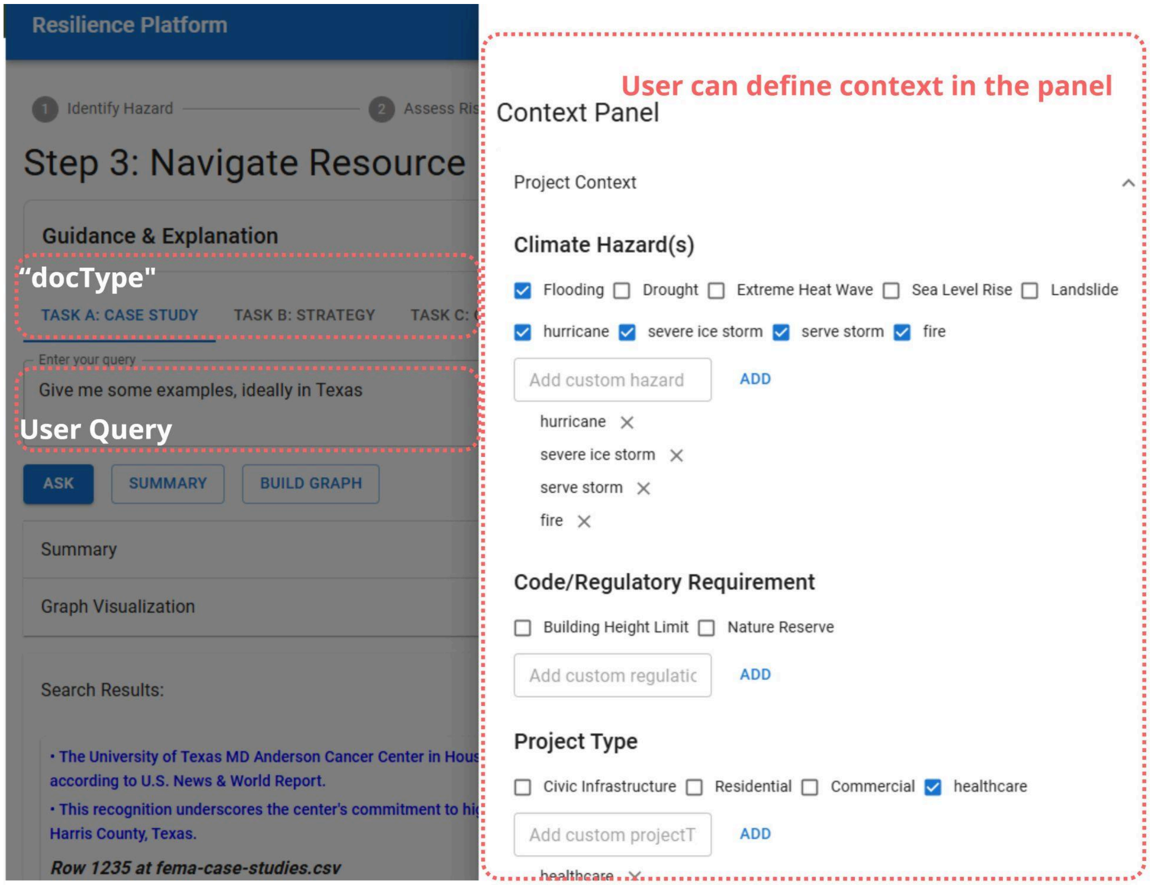
User Message Part	Captured Information	Source	Why it matters
Project Context (including custom field)	*“What is the background information of my question”* Typology, location, hazards, and user’s custom tags	User Picked once there is a change in the context panel	Re-used silently so the user never has to repeat.
User Query	*“What do I want to get”* What the designer wants to know right now	User Typed once per question	Just change the necessary part of the message.
docType	*“Where I am asking this question”* Case Study / Strategy / Other Resource	Automatically inferred from the user is	Narrows the search space before any vector search.

Table 4.4 : 3 Components in a User’s Message

The construction of user’s message is handled with the integration of three parts, each responsible for capturing a distinct layer of context:

1. Project Context – This includes essential background information such as hazard type, geographic location, building typology, and any custom project-specific tags. It is configured through the Context Panel, where users can define relevant parameters.;
2. Document Type (docType) – This refers to the category of resources being queried (e.g., Case Study, Strategy, or Other Resource). The platform automatically infers this based on the current workspace or tab where the user initiates the query; and
3. User Query – This is the natural language question entered by the user, representing their specific information need.

By seamlessly combining these three elements behind the scenes, the platform can formulate a more precise, context-aware query targeted to the appropriate subset of data, eliminating the need for the user to repeatedly re-enter background information. This design reduces cognitive load, allowing the user to focus on design exploration rather than query syntax.



Enter your query: Give me some examples, ideally in Texas

• The University of Texas MD Anderson Cancer Center in Hous
according to U.S. News & World Report.
• This recognition underscores the center's commitment to hi
Harris County, Texas.
Row 1235 at fema-case-studies.csv

Climate Hazard(s): ☑ Flooding ☐ Drought ☐ Extreme Heat Wave ☐ Sea Level Rise ☐ Landslide
☑ hurricane ☑ severe ice storm ☑ serve storm ☑ fire
hurricane ×
severe ice storm ×
serve storm ×
fire ×

Code/Regulatory Requirement: ☐ Building Height Limit ☐ Nature Reserve

Project Type: ☐ Civic Infrastructure ☐ Residential ☐ Commercial ☑ healthcare
healthcare ×

Figure 4.8 : Interface of Step Three, Constructing Context in the Context Panel

4.3.4.2 After the user's message is sent to the backend: chunk retrieval & LLM process

When the combined user message reaches the backend, a mini function would run to make sure that only files whose docType matches the active tab are considered. Then, the combined (Query + Project Context) message is embedded in a vector, and the vector is compared against the pre-indexed document chunks inside those n pre-filtered files using cosine similarity; the top-k matches (by cosine similarity) of each matching file are returned, with a total of *n*k* chunks. Each chunk carries its raw text, metadata source coordinates, like file name, page or row, to provide enough metadata for traceability.

For each retrieved chunk, an LLM would be called, and here the OpenAI api is used for processing the chunk with the GPT-4 mini model. Given raw chunks of data and a query, the LLM would function as an "editor: to process a concise natural-language synopsis. After all chunks are finished, each now with raw text, source coordinates, and the natural-language synopsis attached, would be sent back to the front-end as a single enriched object "allDocs", ready for display.

	LLM Process Components		What's it for
LLM process input	context	Typology, location, hazards, and user's custom tags entered in the context panel	
	userQuery	User Query entered in the query box	
	Prompt (not visible to user, just sent to LLM)	Example: const template = \` You are an expert in AEC consulting. We found these chunks from MULTIPLE files: ${context} Now answer the question below concisely: ${userQuery} \`;	To give LLM instructions on how to process
LLM process output	allDocs.doc.chunkSummary	LLM processed natural-language synopsis	Give user a quick overview of each result
	allDocs.doc.pageContent	Raw chunk information (plain text)	Give user the exact information from the file
	allDocs.doc.metaData	Example: { "fileName": "Building Code Funding Opportunities.pdf", "page": "1", },	Offer traceability and "trust"

Table 4.5 : Input and Output of LLM Process

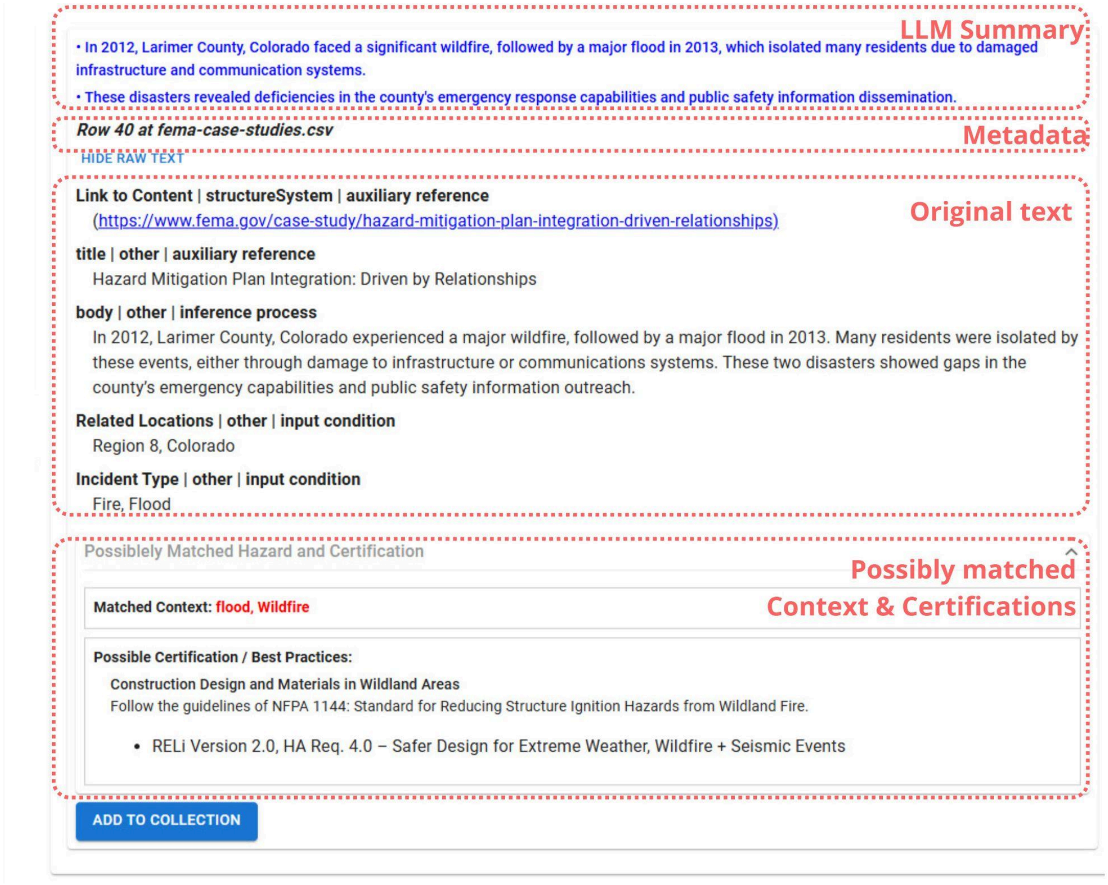
4.3.4.3 After LLM-processed Result Ready: Frontend Display of Search Result

Chunks after LLM processing, each now with a natural language summary appended, would be sent to the frontend. Each chunk is then displayed with four layers, with the emphasis on **provenance and traceability** supporting trust-building, especially in response to LLM hallucination concerns:

1. LLM summary – a quick sentence on why this chunk answers the question.
2. Metadata – exact page number or row of exact file name.

3. Original text – the exact table row or paragraph chunk, with column headers and tags if the source file is tabular.
4. Possibly matched Context & Certifications – auto-highlighted terms that match the project context plus any certification citations detected in the text.

This highlighting is intentionally lightweight. Context terms are taken from the structured selections in the context panel and from any free text in the query box, then compared to a small, pre-defined JSON vocabulary. Certification cues are matched in the same way, using a second JSON file populated with keywords from Perkins & Will's public PRECEDE ACT repository, which currently covers guidance for wildfire, extreme heat, and drought drawn from standards such as LEED, WELL, SITES, Fitwel, and RELi (Perkins & Will, n.d.). Because the prototype relies on exact keyword hits, the matches can be incomplete or occasionally spurious. Future development would implement NLP-based semantic detection or an LLM-assisted reranker, yielding more accurate and dynamically adaptable highlights.



- In 2012, Larimer County, Colorado faced a significant wildfire, followed by a major flood in 2013, which isolated many residents due to damaged infrastructure and communication systems.
- These disasters revealed deficiencies in the county's emergency response capabilities and public safety information dissemination.

Row 40 at fema-case-studies.csv

Link to Content | structureSystem | auxiliary reference
(https://www.fema.gov/case-study/hazard-mitigation-plan-integration-driven-relationships)

title | other | auxiliary reference
Hazard Mitigation Plan Integration: Driven by Relationships

body | other | inference process
In 2012, Larimer County, Colorado experienced a major wildfire, followed by a major flood in 2013. Many residents were isolated by these events, either through damage to infrastructure or communications systems. These two disasters showed gaps in the county's emergency capabilities and public safety information outreach.

Related Locations | other | input condition
Region 8, Colorado

Incident Type | other | input condition
Fire, Flood

Matched Context: flood, Wildfire

Possible Certification / Best Practices:
Construction Design and Materials in Wildland Areas
Follow the guidelines of NFPA 1144: Standard for Reducing Structure Ignition Hazards from Wildland Fire.

- RELi Version 2.0, HA Req. 4.0 – Safer Design for Extreme Weather, Wildfire + Seismic Events

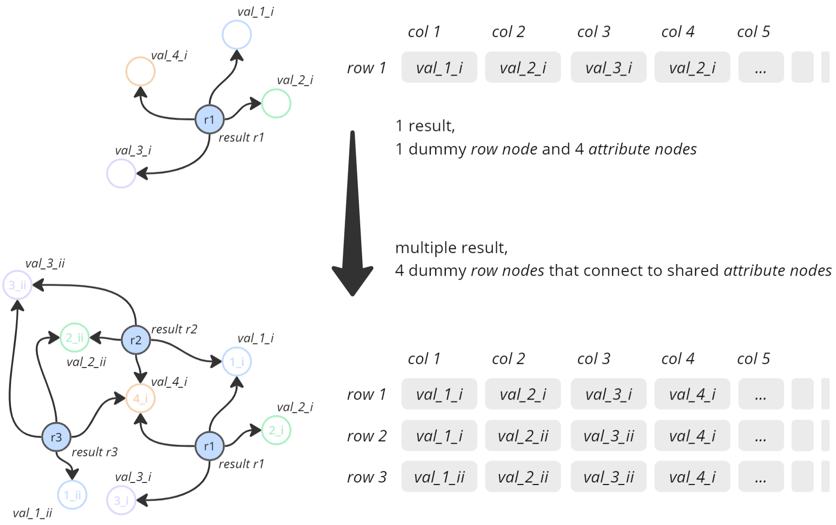
Figure 4.9 : Interface of Step Three, Example of One Returned Search Result

4.3.4.4 Visualization and Summary of Search Result (Retrieved Chunks)

With many results returned, users may easily experience information overload. Therefore, it becomes essential to provide higher-level visual and comparative tools that help users understand the overall picture and evaluate relationships across multiple results. To address this, the platform introduces two alternative viewing modes. Both operate entirely on the already-retrieved data, ensuring fast interactions without re-querying the vector store.

- Graph Visualization:

  To support intuitive pattern recognition, the platform offers a graph-based visualization mode. In this view, each result, typically a row from a table file, is represented as a row node, while each data value it contains (e.g., column entry such as hazard type or building system) becomes an attribute node. When multiple results share the same value in a given column, they are connected via a shared attribute node. In this structure, each result chunk is decomposed into nodes (entities or fields) and edges (pointing from the row node to its corresponding attribute node). Common attributes collapse to a single node, letting users review connections between different results and spot clusters and outliers at a glance.



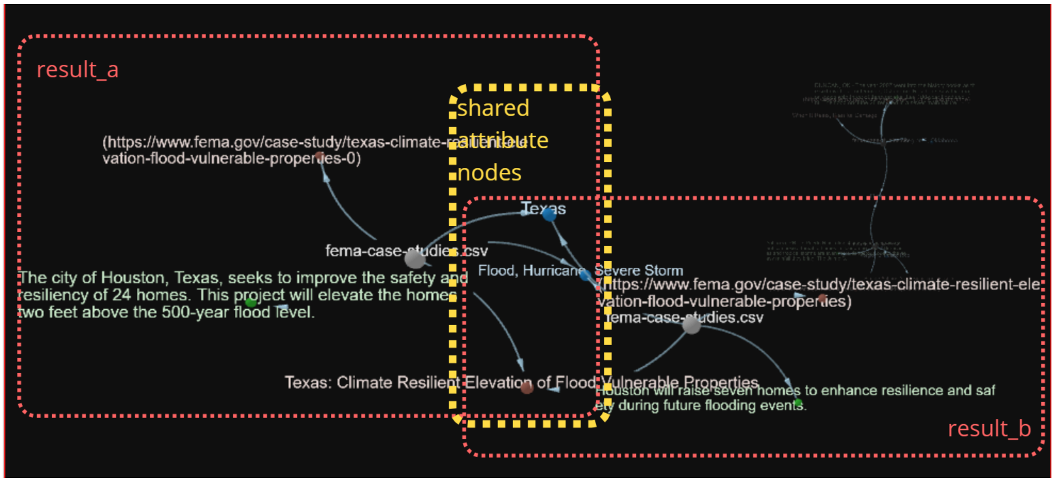
	col 1	col 2	col 3	col 4	col 5
row 1	val_1_i	val_2_i	val_3_i	val_2_i	...

1 result,
1 dummy *row node* and 4 *attribute nodes*

multiple result,
4 dummy *row nodes* that connect to shared *attribute nodes*

	col 1	col 2	col 3	col 4	col 5
row 1	val_1_i	val_2_i	val_3_i	val_4_i	...
row 2	val_1_i	val_2_ii	val_3_ii	val_4_i	...
row 3	val_1_ii	val_2_ii	val_3_ii	val_4_i	...

Figure 4.10 : A Basic Graph with Shared Attribute Node



(https://www.fema.gov/case-study/texas-climate-resilient-ele vation-flood-vulnerable-properties-0)

fema-case-studies.csv

Texas

Flood, Hurricane, Severe Storm

The city of Houston, Texas, seeks to improve the safety and resiliency of 24 homes. This project will elevate the homes two feet above the 500-year flood level.

(https://www.fema.gov/case-study/texas-climate-resilient-ele vation-flood-vulnerable-properties)

fema-case-studies.csv

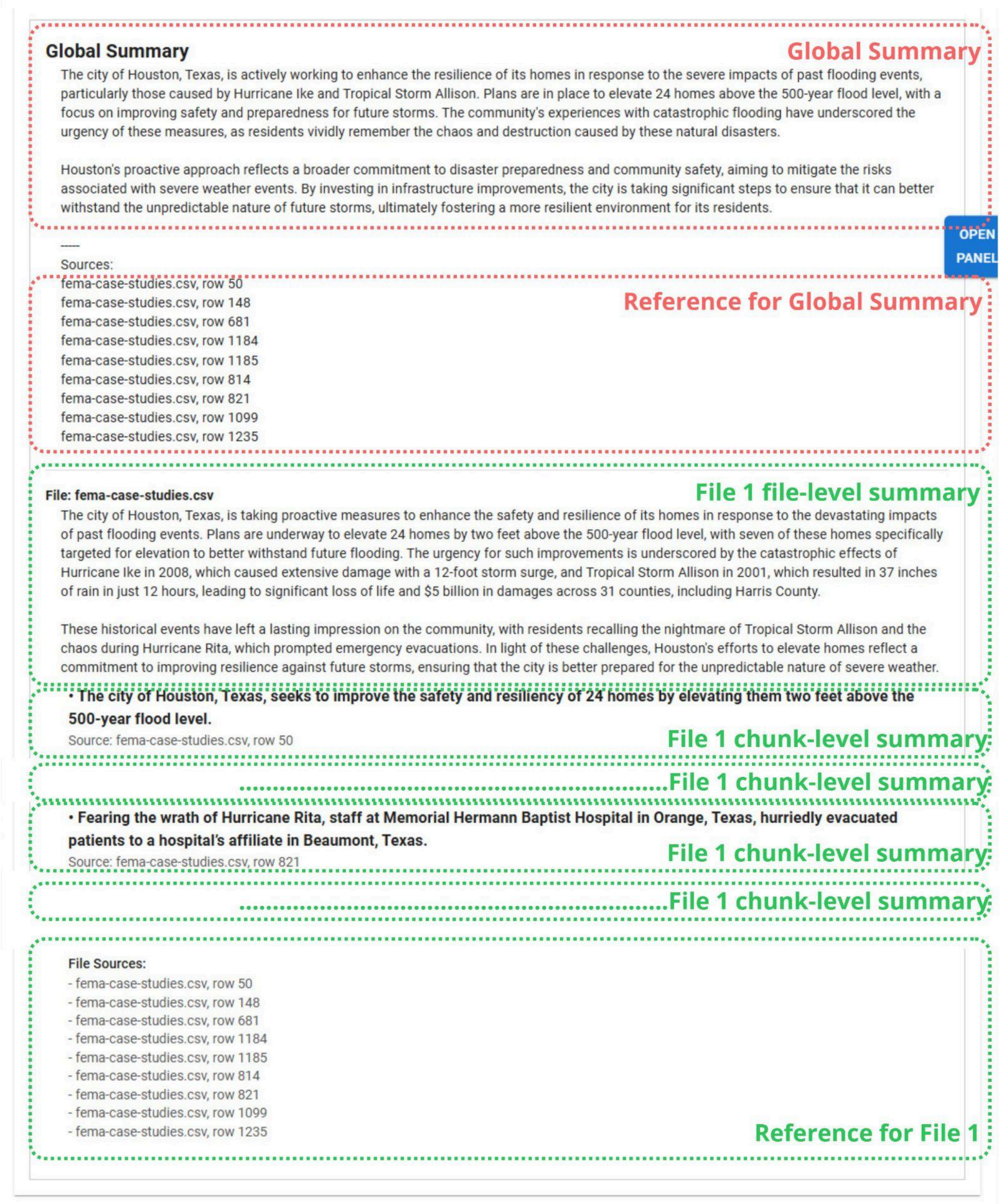
Texas: Climate Resilient Elevation of Flood Vulnerable Properties

Houston will raise seven homes to enhance resilience and saf ety during future flooding events.

Figure 4.11 : Interface of Step Three, Graph Visualization of Multiple Search Results

- Global / Per-file Summaries:

An LLM is utilized to generate concise digests. All retrieved chunks are fed to the LLM again with a dedicated summarization prompt to generate both global-level and file-level summaries. The Global summaries provide a high-level overview of the entire result set, while Per-file summaries condense key insights from each source document, offering users an “at-a-glance” understanding of the retrieved content without needing to review each chunk individually.



Global Summary

The city of Houston, Texas, is actively working to enhance the resilience of its homes in response to the severe impacts of past flooding events, particularly those caused by Hurricane Ike and Tropical Storm Allison. Plans are in place to elevate 24 homes above the 500-year flood level, with a focus on improving safety and preparedness for future storms. The community's experiences with catastrophic flooding have underscored the urgency of these measures, as residents vividly remember the chaos and destruction caused by these natural disasters.

Houston's proactive approach reflects a broader commitment to disaster preparedness and community safety, aiming to mitigate the risks associated with severe weather events. By investing in infrastructure improvements, the city is taking significant steps to ensure that it can better withstand the unpredictable nature of future storms, ultimately fostering a more resilient environment for its residents.

Sources:
fema-case-studies.csv, row 50
fema-case-studies.csv, row 148
fema-case-studies.csv, row 681
fema-case-studies.csv, row 1184
fema-case-studies.csv, row 1185
fema-case-studies.csv, row 814
fema-case-studies.csv, row 821
fema-case-studies.csv, row 1099
fema-case-studies.csv, row 1235

File: fema-case-studies.csv

The city of Houston, Texas, is taking proactive measures to enhance the safety and resilience of its homes in response to the devastating impacts of past flooding events. Plans are underway to elevate 24 homes by two feet above the 500-year flood level, with seven of these homes specifically targeted for elevation to better withstand future flooding. The urgency for such improvements is underscored by the catastrophic effects of Hurricane Ike in 2008, which caused extensive damage with a 12-foot storm surge, and Tropical Storm Allison in 2001, which resulted in 37 inches of rain in just 12 hours, leading to significant loss of life and $5 billion in damages across 31 counties, including Harris County.

These historical events have left a lasting impression on the community, with residents recalling the nightmare of Tropical Storm Allison and the chaos during Hurricane Rita, which prompted emergency evacuations. In light of these challenges, Houston's efforts to elevate homes reflect a commitment to improving resilience against future storms, ensuring that the city is better prepared for the unpredictable nature of severe weather.

- **The city of Houston, Texas, seeks to improve the safety and resiliency of 24 homes by elevating them two feet above the 500-year flood level.**

  Source: fema-case-studies.csv, row 50

- **Fearing the wrath of Hurricane Rita, staff at Memorial Hermann Baptist Hospital in Orange, Texas, hurriedly evacuated patients to a hospital's affiliate in Beaumont, Texas.**

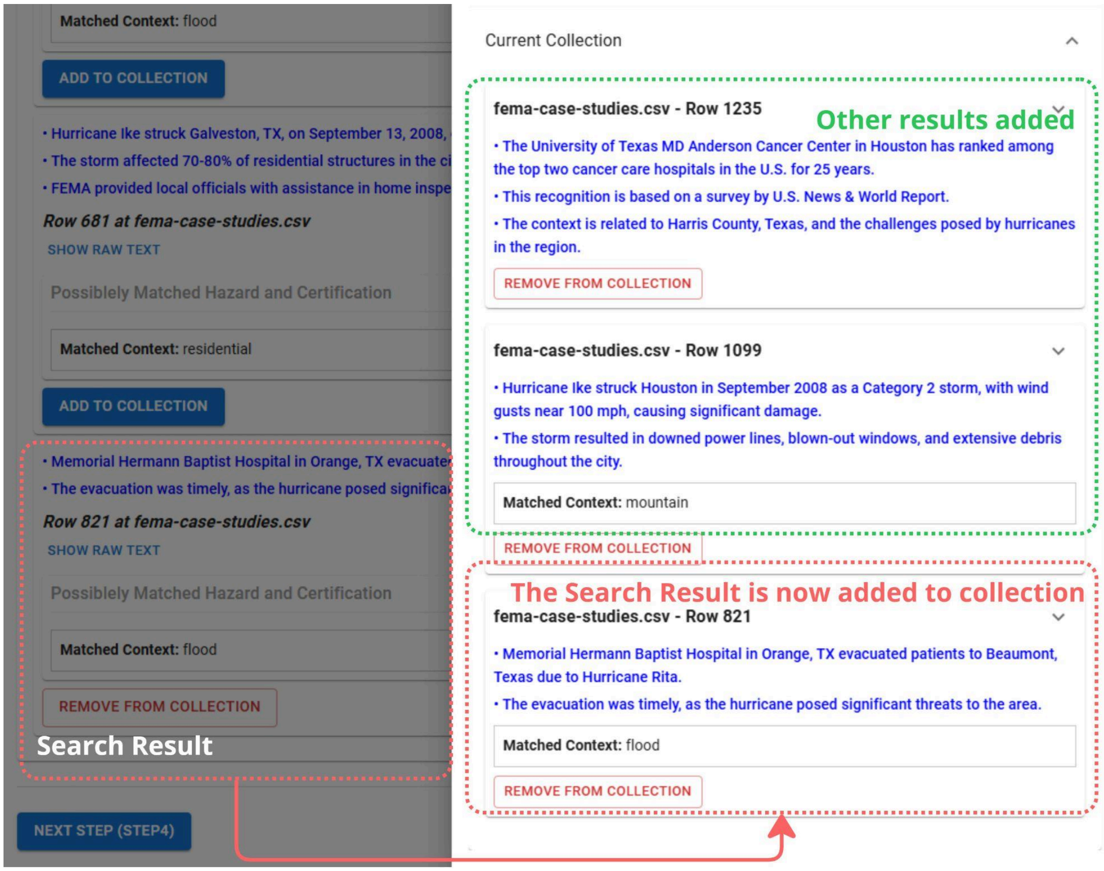
  Source: fema-case-studies.csv, row 821

File Sources:
- fema-case-studies.csv, row 50
- fema-case-studies.csv, row 148
- fema-case-studies.csv, row 681
- fema-case-studies.csv, row 1184
- fema-case-studies.csv, row 1185
- fema-case-studies.csv, row 814
- fema-case-studies.csv, row 821
- fema-case-studies.csv, row 1099
- fema-case-studies.csv, row 1235

Figure 4.12 : Interface of Step Three, Summary of All Search Results

4.3.4.5 Step 3: Collection of Result

Designers can bookmark any card in a personal Collection section in the Context Panel. Items can be added or removed with one click, allowing the user to continue exploring without losing important references. The user can save/unsave some results to “collection”, and review and manage saved results in the side panel.



Matched Context: flood

- Hurricane Ike struck Galveston, TX, on September 13, 2008,
- The storm affected 70-80% of residential structures in the ci
- FEMA provided local officials with assistance in home inspe

Row 681 at fema-case-studies.csv

Possiblely Matched Hazard and Certification

Matched Context: residential

- Memorial Hermann Baptist Hospital in Orange, TX evacuate
- The evacuation was timely, as the hurricane posed significa

Row 821 at fema-case-studies.csv

Possiblely Matched Hazard and Certification

Matched Context: flood

Current Collection

fema-case-studies.csv - Row 1235

- The University of Texas MD Anderson Cancer Center in Houston has ranked among the top two cancer care hospitals in the U.S. for 25 years.
- This recognition is based on a survey by U.S. News & World Report.
- The context is related to Harris County, Texas, and the challenges posed by hurricanes in the region.

fema-case-studies.csv - Row 1099

- Hurricane Ike struck Houston in September 2008 as a Category 2 storm, with wind gusts near 100 mph, causing significant damage.
- The storm resulted in downed power lines, blown-out windows, and extensive debris throughout the city.

Matched Context: mountain

fema-case-studies.csv - Row 821

- Memorial Hermann Baptist Hospital in Orange, TX evacuated patients to Beaumont, Texas due to Hurricane Rita.
- The evacuation was timely, as the hurricane posed significant threats to the area.

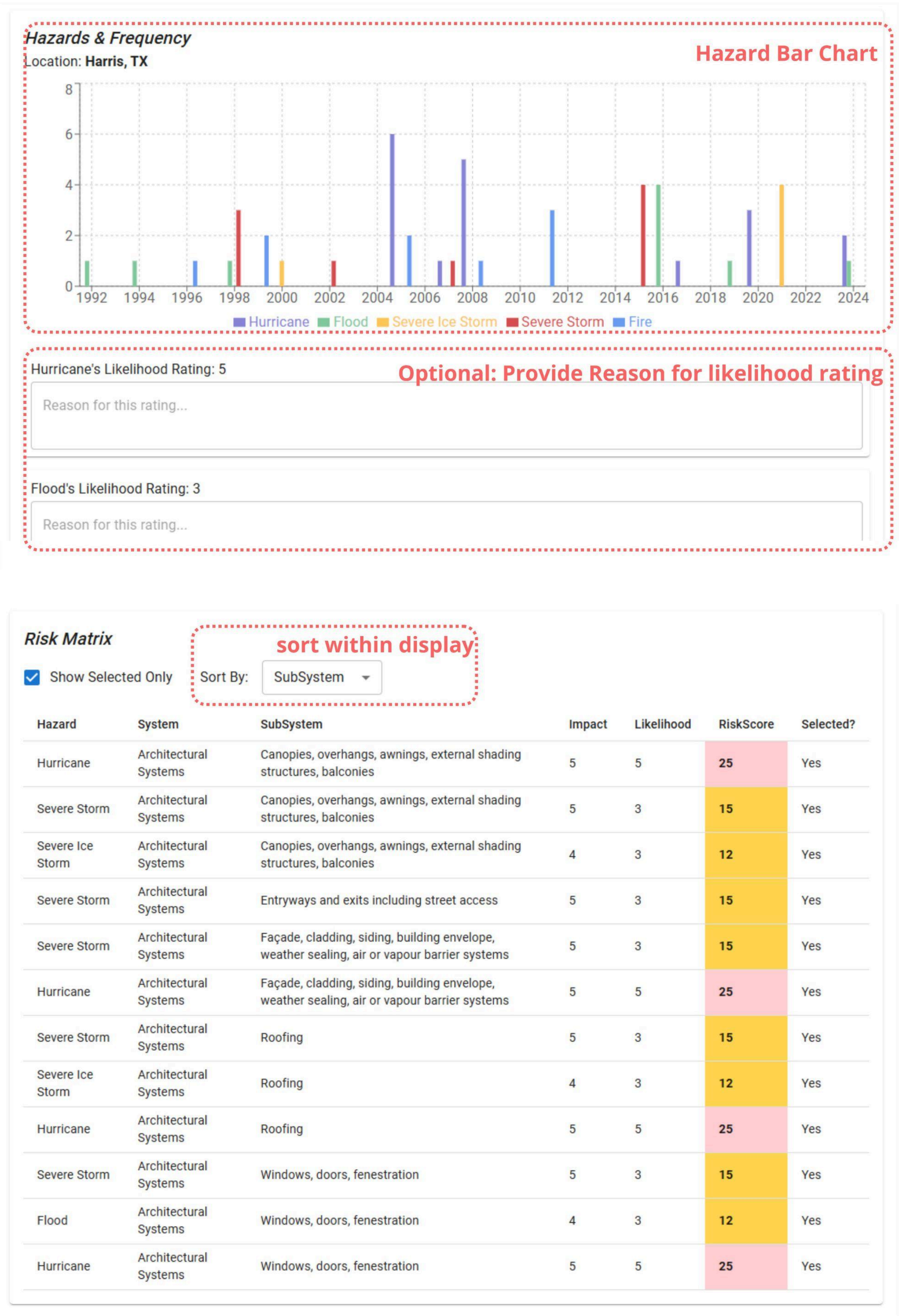
Matched Context: flood

Figure 4.13 : Interface of Step Three, Collection Section in the Context Panel

4.3.5 Step 4: Documentation

The final stage, Step 4, would turn the research the user has already gathered into a share-ready brief. Within a single dashboard, everything produced so far is listed:

- A bar chart of selected hazards and their historical frequency (Step 1)
- The hazard × building-subsystem risk table, together with your prioritised risks (Step 2)
- Curated references grouped by type: case studies, strategies, and other resources (Step 3).



Hazards & Frequency

Location: **Harris, TX**

Hazard Bar Chart

Hurricane's Likelihood Rating: 5

Optional: Provide Reason for likelihood rating

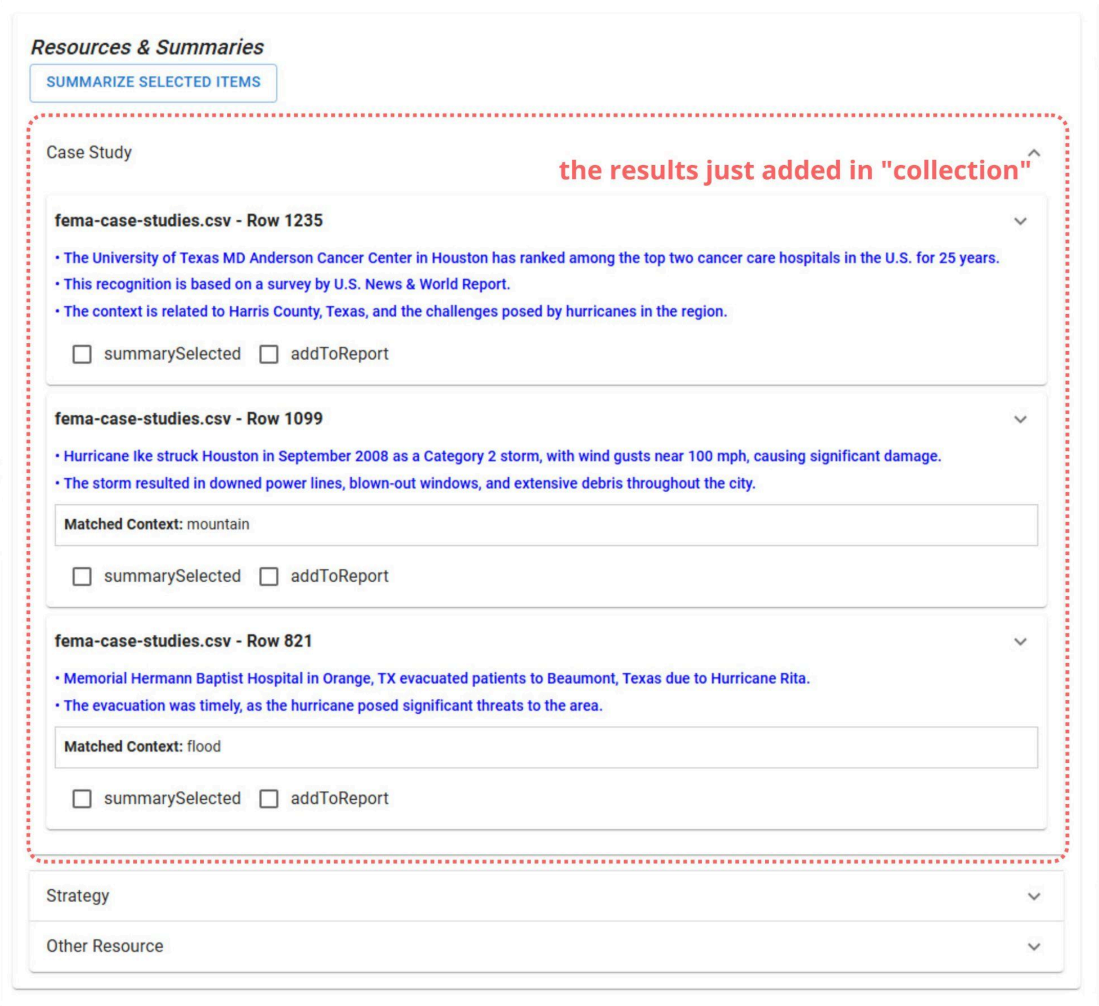
Flood's Likelihood Rating: 3

Risk Matrix

sort within display

Hazard	System	SubSystem	Impact	Likelihood	RiskScore	Selected?
Hurricane	Architectural Systems	Canopies, overhangs, awnings, external shading structures, balconies	5	5	25	Yes
Severe Storm	Architectural Systems	Canopies, overhangs, awnings, external shading structures, balconies	5	3	15	Yes
Severe Ice Storm	Architectural Systems	Canopies, overhangs, awnings, external shading structures, balconies	4	3	12	Yes
Severe Storm	Architectural Systems	Entryways and exits including street access	5	3	15	Yes
Severe Storm	Architectural Systems	Façade, cladding, siding, building envelope, weather sealing, air or vapour barrier systems	5	3	15	Yes
Hurricane	Architectural Systems	Façade, cladding, siding, building envelope, weather sealing, air or vapour barrier systems	5	5	25	Yes
Severe Storm	Architectural Systems	Roofing	5	3	15	Yes
Severe Ice Storm	Architectural Systems	Roofing	4	3	12	Yes
Hurricane	Architectural Systems	Roofing	5	5	25	Yes
Severe Storm	Architectural Systems	Windows, doors, fenestration	5	3	15	Yes
Flood	Architectural Systems	Windows, doors, fenestration	4	3	12	Yes
Hurricane	Architectural Systems	Windows, doors, fenestration	5	5	25	Yes

Figure 4.14 : Interface of Step Four, Documentation



the results just added in "collection"

fema-case-studies.csv - Row 1235

- The University of Texas MD Anderson Cancer Center in Houston has ranked among the top two cancer care hospitals in the U.S. for 25 years.
- This recognition is based on a survey by U.S. News & World Report.
- The context is related to Harris County, Texas, and the challenges posed by hurricanes in the region.

☐ summarySelected ☐ addToReport

fema-case-studies.csv - Row 1099

- Hurricane Ike struck Houston in September 2008 as a Category 2 storm, with wind gusts near 100 mph, causing significant damage.
- The storm resulted in downed power lines, blown-out windows, and extensive debris throughout the city.

Matched Context: mountain

☐ summarySelected ☐ addToReport

fema-case-studies.csv - Row 821

- Memorial Hermann Baptist Hospital in Orange, TX evacuated patients to Beaumont, Texas due to Hurricane Rita.
- The evacuation was timely, as the hurricane posed significant threats to the area.

Matched Context: flood

☐ summarySelected ☐ addToReport

Figure 4.14 (continued): Interface of Step Four, Documentation

Within this page, the user can still annotate each section, for instance, explaining why certain hazards were retained or how specific strategies align with the project brief, and may trigger an additional LLM pass to generate concise, client-friendly summaries. When the content appears correct, a single click exports the entire package to PDF or DOCX, or prints it directly, providing an instantly editable starting point for client conversations or internal reviews. * (Current export routines operate in beta-mode, these constraints are discussed in Section 5.2.)

Chapter 5. Result & Discussion

5.1 Contribution

Building on the platform's core objective, lowering the barrier to early-phase resilience work, its contributions can be viewed through four lenses: the day-to-day needs of design teams, the collective interests of the resilience community, the strategic goals of design firms, and the broader potential of lightweight in-house software.

For design teams, the platform functions as an intuitive, "zero-ramp" entry point into resilience planning. Even practitioners with limited resilience expertise, or constrained by time and budget, can complete foundational research tasks rapidly. Unlike earlier toolkits that require users to jump between multiple unconnected sources, this platform centralizes key functions within a single interface. Hazard data, precedents, and strategy suggestions are presented in one location, with automatic citation logging for future reference.

For the resilience-design community, the platform serves as a living, open-access repository that promotes knowledge sharing rather than hoarding. Researchers, NGOs, and municipalities might be able to "plug in" new datasets. This fosters the growth of a transparent knowledge commons, where junior designers can learn from vetted examples and smaller studios can contribute alongside large enterprises, without the barrier of enterprise licensing.

For architecture and design firms, the platform offers a template for transforming latent intellectual property into a searchable and shareable asset. While the current prototype focuses on healthcare resilience, its Step 3 resource-navigation layer, powered by RAG and LLM summarization, is easily transferable to other domains, such as climate adaptation, carbon-conscious materials, or water-sensitive urban design. In this way, static PDF archives can be transformed into searchable, living knowledge that supports proposal development, internal training, and project delivery, ultimately improving project performance.

Finally, the project demonstrates a practical, low-friction pathway for in-house digital innovation. By combining modular web components, vector search infrastructure, and open-source AI tools, the platform delivers measurable value without requiring enterprise-scale BIM overhauls. This approach shows how modern AI technologies can be adopted incrementally, reducing development risk, accelerating time-to-value, and laying the groundwork for broader digital transformation across the AEC industry.

5.2 Prototype Evaluation

No formal quantitative evaluation has yet been conducted on the retrieval layer. Preliminary trials with demo data show that, when a file is topically aligned with a query, the passages retrieved are generally accurate across both PDF and tabular sources. Nevertheless, two architectural constraints currently limit overall precision:

1. Users cannot confine searches to specific files within a tab (e.g., case studies, strategies, or other resources), so non-relevant documents are still queried;

2. The **top-k** parameter is hard-coded at 10; when a file contains fewer than five pertinent passages, the remaining slots are typically populated by off-topic results.

Because the retrieval pipeline relies on a basic single-stage RAG configuration, it lags behind state-of-the-art multi-stage reranking approaches. Rigorous evaluation using metrics, such as precision@k (Alinejad et al., 2024) or Normalized Discounted Cumulative Gain (nDCG) (Salemi & Zamani, 2024), and comprehensive user-study methodologies have yet to be applied and are therefore identified as critical next steps.

5.3 Limitation

This research has several limitations, which can be grouped into three categories: data, technical implementation, and use case scope.

On the data side, Step 1 relies exclusively on historical hazard records from FEMA, which limits coverage to the United States and provides no forward-looking climate projections. This constraint reduces the platform's applicability for projects in non-U.S. regions or for future-focused design scenarios. In Step 3, the dataset comprises only publicly available sources, which are relatively small in scale and not specifically focused on healthcare facility design. While the current schema was intentionally modeled to reflect high-quality in-house datasets, the absence of proprietary case studies and strategies limits the platform's current depth and realism.

From a technical standpoint, the platform currently supports only tabular and PDF file formats. Embedded images, particularly those within PDF documents, are not yet processed or parsed, which restricts the utility of diagram-heavy sources. Additionally, the retrieval mechanism within the RAG framework does not reflect state-of-the-art capabilities; it lacks advanced query routing, reasoning capabilities, and multi-stage retrieval, all of which could significantly improve both accuracy and efficiency. Furthermore, the context-matching mechanism relies on simple keyword heuristics, rather than more robust semantic alignment or embedding-based filtering, which may lead to false positives or the omission of relevant content. The export module is likewise in a beta state; PDF export cannot yet paginate long tables that span multiple pages, and DOCX output omits embedded charts, so deliverables often require manual touch-up before client use.

To date, the prototype has been evaluated only through formative, qualitative methods (see Section 5.2). Retrieval accuracy was judged heuristically on a small convenience set of queries, and usability insights were obtained from three designers. No quantitative metrics have yet been collected. Furthermore, all tests relied on publicly available placeholder data rather than live project files. Robust, generalisable conclusions will require a larger and more diverse participant pool, real-world datasets, and a rigorous programme of quantitative evaluation.

In terms of functional scope, Step 2's impact-assessment and likelihood-estimate table remains semi-automated: users must still manually specify how each hazard might impact a given building subsystem. This manual step introduces subjectivity and limits scalability. In Step 3, while search results are meaningfully enriched with summaries and metadata, they lack ranking, scoring, or filtering mechanisms that would improve navigability, particularly in cases where many documents match a query.

5.4 Feedback and Future Work

Following the development of the platform prototype, feedback was solicited from several ZGF design professionals as representative early-phase users. Although the sample size was limited, several clear feedback clusters emerged. Additional feedback was also gathered during the public thesis presentation session. Responses largely centered around four themes: interface and user experience (UX), integration of additional data sources, bridging workflow and data, and the platform's broader utility for the architectural design community.

Several users emphasized the importance of keeping the interface clean, intuitive, and non-technical. For the majority of potential users, particularly those without data science or engineering backgrounds, only essential controls (e.g., where to input project context, how to retrieve data) should be visible by default. More technical or mathematical details (e.g., embedding algorithms) should be hidden but accessible, allowing advanced users to explore deeper layers as needed without overwhelming others.

Participants suggested the integration of broader and more granular datasets. One recurring request, especially from international colleagues, was for non-U.S. hazard data, which would increase the platform's global relevance. Another suggestion involved incorporating fine-grained impact and likelihood data from insurance firms or engineering consultancies, though users acknowledged the challenges in accessing proprietary or commercially sensitive datasets. Collaborations with technical consultants or structural engineering firms were also seen as viable pathways for enhancing the data foundation of Step 2.

Users acknowledged that Step 2 (Risk Assessment) remains partially manual, especially regarding impact and likelihood scoring. While the current version significantly improves ease-of-use compared to tools like the original Building Resilience Planning Worksheet (City of Vancouver, 2023), it does not yet achieve full automation. From the perspective of a "resilience champion" within a firm, a proposed future enhancement is the development of an in-house calculator that applies firm-specific knowledge to semi-automate scoring based on past projects and internal standards.

Feedback also highlighted the platform's potential value to small and mid-sized architecture firms, especially those lacking the capacity to build or maintain their resilience workflows. By democratizing access to structured workflows and public datasets, the tool could help level the playing field for offices with limited in-house research capabilities. Users also noted the cross-disciplinary applicability of the platform, which could eventually serve related fields such as urban planning, landscape architecture, and infrastructure design, especially as resilience becomes an increasingly integrated design mandate.

Beyond the limitations and feedback addressed above, the platform offers longer-term implications for knowledge infrastructure in architectural practice. As more firms establish in-house resilience teams and design technology units, this platform could serve as the backbone of a firm-specific knowledge base. With appropriate data privacy measures, firms could integrate proprietary high-quality case studies, internal strategies, and performance metrics into the existing schema, enabling the creation of a private yet navigable knowledge layer. More broadly, this work demonstrates the potential for combining modular web infrastructure, open-source AI models, and distributed data stewardship to drive accessible innovation, both within individual firms and across the design profession.

Reference

Alinejad, A., Kumar, K., & Vahdat, A. (2024). *Evaluating the Retrieval Component in LLM-Based Question Answering Systems* (arXiv:2406.06458). arXiv. https://doi.org/10.48550/arXiv.2406.06458

All Options Embed. (n.d.). Airtable. Retrieved June 9, 2025, from https://airtable.com/apppEQekkkpbTtdBe/shr4XOlRsOoaMyGmh/tblO7BbuRztHLgfVS

AR5 Synthesis Report: Climate Change 2014 — IPCC. (n.d.). Retrieved November 11, 2024, from https://www.ipcc.ch/report/ar5/syr/

Berke, P., Kates, J., Malecha, M., Masterson, J., Shea, P., & Yu, S. (2021). Using a resilience scorecard to improve local planning for vulnerability to hazards and climate change: An application in two cities. *Cities*, *119*, 103408. https://doi.org/10.1016/j.cities.2021.103408

Bianchi, S. (2023). Integrating resilience in the multi-hazard sustainable design of buildings. *Disaster Prevention and Resilience*, *2*(3), N/A-N/A. https://doi.org/10.20517/dpr.2023.16

Brambilla, A., Sun, T., Elshazly, W., Ghazy, A., Barach, P., Lindahl, G., & Capolongo, S. (2021). Flexibility during the COVID-19 Pandemic Response: Healthcare Facility Assessment Tools for Resilient Evaluation. *International Journal of Environmental Research and Public Health*, *18*(21), 11478. https://doi.org/10.3390/ijerph182111478

Building Resilient Infrastructure and Communities | FEMA.gov. (2025, April 8). https://www.fema.gov/grants/mitigation/learn/building-resilient-infrastructure-communities

City of Vancouver. (2023, May 26). *Resilient Buildings Planning Worksheet*. https://vancouver.ca/files/cov/resilient-buildings-planning-worksheet.xlsx

De Genaro Chiroli, D. M., Menezes, M. G., Zola, F. C., Aragão, F. V., Almeida, R. D. de, & Tebcherani, S. M. (2023). Integrating resilience and sustainability: A systematic analysis of resilient cities using ISO 37123. *International Journal of Disaster Risk Reduction*, *96*, 103960. https://doi.org/10.1016/j.ijdrr.2023.103960

Di Pilla, L. (2021). From the 3 R’s Rule of Sustainability to the 4 R’s of Resilience: An Architectural Approach. *Journal of Design Sciences and Applied Arts*, *2*(1), 129–140. https://doi.org/10.21608/jdsaa.2021.43360.1077

Dong, B., Liu, Y., Fontenot, H., Ouf, M., Osman, M., Chong, A., Qin, S., Salim, F., Xue, H., Yan, D., Jin, Y., Han, M., Zhang, X., Azar, E., & Carlucci, S. (2021). Occupant behavior modeling methods for resilient building design, operation and policy at urban scale: A review. *Applied Energy*, *293*, 116856. https://doi.org/10.1016/j.apenergy.2021.116856

Drăgoicea, M., Walletzký, L., Carrubbo, L., Badr, N. G., Toli, A. M., Romanovská, F., & Ge, M. (2020). Service Design for Resilience: A Multi-Contextual Modeling Perspective. *IEEE Access*, *8*, 185526–185543. IEEE Access. https://doi.org/10.1109/ACCESS.2020.3029320

Federal Emergency Management Agency. (2018, June). *Natural Hazard Mitigation Saves Interim Report: Fact Sheet*. U.S. Department of Homeland Security, Federal Emergency Management Agency. https://www.fema.gov/sites/default/files/2020-07/fema_mitsaves-factsheet_2018.pdf

FEDERAL help offered for storm damage at Texas hospitals. (n.d.). Retrieved June 9, 2025, from https://www.newson6.com/story/5e3681922f69d76f62095ea0/federal-help-offered-for-storm-damage-at-texas-hospitals

Forgaci, C. (2020). Smart and resilient cities: How can big data inform spatial design and planning for urban resilience? *Contesti. Città, Territori, Progetti*, *1*, Article 1. https://doi.org/10.13128/contest-12035

Galehouse, M. (2017, August 29). *Despite Hurricane Harvey, TMC Institutions Are Operational and Accessible*. TMC News. https://www.tmc.edu/news/2017/08/despite-hurricane-harvey-tmc-institutions-operational-accessible/

Gil-Ozoudeh, I., Iwuanyanwu, O., Okwandu, A. C., & Ike, C. S. (2023). Sustainable urban design: The role of green buildings in shaping resilient cities. *International Journal of Applied Research in Social Sciences*, *5*(10), Article 10. https://doi.org/10.51594/ijarss.v5i10.1481

Home | U.S. Climate Resilience Toolkit. (n.d.). Retrieved June 9, 2025, from https://toolkit.climate.gov/

Introducing Advanced Employee Search. (2025, June 2). Knowledge Architecture. https://www.knowledge-architecture.com/blog/introducing-advanced-employee-search

Lewis, P., Perez, E., Piktus, A., Petroni, F., Karpukhin, V., Goyal, N., Küttler, H., Lewis, M., Yih, W., Rocktäschel, T., Riedel, S., & Kiela, D. (2021). *Retrieval-Augmented Generation for Knowledge-Intensive NLP Tasks* (arXiv:2005.11401). arXiv. https://doi.org/10.48550/arXiv.2005.11401

Linc AI. (n.d.). *Linc AI* [Computer software]. Linc AI. https://www.withlinc.com/#search

Mace, S. E., & Sharma, A. (2020). Hospital evacuations due to disasters in the United States in the twenty-first century. *American Journal of Disaster Medicine*, *15*(1), 7–22. https://doi.org/10.5055/ajdm.2020.0351

Material UI: React components that implement Material Design. (n.d.). Retrieved June 10, 2025, from https://mui.com/material-ui/

NOAA National Centers for Environmental Information (NCEI). (2025, January 10). *U.S. Billion-Dollar Weather and Climate Disasters: State Summary—United States*. https://www.ncei.noaa.gov/access/billions/state-summary/US

Node.js—Run JavaScript Everywhere. (n.d.). Retrieved June 10, 2025, from https://nodejs.org/en

Options Database | U.S. Climate Resilience Toolkit. (n.d.). Retrieved June 9, 2025, from https://toolkit.climate.gov/option

Perkins & Will. (n.d.). *Act – PRECEDE – Public Repository to Engage Community and Enhance Design Equity*. Retrieved June 13, 2025, from https://precede.perkinswill.com/act/

Pilanawithana, N. M., Feng, Y., London, K., & Zhang, P. (2022). Developing resilience for safety management systems in building repair and maintenance: A conceptual model. *Safety Science*, *152*, 105768. https://doi.org/10.1016/j.ssci.2022.105768

React. (n.d.). Retrieved June 10, 2025, from https://react.dev/

Rebuilding a More Resilient Nepal: Key recommendations for reconstruction and recovery. (n.d.). Oxfam Policy & Practice. Retrieved November 11, 2024, from https://policy-practice.oxfam.org/resources/rebuilding-a-more-resilient-nepal-key-recommendations-for-reconstruction-and-re-581286/

Salemi, A., & Zamani, H. (2024). *Evaluating Retrieval Quality in Retrieval-Augmented Generation* (arXiv:2404.13781). arXiv. https://doi.org/10.48550/arXiv.2404.13781

Scott, D. R., Cerino, A. C., Pekelnicky, R. G., & Yu, K. (2023). *Resilience for critical facilities* (NIST GCR 23-037; p. NIST GCR 23-037). National Institute of Standards and Technology (U.S.). https://doi.org/10.6028/NIST.GCR.23-037

Shams, S., Barton, A., Fox, A., & Hsu, J. (n.d.). *Resilience Design Toolkit, Resilience Design Integration for Architectural Projects.* Retrieved November 11, 2024, from aia.org/resiliencedesigntoolkit

Shi, W., Min, S., Yasunaga, M., Seo, M., James, R., Lewis, M., Zettlemoyer, L., & Yih, W. (2023). *REPLUG: Retrieval-Augmented Black-Box Language Models* (arXiv:2301.12652). arXiv. https://doi.org/10.48550/arXiv.2301.12652

Sustainable and Climate-Resilient Health Care Facilities Toolkit. (n.d.). *ClimaHealth*. Retrieved June 9, 2025, from https://climahealth.info/resource-library/sustainable-and-climate-resilient-health-care-facilities-toolkit/

Verweij, P., Cormont, A., Eupen, M. van, Winograd, M., & Hardoy, J. (2020). Participatory Modeling With QUICKScan to Shape Sustainable Urban Development. *Frontiers in Environmental Science*, *8*. https://doi.org/10.3389/fenvs.2020.550799

When Hurricane Harvey Hit, the Texas Medical Center Stood Ready | BuildingGreen. (n.d.). Retrieved June 9, 2025, from https://www.buildinggreen.com/feature/when-hurricane-harvey-hit-texas-medical-center-stood-ready