Optimizing Housing Recovery: Industrialized Solutions for Post-Disaster Survivors

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ABSTRACT

Natural disasters in the United States are increasing in frequency and severity, resulting in significant housing loss and prolonged displacement for survivors. Traditional onsite construction methods for post-disaster housing are often slow, costly, and hampered by supply chain disruptions, regulatory delays, and labor shortages. This capstone evaluates the potential of industrialized housing-homes built off-site and rapidly deployed-to address these challenges and accelerate recovery for affected communities. Through workflow mapping, supply chain analysis, and case studies including the 2023 Lahaina wildfire, Reframe Systems, and Brownsville's cdcb response, the study identifies key bottlenecks in both traditional and industrialized construction approaches. The findings highlight that industrialized solutions can reduce deployment timelines and improve scalability, but face challenges related to transportation, site preparation, onsite assembly, and complex building codes. The research offers insights for optimizing the post-disaster housing supply chain and recommends strategies for leveraging industrialized housing to deliver timely and resilient shelter for disaster survivors and their communities.

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1 INTRODUCTION

1.1 Background

Shelter is one of society's most basic needs, according to Maslow's Hierarchy (Maslow's Hierarchy of Needs, McLeod). It is important to all, but it becomes especially clear that it is needed when natural disasters strike. A home not only provides shelter; it also carries cultural significance and is a source of generational wealth for many families. Therefore, when a home is destroyed in a natural disaster, the family loses not only their shelter but also a repository of memories and their sense of agency. It is vital that all disaster survivors have the opportunity to build back their homes so they can move on after natural disasters. The rebuilding of these homes is also important to the communities impacted by the disaster to ensure the community can not only survive but also thrive in future years.

In just the last year, many natural disasters have impacted the United States: hurricanes, wildfires, tornadoes, and other natural phenomena. The impacts of climate change may cause more frequent and more destructive catastrophes, which could cause the loss of additional homes. In 2024, the United States experienced over 25 natural disasters with each disaster causing over one billion dollars in damages (National Centers for Environmental Information, n.d.). One recent example is the 2023 Lahaina wildfire in Hawaii, which destroyed approximately 4,000 housing units and displaced around 13,000 people (Lahaina Wildfire Study: Impacts of Post-Disaster Housing Programs on Maui's Economy, 2024). This disaster will be discussed further in the case study portion (section 4) of this capstone project.

1.2 Motivation

Currently, the process of constructing new houses after disasters takes too long and is too expensive (RAPIDO, n.d.). MIT's Humanitarian Supply Chain Lab has been studying ways to improve housing construction after disasters to improve survivor experience and community recovery.

Traditional housing construction has been done through onsite, stick-built construction. This process can be prolonged through supply chain disruptions, labor shortages or permitting delays. Some research has been completed on leveraging manufactured or factory-built homes to rebuild homes more efficiently and mitigating such delays in the construction process (Disaster housing construction challenges in America: Exploring the role of factory-built housing, 2019 & Scaling Post-Disaster Housing Capacity, 2024). Industrialized homes are defined as homes built off-site and transported to the site for final construction. This capstone project will build on the existing research.

1.3 Problem Statement and Key Question

The project investigates bottlenecks in the housing construction supply chain for traditional and industrialized solutions. The aim is to develop a systematic approach that addresses supply chain inefficiencies while ensuring timely housing deployment for disaster survivors. The feasibility of rapidly deployed industrialized solutions that can be reconfigured to permanent homes and help mitigate the current process' bottlenecks is also explored.

In this context, the main question this capstone addresses is "What are the key supply chain opportunities for industrialized housing to deliver viable solutions to survivors and their community?"

1.3.1 Project Goals and Expected Outcomes

This study provides a comprehensive evaluation of how industrialized housing can be used effectively to address the urgent need for temporary and permanent housing following disasters.

1. **Supply Chain and Workflow Optimization:** Analyze the current housing and industrialized housing construction supply chain to deliver housing after disasters including the response time, cost, and community impact for supply chains that provide post-disaster housing. The expected outcome is a full supply chain and process flow map of the construction process along with material and time constraints.
2. **Case Study and Cross-Case Study Analysis:** Develop case studies using examples like the Brownsville cdcb response, Lahaina Wildfire, and Reframe Systems to ground our findings from the Workflow Optimization and Material Supply Chain Challenge analysis to real-life specific examples and to gather a clearer picture of survivor housing demand. These case studies will provide the necessary insights, data, and guidance to perform the other methodologies targeted in the research project. There is also an opportunity to engage in cross-case study analysis to compare the various examples to identify common themes or key differences.

2 STATE OF THE PRACTICE

To address our central research objective, understanding the industrialized-housing workflow and pinpointing strategies to prioritize and relieve bottlenecks, we conducted a targeted review of the disaster-housing literature. Although many actors contribute to post-disaster temporary housing and sheltering in the United States, the Federal Emergency Management Agency (FEMA) has authority under the Stafford Act to provide this for major disasters and thus sets most of the demand signals, procurement rules, and design constraints that industrialized builders must satisfy. Accordingly, the discussion that follows gives FEMA’s programs prominence; however, it also spotlights other influential providers, including the U.S. Department of Housing and Urban Development’s Community Development Block Grant-Disaster Recovery (CDBG-DR) funds, Small Business Administration home-reconstruction loans, state “shelter-in-place” repair schemes, and non-profit builders such as Habitat for Humanity and SBP, to surface complementary models and supply-chain lessons. The chapter first summarizes this broader state of practice, comparing onsite (“stick-built”) and off-site (industrialized) construction workflows, and then reviews analytic tools such as workflow mapping that drive our bottleneck analysis.

2.1.1 FEMA and disaster housing

Established in 1979, FEMA’s housing authority originates from the Robert T. Stafford Disaster Relief and Emergency Assistance Act of 1988, commonly referred to as the Stafford Act. This legislation outlines FEMA’s responsibilities for providing shelter, temporary housing, and transitional assistance to disaster survivors (Robert T. Stafford Disaster Relief and Emergency Assistance Act, 2023). Over the years, FEMA has become synonymous with disaster recovery in the United States, yet its methods have faced limitations that underscore the need for innovation and systemic improvement.

2.1.2 FEMA’s Housing Programs and Operations

FEMA’s disaster housing programs can be broadly categorized into three areas:

1. Sheltering: Provides immediate, short-term solutions such as congregate shelters, hotels, and rapid repair programs like the Sheltering and Temporary Essential Power (STEP) program. These solutions are geared toward keeping survivors safe and close to their communities during the initial phases of recovery (Scaling Post-Disaster Housing Capacity, 2024).
2. Temporary Housing: This includes financial rental assistance, travel trailers, and manufactured homes. Temporary housing is typically available for up to 18 months, but extensions are granted in certain cases where survivors are unable to secure permanent solutions (MIT Humanitarian Supply Chain Lab [HSCL], 2019).
3. Permanent Housing: FEMA may finance permanent or semi-permanent construction only in very limited situations when no other housing resources are available, as permitted by the Stafford Act (2023). For most survivors, long term rebuilding depends on HUD programs, especially Community Development Block Grant Disaster Recovery (CDBG-DR) funds that Congress appropriates after major events. FEMA therefore focuses on hazard mitigation grants and shares damage and cost data that help HUD shape its recovery

allocations. The MIT Humanitarian Supply Chain Lab report notes that HUD often receives its recovery funding years after the disaster, while FEMA support for permanent housing remains constrained (MIT Humanitarian Supply Chain Lab [HSCL], 2019).

2.1.3 Challenges of a temporary housing mission

This section highlights challenges that FEMA and other public, private, and non-profit entities encounter when delivering a temporary housing mission. One challenge is the lengthy timelines required for funding and execution of a temporary housing mission. Bureaucratic processes and delays in preconstruction activities such as permitting, site identification, and site preparation often hinder the agency's ability to respond promptly, leaving survivors displaced for extended periods. After Hurricane Katrina, news reports showed that almost six months after landfall many families were still waiting for FEMA travel trailers (Six Months Later, 2006). For Hurricane Harvey, a Department of Homeland Security Office of Inspector General review found that FEMA did not authorize the Texas General Land Office to move forward with its full direct housing program until seventy-nine days after the disaster declaration, delaying the placement of manufactured housing units during a critical recovery window (Office of Inspector General, 2021).

A second challenge is regulatory hurdles and coordination gaps which can lead to mismatches between the type of housing offered and what survivors need. For example, in past natural disasters, local officials told the Government Accountability Office that they struggled to align FEMA recreational vehicles and other transportable units with household requirements (U.S. Government Accountability Office, 2020). These obstacles underscore the complexity of large-scale disaster response and point to a need for systemic improvement. Our capstone therefore focuses on industrialized housing solutions, which offer a supply chain-oriented path to greater efficiency, scalability, and responsiveness in disaster recovery.

A third challenge are the units themselves, including their cost and durability. FEMA relies mainly on manufactured housing units (MHUs) for direct temporary housing assistance. An MHU is a factory built single or double section dwelling constructed on a permanent steel chassis to the federal Manufactured Home Construction and Safety Standards, often called the HUD Code (U.S. Department of Housing and Urban Development, n.d.). Because the HUD Code preempts local building codes, local officials need to permit only the foundation, utility hookups, and occupancy, not the structure itself. This national precertification allows FEMA to place units quickly once a site is prepared. Although MHUs are built to the same permanent standards as retail manufactured homes and are durable enough for multiyear occupancy, several factors limit their broad or long-term use. The average purchase and delivery price was estimated at $110,000 to $129,000 dollars per unit in 2018 dollars, not including site work (MIT HSCL, 2019). In addition, MHUs require sizable parcels, paved access roads, and full utility connections, which raise total program costs and slow large-scale deployment. For these reasons FEMA treats MHUs as a time bounded bridge solution rather than a permanent replacement home.

While not the focus of this capstone, another obstacle to rapid deployment of housing after disasters is the fragmented regulatory environment in the United States. Local zoning laws, permitting requirements, and federal guidelines are not always aligned, creating a disjointed patchwork that complicates the deployment of both temporary and permanent housing solutions. For example, inconsistent local regulations often lead to delays in site preparation and installation, further prolonging the housing recovery process (MIT HSCL, 2019). This contributes to the first challenge highlighted above, of extended timelines for delivery of temporary housing.

Finally, FEMA's limited range of housing options allowed in the Stafford Act and challenges – often outside of the agency's control – connecting temporary solutions to permanent ones often results in temporary programs extending well beyond their intended duration. In many cases, temporary housing becomes a de facto permanent solution without the necessary infrastructure or community integration to support long-term stability. This mismatch not only undermines the effectiveness of recovery efforts but also exacerbates the social and economic challenges faced by survivors (Scaling Post-Disaster Housing Capacity, 2024).

This capstone talks about off-site construction applications for disaster housing, which has the potential to address the speed, cost, and durability challenges presented here. The mismatch between disaster needs and housing options will also be addressed.

2.1.4 Other Providers of Disaster Housing

Beyond FEMA, several public- and private-sector actors step in to meet post-disaster housing needs.

- **U.S. Department of Housing and Urban Development (HUD).** Through the Community Development Block Grant – Disaster Recovery (CDBG-DR) program, HUD allocates flexible funds that states can use to repair, replace, or construct permanent housing, filling the gap once FEMA's temporary assistance ends (HUD, 2024).
- **State and Territorial Emergency-Management Agencies.** Many states run "shelter-in-place" repair programs—e.g., Florida's Sheltering at Home for Recovery Continuation (SHRC) repaired 500 homes within a year of Hurricane Ian (Tidal Basin Group, 2023) while Louisiana's LA SAFE initiative channels CDBG-DR funds into resilient-housing projects (Louisiana Office of Community Development, 2018).

- **Small Business Administration (SBA).** SBA disaster-home loans now provide up to US $500,000 for owners to rebuild, a common complement to HUD grants (Congressional Research Service, 2023).
- **Non-profits and Philanthropy.** Organizations such as SBP and Mennonite Disaster Service marshal volunteers, donated materials, and case-management programs that bridge survivors from temporary shelter to permanent homes (SBP, n.d.; Mennonite Disaster Service, n.d.).

Recognizing how these players complement FEMA clarifies supply-chain touchpoints (e.g., material sourcing, labor mobilization) that industrialized builders must navigate.

2.1.5 Innovations to Improve Housing Recovery

Federal, state, and local partners have launched several initiatives that cut lead times, lower costs, and bridge the gap between temporary shelter and permanent rebuilding. A 2019 FEMA–MIT–Lincoln Laboratory study tested industrialized housing as a way to shorten site work and reduce total program expense (MIT Humanitarian Supply Chain Lab [HSCL], 2019). Building on that evidence, Texas now accepts volumetric units through its Industrialized Housing and Buildings program; local inspectors review only the foundation and utility hookups because the structure already carries a single factory certification, eliminating repeat site inspections (Texas Department of Licensing and Regulation [TDRL], n.d.). At the federal level, new guidance from FEMA and HUD permits states to pair Community Development Block Grant Disaster Recovery (CDBG-DR) funds with FEMA dollars when they submit off the shelf housing action plans that identify factory partners in advance, allowing money to flow within weeks rather than months (Federal Emergency Management Agency & HUD, 2020).

FEMA has also strengthened its own readiness by retaining a stockpile of manufactured housing units and maintaining standing surge contracts with builders so that additional units can roll off production lines on short notice. These steps, combined with refined pre disaster planning templates, aim to reduce cycle times from declaration to occupancy and improve overall program resilience (Scaling Post-Disaster Housing Capacity, 2024).

Outside government, nonprofit and academic collaborations continue to pilot models that start as rapid shelter and evolve into permanent homes. The RAPIDO program, for example, deploys a core unit within days and then expands it into a finished house as funding and labor become available, aligning short term survival needs with long term community rebuilding goals (RAPIDO Technical Guide, 2015). Projects like RAPIDO underscore a growing commitment to survivor centered design and local engagement, ensuring that industrialized solutions respect cultural norms and regional building practices while still delivering the speed and scale that modern disasters demand (Scaling Post-Disaster Housing Capacity, 2024).

2.2 Types of Housing Solutions

This section includes descriptions of common housing solutions used after disasters, classified by the construction method. This includes solutions used by FEMA and those that a homeowner might use on their own home, in order to place the work of this capstone in the broader disaster housing context.

2.2.1 Onsite Stick Built Construction and Repairs

Onsite stick-built repair or replacement of existing home on the survivor's own parcel, keeping people close to jobs, schools, and support networks. Even in routine market conditions a single-family house takes about nine to ten months from permit to completion, and custom work can exceed thirteen months (National Association of Home Builders, 2023). Post-disaster shortages of labor, materials, and inspectors lengthen that schedule by many additional months. A Harvard Joint Center review found that only seventy percent of storm-damaged properties in Louisiana and Mississippi were rebuilt by early 2010, more than four years after Hurricanes Katrina and Rita (Joint Center for Housing Studies, 2017).

2.2.2 Industrialized Housing Construction

Industrialized housing refers to any construction process that includes any use of industrialized production methods, regardless of the method, physical location, or step in the construction process that is industrialized (Finnigan, 2025 & National Renewable Energy Laboratory, n.d.). There is limited research on the specific use of industrialized off-site housing solutions for natural disaster survivors. MHUs, FEMA's current solution, are a type of industrialized housing construction referred to as "manufactured housing", designed to meet the HUD code rather than a given state or local building code. A modular home is defined as, "homes that are constructed using individual sections, called modules, built in a factory, and assembled on site" (U.S. Department of Housing and Urban Development, n.d.).

Findings from a recent roundtable suggest that some members of the emergency response and housing community view industrialized houses beyond MHUs (e.g., modular housing units) as a potentially feasible way to deliver housing to survivors more quickly and at lower cost (Scaling Post-Disaster Housing Capacity, 2024). Our capstone research will focus on mapping the industrialized housing supply chain and manufacturing process to identify obstacles and understand the nuances of survivor housing demand.

Most of the literature on current industrialized housing manufacturing processes comes from industry resources such as the Modular Building Institute (MBI). MBI highlights the benefits of industrialized houses such as, “shorter construction times... and cost certainty (obtained through fewer mid-project changes and weather delays, and, to a lesser degree, fewer onsite injuries)” (Inside the Modular Building Process, 2022).

Industrialized housing can be divided into two manufacturing approaches: volumetric and panelized. The volumetric approach delivers a full modular house with both interior and exterior features manufactured in a designated off-site location and then transported to be installed on site as a complete “box.” This often means shorter onsite construction timelines as the box generally requires minimal exterior and interior finishing once placed on a foundation but can be harder to transport depending on local oversize load restrictions and requirements. The panelized approach involves manufacturing portions of buildings off site such as walls or floors and then transporting them in pieces (panels) to be configured onsite. This approach requires a bit longer for onsite construction, but transportation may be easier, and it offers more flexibility in the construction process (Kilander, 2024).

Offsite housing leverages the benefits of mass production to reduce construction timelines and improve efficiency. Brian Potter of the Construction Physics Blog writes, “mass production is designed around achieving economies of scale by producing things in huge quantities. The greater your production volume, the more you can afford the high fixed costs of specialized machines and equipment, the more it’s worth it to capture small efficiencies by vertically integrating, the more you can take advantage of labor specialization by having workers do extremely narrowly defined jobs, and the greater volume discounts you can secure from your suppliers.” (Potter, 2021a)

To dive deeper into how off-site construction methods shorten the overall construction timeline, Module, a modular home manufacturer located in Pittsburgh, uses the Gantt chart shown in Figure 1 to highlight the differences between typical onsite construction and modular construction. The main differences are the efficiencies that offsite housing can provide such as setting foundation at the same time the house is being constructed offsite at a much faster pace than traditional onsite construction. The timeline will vary depending on project location and requirements, but Figure 1 shows that their projects take about 8 months to construct compared to 11 months for traditional construction, a 27 percent reduction in overall construction time in this example.

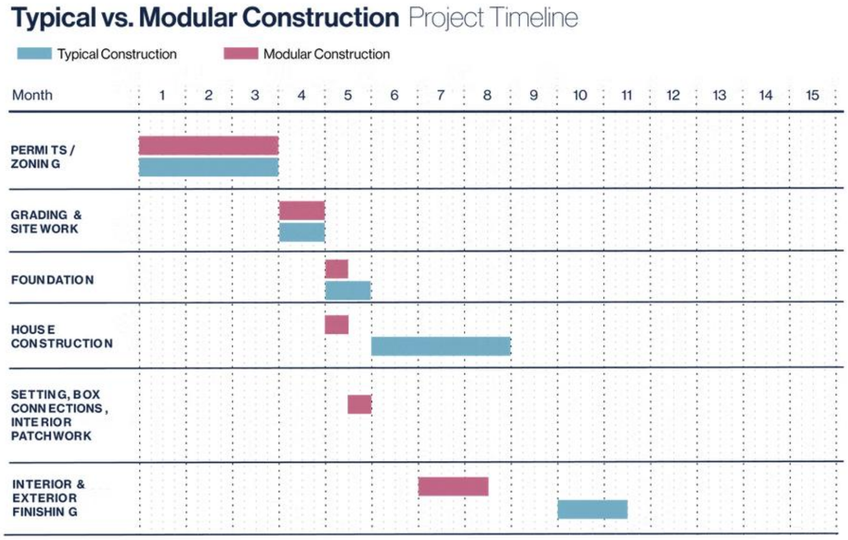


Figure 1: Timeline comparison between Typical and Modular Construction (Module | Energy Efficient Homes | Pittsburgh, 2024)

Some potential challenges connected with industrialized housing are the transportation of the home or panels to the housing site, permitting concerns, high raw material and Work-in-Progress (WIP) inventory levels, and potential lack of customization to fit survivors' needs. In another Construction Physics Blog post, Brian Potter explains that "one reason building production looks like it does - buildings have low product-value density, and the logistics costs for transporting a fully assembled building are enormous... Even if you somehow get your house to the site in a single piece (no easy feat), there are still significant site costs. Permitting, grading, setting foundations, etc. can be up to 20% of overall construction costs, and aren't easily addressed by any sort of mass-production method" (Potter, 2021b). Given these challenges, more work needs to be done to understand industrialized housing, especially in the disaster context, when many of these barriers are even higher (e.g., transportation bottlenecks or delays, permitting delays). The next section presents one approach to mapping and identifying these barriers.

2.3 Process Flow Mapping

One way to better understand industrialized housing solutions is to map the processes of their manufacturing operations. A process map is used to highlight the activities and flows of materials from one step to another in a specific process. By visualizing the process, it is easier to gain insights into what is working well and what can be improved, and where bottlenecks might emerge. A bottleneck can be defined as a point of congestion in a production process that causes inefficiencies such as delays or disruptions (Kenton, 2023). Process mapping also allows you to identify best practices and enable knowledge sharing of the process (What Is Process Mapping & How to Create It?, 2023).

Process maps use basic geographic shapes to represent different steps. An oval represents starting or stopping points, rectangles represent activities/tasks, arrows represent flows (materials, information, financial, etc.) or connections between steps, diamonds denote decisions points, and triangles represent delays or waiting periods (Think | IBM, 2024). An example of a process map is shown in Figure 2.

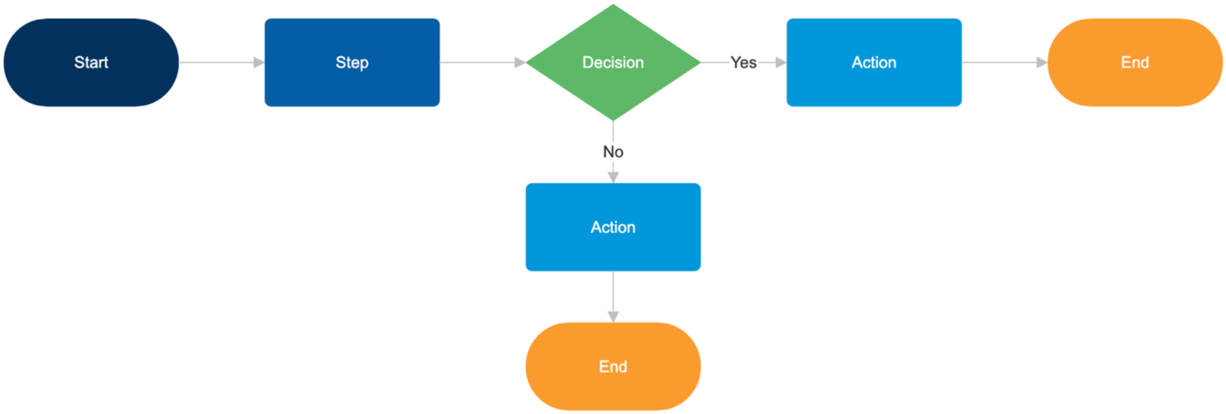


Figure 2: Example of basic process map (SmartDraw, 2019)

There are several different types of process maps: basic process maps that visualize details like inputs and outputs; deployment maps that plot cross-functional relationships and often use swim lane diagrams; detailed process maps that show more granular details of the process and subprocesses; rendered process maps that show current vs. future states; and value stream maps that map specific products or services for the end user (Think | IBM, 2024).

To create an effective process flow map, it is vital to define the specific process to map, including a starting and stopping point. The next step is gathering pertinent data and collaborating with all relevant stakeholders. Once data is gathered, a list of all activities should be drafted as an outline. This outline then can be transformed into the flow map visualization using the basic shapes previously defined. The last and most important step is to review with stakeholders and incorporate their feedback to finalize the process map.

Diving deeper into the flows that make up process flow maps, a flow is “series of operations that move goods from supply to demand” (Goentzel, 2023). These operations include manufacturing, transportation, and warehousing, for example. Flows can be further broken down into “subflows,” which distinguish specific actions within each flow such as picking and packing within the warehousing operation. By analyzing these subflows, one can ensure resources (e.g. facilities, equipment, and workers) are being used effectively and proper contingency plans are in place. It is vital to capture the specific details related to resources when mapping out supply chains.

Three approaches to process flow are continuous flow, variability, and batch manufacturing. The concept of “continuous flow” is that the products in the manufacturing process move through each step without delays and at a constant rate. The closer the process gets to “continuous flow”, the more efficient the process is, reducing lead times and work-in-process inventories. Another area of analysis will be evaluating the process for variability and batch manufacturing. Variability causes inefficiencies within the process, so it is best to identify and mitigate variability in a process. However, variability will always exist in real life and can be hard to eliminate fully. (Potter, 2022).

When there is significant variability in a process, buffer stocks often exist to combat this variability. One example is when a process unexpectedly produces supply over the amount of needed demand, the product will need to be stored until demand arises for the product which can lead to high inventory and warehousing costs. However, the flip side is that demand for the product could arise in an emergency and supply is not available. Therefore, there may be a need to increase the inventory to have products on hand in case it is needed. A process flow map can help identify where buffers might be needed and where they can potentially be eliminated (Goentzel, 2023).

Batch manufacturing is when higher quantities of material are processed at the same time. This increases Work in Process (WIP) inventory and lowers system efficiency, but it can be beneficial if batching increases economies of scale, especially for fixed costs (Potter, 2022).

3 METHODOLOGY

This capstone project explored three case studies where we described and analyzed the supply chain and manufacturing process of specific industrialized housing solutions. The case study method allowed for a comprehensive review and comparison of offsite housing solutions in the context of providing housing for natural disaster survivors. The cases provided valuable insights into common challenges or unique benefits to these solutions. The following sections provide an overview of the steps in the capstone project: case studies, interviews, supply chain & workflow mapping, and scenario analysis.

3.1 Case Studies

Literature on the case study approach goes back to the 1960s, however, the case study approach was more thoroughly defined in Kathleen Eisenhardt's 1989 paper titled "Building Theories from Case Study Research." In this paper, the case study approach is defined as "a research strategy which focuses on understanding dynamics present within… settings." (Eisenhardt, 1989). A case study is a research paper that " examines a person, place, event, condition, phenomenon, or other type of subject of analysis in order to extrapolate key themes and results that help predict future trends, illuminate…issues that can be applied to practice, and… provide a means for understanding an important research problem with greater clarity" (Labaree, 2023). To write a case study, it is vital to start with a research question and find a relevant case to study. The case should properly conceptualize a problem and include analysis and discussion to ultimately provide valuable insights that can be researched further and/or spark potential actions for solutions in the future (Labaree, 2023). There are various types of case studies. An illustrative or descriptive case study describes a case to further understanding of a specific, existing topic. An exploratory case study focuses on highlighting a new topic on which existing research is limited or when the case study is done prior to a more in-depth case study. Another type of case study is a cumulative case study, which compares data from multiple "sites" or cases to find commonalities or generalizations (Writing@CSU Writing Guide Case Studies, 2017). This capstone is a hybrid approach as it serves the purpose of furthering understanding of existing examples of industrialized housing for disaster recovery while sparking future research into the topic. Multiple cases will be investigated and compared to create key findings and recommendations.

The focus of the case studies included here was to document three different strategies for industrialized housing that could be or has been scaled after a disaster. The three cases are: the Kilohana temporary housing site in Maui, Hawaii, Brownsville, Texas' Come Dream, Come Build (CDCB) non-profit community housing development organization, and Reframe Systems, a private modular builder offering a unique approach to industrialized construction. Comparing these distinct cases allowed us to find commonalities and best practices. These solutions will be discussed further in the scenario analysis/cross referencing section below.

One important piece of literature for this capstone project is a paper titled “Product platform alignment in industrialized house building” by Djordje Popovic, Tobias Schauerte, and Fredrik Elgh. The authors evaluate product platforms of two industrialized housing manufacturers in Sweden. The article uses the two companies as case studies to better understand both company’s product platforms and concludes with an alignment model with multiple modes. The article begins with an introduction, followed by a “frame of reference” or literature review, method (data collection and analysis), key findings, and ends with discussion and conclusion (Popovic et al., 2021). This study will serve as model for this capstone project.

Unlike the Popovic et al. study and this capstone will focus on the workflow mapping of industrialized housing manufacturing process located in the United States (not Sweden). To gather the data needed for this research, the project relies heavily on interviews with case study participants.

3.2 Interviews

In disaster recovery housing, especially when viewed from a supply chain perspective, understanding the materials, services, demand, and supply dynamics is critical. However, it is difficult to compile reliable data after disasters due to the chaotic and dispersed nature of disaster response, with multiple stakeholders operating in “compressed timelines and “high levels of uncertainty” (Van den Homberg, 2018). This absence of structured information hinders efforts to draw meaningful comparisons between stick-built and industrialized housing construction in terms of supply chain efficiencies, lead times, and resource allocation.

Given this limitation, our methodology relies heavily on qualitative data collected through interviews with key stakeholders directly involved in the disaster housing ecosystem. These stakeholders include representatives from:

- Non-profit organization active in disaster housing (Habitat for Humanity): To understand community-driven housing solutions and their supply chain challenges in both onsite and off-site construction.
- Disaster Housing Providers: To gain insights into operational challenges, resource planning, and current approaches to housing solutions.

- Trade Associations: To explore the perspectives of traditional onsite builders regarding construction timelines, material sourcing, and labor constraints in disaster scenarios.
- Modular Housing Companies: To analyze the potential of industrialized construction methods, focusing on their scalability, supply chain integration, and deployment logistics.

The interviews address the in quantitative data by gathering first-hand insights and practical experiences from stakeholders. These conversations explore key topics, including the bottlenecks that arise in the supply chain for both onsite and industrialized housing construction. They also examine the comparative advantages of industrialized vs. traditional construction methods, focusing on factors such as speed, cost, and resource efficiency. Additionally, the interviews delve into the challenges of aligning material procurement and labor supply with the demands of disaster housing, providing a comprehensive understanding of the operational dynamics involved.

By engaging with individuals and organizations actively working in disaster recovery, we construct a more nuanced understanding of the housing supply chain. The data collected serves as a cornerstone for our analysis, allowing us to identify patterns, validate assumptions, and develop informed recommendations for any organization delivering housing after a disaster. This approach ensures that our findings are grounded in the realities of disaster recovery operations, bridging the gap between theoretical models and practical application.

3.3 Supply Chain and Process Flow Mapping

The data collected in interviews were transformed into process flow maps to visualize the step-by-step industrialized housing process from material sourcing to onsite assembly. Process flow maps help identify bottlenecks and inefficiencies, which in turn can inform the development of potential solutions or identification of levers that can be pulled to restore flow in the system. Each case study includes a high-level flow map encompassing things like manufacturing and transportation, as well as a more detailed process map highlighting the "subflows" within the manufacturing segment of the process. This might include things like building an individual wall panel or installing plumbing fixtures.

3.4 Cross-Case Analysis: Comparing Industrialized Construction Case Studies to Develop Recommendations

The methodology for this portion of the project focuses on employing cross-case analysis as a tool to compare the effectiveness of onsite and industrialized housing construction methods in disaster recovery. This cross-case analysis helps develop actionable, evidence-based recommendations, specifically aimed at improving the speed, cost-effectiveness, and sustainability of post-disaster housing solutions (HSCL, 2019; Finegan et al., 2024).

For this project, we use cross-case analysis to examine potential disasters where traditional and industrialized construction methods are deployed, providing a basis to compare their effectiveness in meeting housing needs. This approach also helps identify key supply chain and operational challenges inherent in each method, shedding light on areas such as material procurement, labor availability, and logistical constraints. Furthermore, the analysis assesses outcomes related to time and survivor satisfaction, ensuring that both efficiency and the needs of affected communities are prioritized. In creating the scenarios, we draw upon a combination of historical case studies and hypothetical disaster situations, enabling a thorough evaluation of the viability and scalability of different housing strategies under diverse circumstances (Scaling Post-Disaster Housing Capacity, 2024).

To construct meaningful theories, the analysis will rely heavily on insights gathered from case studies, particularly the Maui Kilohana Case. This program, implemented in response to the Lahaina Wildfire, serves as a groundbreaking example of how industrialized housing solutions can bridge the gap between temporary relief and permanent recovery.

In addition to the Kilohana case, the analysis will integrate data from other approaches to industrialized housing, such as Brownsville's come dream, come build initiative and Reframe Systems. Stakeholder interviews with industrialized housing companies, traditional construction organizations, and community-based groups further shaped the scenarios. These interviews provided first-hand accounts of supply chain dynamics, operational challenges, and survivor-centered design considerations; filling gaps left by the lack of comprehensive datasets (MIT HSCL, 2019).

We examined supply chain dynamics, focusing on material sourcing, labor availability, and logistical constraints that impact both onsite and off-site construction. The analysis will reflect diverse disaster contexts to evaluate the adaptability of these housing solutions.

By cross-referencing the Kilohana case with other manufacturing approaches and stakeholder insights, this analysis provides a nuanced understanding of how stick-built and industrialized construction methods can be optimized for disaster recovery. The findings inform actionable recommendations, addressing both immediate response and long-term recovery goals.

4 CASE STUDIES

This section contains three unique case studies highlighting the benefits and challenges of industrialized housing solutions: first the Kilohana Group Site in Maui, HI, ReFrame Systems, and the come dream, come build initiative in Brownsville, TX. The cases each describe a unique approach to industrialized housing which will be analyzed using cross case analysis in the Results and Discussion section of this capstone.

4.1 Case 1: Kilohana Group Site

This case study describes the Kilohana housing group site in Maui, HI, constructed following the August 2023 wildfires in Maui. The sections below describe the purpose and scope of the case study, housing demand that the group site was built to meet, key stakeholders, and the process for developing and delivering the housing units: preconstruction activities including design and material sourcing, followed by the manufacturing, transportation, and onsite assembly of units.

Figure 3: Photo of Kilohana Site (Source: Dynamic Group)

4.1.1 Purpose and Scope

The purpose of this case study is to describe the application of a rapidly deployed volumetric industrialized housing solution to an island location to help people begin to rebuild after a natural disaster. This study presents a specific example of how this solution was used to provide satisfactory housing options and will be used to compare this solution to other potential solutions in the Come Dream, Come Build (CDCB) and Reframe Case Studies. The scope of the case study includes the total supply chain process, beginning with design conception through raw material procurement, factory manufacturing, transportation to site, and final onsite construction.

4.1.2 Housing Demand

In August 2023, Maui, Hawaii experienced one of the deadliest wildfires in the United States. The fire destroyed the town of Lahaina, killing over 100 people and damaging over 4,000 homes. The fire left 13,000 people displaced and in need of housing (Hyde et al., 2024). This displaced population encompasses the key source of housing demand after the fire and the focus of this case study. Other sources of demand for housing include first responders and other disaster response support personnel.

Some options for displaced people offered by the state and federal government included temporary solutions such as living in a hotel with lodging expense reimbursement, finding another rental property with rental assistance, requesting home repairs to their homes depending on the damage, and lastly, direct temporary housing such as trailers or other temporary units (FEMA, n.d.).

For this case study, we will focus on a housing site for over 100 units that was created on 34 acres of state-owned property. This site was designed as a temporary post-disaster housing solution but was also informed by the demand for a longer-term solution for the community for rebuilding and affordable housing. Families were able to move into these homes beginning on November 22, 2024, over a year after the initial disaster. The following sections detail how this housing site was made possible through adaptable supply chains.

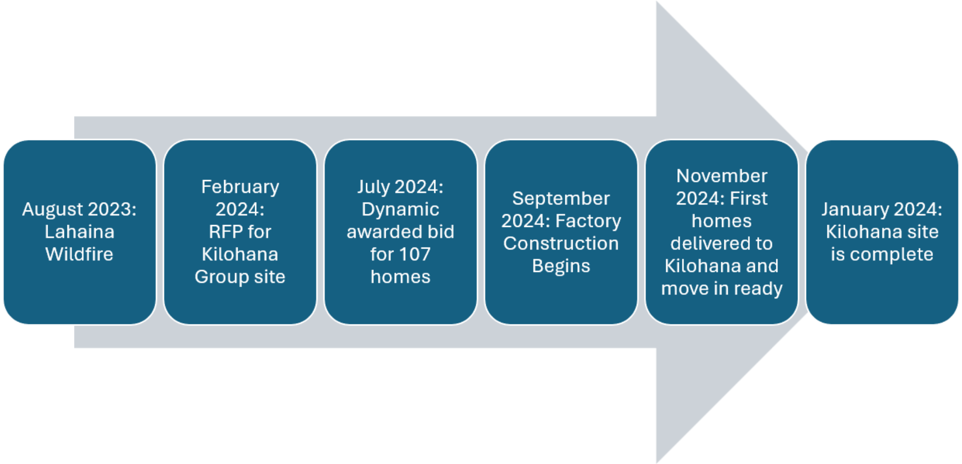


Figure 4: Timeline of the Kilohana Site Construction

Figure 4 above summarizes the major milestones in the Kilohana group site construction.

4.1.3 Key Stakeholders

To set the scene for the case study, it is important to understand the key stakeholders. The most important stakeholders are the survivors of the natural disaster who will be living in the housing units. It is vital that the houses are designed and constructed with their needs in mind to ensure the group site is successful in helping these individuals and families rebuild and return to their normal lives in a timely manner.

The local, state, and federal governments are also stakeholders in this group site. The local government must be involved to make sure the housing site is appropriate and is effective for long-term recovery of their community. The state and federal government provide key funding and coordination support to make the group site possible. As part of the coordination, state and federal government organizations often select contractors to execute on the construction of the site when the activities exceed their capacity and/or technical capabilities. In this case, this involved FEMA, the State of Hawaii and Maui County as key government stakeholders.

The primary contractor highlighted throughout this study is Dynamic Group. In the Kilohana project, Dynamic was the prime contractor responsible for delivering modular units to the site. They have expertise in government services specifically in construction, emergency response, and long-term recovery efforts (Dynamic Group, 2023). They worked on multiple previous disasters in the United States such as hurricanes Ida, Laura, and Delta as well as the 2016 Louisiana Floods.

As a prime contractor, they hired and oversaw subcontractors responsible for the design, construction, and transportation of the homes. Each of the subcontractors is also a key stakeholder responsible for the successful completion of the group site.

4.1.4 Preconstruction Activities

FEMA issued the Request for Proposal (RFP) for the manufacturing, transportation, and installation of the Kilohana Group Site housing units in February 2024, six months post-disaster. Three vendors were chosen to provide the units for this project in late August 2024. This case study focuses on the total supply chain process of one of the three housing providers, Dynamic Group, from material sourcing to installation on site. Dynamic was responsible for delivering 107 homes to the group site. Dynamic collaborated with many different organizations in its bid for the project, including Liv-Connected to help them design the housing unit, and companies responsible for the construction/manufacturing, like Fading West, and transportation of units, Marex Services.

4.1.4.1 Design

Many of the design specifications of the homes for the Kilohana group site were outlined in the RFP from FEMA. These included the dimensions of the homes and number of bedrooms (1, 2, and 3 bedrooms) along with storage, lighting, and cooling requirements. The design also had to consider the foundation type which the team selected as pre-cast pier and beam to ensure the homes could be set as soon as they arrived onsite to hit ambitious move in dates set in the RFP. The homes also had to adhere to Maui County Building Codes, which required considerations such as hazard resistance to reduce the risk of future damage to the home.

Certain additional requirements specific to this site further influenced the unit design. The Kilohana site is unique in terms of its location and cultural heritage. In addition, the state and local governments expressed a need for homes to fit into a longer-term solution to increase the supply of affordable housing. Further, Dynamic and Liv-Connected were mindful of the house needing to be a soothing and suitable place for families to heal and rebuild from the disaster. Lastly, all stakeholders including the state of Hawaii wanted the home design to incorporate Hawaiian design elements, so they fit in culturally for longer term use. As a result, Dynamic's design was much different than what is typically used for temporary group sites after disasters.

The resulting unit (shown in Figure 5) required extensive collaboration between parties to ensure manufacturing and installation of the homes went smoothly as it had not been implemented before and the logistics of quickly building and moving homes to an island are challenging.

HAWAIIAN ARCHITECTURAL STYLE STUDY

Hawaiian Architectural Style Study

One of our top priorities in designing the home is ensuring it aligns with the cultural, historical, and environmental precedents throughout Hawaii. We did that by studying homes of Hawaii throughout the years and directly incorporating them into our design to create a contemporary structure that belongs in Maui and will make families feel at home.

INCORPORATED HAWAIIAN DESIGN ELEMENTS:

- Pitched roof
- Large, open living spaces
- Vertical siding
- Porches
- Indoor/outdoor connection
- Multi-colored siding/entry
- Large windows for natural light & air
- Light, natural materials

HALE PILI
- High pitched Roof for climate control
- Large open living spaces

DICKIE ROOF
- Pitched for climate control
- Wood features

PLANTATION HOMES
- Multi-colored wood siding
- Metal roof
- Accented trim & features
- Porches for wala'au with the neighbors
- Indoor/outdoor connection

OLD LAHAINA STYLE
- Vertical wood siding
- Multi-colored wood siding
- Recessed entrances
- Places for gathering at front
- Large, operable windows

MID-CENTURY MODERN
- Large windows for connection to outside, natural air & light
- Light, natural materials
- Open living space

Figure 5: Specific design aspects from Liv Connected and Dynamic

4.1.4.2 Material Sourcing

Prior to manufacturing, procurement of raw materials must occur. Typically, procurement is handled by the manufacturer, but the homes for the Kilohana site required several unique raw materials that proved hard to find. For example, pressure-treated lumber was needed to resist termite damage in an island setting. To ensure these materials were delivered on time and avoid any delays, the manufacturer of the homes took the lead in sourcing materials. They accomplished this by leveraging their prior relationships with suppliers. The incredibly short time between the award of the bid and the start of the manufacturing to meet onsite delivery deadlines made the procurement process much more difficult as the number of supplies needed was not abundantly available. Dynamic and Liv-Connected assisted as well to locate additional suppliers when needed. Once the raw material supplies arrived onsite at the factory, where the homes were being built, the assembly of the houses began.

4.1.5 Manufacturing

Once the design of the home was selected, Dynamic had to ensure they could manufacture the required number of homes on a tight schedule. Dynamic worked with Fading West in Buena Vista, Colorado, which specializes in offsite volumetric housing construction, with their state-of-the-art 110,000 square foot facility designed with 18 stations, 6 cranes (with 2 hoists and 3-ton capacity), automated framing/cutting tools, CAD-Based laser marking system, and air cushion module transport system. Their approach is based on standardization and lean manufacturing practices, which we will discuss in more detail below.

The construction begins by building the floors, walls, and ceilings at the “Table Stations” then the full house physically moves through the rest of the 18 stations until it is fully constructed and ready for shipment (flow diagram in Figure 6). The stations following the construction of the frame of the house include plumbing, electricity, insulation, trim (interior and exterior), paint, sheathing and function testing. The factory employs approximately 125 people total, with each station of the factory manned by 3-10 people depending on the task. Each station takes 4 hours to complete, and the factory typically runs one 10-hour shift. Therefore, the first house is usually completed in about 10 business days, and then two houses are completed every business day after that. With the help of overtime (up to two or three shifts daily), some houses were completed in as short as 7 business days and up to four homes could be completed in one day depending on the home size. Manufacturing of the Kilohana houses began in September 2024, and all homes were completed by November 2024.

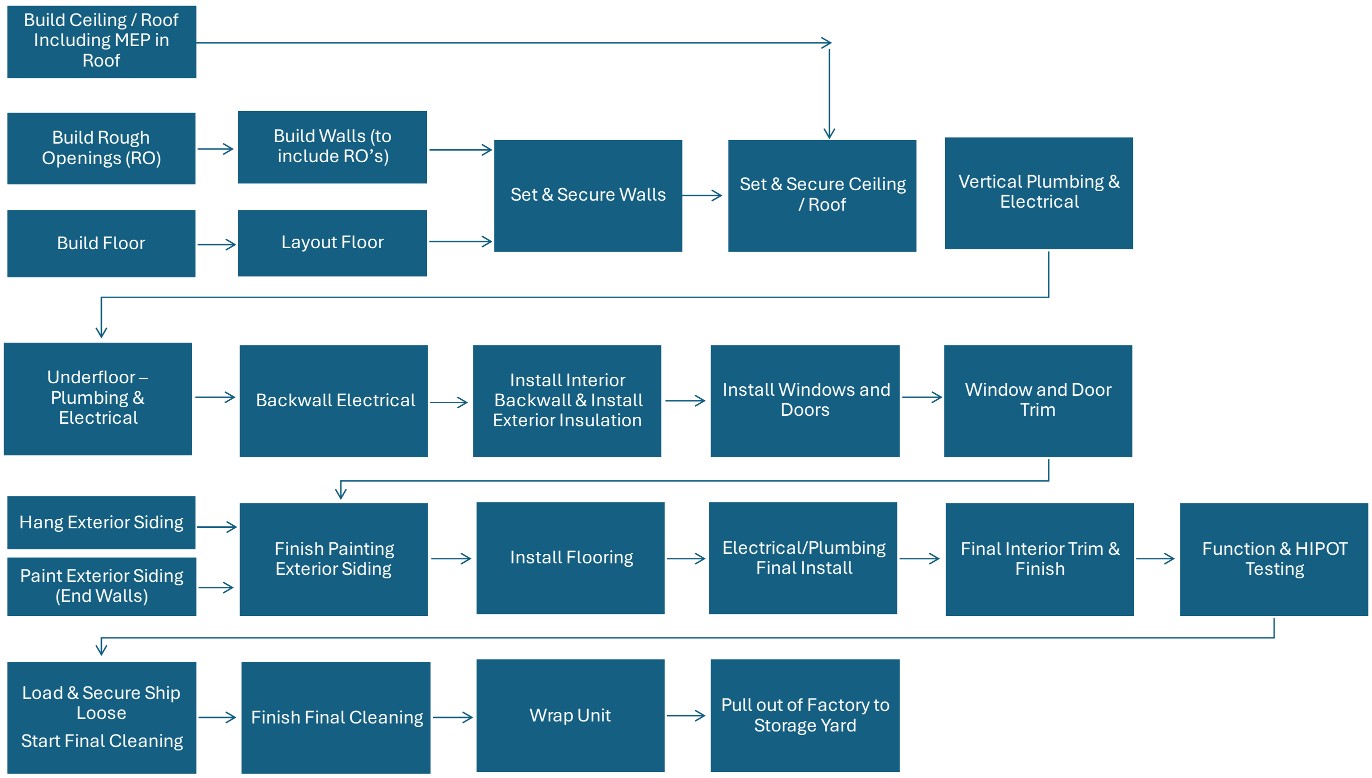


Figure 6: Sub flow Diagram of the Construction Process

4.1.6 Transportation

Once the homes were fully constructed, they were transported to the site. Dynamic worked with a trusted transportation partner, Marex Services, for this piece of the process. At a high level, most units were transported by truck from the factory to a barge located at the Port of Seattle. Once in Seattle, they were loaded onto a barge and shipped to the Kahului Harbor in Maui. Then they were transported by truck to the Kilohana site for onsite construction. The following paragraphs explain in more detail the steps of transport.

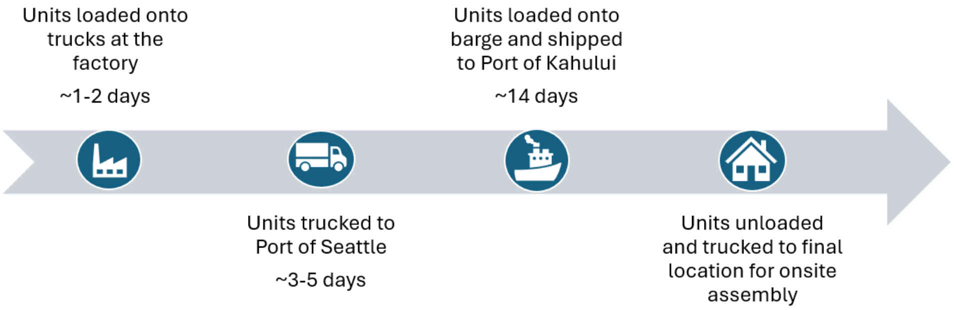


Figure 7: Sub flow of Transportation for units at Kilohana Site

Once houses were completed in the factory, Marex and Dynamic aimed to have the homes loaded onto trucks the same day or next day. This helped to avoid excess inventory of fully constructed housing units at the factories, which have space only for a few completed units on site. The team tracked the status of construction of each unit in real-time as well as the location of each truck to coordinate truck arrivals as efficiently as possible and cut down on truck idle time. This also allowed the team to monitor arrival times of trucks at the factory and port.

Since these were volumetric homes, they required oversized load truck transportation which requires the escort of pilot cars. For the route these homes were taking, one truck required two pilot cars, and two trucks required three pilot cars as escorts, so two trucks were often sent at one time to leverage the economy of scale for pilot cars. Over the course of shipping units, there were up to 14 trucks completing routes from the manufacturer to Seattle and then returning to pick up additional modules. Each home took 3-5 days to travel from the factory to Seattle. However, Dynamic and Marex ran into shipping problems due to summer highway closures for construction. On several occasions, this meant only shipping from Friday to Sunday and increasing the number of trucks over the weekend to complete additional shipments.

The homes were shipped on three barges originating in Seattle directly to the Kahului Harbor in Maui. Dynamic chartered these barges for this project. In Seattle, the homes were loaded onto the barge by forklifts. Those forklifts were loaded and shipped on the barge with the homes to be used for unloading. Each barge carried 20-25 homes and had a 14-day sailing time before arriving in Maui.

The Port of Seattle was chosen for several reasons. The first was that it had the capability to handle this type of cargo: it offered a Roll-On, Roll-Off (RORO) option, which sped up the loading/unloading process. RORO port facilities are equipped to handle ships where the cargo is rolled or drives on and off the ship (e.g., a vehicle or piece of farm equipment), and typically have staging area sufficient to hold this type of cargo, which cannot be stacked like containers. This also allowed the transportation company to use forklifts to load rather than cranes, which eliminates the need to engineer lift points for the homes and the need for specialized equipment. The RORO option does require a ramp from the dock to the barge, which Seattle had available. The second was that the port had availability on short notice: they were ramping down their busy season, which consists of a lot of shipments to Alaska during the summer while Alaska ports are accessible.

It was important to Dynamic to ship as many homes as possible by barge for two reasons. First, they could be shipped directly to Maui as a direct route was available. Four homes had to be shipped by liners, which had to go through the port of Honolulu before they could be shipped to Maui. Second, barges could better accommodate the width of the housing modules. Each module took up one and half lanes on a cargo ship, resulting in increased costs compared to the liner.

The arrival date of the barge in Maui was very important. Marex targeted arrival on Saturday mornings. This allowed them the weekend to unload the barge, which was vital since the port is small and has a full schedule of cruise ships, container vessels and interisland barges. Once unloaded, the homes were placed in holding areas close to the port until they could be transported to the Kilohana site. Once the home site was ready, the homes were trucked to site for onsite construction. Dynamic oversaw the trucking from the port to the site, navigating a tunnel and narrow local roads to deliver units safely and on schedule.

Figure 8: Barge en route to Maui with 20-25 modular homes for the Kilohana Site

4.1.7 Onsite Assembly

Once homes arrived at the site, Dynamic successfully managed the installation of 107 homes by coordinating multiple trades, overcoming logistical challenges, and ensuring each unit was fully prepared for occupancy. This section describes the steps required to assemble and install each home on site.

When a home arrived on site, it was immediately set on a pre-cast foundation, leveled, and connected to utilities by a workforce of 108 dedicated carpenters, electricians, HVAC technicians, and plumbers. Each unit included a solar water heater, which was procured and installed locally. To ensure units were move-in ready, Dynamic managed the installation of furniture, final cleaning, and quality inspections. A real-time tracking system monitored progress, allowing for proactive scheduling adjustments.

An important element of the installation process was engaging local partners to mitigate supply chain constraints and, importantly, contribute to local economic recovery. By working with trusted local contractor Alpha, Inc., Dynamic was able to secure the necessary skilled trades, large labor force, and local equipment to complete the installation on an expedited schedule. A photo of the onsite assembly process is shown in Figure 9.

Figure 9: Homes being installed onsite at Kilohana site

4.1.8 Conclusion

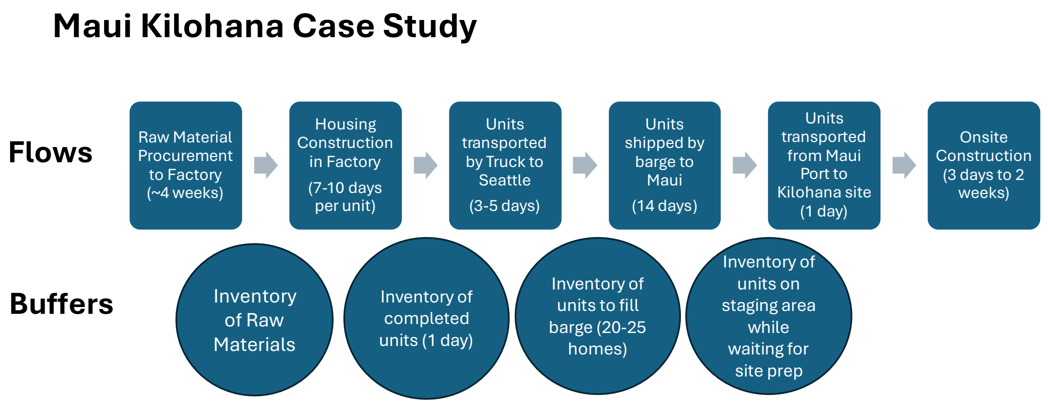
To describe the elements of the supply chain for the housing units at the Kilohana Group Site, we created a flow and buffer diagram (see Figure 10). This generalizes the process flow and allows for continued research into the ways to modify the process flow and improve in future disasters.

The flows start with incoming raw materials to the factories for the homes. This creates a potential buffer of raw material inventory that can be stocked for future orders of homes which could be helpful in future disaster recovery. However, most modular homes are made to order so limited raw material inventory is typically stored at factories. This is in part because houses may have unique raw material requirements as we saw with the pressure-treated lumber used for termite resistance in the Kilohana Case. A hybrid approach would be that factories are stocked with universal products such as nails, screws, etc., and orders for unique raw materials are placed closer to the time of assembly. All raw material orders in this case typically have around a four-week lead time for delivery.

The next flow is the construction of the homes through the factory which takes approximately seven to ten days in the Kilohana case. Levers such as overtime and surge staffing can be pulled to scale up production and reduce the cycle time of the unit through the manufacturing process. However, there are also risk factors that could extend manufacturing time such as shortages in labor, raw materials, or production capacity and key machine outages. Contingency plans must be developed for such risks. This flow leads to our next buffer of completed units. In the Kilohana case, the plan was that once the unit was completed that it would be shipped out that day or the following day. If that didn’t occur, there was room onsite to keep some finished product. Since the homes were completed and waterproof, they could also sit outside if needed.

Once the homes were shipped via truck to Seattle, they were loaded onto barges, creating the next buffer of completed units waiting on the barge until it was fully loaded. The transportation partner wanted to ensure as many homes as possible were shipped on each barge.

Once full barges were loaded, they were shipped to Maui which took approximately 14 days. They were then unloaded in one day and set in a staging area to wait for their sites to be ready for onsite assembly, creating the next buffer of units. In a perfectly efficient process flow, the sites would be ready as soon as the homes arrived in the Maui port so homes could be directly transported to the site eliminating the need for a staging area. However, the buffer at the staging area allowed for flexibility to bring the houses once the sites were ready. It also helped keep the onsite assembly process organized as a lot of homes were being set in a short amount of time. The last flow is the onsite assembly of the home to be move in ready.



Units: completed volumetric unit (module)
Alternate route: Factory to San Diego to Maui on “liner” (4 homes)

Figure 10: Flow and Buffer Model of the Kilohana Homes Supply Chain

4.1.8.1 Main Takeaway

Federal, state, and local governments, Dynamic, and their subcontractors collaborated to successfully deliver an innovative solution to improve the lives of survivors and help communities rebuild their community for the long-term. All parties had to take risks to make this project possible, which all paid off in the end.

4.2 Case 2: Reframe Systems

This case study describes Reframe Systems located in Massachusetts. The sections below describe the purpose and scope of the case study, targeted housing demand, key stakeholders, and the process for developing and delivering the housing units: preconstruction activities including design and material sourcing, followed by the manufacturing, transportation, and onsite assembly of units.

4.2.1 Purpose and Scope

The purpose of this case study is to document and analyze Reframe Systems' off-site construction process, particularly its microfactory approach, and assess its potential for scalability in disaster recovery settings. The scope includes a close look at Reframe's design, procurement, manufacturing, and onsite assembly steps, as well as how these steps might integrate with broader disaster-housing solutions.

4.2.2 Housing Demand

The U.S. housing market faces multiple pressure points: an ongoing shortage of affordable units, a skilled labor deficit that inflates construction costs, and the urgent need to reduce the built environment's carbon footprint, which currently accounts for over 40% of global emissions (Reframe Systems, 2025). In particular, the "missing middle" segment between single-family homes and large apartment complexes remains underserved, despite strong demand for smaller multifamily formats.

These structural constraints grow sharper after major disasters. Storm damage removes a share of already limited housing stock while labor and materials shift to emergency work. Longitudinal studies of Hurricane Andrew and Hurricane Ike show that even four years after landfall many neighborhoods had not regained their pre-storm housing value, with recovery lagging farthest in lower income communities and in rental units (Peacock et al., 2014). Disasters therefore magnify shortages, widen inequities, and lengthen the time that families wait for safe housing, all factors that reinforce the need for faster, scalable construction methods.

At the same time, traditional construction practices are labor-intensive and often limited in throughput, making it difficult to rapidly scale production of homes, especially net-zero or high-performance homes. Although modular and prefab solutions can shorten build times, high capital expenses and rigid production lines have historically constrained the reach of large, centralized factories.

4.2.3 Reframe Solution Overview

Reframe Systems proposes to meet those demands by replacing the one-big-factory model of off-site construction with a distributed network of compact microfactories (Karasin, 2023). Each 17- to 50-thousand-square-foot plant is designed to open in roughly three months for about USD $5 million, an order of magnitude faster, and far cheaper, than a conventional modular plant (Karasin, 2023). Although only one pilot facility is now running in Massachusetts, Reframe's roadmap calls for dozens more, aiming for "one microfactory for every four Home Depot stores in a region" (Castenson, 2024).

Traditional modular and prefab solutions do shorten build times, but their high capital costs and rigid production lines have limited their reach, especially when acute housing needs spike after a disaster. By contrast, Reframe's approach would allow them to position microfactories close to demand surges, whether chronic shortages or sudden catastrophes, so that walls, floors, and roof cassettes roll out near the job site rather than crossing the country on flatbeds.

Inside each plant, Reframe plans several linked process innovations. Walls are framed vertically, eliminating expensive flipping tables and shrinking the production footprint (Tinelli, 2024). Every stud, plate, and panel are inkjet printed with alignment marks and QR codes before it reaches the line; as components move through work cells, LED "pick-to-light" prompts and quick scans tell semi-skilled workers exactly where to drive screws or drill conduit holes for plumbing and electrical runs (Tinelli, 2024). These dual cues minimize training time and rework.

The floor is tied together by a software-defined workflow built on Tulip's industrial operations platform (Digital Guidance, 2025). When an architect changes a window size or a municipality adds a hurricane-strap requirement, the updated BIM model propagates instantly to scanners, sensors, and on-screen instructions, without pausing production. Because work cells are small (≈ 500 sq ft) and reprogrammable, a microfactory can pivot from a two-story duplex to a single-story ADA-accessible unit within a shift (Zivid, 2024).

Although these capabilities remain at the pilot stage, the intended impact is clear: by launching microfactories near demand spikes, whether chronic shortages or sudden disasters, Reframe aims to deliver net zero ready, code compliant homes weeks or months sooner than the current construction pipeline allows. Local production shortens haul distances, trims travel time for both materials and finished assemblies, lowers transport emissions, and relies on a smaller, less specialized labor pool. If the expansion plan succeeds, communities recovering from catastrophe could rebuild faster and at the same time leapfrog toward a more resilient, low carbon housing stock instead of merely replacing what was lost.

4.2.4 Key Stakeholders

Below are the key stakeholders who we propose would be involved in delivering a solution by Reframe systems in a post-disaster context.

- Reframe Systems: A Massachusetts-based startup founded by former Amazon Robotics engineers.
- Local Governments and Emergency Agencies: Entities like state governments, FEMA, and municipalities that coordinate post-disaster housing.
- Community and Displaced Residents: Those in need of safe, permanent housing after a disaster.
- Local Workforce and Suppliers: Regional labor pools, building materials suppliers, and potential partners for microfactory deployment.
- Financial Stakeholders: Investors, insurance companies, and philanthropic organizations interested in reducing the financial impact of disaster recovery.

4.2.5 Preconstruction Activities

This section explains every step Reframe must complete before a finished volumetric module rolls out of the microfactory gate. It covers how digital designs are converted to machine instructions, how materials and equipment are procured, and what site and permitting actions are needed to launch a microfactory in a disaster area. The description is based on our April 2025 tour of Reframe's pilot facility in Massachusetts, where we observed vertical framing, robotic cells, and the plant wide digital workflow.

4.2.5.1 Design, Procurement, and Other Preparations

Reframe's process begins with a digital integration of architectural design and manufacturing. Architects and engineers feed 3D models into Reframe's proprietary software, which automatically generates instructions for computer numerical control (CNC) machines and robotic arms. During our tour, Reframe staff demonstrated how new designs can be rapidly prototyped with minimal downtime, showing that the system can handle a high mix of different home layouts and finishes while still maintaining high volume output.

Procurement involves standard materials (dimensional lumber, drywall, windows, etc.) sourced from local or regional suppliers (Castenson, 2024). This availability of widely used inputs helps keep costs predictable and streamlines logistics. Prior to setting up a microfactory in a disaster zone, Reframe would need to:

- Secure suitable land (roughly 17,000–50,000 sq. ft. of industrial space).
- Acquire or lease the necessary robotics and CNC equipment (approximately USD $1 million in capital per microfactory).
- Coordinate local building code reviews and secure relevant permits, ideally with support from local authorities.

Reframe staff noted during 2025 site visit that the robotic assets are modular. A robotic arm can be removed from one facility, transported, and fully operational in a new microfactory within about one week, allowing capacity to shift quickly as demand changes (Reframe Systems staff, personal communication, 2025).

4.2.6 Manufacturing

This section describes Reframe's manufacturing process. Table 1 summarizes each of the elements of the manufacturing process covered in the subsections below, including what the element is, what changes compared to a more traditional off-site construction manufacturing process, and the primary benefit of the manufacturing element.

Table 1: Automation elements of the manufacturing process

Element of Manufacturing Process	**Core Idea**	**What It Changes**	**Primary Benefit**
4.2.6.1 Vertical Framing	Build walls upright from the start (no "butterfly" flipping tables).	Shrinks equipment footprint and capital outlay; easier to integrate LED guidance at standing height.	Cut factory setup cost/time; faster, safer wall assembly.
4.2.6.2 Light-Guided Assembly	Amazon-style pick-to-light LEDs and on-screen prompts direct each task.	Lowers skill barrier; slashes assembly errors and training time (60 % apprentices succeeded with minimal rework).	Rapid workforce onboarding—vital after disasters; more consistent quality.
4.2.6.3 Digital Integration / Tulip	Architectural model feeds real-time work instructions, scanners, sensors, QC data.	"Software-defined" work cells (≈ 500 sq ft) can be reprogrammed instantly for code or design changes.	Near-zero downtime for modifications; continuous feedback loop drives kaizen.

Reframe's manufacturing approach, when scaled, would center on a network of microfactories. At scale, each compact facility is equipped with software-guided work cells and semi-automated stations, rather than a traditional large assembly line. Rather than relying on a single enormous factory, Reframe's model allows multiple microfactories to be deployed regionally, which could reduce lead times for local demand. Critically, a microfactory can become operational in a few months, significantly faster than the 2–3 years often required to build a conventional modular construction factory (Karasin, 2023). For example, Reframe's first 17,000-square-foot microfactory was established in about three months and cost approximately USD $5 million to set up, whereas a typical large factory could require tens of millions (Karasin, 2023).

From a value-stream perspective, Reframe's process stream begins with in-house design and engineering, which feed directly into the microfactory's production cells. Semi-automated stations, some assisted by robotics and guided by real-time software updates, handle critical tasks such as framing, sheathing, and even specialized functions like plumbing layouts. Finished modules or assemblies then undergo quality checks before being shipped for onsite installation. By synchronizing design, manufacturing, and installation in one continuous workflow, Reframe compresses the time from architectural concept to completed home. This integration (sometimes called "software-defined manufacturing") helps drive down capital costs, minimize wasted materials, and ensure that even changes in building codes or regional design preferences can be accommodated swiftly.

Figure 11 below presents the end-to-end production flow inside a Reframe microfactory. It serves two purposes. First, it gives the reader a top-level map of every station that a volumetric module passes through, from raw-material receipt to finished unit staging. Second, it shows how the three innovations discussed in the subsections that follow, vertical framing, light-guided assembly, and software-defined production, fit within that broader sequence. Briefly, the steps are:

- Material receiving and kitting. Parts arrive, are scanned into inventory, and are staged in pick-to-light carts.
- CNC cutting and component fabrication. Robotic saws and routers cut studs, plates, and sheathing to exact length.
- Vertical framing cell. Walls are assembled upright in their final orientation.
- Sheathing and fastening. Panels are applied and fastened while the wall is still vertical.
- MEP prefab, Major mechanical, electrical, and plumbing runs are pre-installed in an indoor bay.
- Module or panel assembly. Walls, floors, and roof cassettes are joined into a sealed module.
- Window and door installation. Openings are glazed and weather-stripped.

- Interior and exterior pre-finishes. Drywall, insulation, and cladding are added where possible.
- In-line quality scan. Vision systems and barcode checks confirm tolerances and material traceability.
- Packaging and staging. Completed modules are wrapped, labeled, and queued for short-haul delivery.

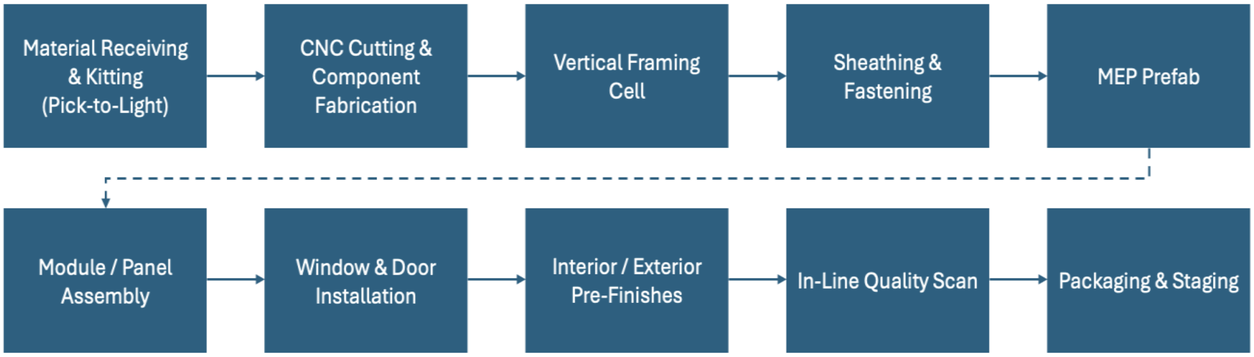


Figure 11: Reframe microfactory production flow, from material receiving to packaging. (Source: Authors, adapted from Reframe Systems 2025)

The following sections describe the key elements of Reframe's manufacturing process in more detail.

4.2.6.1 Vertical Framing

One of Reframe's most distinctive innovations is vertical framing, shown in Figure 12, which challenges the conventional practice of building walls horizontally on large framing tables. In a typical modular factory, substantial equipment is used to flip completed wall panels upright, an expensive and space-intensive process. By contrast, Reframe eliminates the flipping altogether by framing walls in the orientation they will ultimately occupy (Tinelli, 2024). This change reduces the capital expense of specialized "butterfly tables" or overhead cranes, and it allows the manufacturing footprint to remain smaller, one reason Reframe can set up "microfactories" more quickly and cost-effectively.

Figure 12: Robotic arm assembling a wall panel in the upright position at Reframe's Massachusetts pilot microfactory. Source: Authors, photograph taken 2025.

In practice, vertical framing also facilitates easier incorporation of software-driven instructions or "pick-to-light" systems (described in the following section), since workers are assembling each wall at a standing height and can follow on-screen or LED-guided prompts without flipping heavy panels. Overall, this seemingly simple shift in orientation highlights Reframe's core philosophy: rethinking every traditional step of modular construction to eliminate unnecessary complexity and align the physical build process with the final outcome.

4.2.6.2 Light-Guided Assembly

Figure 13 shows Reframe's adaptation of the Amazon style pick to light system for construction tasks. At each workstation LED indicators flash on the bin holding the correct fastener, bracket, or pipe fitting, while the tablet above displays the step-by-step instruction. The lights then guide the operator to the exact spot on the upright wall where the part must be installed (Tinelli, 2024). This method cuts errors, shortens training, and reduces reliance on licensed trades. In an early pilot 60% of the build crew were apprentices yet still completed plumbing and electrical tasks with minimal rework (Tinelli, 2024). Lowering the skill threshold is valuable after a disaster, when experienced labor may be scarce or displaced.

Figure 13: Pick to light cart with tablet-based work instructions at Reframe's pilot microfactory. Source: Authors, photograph taken 2025.

Figure 14 illustrates how Reframe complements the pick to light workstations with laser printed alignment marks and QR codes on every stud, plate, and sheathing sheet. The inked icons show operators exactly where to drive screws, cut openings, or drill conduit holes, and a quick scan of the QR code confirms that the correct part is in position. This dual cue system removes tape measure layout, keeps tolerances tight, and lets semi-skilled apprentices perform electrical and plumbing tasks with confidence and minimal rework.

Figure 14: Wall studs preprinted with alignment lines and QR codes ready for assembly at Reframe's pilot microfactory. Source: Authors, photograph taken 2025.

Each of these innovations serves to expand the labor pool available to Reframe, save time in their process, and reduce rework.

4.2.6.3 Digital Integration with Tulip and "Software-Defined" Production

Reframe integrates its digital design environment with the shop floor via Tulip's industrial operations platform. The platform links architectural models to real-time manufacturing instructions, which operators access through tablets or displays (Tinelli, 2024). Tulip also manages pick-to-light hardware, barcode scanners, and sensors to confirm that each part is correctly placed (Digital Guidance, 2025). This closed-loop system generates continuous feedback on cycle times, defect rates, and production bottlenecks, allowing supervisors to refine workflows dynamically.

Crucially, this level of digital linkage means that each microfactory's production cells, roughly 500 square feet apiece, can be reprogrammed or reconfigured with minimal downtime. Design modifications (e.g., adding hurricane tie-downs or switching to fire-resistant siding) automatically update the work instructions without halting production (Karasin, 2023). By uniting design, production, and quality control in one digital ecosystem, Reframe achieves a "software-defined" manufacturing process that is both flexible and precise.

4.2.6.4 Advantages of the Manufacturing Workflow

These combined innovations significantly shorten production time and boost consistency. Tasks typically done sequentially by onsite subcontractors are converged into a streamlined, parallel process in the microfactory. Reframe aims to assemble a volumetric module in under four hours, much faster than the 12–14 days often needed in traditional prefab methods (Karasin, 2023). This accelerated cycle time is critical when entire communities need rapid housing recovery. Moreover, the controlled factory environment improves quality by standardizing components, reducing errors, and minimizing the rework often required in site-built construction. From a training standpoint, operators continually learn and improve through immediate digital feedback, and the skills they gain have broader applicability to advanced manufacturing settings.

4.2.7 Transportation

Reframe's regional microfactories reshape transportation logistics for modular homes, an advantage particularly relevant in disaster scenarios. Traditional off-site construction typically involves hauling large volumetric modules, 12 to 16 feet wide and requiring special permits, across state lines (Manufactured Housing and Mobile Homes Transport, 2025). Such oversized loads are subject to restricted routes, escort vehicles, daytime-only travel, and varying regulations in each jurisdiction. This coordination can be costly, slow, and complex, especially when roads or bridges are damaged by a disaster.

4.2.7.1 Materials vs. Finished Units

Reframe's model focuses on transporting raw materials (e.g., lumber, drywall, connectors) to the microfactory closest to the housing demand rather than shipping finished modules from a distant plant. Bulk materials can be flat-packed or palletized for standard freight trucks, avoiding the constraints of oversize loads. One truckload can often supply multiple homes because it does not carry "empty interior space," as is the case with volumetric modules (Manufactured Housing and Mobile Homes Transport, 2025). This efficiency is vital in situations where infrastructure is compromised, allowing deliveries to be split into multiple smaller shipments if necessary.

4.2.7.2 Localized Codes and Regulations

Placing a microfactory inside the disaster state offers two practical advantages. First, it taps carpenters, inspectors, and code officials who already understand local amendments and inspection routines, reducing rework and shortening field approvals. Second, it trims the distance that oversized volumetric modules must travel, cutting the number of state lines crossed and the array of permits, escorts, and curfews each jurisdiction requires, factors that routinely add fees and delays to out-of-state shipments (Unlocking Housing Production Commission, 2025).

4.2.7.3 Just-in-Time Delivery and Flexibility

Because production occurs close to the final assembly site, completed modules can be delivered on-demand with minimal staging. This short-haul approach reduces the risk of damage or theft that can occur when homes are stored off-site for extended periods. Should a last-minute design tweak be needed, such as a different roofing material for better storm resilience, the microfactory can rapidly implement the change without incurring substantial logistical delays.

4.2.7.4 Context-Specific Adaptations

Most off-site builders say they can engineer modules for any state or local code, so that claim isn’t unique to Reframe. The edge of a nearby microfactory is speed of coordination. Local officials, trades, and residents can walk the plant, approve a fire-rated siding detail, or request a higher finished-floor in a flood zone, and those changes go straight into Tulip’s live work instructions the same day (Zivid, 2024). Short hauls then move finished units without oversize permits or long delays. The real gain is a tighter feedback loop, fewer calls, faster signoffs, quicker keys-in-hand.

4.2.8 Onsite Assembly

Once Reframe’s modules arrive onsite, final assembly is designed to be straightforward. The same digital tools that guide production also assist local contractors or Reframe personnel in stacking and sealing modules. In a post-disaster setting, these modules can be tailored to meet:

- Local Structural Requirements: For instance, hurricane-rated roofs or wildfire-resistant siding.
- Local Aesthetics and Zoning: Exterior finishes and layouts that fit regional styles.
- Speed of Deployment: Permanent housing that can be stood up more quickly than traditional site-built options.

4.2.9 Scalability

Reframe’s microfactory model is designed for incremental expansion. Because each 17- to 50-thousand-square-foot facility can be launched in roughly three months for about $5 million, capacity can be added quickly and strategically across the United States. During a recent factory visit, the Reframe team noted an ambition of one microfactory for every four Home Depot stores in a region, placing production close to major suppliers and pockets of construction demand while sharply reducing haul distance to job sites.

Distributing many microfactories rather than anchoring on a single mega-facility lets Reframe match output to demand in real time. Local plants can coordinate and ramp up capacity when wildfires, hurricanes, or market booms create sudden spikes in housing need, then taper back when demand normalizes. Each small footprint also lowers capital at risk; if one site underperforms, the broader network continues operating without a crippling hit.

By deploying software-guided, light-guided, digitally integrated microfactories near end users, Reframe scales production rapidly yet remains agile to local codes, environmental hazards, and market pressures, delivering a flexible, high-throughput system that reduces reliance on specialist labor, enables on-the-fly design changes, and accelerates both disaster recovery and long-term community resilience.

4.2.10 Conclusion

Figure 15 below summarizes Reframe’s end-to-end supply chain**.** The arrows trace a home from digital design through procurement, microfactory production, quality checks, and finally onsite assembly. This overview reinforces the case’s main point: Reframe integrates supply-chain thinking with construction practice to shorten lead times after a disaster.

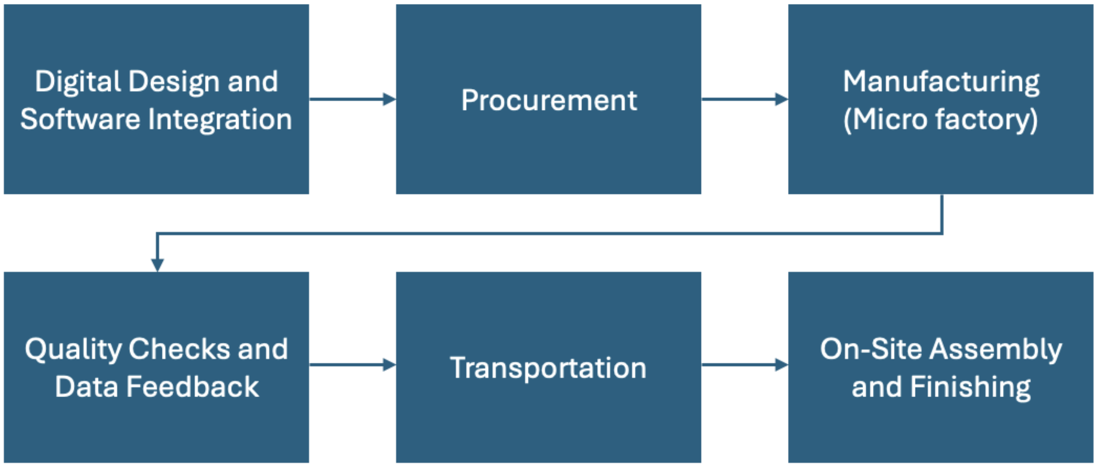


Figure 15: Reframe delivery chain from digital design to onsite finishing.

Reframe Systems offers a disruptive model for off-site construction. Its microfactories, robotics, and integrated software can deliver code-compliant, energy-efficient homes within three months of securing a site (Castenson, 2024). That speed makes the approach attractive for disaster-stricken regions, where time and resources are scarce.

Key Challenges:

- Setup time: Even three months can feel slow for families that need shelter immediately; pairing Reframe units with interim solutions is prudent.
- Workforce: Automated cells still require technicians, so local labor must be trained and certified.
- Permitting: Zoning and building approvals must move as fast as the factory schedule.

Policy support, public–private partnerships, and streamlined permitting can remove these constraints. If that occurs, Reframe's microfactory network can narrow the gap between disaster and permanent housing while leaving communities with upgraded construction infrastructure and a newly skilled workforce.

4.3 Case 3: come dream, come build (cdcb/Brownsville)

This case study describes come dream, come build (cdcb) organization in Brownsville, TX. The sections below describe the purpose and scope of the case study, targeted housing demand, key stakeholders, and the process for developing and delivering the housing units: preconstruction activities including design and material sourcing, followed by the manufacturing, transportation, and onsite assembly of units.

4.3.1 Purpose and Scope

The purpose of this case study is to outline the end-to-end supply chain process for community driven approach to industrialized housing construction. This case highlights a low-cost modular housing solution utilizing an unique approach to the offsite manufacturing process. The approach is currently being used to assist with increasing affordable housing supply in Texas. However, the approach will be later evaluated in the cross-case analysis on how it could be leveraged for disaster recovery housing.

4.3.2 Housing Demand

The Community Development Corporation of Brownsville, founded in 1974 for the purpose of building affordable houses in Brownsville, Texas, is better known today as cdcb, short for come dream, come build. Cdcb is a 501c(3) nonprofit community housing development organization. The mission, vision, and philosophy of the organization align around a common theme: to provide affordable homes while giving the homeowner choices about the look and feel of their home, which cdcb believes is the key to equity. The cdcb website states that “choice empowers” meaning that communities and residents who have agency and control over their homes feel as they have power to make their communities better. Cdcb has served over 1,600 families and over 150 people have graduated from their YouthBuild job training program (Community Development Corporation of Brownsville, n.d.).

Cdcb also has experience with disaster recovery efforts. Hurricane Dolly hit the area in 2008 and created an urgent need for housing in an already economically “at risk” community. This is where RAPIDO, or the Lower Rio Grande Rapid Recovery Re-Housing Program comes in. Cdcb together with several partners, created the program with the goal of getting families in a home in four to six months, providing a core living structure that a family can then add on to (NeighborWorks America, 2017). For disaster survivors and the communities impacted by Hurricane Dolly, RAPIDO offered a new approach to disaster recovery. This program focused on the importance of pre-planning for disasters and created a unique design with the core living structure to serve both short and long-term housing needs for disaster survivors (RAPIDO Recovery, n.d.). In addition to the work related to RAPIDO, cdcb has ongoing affordable and disaster-related housing to build. This case study will focus on the current cdcb affordable housing manufacturing process and how it could respond to disaster housing demand.

4.3.3 Key Stakeholders

The central stakeholder in the cdcb process is the homeowners and residents living in the homes. The families in cdcb’s target market live in or near Brownsville, Texas and are often actively in the workforce but may have low wages or wages that don’t cover their needs. This results in some people working multiple jobs to make ends meet. This is why providing affordable housing is crucial. These families may also have a hard time saving up for emergency funds in times of disasters, so they are also adversely affected by natural disasters that hit the area.

Cdcb works with local, state, and federal governments to collaborate and provide services such as down payment assistance. Cdcb plays a part in developing and growing the Brownsville community so they must coordinate with local and state governments, other key stakeholders, to be successful in their efforts. They also help shape policy improvements to fix issues facing low-income families living in their area (Community Development Corporation of Brownsville, n.d.).

4.3.4 Design

As discussed, the power of choice and empowering their homeowners to make them is of critical importance to cdcb. This empowerment starts with the design process where those building a new home can choose among various finishing options to customize their homes. There are 24 finishing choices including siding, flooring, kitchen & bathroom finishes, porches, lighting, etc. However, the floor plan of the home stays relatively standard as homes are 3 bedrooms with 2 bathrooms and 1,152 square feet. They are designed to be four modules that are built offsite and then delivered to the housing site for onsite assembly. The standardization of floorplans also allows for procurement efficiencies which will be discussed in the following section.

4.3.5 Material Sourcing

The homes are made to order so much of the procurement process is project specific as cdcb must order the correct finishing options selected during the design process. Cdcb typically holds project specific inventory for only the ongoing projects plus one future project to ensure they are not space constrained. However, they can hold general inventory needed for all projects such as nails, screws, certain types of lumber, etc. While there are some efficiencies for bulk orders in terms of delivery costs, bulk orders typically increase high holding costs such that they negate the delivery cost savings. The typical lead time for raw materials is 35 to 40 days.

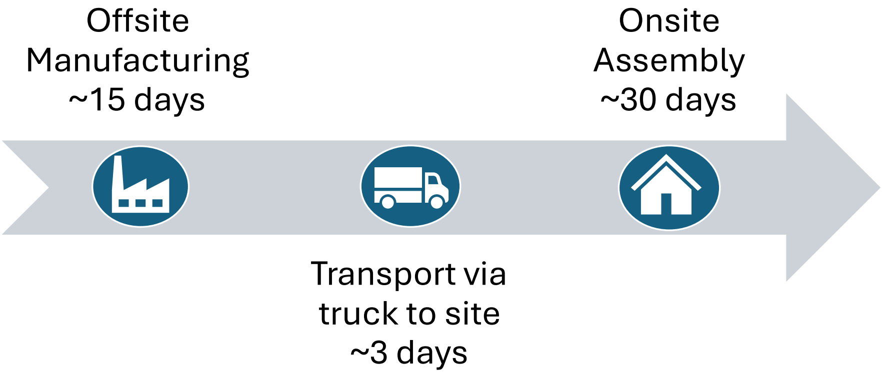


Figure 16: cdcb's construction timeline takes approximately 45 days from beginning to end

4.3.6 Manufacturing

Figure 16 above provides a high-level description of the construction process for a cdcb home. The process begins with the offsite manufacturing of the modules once the raw materials have been sourced and delivered. This process takes place in what cdcb refers to as the "farm," a 7,000 square foot pavilion as pictured in Figure 17.

Figure 17: Photos of the cdcb "farm" Source: (Treviño, 2024)

Three homes (or twelve modules) can be in construction at one time in the pavilion, with each taking on average 15 days to complete. There are 35 technicians employed who cover various job functions including framers, plumbers, roofers, electricians, carpenters, painters, warehouse technicians, and movers. Each home is constructed in four separate modules which remain stationary in the farm and teams of the technicians rotate to the different modules to do the work. Therefore, people move, but the product does not which allows cdcb to operate a much smaller space than other modular housing manufacturers.

Figure 18 outlines the thirteen steps in cdcb's manufacturing process flow. The longest step is the exterior wall framing which takes approximately 17 hours followed by the Dry-In and Systems Checking processes. Once all the steps are completed, the homes are ready to be shipped to the home site which is being prepped in parallel to the offsite construction and completed prior to the modules leaving the farm. Site prep is out of scope for this case study. However, cdcb subcontracts this process.

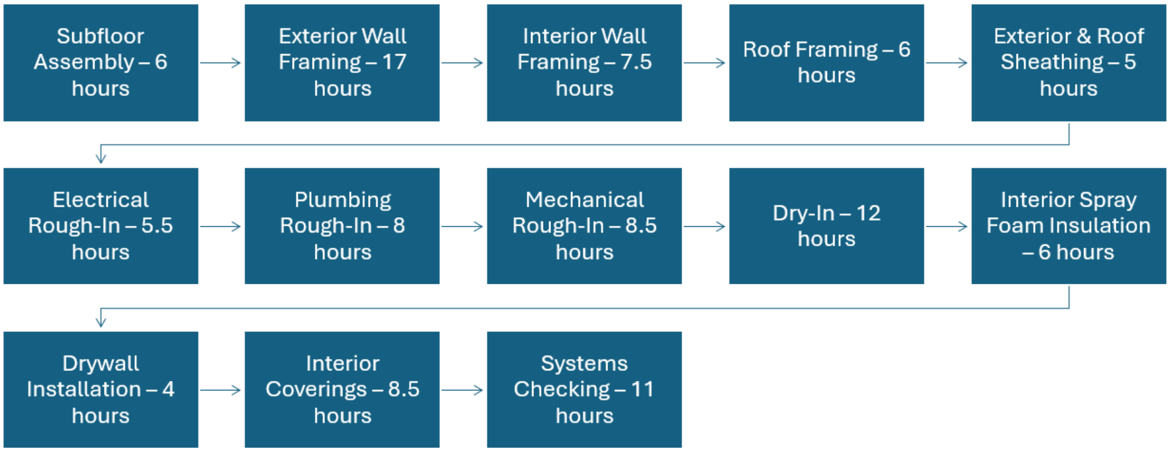


Figure 18: Process map of the cdcb offsite manufacturing process

4.3.7 Transportation

Once modules are completed on the farm, they are shipped via truck, specifically diesel F150 trucks and trailers. The modules are sized so that they are not considered oversized loads which simplifies the transportation process. On average, home sites are about 15 miles away from the farm, but they can be shipped up to 120 miles away. It takes approximately 3 days to get all four modules to the site for onsite assembly. When possible, cdcb handles transportation with their own resources, but will outsource if they need extra capacity. The transportation requires seven people, but no crane is needed for the process. Instead, they use a mule (hybrid forklift) to load modules on to the truck and set them in place onsite. The modules are on skates with breaks for ease of moving them. The longest part of the process is positioning the diesel trucks for drop off at the site.

4.3.8 Onsite Assembly

After the modules arrive onsite, they are locked and sealed into place and the onsite assembly can begin. Cdcb oversees this process and dispatches their workforce to each site. Onsite assembly takes 25-30 days to complete and includes utility connections and interior/exterior finishes. Mechanical, electrical, and plumbing must all be tied into the local utilities on site and verified that they’re working properly. Interior onsite assembly includes installing flooring, trim/interior doors, plumbing fixtures, countertops, and electrical fixtures. It also includes finishing final coats of paint and interior caulking and sealing. Exterior onsite assembly includes constructing porches & exterior stairs, installing siding and roofing, and applying a final coat of exterior paint. Lastly, exterior caulking and sealing is completed. There is a final inspection for all interior and exterior specifications to ensure it meets the project requirements, and then the home is ready for move in.

4.3.9 Conclusion

A high-level construction timeline for each cdcb home is depicted in Figure 16 along with the approximate number of business days needed for each step. The whole process takes on average about two and a half months. The expedited timeline, efficient manufacturing process, and low-cost raw materials keep the homes cost competitive for families. The cdcb team constantly looks for process improvements using a first principle approach to drive down prices and speed up construction to reduce this timeline. For example, the team identifies certain processes within the manufacturing procedure that can be either eliminated or standardized. One example is expanding the current cut station into a full sub-assembly station to increase efficiency.

Although this approach is currently used to provide affordable housing, it can also be considered for disaster recovery housing. The process has low start up barriers and costs, is light on specialized equipment or capital assets, and does not require vast amounts of resources like labor which can be scarce after disasters.

5 RESULTS AND DISCUSSION

In this section, the benefits and challenges of using industrialized housing for disaster recovery are discussed in detail. It also contains a cross-case analysis of the Kilohana, Reframe, and cdcb case studies which are found in section 4 of this capstone. The cross-case analysis explores four aspects of the cases: procurement, manufacturing, automation, and transportation. This section ends with best practices and shared challenges.

5.1 Benefits and Challenges of Industrialized Housing Construction for Post-Disaster Housing Recovery

Through the research conducted for this capstone, several key themes have emerged regarding the benefits and challenges of using industrialized housing construction for post-disaster housing recovery (Figure 19). Industrialized housing solutions offer several advantages, including accelerating the construction process, reducing the reliance on local skilled labor, and lowering barriers to workforce training. However, there are also some challenges such as transporting volumetric homes, large order quantities, accommodating a patchwork of local building codes, and delays associated with onsite assembly and inspections.

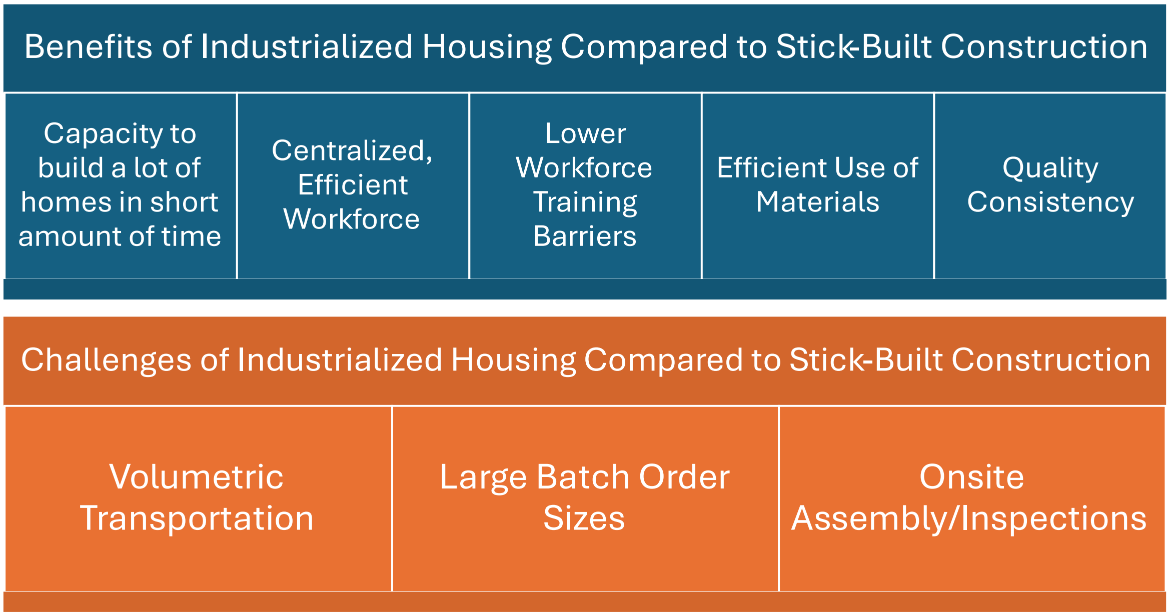


Figure 19: Key Benefits and Challenges of Industrialized Housing Compared to Stick-Built

As demonstrated in our case studies, offsite construction enables the production of many homes in a much shorter time compared to traditional onsite building methods. For example, in the Kilohana case, the housing provider was able to produce 107 homes in just four months — a pace significantly faster than conventional onsite construction, where completing a single home can take several months. This expedited timeline is achieved by standardizing the manufacturing process and allowing site preparation to occur simultaneously with offsite construction of the unit. The shorter timeline also means disaster survivors have a safe space to call home sooner.

Another advantage of industrialized construction is the ability to centralize the workforce in a controlled environment. Instead of workers traveling to multiple home sites, skilled laborers remain in one location, working on several homes each day. This setup not only increases workforce efficiency but also provides a safe, stable environment for workers — a critical need after natural disasters when rebuilding efforts must be both rapid and coordinated.

Finally, the factory setting lowers the training barrier for new construction workers. In an industrialized manufacturing environment, workers can be assigned to specific stations or tasks, similar to traditional assembly lines, allowing them to quickly gain experience and develop new skills. Additionally, the high volume of homes being built enables workers to hone their abilities in a relatively short period. As we will discuss further in the cross-case analysis (section 5.2), Reframe Systems exemplifies this approach by using innovative automation technologies, such as the light-guided assembly, to streamline training and lower skill requirements even further.

In addition to these advantages, using offsite construction for housing recovery also presents several challenges. One notable challenge is the transportation of homes from the factory to the final assembly site. Depending on the size of the modules, oversized load transportation may be necessary. This introduces additional complexity, as regulations for oversized loads vary from state to state, creating potential hurdles when transporting homes across state lines. Typically, oversized shipments require pilot cars to escort trucks, adding both cost and logistical coordination. Furthermore, shipping volumetric homes is inherently expensive because it involves transporting a significant amount of empty space — something transportation professionals generally seek to avoid. Finally, access to disaster damaged areas may be limited and unable to accommodate the trucks or equipment needed to set the home on its foundation.

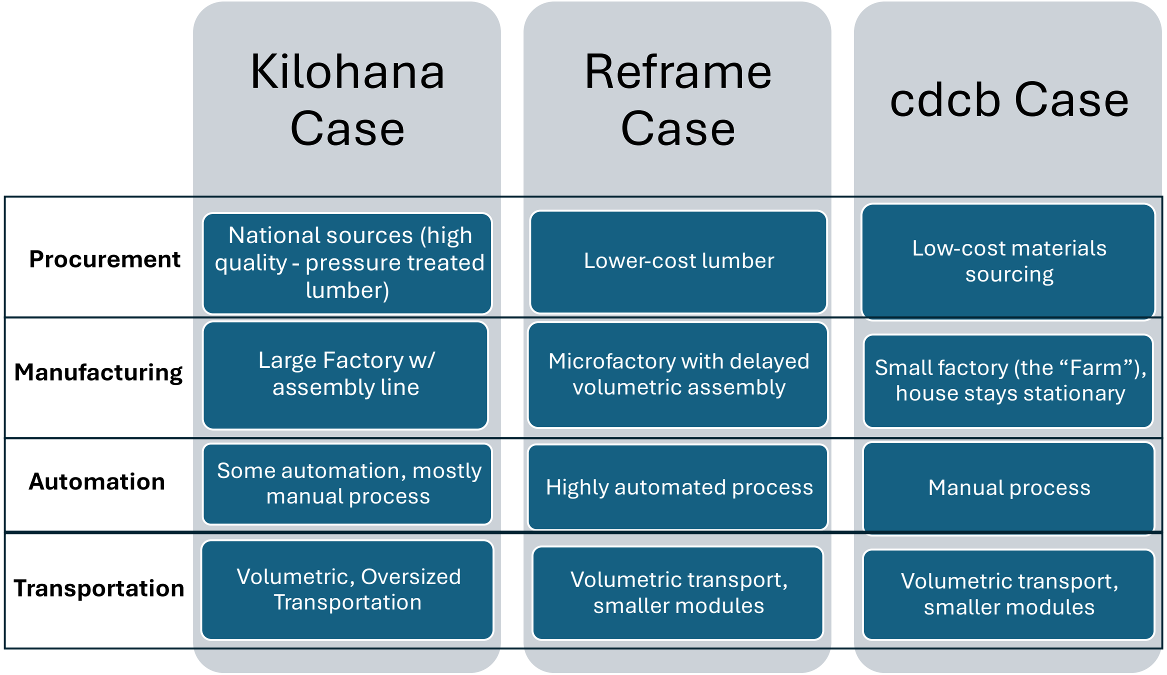
There are several potential solutions to mitigate these transportation challenges. These include using panelized (flat-pack) systems, reducing the size of modules to avoid oversized load requirements, and locating factories closer to the build sites to minimize transportation distances and costs.

Another challenge of using industrialized construction is the large order sizes typically associated with group housing sites after disasters. Factories may struggle to schedule and fulfill these large orders while continuing to serve their regular customers. If standard customers experience delays or service disruptions, they may turn to alternative manufacturers, potentially harming long-term business relationships and the ability of a factory to remain in business after a disaster order has been completed. This risk, however, can be reduced through collaboration between multiple factories to spread production of large orders or through proactive production scheduling by manufacturers.

Finally, variations in building codes across states and local municipalities create complications for offsite construction. These differences can impact inspection schedules and onsite assembly processes. While this challenge is critical to address for the broader success of offsite housing recovery, it falls outside the scope of this capstone.

5.2 Cross Case Analysis

The case studies of Kilohana, Reframe, and cdcb offer valuable insights into different approaches to industrialized housing that could be leveraged for disaster recovery. Each case represents a distinct model with unique trade-offs. The following analysis compares these three cases across key dimensions of the housing supply chain: Procurement, Manufacturing, Automation, and Transportation (Figure 20).



	Kilohana Case	Reframe Case	cdcb Case
Procurement	National sources (high quality - pressure treated lumber)	Lower-cost lumber	Low-cost materials sourcing
Manufacturing	Large Factory w/ assembly line	Microfactory with delayed volumetric assembly	Small factory (the "Farm"), house stays stationary
Automation	Some automation, mostly manual process	Highly automated process	Manual process
Transportation	Volumetric, Oversized Transportation	Volumetric transport, smaller modules	Volumetric transport, smaller modules

Figure 20: Cross Case analysis evaluating four aspects: procurement, manufacturing, automation, and transportation

5.2.1 Procurement

All three models employ make-to-order manufacturing, which reduces the need for extensive raw material inventories. However, this approach can pose procurement challenges when large, urgent orders require specific materials, as demonstrated in the Kilohana case, where sourcing sufficient pressure-treated lumber strained production timelines. Notably, the Kilohana site's manufacturer had to engage multiple national suppliers to meet material requirements, whereas the Reframe and cdcb models prioritized sourcing lower-cost lumber from regional suppliers. Across all cases, balancing inventory costs against material lead times is critical—particularly in disaster response scenarios.

A surprising finding across the case studies was the limited impact of economies of scale. Initially, the capstone team anticipated that consolidating orders for multiple homes would yield significant cost savings. While some efficiencies were realized in delivery and ordering, industrialized home manufacturers did not experience substantial price reductions for large order quantities. In fact, in Maui, the large order of pressure-treated lumber added complexity to the procurement process. This is an important consideration when designing homes for post-disaster recovery efforts. Another challenge with procurement is the limited space available to store large quantities of raw materials. This limits how much inventory can be ordered so it’s helpful to segment materials between general parts and project specific raw materials. By engaging in segmentation and only buying the general parts in bulk, the factories are ensuring that they can be used in a future project if they’re not used right away to ensure they do not go to waste.

5.2.2 Manufacturing

As discussed previously, all three approaches significantly reduce construction timelines compared to traditional methods, with total project durations ranging from two to three months versus eight to eleven months for conventional building. The average offsite construction duration per home is shown by case in Figure 21. Each model demonstrates the ability to produce multiple homes simultaneously, increasing throughput during critical recovery periods. Additionally, all benefit from concentrating on the workforce in controlled environments, minimizing weather-related delays and improving quality control. However, process flow varies substantially among the models: Kilohana operates a large factory with 18 assembly stations along a traditional production line; Reframe uses a microfactory with highly automated processes, where wall, floor, and ceiling panels move through production stations before full home assembly at the final step; meanwhile, cdcb keeps modules stationary at "The Farm," with workers rotating around them.

Workforce requirements also differ significantly. cdcb runs its operations with 35 technicians in a 7,000-square-foot pavilion. Kilohana’s manufacturer employs approximately 125 people in a 110,000-square-foot facility. Reframe’s higher level of automation reduces labor needs but demands greater technical skills from its workforce.

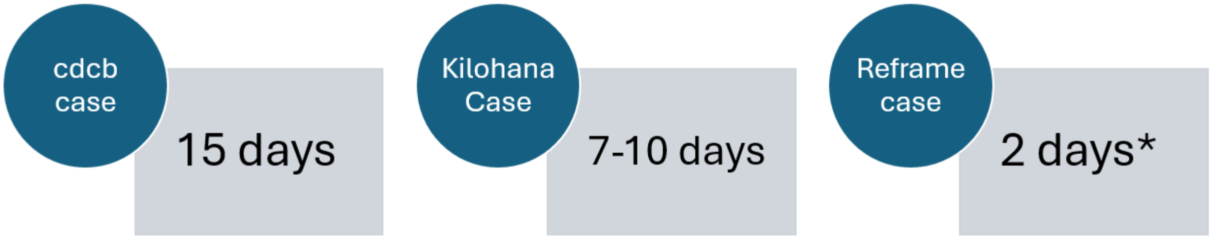


Figure 21: Offsite construction time to build one home

**Reframe aims to build one module in 4 hours. Assuming 4 modules for one home like cdcb*

5.2.3 Automation

The level of automation across the three models also spans a wide spectrum. The cdcb initiative relies primarily on manual processes. Their focus is on standardizing and eliminating unnecessary steps to make the process more efficient before investing in any automation. The Fading West facility from the Kilohana Case incorporates moderate automation, such as CAD-based laser marking systems. In contrast, Reframe is highly automated, utilizing robotics, light-guided assembly, and digital integration through Tulip's manufacturing platform. Their extensive use of automation allows them to operate in a smaller factory and lowers the barrier for some workforce training.

5.2.4 Transportation

All models encounter challenges in transporting completed housing modules to their final sites, with scheduling and coordination emerging as critical logistics hurdles across all three approaches. However, key differences exist in delivery distance, module sizing, and transportation methods.

The cdcb model typically transports modules on average of 15 miles, with a maximum distance of 120 miles. Similarly, Reframe Systems emphasizes a local microfactory approach minimizing transportation to a 50-mile radius. In contrast, the Kilohana Group Site presented a much greater logistical challenge, with modules constructed in Buena Vista, Colorado, and transported thousands of miles to Maui.

Module size also significantly influences transportation strategies. Both cdcb and Reframe design their modules to stay within standard size limits, avoiding the need for oversized load permits and enabling more flexible transport options. cdcb, for example, uses F-150 trucks with trailers and requires only a hybrid forklift for loading and unloading. By comparison, Kilohana's modules exceeded standard size limits, requiring oversized-load trucks escorted by pilot cars, as well as barges, forklifts, and cranes to complete transportation and onsite assembly. This resulted in a far more complex logistics operation.

5.2.5 Cross-Case Best Practices and Shared Challenges

The cross-case analysis revealed several key insights for disaster recovery housing. The Kilohana case demonstrates the feasibility of large-scale, long-distance deployment but also highlights the challenges associated with complex logistics chains that are vulnerable to disruption. Despite these hurdles, the parties involved succeeded in delivering and completing a large volume of homes in a short timeframe, providing families with urgently needed shelter. This case also underscored the importance of aligning disaster housing efforts with long-term recovery and affordable housing goals.

Reframe’s microfactory approach offers speed, workforce efficiency, and local adaptability, though it requires upfront setup time and investment, which may limit its practicality for immediate disaster response. However, its smaller factory footprint, minimal transportation requirements, and lower barriers to workforce training make it well-suited for rapidly scaling post-disaster operations. Meanwhile, cdcb’s low-tech, low-cost model emphasizes accessibility and flexibility with minimal capital investment, making it particularly attractive in resource-constrained environments.

These insights suggest that an ideal disaster housing strategy could integrate elements from all three models—combining Reframe’s technological innovation, Kilohana’s capacity for scale, and cdcb’s simplicity and cost-effectiveness—to create a more responsive, adaptable system for post-disaster housing recovery. For example, Reframe’s QR-coded alignment marks and tablet instructions could enable cdcb to raise throughput without enlarging its footprint, while cdcb’s low-capital pavilion offers Reframe a testbed template for resource-constrained regions. The Maui manufacturer’s (Fading West) cycle time playbook can guide both Reframe and cdcb when order spikes require higher production cadence, and Reframe’s local-sourcing model plus cdcb’s homeowner-choice finishes could help future Maui-style programs meet cultural expectations without slowing the line.

Yet each faces the same hurdles. All rely on rapidly training semi-skilled workers; Maui still needed 108 tradespeople for installation and Reframe depends on technicians to keep its robotics running. Supply chains can pinch when unique materials, such as termite-resistant lumber for Maui, are scarce, and zoning or code approvals often move slower than any factory clock, blunting the promise of rapid deployment.

Table 2 summarizes the most important process features, procurement tactics, workforce approaches and logistics models in each case, and identifies where cross-learning could yield immediate gains.

Table 2: Cross-learning opportunities

Domain	Reframe Systems	Maui Kilohana	cdcb	Cross-learning opportunity
Factory scale & layout	Microfactory 17-50 k sq ft, vertical framing, pick-to-light	110 k sq ft line with 18 stations, 2–4 homes ⁄ day	7 k sq ft farm, stationary modules, rotating crews	cdcb layout can seed Reframe pilots; Maui cycle times can guide both cdcb and Reframe when scaling
Procurement model	Local commodity inputs, keep inventory low	National sourcing	Project-specific small-lot buys to cut cash lock-up	Use regional suppliers when possible to lower cost and increase flexibility, cdcb JIT inventory lowers cash burn for all
Workforce strategy	Digital guidance allows 60 % apprentices	125 staff in factory, 108 in field, heavy trade mix	35 local technicians	Reframe guidance can upskill cdcb crews; Maui trade roster informs surge hiring plans
Transportation	Short-haul delivery within one hour of plant	Intermodal chain thousands of miles	Standard-width modules on pickup trailers, ≤ 120 mi	Narrower modules or flat-pack kits could cut Maui escort costs; Maui roll-on/roll-off lessons help others; Maui barge playbook useful for other island builds

Each of the three approaches—cdcb, Reframe, and Maui—offers a distinct factory layout strategy, and combining their strengths could drive efficiency in future pilots for disaster recovery. Reframe's compact microfactory model, utilizing vertical framing and pick-to-light systems, allows flexible, small-batch production in tight spaces. In contrast, Fading West's 110,000 sq ft facility emphasizes throughput with an assembly line and multiple homes produced daily. cdcb's stationary-module model with rotating crews provides agility in smaller spaces. Cross-learning here suggests that cdcb's layout could serve as a testbed for scaling some Reframe-style automation, while Maui's established cycle times and high-volume layout can serve as a benchmark for scaling efforts across both Reframe and cdcb.

The procurement approaches across the models reflect varying balances of cost, speed, and cash efficiency. cdcb emphasizes local commodity sourcing and just-in-time (JIT) inventory to minimize capital lock-up. Maui's national sourcing supports scale but may be more rigid, while Reframe focuses on regional suppliers. By adopting regional supplier strategies, all models can benefit from shorter lead times and lower costs.

The workforce strategies across the organizations showcase different strengths that could be complementary when shared. Reframe leverages digital guidance to enable 60% of its workforce to be apprentices, offering a scalable upskilling model. Maui operates with a large dual team of factory and field staff with a deep trade skillset, while cdcb maintains a smaller team of local technicians. Cross-learning opportunities lie in applying Reframe's digital training systems to upskill cdcb's workforce, while Maui's extensive trade roster can inform surge hiring strategies for both Reframe and cdcb during peak demand periods or disaster response scenarios.

Transportation logistics vary widely across the models. Reframe uses short-haul delivery within an hour of its factory, minimizing cost and complexity. Maui's case handles long-distance, intermodal transport, including barge logistics, for thousands of miles, while cdcb ships standard-width modules on pickup trailers within a 120-mile radius. Future strategies could include adopting narrower modules or flat-pack kits to reduce Maui's costly oversized shipping, while Maui's roll-on/roll-off and barge logistics experience can provide invaluable guidance for other teams building in remote or island environments.

6 CONCLUSION

This section includes recommendations and future work ideas for additional research on this topic. Building on the findings and insights gathered throughout this capstone, the following discussion outlines key areas where further investigation and action could enhance the effectiveness of industrialized housing in disaster recovery.

6.1 Recommendations and Future Work

This capstone explored different approaches to industrialized housing through case studies, with a focus on how these models could support disaster recovery efforts. The main objective was to examine the supply chain advantages and challenges associated with each approach. To achieve this, interviews were conducted with key stakeholders from the featured case studies, as well as industry experts in housing and construction.

These conversations revealed insights that extended well beyond supply chain logistics. Topics ranged from government policies and regulations to the needs of disaster survivors, as well as the realities of permitting, site prep, and onsite assembly. While this project doesn't cover every issue tied to industrialized housing in disaster contexts, it aims to provide a strong foundation centered on supply chain dynamics. Further research is encouraged in other critical areas, such as building codes, zoning, and policy frameworks, to fully understand the broader landscape and challenges.

One promising area for future exploration is flat pack industrialized housing for disaster response. These homes are constructed from prefabricated panels for walls, floors, and ceilings, often with compartments for spaces like bathrooms. Because they can be manufactured and stored in advance, flat pack homes have the potential to drastically reduce the time needed to provide shelter after a disaster. This concept could play a vital role in building a more agile and responsive housing system in times of crisis.

Another area of potential research could include scenario planning and analysis on how industrialized housing solutions could have been used for past natural disasters as well as future disasters based on geographic, economic, and environmental factors. This analysis could also include a quantitative analysis of industrialized supply chains to identify bottlenecks and opportunities to grow the industry capacity.

This capstone sheds light on how industrialized construction can help bridge the gap between immediate shelter and long-term recovery. It offers both speed and flexibility that traditional onsite construction models often lack. By examining real-world examples and engaging with industry stakeholders, this research highlights not only the potential of these solutions, but also the barriers that must be addressed to make them truly effective. While industrialized housing isn't a one-size-fits-all answer, it offers a promising pathway forward. Continued research, collaboration, and policy reform will be essential to ensure that every family can rebuild with dignity after disaster strikes.

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