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# Advancing Appalachia Through Industrialized Off-Site Construction (IOC): Affordable Housing and Workforce Perspectives

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Article

# Advancing Appalachia Through Industrialized Off-Site Construction (IOC): Affordable Housing and Workforce Perspectives

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## Abstract

Amid U.S. housing and labor shortages, Appalachia needs solutions that strengthen communities. This study examines how establishing an industrialized off-site construction (IOC) ecosystem can address regional housing, workforce, and construction challenges. From March–June 2024, we conducted seven participatory design workshops across Appalachia (n=129). Using a standardized prompt sequence (status quo, opportunities, IOC solutions), affinity clustering, and PICK chart prioritization, participants identified needs, capacities, and gaps, then ranked actions to advance IOC. Validity was tested through independent re-clustering with a shared codebook; inter-rater agreement was substantial (weighted  $\kappa=0.80$ ). Five cross-cutting levers emerged: Education & Training; Policy & Regulation; Marketing & Awareness; Financing & Funding; and Technology & Innovation. Marketing & Awareness were consistently viewed as high-impact and easier to implement near term; Education & Training were high-impact but resource-intensive; Policy and Financing were impactful yet harder to shift; Technology & Innovation should be introduced incrementally to fit tradition-bound industry and regional norms. The resulting roadmap emphasizes near-term pilots, targeted talent pipelines, permitting/code alignment, and fit-for-purpose capital. The main contribution is a globally reproducible participatory protocol with transparent prompts, a shared codebook, independent re-clustering, and reliability metrics that enable replication and benchmarking across regions.

**Keywords:** affordable housing; off-site construction; industrialized construction; industrialized off-site construction; participatory design; construction management

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## 1. Introduction

The construction industry is going through a historic labor shortage in the United States, a complex issue that has had significant repercussions on localized growth, economic development, and housing availability across the nation (Anthony, 2023; Howard et al., 2024; Kortekaas, 2024; White et al., 2025). The labor shortage issue is compounded by the anticipated population growth as well as a widening age gap among skilled workers. With the workforce at historically low levels, it is critical to explore opportunities that will allow the construction industry to reverse this trend, keep up with current demands, and support community development. The ongoing housing crisis is exacerbated by the lack of skilled labor in the workforce. The Associated Builders and Contractors (ABC) estimates that the U.S. requires approximately 8 million construction workers to meet the current demand, which is roughly half a million workers short of individuals currently employed (ABC, 2024).

The construction industry's labor shortage directly fuels the housing deficit, as insufficient skilled personnel limit the industry's ability to meet growing housing demand. This dynamic is

especially pronounced in Appalachia, where both demographic trends and economic changes amplify the gap between available labor and housing supply. (Larussa Raegan, 2023). To address the current housing deficit in the United States, recent analyses indicate the US is underbuilt by about 3.8–3.85 million homes, while the affordability gap for extremely low-income renters is roughly 7.1 million units (Khater et al., 2021; National Low Income Housing Coalition, 2025; Kingsella & MacArthur, 2022). To achieve the production of additional housing units, it would require an additional 400,000 workers each year, apart from the existing workforce (National Association of Home Builders, 2024). Without immediate action, the trends of labor shortages and housing crises will continue to worsen, making a comprehensive solution more urgent than ever.

Given the region's insufficient affordable housing and a strained construction workforce, industrialized off-site construction (IOC) could be a solution. IOC shifts value creation into controlled factory settings and stabilizes delivery performance (Blismas et al., 2006). IOC leverages efficiencies from advanced manufacturing and allows for the rapid deployment of building products. This approach reduces the overall time and cost required for construction projects. Integrating emerging technologies into construction manufacturing processes unlocks further possibilities, including improvements in productivity, quality, and sustainability. "Off-site" construction methods, where the majority of construction processes are conducted in a factory setting, enable optimized quality control due to the controlled environment. Furthermore, the controlled environment provided by off-site construction improves working conditions and creates a safer workplace for individuals (McKay et al., 2005). The IOC attracts more people to the construction industry for enhanced working conditions, along with increased technology integration (Ahn et al., 2020; Assaf et al., 2025; Wang et al., 2020). Incorporating IOC methods into the tradition-bound industry poses a viable solution that could revitalize the workforce and strengthen communities.

Accordingly, a region-wide, participatory study was undertaken to test whether locally co-designed IOC strategies can address Appalachian housing and workforce constraints, structuring the work around four research objectives. To develop IOC solutions for the Appalachian workforce, this research is guided by four research objectives (ROs):

RO1: Develop a comprehensive, literature-based definition for Industrialized off-site construction (IOC).

RO2: Employ design thinking methods to evaluate regional housing, workforce, and construction challenges in the Appalachia region of the United States.

RO3: Identify and prioritize opportunities for industrialized off-site construction to improve housing, workforce, and construction challenges within and across the Appalachian region.

RO4: Recommending data-driven solutions/Develop data-driven recommendations to improve housing, workforce, and construction outcomes in Appalachia.

Reports have documented the housing and labor challenges in Appalachia. This study uniquely combines a region-wide participatory approach with design thinking to co-develop, with local stakeholders, practical and context-tuned strategies for establishing an industrialized off-site construction (IOC) workforce. It provides new insights into the socially-embedded barriers and region-specific enablers of IOC adoption that have not been previously articulated in the literature. Previous work provides valuable insights into the advantages of industrialized off-site construction and supports its use as an effective and sustainable practice. There is limited empirical research that operationalizes industrialized off-site construction (IOC) for rural and small-metro regions like Appalachia, especially studies that translate high-level benefits into place-specific implementation frameworks. In particular, the literature lacks participatory, stakeholder-driven evidence that prioritizes workforce, policy, regulatory, financing, marketing, and technology actions for IOC adoption at the regional scale. This study asks how participatory workshops, grounded in local expertise, can be used to identify and focus on actionable strategies for building an IOC workforce that addresses the dual crises of housing and labor in Appalachia. This research aims to bridge these gaps in the literature by providing tangible insight into a localized area, evaluating the opportunities and challenges of introducing industrialized off-site construction within central Appalachia. By

specifically focusing on Appalachia, researchers are provided with the opportunity to engage with local experts, evaluate individualized needs, and ultimately recommend solutions that are catered specifically to the area.

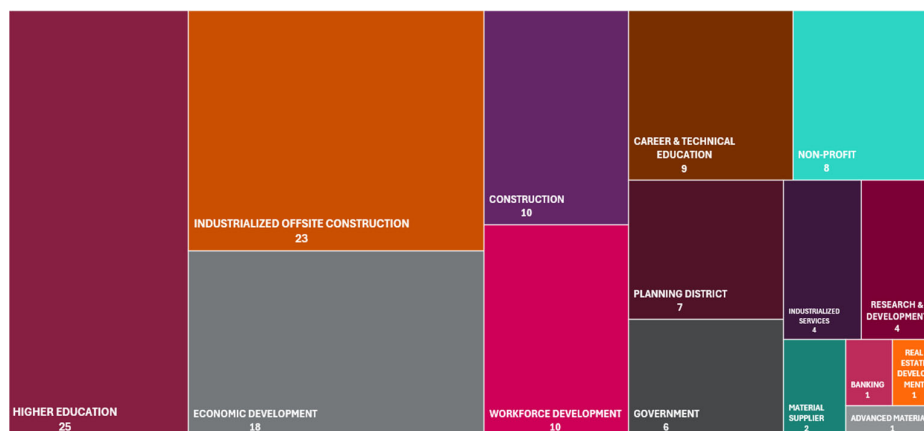
The research team, comprising economists and researchers from construction and engineering, conducted seven participatory workshops in Central Appalachia between March 7 and June 6, 2024. The participatory design workshops employed design thinking methods to support potential work system designs in user and local needs. The goal of the workshops was to identify the current capacity, gaps, needs, and opportunities for establishing an IOC workforce for housing in Appalachia. When problems are socio-technical and multi-stakeholder, participatory design and design-thinking methods are well-suited to elicit needs, generate options, and prioritize actions that communities will adopt. (Steen, 2013a)

Figure 1 characterizes the workshop locations. Workshops were held in Bluefield, West Virginia; Morganton, North Carolina; Pittsburgh, Pennsylvania; Knoxville, Tennessee; Huntington, West Virginia; Prestonsburg, Kentucky; and Marietta, Ohio. Each workshop had approximately 19 participants. A diverse group of participants were recruited from each region based on their leadership across various industries, including higher education, economic development, finance, workforce development, construction, and government officials. Local convening partners were employed to help the research team identify and recruit participants for each participatory workshop.



**Figure 1.** Workshop locations across Appalachia, USA.

Due to the complexity of the problem around workforce and housing development needs, it was critical to have participants representing diverse perspectives to get closer to a systems view of the region. Figure 2 provides a distribution of industry background representation among the participants.



**Figure 2.** Distribution of industry background of workshop participants (n=129).

The following sections will provide a detailed background on the interconnected issues contributing to the housing crisis within Appalachia, examining three distinct segments: housing and workforce conditions, trends, and challenges specific to the participatory workshop locations, as well as a broad analysis of Industrialized Off-site Construction. The information obtained through the literature review informs the methodology of the following section, where the data collection, analysis, and validation processes of the research are presented. Subsequent sections focus on the results from the participatory design workshops, a discussion of the research findings, and concluding recommendations for implementation and further research.

### Background

A region historically known for its rich, diverse history and effective manufacturing industries, Appalachian communities are confronted with complex issues that hinder economic growth, community development, and revitalization of the area. Specifically, a shortage of affordable housing coupled with the lack of a skilled workforce plagues the region and produces pervasive barriers to the sustainment or growth of local communities. This section of the paper provides insight into the current housing and workforce conditions in each of the seven workshop locations, along with an overall look into national industrial construction trends.

### Housing in Appalachia

The Appalachian region features a diverse range of historic industries and opportunities, including tourist hotspots, industrial zones, urban cities, suburban areas, and vacant lots. Widespread housing and workforce challenges act as barriers to the growth and sustainment of local economies and the communities within (Jones et al., 2023; Jones & Spencer, 2018; Mather, 2004); City of Pittsburgh, 2020). In several Appalachian labor markets, employers now identify housing availability and affordability as a direct constraint on workforce recruitment and retention, with extremely low vacancy and largely older units struggling to meet current demand (Bowen National Research, 2023). High-growth Appalachian metros such as Knoxville, TN, are seeing similar pressure, reporting that demand for workforce housing is outpacing supply and that nearly half of renter households are cost-burdened, even after significant local public investment in affordable units (City of Knoxville, 2024). Within increasing populations and demand for affordable housing, solutions need to be identified and implemented to address the housing crisis. This subsection provides insight into the current housing conditions in each of the seven workshop locations; Table 1 provides a summary of these conditions.

**Table 1.** Housing trends of the participatory workshop locations (Data USA, 2022).

Location	Key Challenges	Market Context/Trends	Affordability/Condition	Notable Details
Bluefield	Insufficient affordable housing, aging inventory	Recent tourism/economic growth, but housing/supply lags	Median home cost ~\$113,900, mostly old stock	Investment threatened by slow workforce/housing development
Morgantown	Affordable options not keeping pace	Population/economic growth as an urban-rural corridor	Growing demand from new residents	Recent influx needs tailored, affordable solutions
Pittsburgh	Aged, energy-inefficient stock	Post-industrial transition, strategic public-private effort, but high unemployment rates, population decline, and deteriorating infrastructure (Carter, 2016)	87.6% of units pre-1980 (City of Pittsburgh, 2020)	Working to diversify/modernize stock
Knoxville	Affordability, low inventory, and	Previous rapid value increases, now stabilizing	Median cost ~\$314,700	Value preserved, reliant on demographic/market shifts

	market uncertainty	(University of Tennessee, 2023)		
<b>Huntington</b>	Aging homes, infrastructure deficit	Public health issues, leveraged federal grants (City of Huntington, 2023)	Median home costs ~\$129,600, old homes	Struggling with disrepair, opioid impact
<b>Prestonsburg</b>	Old, less sustainable stock, poverty	Population stagnation, low residential development	Median home costs ~\$172,000	45% in poverty, needs diverse new stock (Data USA, 2022)
<b>Marietta</b>	Investment pressure, older homes	Attracting outside investors, economic restructuring	Median home cost ~\$161,600, 1950s stock	Emerging tourism, housing updates needed

As evident in analyzing these seven cities, increasing levels of poverty, inefficient and unaffordable housing, stagnant construction methods, and an unskilled workforce plague the Appalachian region. The housing crisis is exacerbated by the aging workforce and lack of skilled labor, which is explored further in the following section.

### *Workforce in Appalachia*

Historically, Appalachia has played a critical role in fueling U.S. industry; however, in recent decades, it has seen significant economic decline in many parts of the region, which has driven higher-than-average poverty rates and a reduction in upward mobility opportunities. In the last 10 years alone, 50,000 mining jobs and 10,000 skilled manufacturing jobs have been lost from this region (Appalachian Regional Commission, 2022). Furthermore, manufacturing companies report that talent shortages and skill gaps have reached critical levels, with no visible correction in sight. (*Manufacturing Workforce Development*, 2024). Employment in construction and manufacturing is notably lower among diverse populations; both racial and gender diversity in these industries is drastically lower than the national average (Lightcast, 2022). Workforce sustainability remains an ongoing issue within construction due to the complexity of worksites and hazardous work environments (Gambatese et al., 2019). Labor shortages are expected to continue due to an aging workforce that is disproportionately larger than the number of individuals entering the industry. Today, almost 30% of Central Appalachia's construction and IOC workforce is 55 years old or older, pointing to an aging population facing retirement in the coming years (Henderson, 2023). Despite diverse and interconnected challenges, the combination of anticipated growth in industry jobs, a vibrant entrepreneurial culture, and strong educational resources in the region creates an excellent foundation for fostering and expanding a cutting-edge IOC industry.

Workforce development is a core component of capturing the growth of an industrialized off-site construction market and establishing the region as the nation's hub for IOC integration. Already, Central Appalachia's existing workforce from the once-booming textile, coal, and steel industries has the foundational skill sets to build upon and slowly transition the region to IOC. This first step will help to unlock and leverage additional regional assets from across the region, such as underutilized infrastructure, rail, and factories. All these assets combined illustrate a significant opportunity, particularly when aligned and leveraged through a region-wide effort.

**Table 2.** Workforce trends of the participatory workshop locations (Data USA, 2022).

Location	Population	Housing	Economy	Workforce Driver
<b>Bluefield</b>	Declining	Median cost—\$113,900. Old houses—median year built is 1950	Declining	Healthcare; Education; Retail; Manufacturing
<b>Huntington</b>	Declining	Median cost—\$129,600. Median year built—1950s	Declining	Education; Trade, Transportation, and Utilities; Government; Hospitality
<b>Knoxville</b>	Increasing	Median cost—\$314,700. Median year built—1980s	Growing	Manufacturing; Healthcare; Technology; Tourism

<b>Morganton</b>	Increasing	Influx of new housing stock to meet population demand	Growing	Manufacturing; Healthcare; Hospitality
<b>Marietta</b>	Declining	Median cost—\$161,600. Median year built—1950s	Growing	Healthcare; Social Work; Retail; Education
<b>Pittsburgh</b>	Declining	Median cost—\$158,900. Median year built—1950s. Homes are largely energy inefficient.	Recovering from the previous industry decline	Education; Healthcare; Hospitality
<b>Prestonsburg</b>	Stagnant	Median cost—\$172,000. Median year built—1970s	Declining	Healthcare; Social Work; Hospitality; Food Industry

### *Industrialized off-Site Construction (IOC)*

Within this broad paradigm, Industrialized Off-site Construction (IOC) specifically denotes the practice of shifting substantial construction activities to controlled factory environments, where building components or modules are planned, designed, fabricated, and pre-assembled using advanced manufacturing and digital techniques before being transported for on-site installation (Najafzadeh et al., 2025). Industrialized Construction (IC) refers to a broad approach in which construction adopts manufacturing principles like integrating automation, mechanization, and standardized processes to optimize the building process from design through on-site assembly (Qi et al., 2020). Although the terms are sometimes used interchangeably, IOC is essentially a subset of the wider IC concept, focusing exclusively on off-site production and prefabrication (e.g., modular construction), which is then followed by on-site assembly (Kamar et al., 2011). In other words, all IOC initiatives fall under the IC umbrella, but IC also encompasses other process improvements (including on-site industrialized methods) beyond just off-site work, making it a more comprehensive framework for injecting efficiency and quality gains into construction (Najafzadeh et al., 2025; Qi et al., 2020; Xu et al., 2024).

Industrialized off-site construction (IOC) refers to producing building elements or whole modules in controlled factory settings for installation on site, encompassing practices commonly labeled prefabrication, preassembly, modularization, and off-site fabrication, and sometimes grouped in U.S. project-planning studies as “PPMOF” or “prework” (Lu, 2009; Song et al., 2005; Kamar et al., 2011; Modular Building Institute, 2022). Across diverse markets, reported benefits include shorter schedules, improved productivity and quality, safer working conditions, and greater cost predictability; persistent constraints involve limited flexibility for late design changes, transport and logistics limits, and standardization trade-offs, often amplified by fragmented supply chains and regulatory complexity (Blismas et al., 2006; Pan and Sidwell, 2011; Rahman, 2013; Lu, 2009). Recent U.S. work further connects IOC with the integration of advanced technologies and energy-efficiency strategies characteristic of Industry 4.0, positioning factory-based processes as a lever for performance and decarbonization (Podder et al., 2020). In parallel, industry guidance highlights IOC’s potential to manage cost volatility and schedule risk by shifting labor to controlled environments and tightening procurement and planning windows (Helmsing, 2022). Taken together, these strands frame IOC as a process and management innovation with clear advantages and known constraints, motivating the present study’s focus on how localized, stakeholder-driven frameworks can translate those general benefits into region-specific implementation in Appalachia (Modular Building Institute, 2022; Kamar et al., 2011; Pan and Sidwell, 2011).

Inefficiencies have long plagued the construction industry. Over the previous two decades, the construction sector has experienced an annual growth rate of merely 1% globally, accounting for one-third of the overall global economic growth and one-fourth of the manufacturing sector's growth (Barbosa et al., 2017). Construction projects are notorious for their persistent issues with cost overruns and scheduling delays, while simultaneously facing increasing market pressure to deliver products fast yet being cost-efficient, and with optimum quality (Razkenari et al., 2020). To address this disruptive pressure and failures from the past, the construction industry has gradually adopted

innovative construction methods, such as off-site construction strategies, which have shown promise in minimizing common problems related to costs and schedules (Razkenari et al., 2020). However, despite the improvements that existing off-site construction practices have brought to various aspects of building construction, they continue to encounter numerous internal and external challenges that hinder their advancements towards reaching their full potential, as reported in the literature. Some repeatedly mentioned opportunities and concerns related to the adoption of IC have been explored, supported by both research reports from industry groups and literature review.

With the data generated from the initial research of industrialized off-site construction, the research team identified themes and established an in-depth definition of the term, synthesizing local, national, and global initiatives:

*“Industrialized off-site construction (IOC) refers to an innovative construction system that optimizes the entire build process from design to completion by standardizing building components/systems that can be manufactured/prefabricated, and standardizing the processes used to design, manufacture, and assemble them. IOC integrates industrial principles (i.e., mechanization, standardization, robotics, optimization, digital technologies, and transportation) with onsite, human-based processes through off-site manufacturing capabilities. IOC aims to increase productivity, substitute labor-repetitive or intensive processes, fast-track construction processes and commissioning, reduce costs and risks, improve quality and sustainability, and increase customizable options. However, optimizing the build process remains only part of the equation- IOC needs a holistic approach to training and upskilling the workforce who will implement these innovative, industrialized solutions in construction.”*

Having established the housing and workforce conditions of Appalachia, along with the basis of industrialized off-site construction initiatives, the remainder of this paper aims to employ the IOC definition to explore challenges and opportunities for IOC in the Appalachian region of the United States. In the sections following, the integration of ideas and perspectives from local experts with the baseline application of industrialized construction remains critical in forming localized and actionable solutions that aim to revitalize communities within Appalachia.

#### *Design Thinking & Participatory Workshop*

Because adoption barriers in Appalachia are largely institutional and local, codes and inspection pathways, financing and procurement norms, supply-chain maturity, and public perception, solutions that are co-designed with regional stakeholders are more likely to be implementable (Lessing, 2006; Pan & Sidwell, 2011; Rahman, 2013). Participatory design and design-thinking methods provide a structured route from needs to prioritized actions in socio-technical change, which is why they are appropriate for IOC adoption planning in this region (Brown, T. (2008); Mironcika et al., 2008; Sanoff, 2000; Steen, 2013b).

## **2. Methodology**

This research employed a three-step methodology including literature review, data collection, and analysis and validation. Figure 3 characterizes the methodology process of this study, including the validation approach.

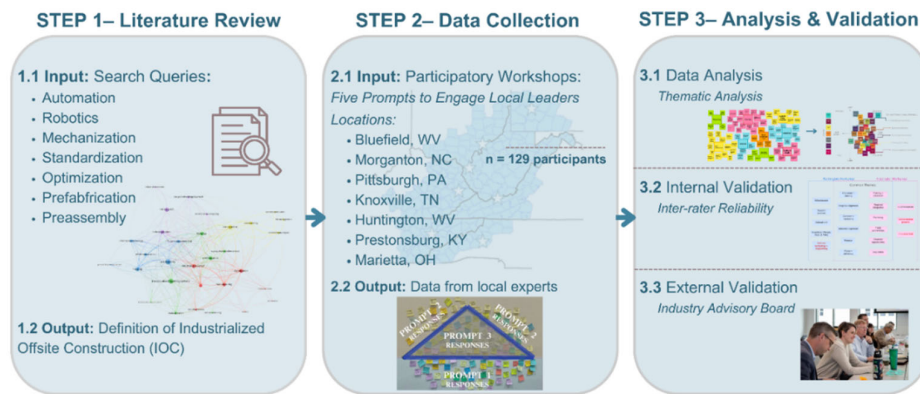


Figure 3. Methodology workflow.

### Step 1. Literature Review

The research team conducted a thorough and all-encompassing literature review to gain an understanding of the current data on industrialized off-site construction, analyzing global and national definitions and applications. The research team mapped prevalent terminology in the industrialized construction literature by querying Scopus for English-language articles published from 2014 to 2023. The search string combined relevant terms with Boolean operators and was documented for transparency and reproducibility. To determine the relevant terms, we began with seed terms from established IC definitions and international terminologies (e.g., industrialized construction/industrial construction, industrialized building, off-site/offsite construction, prefabrication/pre-assembly, and modular construction). We then added process terms and enabling technologies that recur in IC studies (e.g., Digital, Industry 4.0, robotics, automation, planning, optimization). Synonyms, truncations, and spelling variants were normalized (e.g., prefabricate, off-site/offsite), and minimal exclusion terms were introduced to remove obvious noise. The final query was refined through iterative Scopus pilots to balance recall and precision before exporting records for analysis. Figure 4 represents the search query used in the literature review.

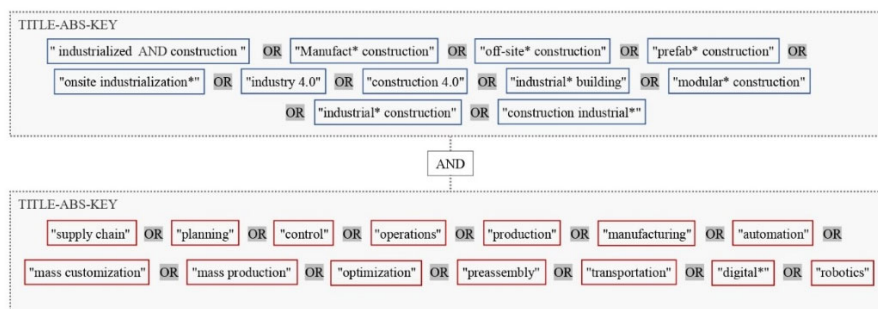
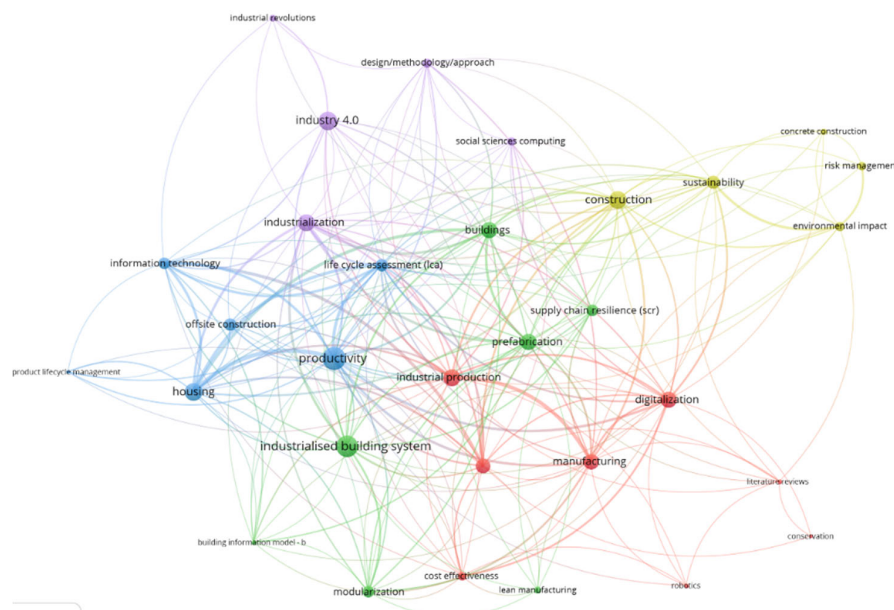


Figure 4. Overview of the search query employed in the literature review.

The search query resulted in 168 articles. Article content (e.g., title, keywords, abstract) was placed into VOSviewer (a software tool that helps visualize bibliometric networks) to analyze data, identify the most used terms, and generate a mapping of research clusters (VOSviewer, 2024). The terms that appear most frequently, listed in descending order, include *Productivity*, *Industrialized Building Systems (IBS)*, *Prefabrication (Preassembly)*, *Construction Technology (Industry 4.0, Digitalization, Building Information Modeling, Robotics)*, *Off-site Construction*, *Sustainability*, *Life Cycle Assessment (LCA)*, *Supply Chain Resilience (SCR)*, *Modularization*, and *Manufacturing*. The relationship between the 30 most frequently used terms within the articles is apparent in the bibliometric map below in Figure 5. In this figure, the size of the term's circle is indicative of its occurrence frequency; larger circles represent terms that have been used more than terms with smaller circles.



**Figure 5.** Bibliometric Mapping of most frequently used terms – VOSviewer.

During the literature review process, researchers also compared global and national definitions of Industrialized Construction and analyzed applications based on the frequency of terms found in the query referenced within recent literature. With this data, the research team identified themes and generated a new definition of Industrialized Construction that synthesizes local, national, and global research initiatives:

*"An innovative construction system that optimizes the entire build process from design to completion by standardizing building components/systems that can be manufactured/prefabricated, and also standardizing the processes used to design, manufacture, and assemble them."*

### Step 2. Data Collection

With the Industrial Construction framework established through the literature review process, the research team began obtaining secondary data (e.g., employment trends, housing studies) throughout the Appalachian region, specific to housing and workforce development. Seven participatory design workshops were held to engage local leaders; a diverse group of stakeholders (n=129) who are thought leaders and influencers in construction, manufacturing, industrialized construction (e.g., manufactured/modular/prefabricated), economic development, local officials and zoning/planning/code enforcement, and education professionals and administrators, were recruited for each workshop. Workshop locations included Bluefield, West Virginia; Morganton, North Carolina; Pittsburgh, Pennsylvania; Knoxville, Tennessee; Huntington, West Virginia; Prestonsburg, Kentucky; and Marietta, Ohio (Appendix B). These locations were chosen by the research team as they met the requirements for metropolitan statistical areas (MSAs) and are central, convenient markets within the Appalachian region. The research team confirmed with community colleges and economic development groups that the seven chosen workshop locations are the centroids where personnel and resources are drawn, along with validating the participants' profiles.

All data collection procedures were reviewed and approved by Virginia Tech's Institutional Review Board (IRB) for compliance with human subjects' research protocols (IRB #: 23-1369). Participants in attendance were briefed on the objectives and societal benefits of the research initiative. Furthermore, participants were informed that their presence at the workshop and compliance in answering any questions were voluntary. While attendance was taken at each

workshop, individual responses to questions would not be collected in a manner that required any personal identifiers.

Workshop participants were engaged in person through a variety of prompts intended to provide insight into the region's current status quo, vision for the future, and potential growth strategies. This design-thinking methodology proved to be an effective approach, as the prompts and instructions engaged local experts and shed light on specific areas of interest. Ideas, discussions, and responses were recorded by participants on sticky notes, which provided the research team with vast qualitative data from each participatory workshop.

The research team began each workshop by placing a blue triangle on a wall or board within the event space. Prompts one, two, and three required workshop attendees to record their answers on sticky notes and place them in designated areas above, below, or in the middle according to the prompt. The questions and instructions for prompts 1-3 are listed below. Figure 6 demonstrates the three-step input solicitation process for the initial phase of data collection related to prompts 1-3.

#### Prompt 1— Status Quo

In Prompt 1, participants were presented with the following questions and instructed to record responses **below** the blue tape triangle:

*“What is the status quo of housing and workforce in your region, including the status of education, infrastructure, and technologies? What challenges or opportunities do you see in each of these areas?”*

#### Prompt 2— Where Do We Want to Go?

In Prompt 2, participants were then prompted to answer the following question and instructed to record responses **above** the blue tape triangle:

*“How could IOC take advantage of opportunities or solve concerns in your region?”*

#### Prompt 3— How Do We Get There?

In Prompt 3, participants drew from and merged with the discussion of the first two prompts. The group then brainstormed and recorded responses based on the following instructions at the **center** of the blue tape triangle:

*Participants were then prompted to determine if IOC initiatives could help us achieve the opportunities or solve the concerns of Prompt 2. Prompt 3, therefore, provides industrialized construction solutions to local needs.*

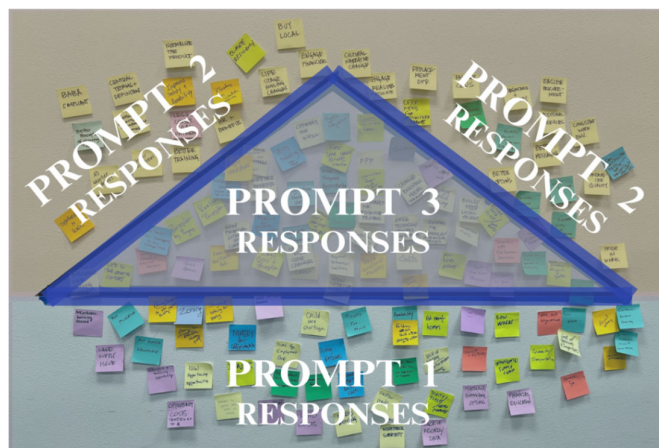


Figure 6. Example of Participatory Design Process, Prompts 1-3.

The output from prompts 1-3 in the Data Collection phase was subsequently utilized and built upon in the Analysis and Validation phase.

### Step 3. Analysis and Validation

The final step in the methodology included analysis and validation processes. The analysis process engaged workshop participants during prompts 4-5 and utilized various design thinking methods to synthesize data collected in previous prompts. Following the conclusion of the workshops, the research team employed both internal and external validation approaches to verify the workshop findings.

#### Prompt 4

*In the Prompt 4 activity, workshop participants were asked to cluster similar solutions from Prompt 3, establishing common themes of needs that require local solutions for industrialized construction to be successful in the future—see Figure 7 for an example output from Prompt 4.*



**Figure 7.** Example of Affinity Diagram - Theme Clustering Output.

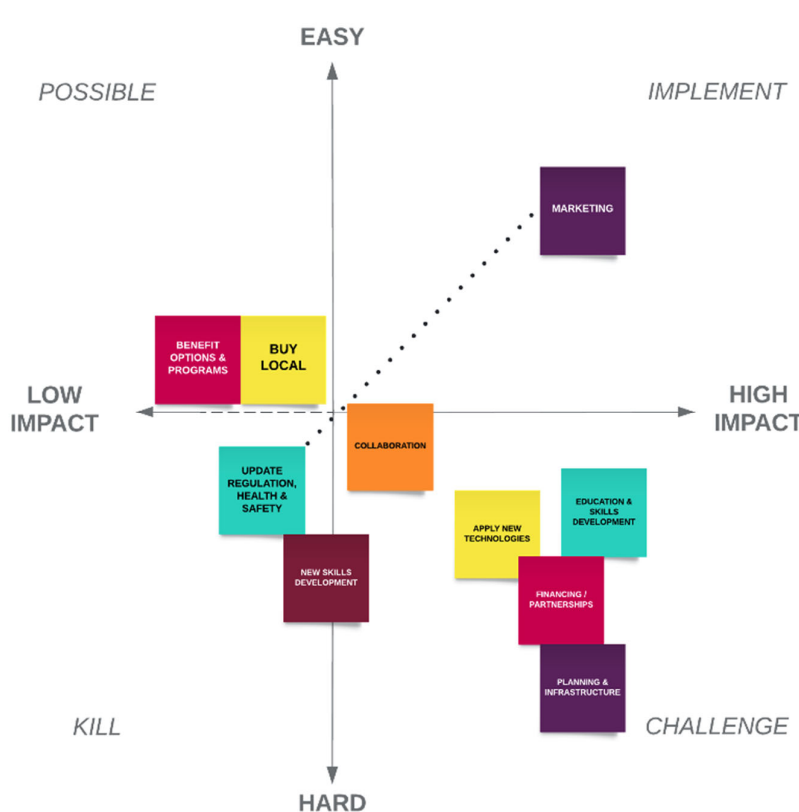
The Prompt 4 activity employed affinity diagramming to disentangle varied viewpoints and surface locally actionable priorities. We selected this technique to synthesize input from regional practitioners and leaders. Originating with Jiro Kawakita's KJ method (1975), affinity diagramming groups items into emergent themes and is widely used to structure qualitative data. As Hanington and Martin (2012) note, it is a generative, human-centered design method well suited to organizing complex inputs. In the workshop, an expansive mix of stakeholders participated. Spanning from higher education, economic development, finance, workforce development, construction, and government. Given the broad stakeholder mix participating in the workshops, affinity diagramming provided a disciplined way to cluster insights and map priorities for industrialized construction.

Across all workshops, participants clustered and agreed upon five general thematic areas across Appalachia that need localized solutions for industrialized construction to be successful. The agreed-upon thematic areas include: 1) *Education & Training*; 2) *Policy & Regulation Frameworks*; 3) *Marketing & Awareness*; 4) *Financing & Funding*; 5) *Technology & Innovation*.

Prompt 5 built off these themes and required workshop participants to organize and rank the feasibility of the solutions into four different quadrants using a PICK Chart. PICK charts are commonly employed in lean or continuous improvement approaches (Badiru & Thomas, 2013). Themes (solutions) deemed to be low impact and easy to implement were categorized as 'Possible' in the upper left quadrant, high impact and easy to implement as 'Implement(able)' in the upper right quadrant, high impact and hard to implement as 'Challenges' in the lower right quadrant, and lastly items of low impact that would be hard to implement were placed in the lower left 'Kill' quadrant. It is also possible for thematic areas to split along a line between quadrants, being "middle-of-the-road" in terms of easy-to-hard and low-to-moderate impact. Figure 8 displays an example of a PICK chart generated at the Bluefield workshop.

**Prompt 5**

*During this final activity, participants were asked to prioritize Prompt 4 thematic areas (solutions) by sorting them both as a) low-to-high impact and b) easy-to-hard to implement.*



**Figure 8.** Example of PICK Chart – Prioritizing Themes.

Through the identification of key challenges and opportunities, participants established and prioritized initiatives that would improve regional housing. Education and training of the local workforce were a consistent, primary focus. Other important and common themes to Appalachia included policy and regulation frameworks that bolster industrialized solutions, marketing and awareness that promote industrialized technologies as a viable market solution and reduce resistance, improved financing and funding opportunities that counteract risk, and the integration of technology and innovation into the workforce and beyond.

Upon completion of the thematic analysis, the research team conducted internal and external approaches to validate findings. The internal validation approach included inter-rater reliability testing (MacPhail et al., 2016). In the internal validation step, the research team took the data collected from workshop prompts 1-3 and re-clustered the data independently from each workshop. The research team took sticky notes from prompt 3 and completed prompts 4 and 5 separately from the

workshops to compare and internally validate that the research team’s results were consistent with those of each workshop. Figure 9 displays an example of the side-by-side comparison of the themes clustered (prompt 4) during the workshop and the research team’s independent re-clustering exercise. The research team prioritized themes from the re-clustering exercise, re-ranked them using a PICK chart (prompt 5), and compared these results with those from the initial workshop.

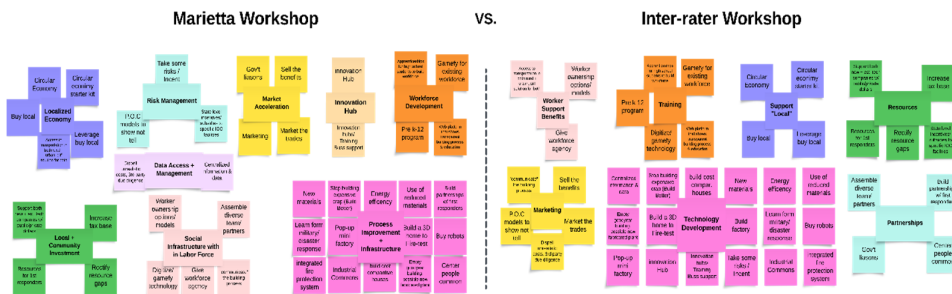


Figure 9. Example of Internal Validation - Theme Re-clustering and Comparison.

For Inter-rater reliability testing, we assessed agreement between workshop theme assignments and the independent re-clustering at the note level using **Cohen’s kappa** for nominal categories, computed from a  $k \times k$  contingency table as  $\kappa = (P_o - P_e)/(1 - P_e)$  and reported with the double-coded sample size  $n$  (Cohen 1960; Viera and Garrett 2005; McHugh 2012). We interpret  $\kappa$  using the Landis and Koch (1977) benchmarks for strength of agreement. These ranges come from Landis & Koch’s original paper and are widely reproduced in methods guides. Here are the (Landis & Koch, 1977) benchmarks for interpreting Cohen’s  $\kappa$  in Table 3.

Table 3. Cohen’s  $\kappa$  benchmarks.

$\kappa$ range	Strength of agreement
< 0.00	Poor
0.00–0.20	Slight
0.21–0.40	Fair
0.41–0.60	Moderate
0.61–0.80	Substantial
0.81–1.00	Almost perfect

The external validation approach involved presenting all research results to the project’s Industry Advisory Board in a final workshop held at Virginia Tech. The profile of the stakeholder spans from Industry, Education, Non-profit to Govt. officials and Economic Development professionals from multiple states, research institutions & agencies, ensuring overall credibility and reliability (Appendix A). This final workshop aimed to vet the results from previous workshops and validate the research team’s analysis of the data. The research team first presented all preliminary findings (e.g., employment trends and data collected from the design thinking workshops) and asked the industry experts for feedback.

Upon presenting the data to stakeholders, the research team led discussions that aimed to establish necessary actions for themed priorities. The group focused on strategy and implementation of central themes that emerged across participatory workshops, including optimizing transportation, advancing housing solutions, and improving education and training. There was an emphasis on improving exposure to IOC opportunities through both education and marketing initiatives, advocating for IOC as not only a solution to the housing crisis but also as an opportunity to increase skilled labor. With the strong sense of pride instilled in each community, coupled with a reluctance to let in large, external resources to fix the issues, it was ultimately determined that the approach

must be multifaceted. There is no one-size-fits-all solution that would feasibly allow for widespread adoption of IOC, even within the Appalachian region.

The following section highlights key findings, themes, and insights that emerged from the research process.

### 3. Results

#### Prompt 1 – Status Quo

Bluefield participants noted issues such as *workforce shortages, insufficient infrastructure, and a lack of affordable middle-income housing*, despite available land. Participants emphasized the need for *improving education* at all levels, while specifically focusing on younger generations. Participants in Morganton shared concerns about the *lack of affordable housing* for current residents, an issue compounded by the *rapidly growing area* due to an influx of students and working professionals. Despite the growing community, Morganton continues to see a *construction workforce shortage* and a *decline in skilled labor*. In Pittsburgh, participants acknowledged the community's *old and energy-inefficient structures*. Furthermore, Pittsburgh's *systemic barriers* and *inadequate public transportation* are barriers for individuals to obtain and maintain employment.

Similar to Pittsburgh, Knoxville also experiences *systemic and interconnected challenges*, including a *generational divide in the construction workforce, regulations and zoning constraints, and socioeconomic issues compounded with the area's opioid crisis*. Although Knoxville is a rapidly growing city, *inadequate education and training* result in a shortage of skilled workers who fail to meet the local demand. Participants in Huntington expressed concern surrounding the *shortage of skilled workers* and the unaffordability of homes, despite the *old, unrenovated, and energy-inefficient housing supply*. Huntington has the opportunity to expand and sees potential within *vacant lots*; however, the *remote nature* of the lots raises concerns due to *infrastructure limitations*. Participants emphasized the *need to form partnerships* with colleges and beyond to *promote training and awareness* of opportunities within the IOC.

Prestonsburg, the most rural area of the workshops held, has experienced *economic disruptions caused by workers leaving the area*. The *lack of middle-income housing, structural issues in the existing housing supply, and susceptibility to flooding* are all contributing factors to the dwindling population and workforce. Marietta, on the other hand, is becoming *increasingly urban* but lacks vital components necessary to cultivate a thriving economy. Participants noted *aging buildings, lack of infrastructure, zoning limitations, and a lack of skilled workers*.

#### Prompt 2 – IOC Opportunities

In Bluefield, participants emphasized the desire for *sustainable, affordable homes* and an *improved workforce*. Participants saw an opportunity to integrate industrialized off-site construction practices to address local concerns through *lowering construction costs and build times* while *improving working conditions*. Additionally, Bluefield participants noted the expectation that incorporating IOC methods would lead to an *increased use of automation and technology*. Improvements in education, training, and marketing, specifically to younger generations, were noted to be essential in the effective implementation of IOC. Similar to Bluefield, Morganton participants envisioned incorporating industrialized off-site construction to *shorten on-site build time* and *reduce the physical strain on workers* by moving most tasks to a controlled environment. Enhancing practices through *increased automation and improved technology* was also discussed as a potential opportunity. Furthermore, participants saw the IOC as a means to *enhance the quality and efficiency of homes* while promoting *durable and sustainable practices*.

Pittsburgh participants envisioned inclusivity and sustainability and saw the IOC as an opportunity to create *energy-efficient, healthy, safe homes*. During Prompt 2, workshop participants reiterated the need for improved infrastructure, enhanced transportation, and paid training programs to effectively implement IOC methods. Similar to previous workshops, Knoxville saw the

IOC as an opportunity to address housing concerns with *reduced construction costs and build times*. Participants also examined the long-term benefits of implementing IOC, such as *career opportunities, improved training and apprenticeship programs, and expanded grant and funding opportunities*. Upon discussing opportunities and benefits provided by the IOC, the need for employer-based childcare and flexible work-scheduling was emphasized. It was specified that providing these benefits to support diverse working-class populations, such as single parents or aging individuals, is essential to overcoming social and logistical barriers. Huntington participants saw opportunities within the IOC to *improve the quality, efficiency, and health of homes*, while also increasing the feasibility of *producing off-grid homes* that utilize renewable energy and local building materials. Participants envisioned a *technologically advanced ecosystem* with IOC but emphasized the importance of educating and training all individuals, especially those of younger generations and underrepresented groups, for the maximum impact.

Like other groups, Prestonsburg highlighted IOC to *cut down on construction costs and build times* and acknowledged the opportunities in *automation and technology advancements*. Participants shared a vision for improving housing while focusing on *sustainability, affordability, and workforce development*. Like previous workshop discussions, Prestonsburg participants reiterated the need for improvements in education, training, and outreach targeted towards younger generations to make the most out of IOC. Participants in Marietta stressed the potential IOC has in *lowering construction costs and build times*, and *increasing productivity and innovation* through enhanced technology applications. Participants recognized the potential IOC has in *creating education and job opportunities* to attract more individuals to the area, but emphasized the need for regulatory changes and affordable development opportunities that are within proximity to local amenities and resources.

#### *Prompt 3 – Using IOC to Address Current Challenges*

In Bluefield, participants touched on the need for a comprehensive approach to address the needs of the area, including *improving home-buying options, having alternative funding sources, and designing structures that mitigate hazards*. Local experts recognized the opportunity IOC has to *bring more individuals into the construction industry*, and therefore desire to *improve education and training*, emphasizing the need to *start exposure to IOC opportunities as early as K-12*. Participants from Morganton highlighted the role the IOC could have in *enhancing public-private partnerships, generating specialized training programs, and lowering manufacturing costs*. In Pittsburgh, participants were excited about the *improvements in technology and collaboration* provided by IOC. Knoxville experts similarly saw the opportunity IOC has in *streamlining processes through the integration of technology*, in addition to *creating realistic training programs that expedite workforce development*.

Huntington participants emphasized opportunities in the IOC for *utilizing renewable and local materials, leveraging technology, and optimizing funding strategies*. Participants discussed the feasibility of establishing a local IOC market due to *nearby vacant industrial sites and lots*. Similar to Bluefield, Prestonsburg participants saw potential in *improving home-buying options, generating alternative funding sources, and integrating education and training opportunities for all levels, with exposure starting at K-12*. Marietta participants discussed a comprehensive approach required to address the local needs and saw opportunities within the IOC to *improve the localized economy, workforce development, and technology integration*.

## Prompt 4 – Generate Themes

Location	Themes	Key Thematic Areas Identified by Participants
Bluefield	n=10	<ul style="list-style-type: none"> <li>• Financing &amp; partnerships</li> <li>• Applying new technologies</li> <li>• Buying local</li> <li>• New skills development</li> <li>• Education &amp; skills development</li> <li>• Updating regulations &amp; health/safety</li> <li>• Benefit options &amp; programs</li> <li>• Planning &amp; infrastructure</li> <li>• Marketing</li> <li>• Collaboration</li> </ul>
Morganton	n=5	<ul style="list-style-type: none"> <li>• Industry funding &amp; opportunity</li> <li>• Training &amp; funding</li> <li>• Regulatory</li> <li>• Marketing</li> <li>• Perception &amp; outreach</li> <li>• Technology</li> </ul>
Pittsburgh	n=7	<ul style="list-style-type: none"> <li>• Funding &amp; resources</li> <li>• Collaboration (people-centered ecosystem)</li> <li>• Sustainability</li> <li>• Community workforce education</li> <li>• Research</li> <li>• Marketing + community awareness demand</li> <li>• Policy + regulation</li> </ul>
Knoxville	n=9	<ul style="list-style-type: none"> <li>• Financing</li> <li>• Technology &amp; infrastructure</li> <li>• Services</li> <li>• Training</li> <li>• Regulatory environment</li> <li>• More attainable options</li> <li>• Support program funding</li> <li>• Marketing</li> <li>• Culture shift</li> </ul>

<b>Huntington</b>	<b>n=11</b>	<ul style="list-style-type: none"> <li>• Infrastructure</li> <li>• Support services</li> <li>• Science/technology &amp; engineering</li> <li>• Culture shift</li> <li>• Finance</li> <li>• Outreach &amp; marketing</li> <li>• Regional alignment</li> <li>• Industrial alignment</li> <li>• Incentives (private, state, local, federal)</li> <li>• Policy &amp; advocacy</li> <li>• Education &amp; training</li> </ul>
<b>Prestonsburg</b>	<b>n=6</b>	<ul style="list-style-type: none"> <li>• Marketing</li> <li>• Job benefits</li> <li>• Skills + training</li> <li>• Regulation + codes</li> <li>• Technology benefits</li> <li>• Business model</li> </ul>
<b>Marietta</b>	<b>n=9</b>	<ul style="list-style-type: none"> <li>• Localized economy</li> <li>• Local &amp; community investment</li> <li>• Risk management</li> <li>• Data access &amp; management</li> <li>• Social infrastructure in the labor force</li> <li>• Market acceleration</li> <li>• Innovation hub</li> <li>• Process improvement &amp; infrastructure</li> <li>• Workforce development</li> </ul>

#### *Prompt 5 – Prioritize Themes*

Identifying key challenges and opportunities in regional housing is crucial because it enables targeted and effective solutions that address specific needs and gaps. Following the workshops, the data analysis revealed five common themes that were ubiquitous across all the workshops – see Figure 10 for the themes and location of the workshops. As previously mentioned in Prompts 4 and 5, workshop participants clustered and agreed upon these common thematic areas across Appalachia: 1) *Education & Training*; 2) *Policy & Regulation Frameworks*; 3) *Marketing & Awareness*; 4) *Financing & Funding*; 5) *Technology & Innovation*.

Focusing on the ability to act on these themes, PICK charts were used to organize the data into quadrants based on participants' perception of their priority (see Figure 11). Participants consistently ranked marketing and awareness as easily implementable with high impact—these IC solutions should be considered as immediately accessible and effective. Participants considered education and training to be highly impactful, yet not as easy to implement as marketing. It is immediately accessible and effective, yet also requires resources, infrastructure, and investment to be successfully implemented. For IC, technology and innovation seem central and critical to any measure of success, while diffusing these technologies into the industry is a major challenge, and we cannot train without them. Financing and funding a challenging themes with high impact- our industry expects high returns quickly for any investments and is slow to change, making it difficult to attract funds and financing options. Participants considered the policy and regulation framework as the most challenging of the themes- the top-down nature of policies and regulation makes it

difficult to influence and change quickly, while they have a high impact when successful. Across seven workshops, inter-rater reliability for thematic clustering ranged from moderate to almost perfect ( $\kappa=0.55-0.88$ ). Five of seven sites achieved substantial to almost perfect agreement ( $\kappa\geq 0.78$ ), while one site (Morganton) was moderate ( $\kappa=0.55$ ). Pooled across all locations ( $n=360$  notes), agreement was substantial (weighted  $\kappa=0.80$ ;  $P_o = 0.84$ ,  $P_e = 0.20$ ). Table 4 provides a summary of the Inter-rater Cohen’s kappa calculation across seven locations.

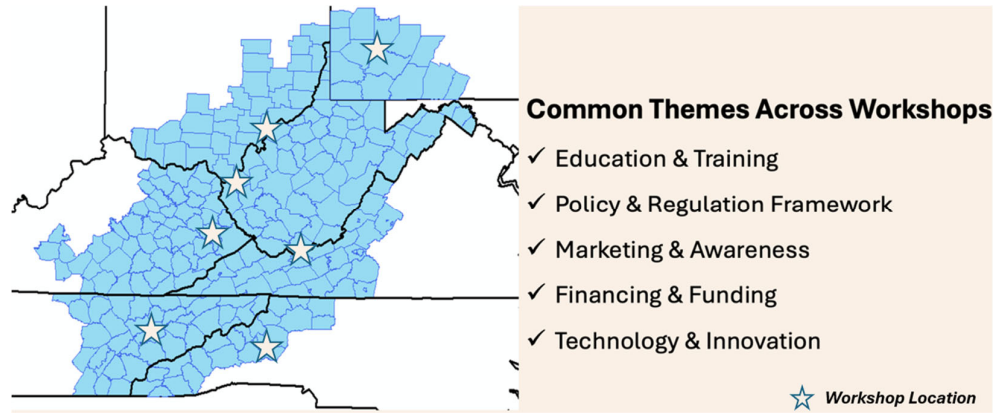


Figure 10. Common themes from workshops.

Table 5. Summary of Inter-rater Cohen’s kappa calculation.

Location	n	Compute observed agreement ( $P_o$ ): Sum the diagonal / n	$P_e =$ SUM over themes of (row_prop $\times$ col_prop)	Kappa: $\kappa =$ ( $P_o - P_e$ ) / (1 - $P_e$ )	Strength of agreement
Bluefield	50	0.82	0.19	0.78	Substantial
Morganton	43	0.65	0.23	0.55	Moderate
Pittsburgh	55	0.84	0.17	0.80	Substantial
Knoxville	61	0.90	0.16	0.88	Almost Perfect
Huntington	47	0.85	0.24	0.80	Substantial
Prestonsburg	72	0.90	0.18	0.88	Almost Perfect
Marietta	32	0.84	0.29	0.78	Substantial

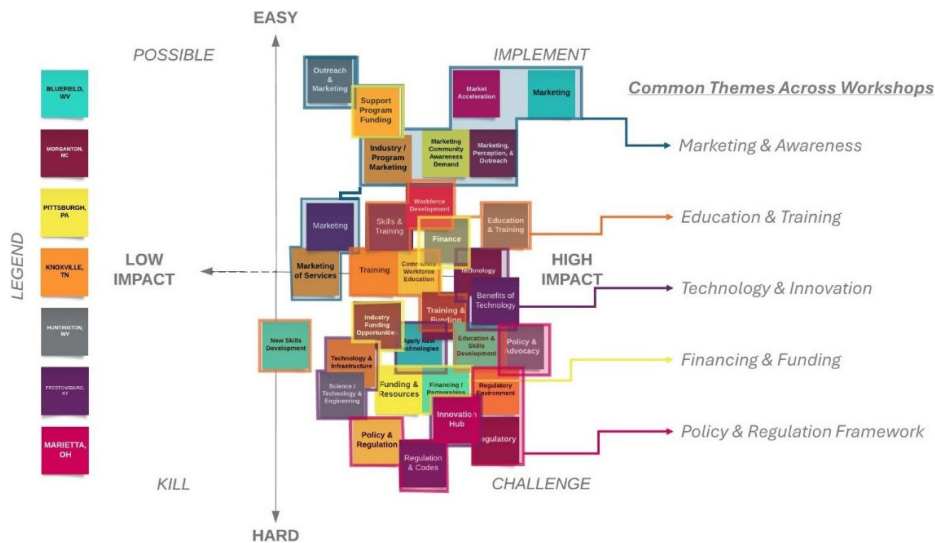


Figure 11. Combined PICK chart reveals common themes.

#### 4. Discussion

The primary aim of this research was to examine regional housing, workforce, and construction challenges in the Appalachian region and identify opportunities for industrialized off-site construction to resolve these issues. Furthermore, the research team aimed to leverage the participatory nature of the research to collaborate with local experts and recommend data-driven solutions to improve the region. While results indicate that IOC offers a promising future, many barriers need to be overcome along the way. Identifying key challenges and opportunities within the region's housing and workforce frameworks is crucial because it enables targeted and effective solutions that ultimately address the specific needs of the area.

The results of this study reveal that Appalachia is simultaneously grappling with workforce shortfalls and an affordability gap in housing. Participants in each workshop highlighted the widening age gap and declining employment levels among the workforce, corroborating previous data that talent shortages and skill gaps have "reached a critical level" (*Manufacturing Workforce Development*, 2024). Furthermore, local experts expressed concern regarding the aging of the construction industry's skilled trade professionals, supporting previous claims regarding the sustainability of employment, where almost 30% of Central Appalachia's construction and IC workforce is facing retirement at 55 years old or older (Lightcast, 2022). Workshop participants provided insight on the existing housing stock, and in most cases, it was discussed that the communities are faced with deteriorating infrastructure, which is insufficient, which is consistent with existing literature (Carter, 2016). Pittsburgh participants discussed the city's outdated and energy-inefficient structures, supporting previous research where nearly 90% of the city's houses are almost 50 years old (City of Pittsburgh, 2020). All workshops emphasized the lack of affordable housing options available, which is consistent with previous research of the Appalachian region, with nearly half of some communities living in poverty (Data USA, 2022). The findings from this research further substantiate previous research initiatives and confirm housing, workforce, and construction challenges present throughout Appalachia.

This research established five common themes that require attention and solutions across Appalachia: 1) Education & Training; 2) Policy & Regulation Frameworks; 3) Marketing & Awareness; 4) Financing & Funding; 5) Technology & Innovation. As a result, we need to optimize logistics, advance housing innovation, grow education and training options, and welcome opportunities for emerging industry trends. Education, training, marketing, and awareness are accessible opportunities that are reportedly easy to pursue immediately. We need to be careful not to see technology as the ultimate solution, though, using an incremental approach to a tradition-bound industry and region. This concept supports existing literature on the need for modernization within the construction industry (Podder et al., 2020).

Inter-rater reliability was generally strong, supporting the reproducibility of our thematic clustering: five of seven sites were "substantial" to "almost perfect", and the pooled, n-weighted  $\kappa=0.80$ . The one moderate result (Morganton,  $\kappa=0.55$ ) likely reflects overlapping themes and skewed category prevalence, conditions known to depress  $\kappa$  even when raw agreement is acceptable. We mitigated this via a shared codebook and brief calibration, and overall Po remained high (0.84), indicating the clusters are substantively stable. Thus, between-site differences in prioritized themes likely reflect real local variation rather than coder noise.

Our five themes align with evidence from mature and emerging IOC markets. In Finland, diffusion of industrialized timber and modular methods is propelled by sustainability/quality goals but slowed by fragmented product/operation models, uneven code interpretation, and contractor-side capacity/financing risks, driving calls for dedicated skills pipelines and clearer standards (Ilgin & Karjalainen, 2024; Jussila et al., 2022; Kinnunen et al., 2025; Toppinen et al., 2022). In Japan, a long-standing prefab housing sector shows how prefab-aware regulation, factory automation, and firm-led upskilling co-evolve to address labor shortages while delivering consistent quality and safer working conditions (Chau et al., 2024; Hiramatsu et al., 2024; Matsumura et al., 2013; Noguchi, 2003; Shimizu Corporation, 2021). In China, national policies position prefabrication to improve quality,

safety, and carbon outcomes, yet wide adoption hinges on mitigating first-cost barriers and building talent through standards, incentives, and training (Jiang et al., 2018; Liu et al., 2024; Mao et al., 2019). Taken together, these cases converge on the same themes we identify for Appalachia, explicitly: (1) Education & Training (upskilling for industrialized/digital workflows), (2) Policy & Regulation Frameworks (offsite construction-aware codes and consistent approvals), (3) Marketing & Awareness (consumer and industry acceptance via demonstration and communication), (4) Financing & Funding (mechanisms to offset upfront plant/process investment and smooth cash flow), and (5) Technology & Innovation (automation, BIM/DFMA, and modular productization), suggesting our recommendations reflect internationally validated pathways for advancing IOC.

The U.S. construction sector has structural traits that create uncertainty and slow the uptake of innovation. R&D spending is relatively low; volume-produced modular solutions still require site-specific adaptation; organizations are anchored to legacy processes and supply-chain norms; liability is fragmented and asynchronous across stakeholders; markets are highly cyclical; the industry is atomized with many small firms and heavy subcontracting; building codes vary wide by jurisdiction; and financing and insurance constraints further discourage experimentation. Without innovative options to these barriers, and the capacity building productivity, the industry is failing to meet market needs. Incorporating IOC methods into the tradition-bound practices poses to be a promising solution to the historical barriers of the construction industry. Future research should explore the effectiveness of integrating IOC methods in improving workforce and housing frameworks while overcoming these systemic barriers.

## 5. Conclusions

This study used a multi-step, participatory design process across seven Appalachian communities to surface what it would actually take for industrialized off-site construction to help address the region's dual pressures of workforce and housing. Despite local differences, participants converged on five cross-cutting needs: Education & Training, Policy & Regulation Frameworks, Marketing & Awareness, Financing & Funding, and Technology & Innovation. Marketing and awareness emerged as high-impact/ready to implement; education and training were judged high-impact but resource-intensive; technology and innovation were viewed as essential enablers; financing and funding remained a major hurdle; and policy and regulation were the most challenging to move, but consequential when they do. Across sites, stakeholders prioritized practical next steps such as credible pilot/demonstration projects, blended training pathways from K-12/CC into IOC occupations, streamlined permitting/code alignment, and packaging capital for

Inter-rater reliability for our independent re-clustering was generally strong (pooled  $\kappa=0.80$ ), which supported the stability of these themes and suggests that between-site differences reflected real local priorities rather than coder noise. Taken together, the findings pointed to a systems approach that is locally led: align talent pipelines, modernize the rulebook, de-risk adoption through pilots, and communicate clearly to build demand. These actions are feasible for regional partners to begin now, while longer-horizon policy and financing reforms proceed in parallel.

Beyond these findings, the approach itself is reproducible. The study used a standardized protocol: common workshop prompts, a shared codebook, structured note capture, independent re-clustering, and PICK-chart prioritization, then verified stability with inter-rater reliability (pooled  $\kappa=0.80$ ). This package can be lifted to other regions with light customization (stakeholder mix, local exemplars, and policy context) while keeping the core mechanics intact. Doing so would enable comparable theme maps, priority quadrants, and reliability scores across locales, creating a consistent evidence base for IOC decisions and letting future researchers track change over time and evaluate interventions with the same yardstick.

### *Limitations and Future Work*

There are limitations with this research that are important to characterize. Findings reflect seven localities in Central Appalachia and are therefore context dependent. Participant composition skewed

toward institutional and industry stakeholders; end-user voices (e.g., renters, first-time buyers) were limited. Outputs capture perceived priorities rather than post-implementation effects. Although the theme assignment was stabilized via a shared codebook and independent re-clustering, some coder subjectivity may remain despite substantial agreement ( $\kappa$ ). We did not quantify implementation costs, capital requirements, or policy feasibility, and we did not track outcomes after the workshops. Several figures were synthesized at the regional level, which may mask finer site-specific nuances.

Future research should focus on replicating the protocol in additional U.S. regions and in mature IOC markets to test external validity and enable cross-region benchmarking. Pair future runs with cost, schedule, and workforce pipeline analytics, including capital stack and permitting feasibility assessments. Design and evaluate pilot interventions (e.g., permitting/code-alignment sprints, blended K-12/CC-to-IOC pipelines, targeted marketing) using pre-registered evaluation plans and longitudinal follow-up tied to delivery metrics (units produced, time-to-hire, retention, safety). Broaden stakeholder participation to include community-based organizations and end users to strengthen equity and adoption insights. Publish an open repository of instruments (prompts, codebook,  $\kappa$  templates) to support transparent reuse, and explore decision-support methods (e.g., MCDA) to prioritize actions under budget and capacity constraints. This agenda preserves the paper's core contribution, a globally reproducible, comparable method, while building evidence on effectiveness, cost, and scalability.

**Author Contributions:** **Nicole Pond:** Conceptualization, Methodology, Validation, Writing original draft – review and editing, Visualization, Formal analysis, Investigation, Data curation; **Vida Babajaniniashirvani:** Writing – review and editing, Data curation, Validation, **Philip Agee:** Supervision, Investigation, Formal analysis, Project administration, Funding Acquisition, Writing – review and editing, Visualization, Validation; **Andrew McCoy:** Supervision, Investigation, Formal analysis, Project administration, Funding Acquisition, Writing – review and editing, Validation; **Akhileswar Yanamala:** Data curation, Validation; **Shafkath Nur:** Validation, Writing, review, and editing.

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**Data Availability Statement:** The data presented in this study are available on request from the corresponding author. The data are not publicly available due to **Reason**.

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**Conflicts of Interest:** The authors declare no conflict of interest.

## Appendix A

Industry Advisory Board people profile:

State	Organization	Stakeholder Type	Role
KY	KY Manufactured Housing Institute	Industry	Convening Partner
KY	NextStep Network	Nonprofit Housing	Industrial Advisory Board Member
KY	Fahe	Industry NP	Industrial Advisory Board Member
KY	Champion Home Builders	Industry	Participating Stakeholder
KY	Shaping our Appalachian Region (SOAR)	Nonprofit ED	Participating Stakeholder/Community Advisory Board
KY	Southeast Kentucky Community & Technical College	Education	Participating Stakeholder/Community Advisory Board
National	Siplast	Industry	Industrial Advisory Board Member
National	Cavco	Industry	Participating Stakeholder
NC	West Piedmont Community College	Education	Convening Partner/Community Advisory Board
OH	Ohio University	Education	Convening Partner/Technical Partner
OH	Ohio Mid-Eastern Government's Association	Govt WF	Participating Stakeholder
OH	Ohio Southeast Economic Development	Govt WF	Participating Stakeholder/Community Advisory Board
OH	Buckeye Hills Regional Council	Govt WF	Participating Stakeholder/Community Advisory Board
PA	The Trade Institute of Pittsburg (PA)	Industry/ Education	Convening Partner
PA	International Brotherhood of Electrical Workers	Industry	Industrial Advisory Board Member
PA	Housing Innovation Alliance	NP Industry	Participating Stakeholder
PA	Module	Industry	Participating Stakeholder
PA	Signature Homes	Industry	Participating Stakeholder
TN	University of Tennessee Center for Industrial Services	Education	Convening Partner/Community Advisory Board
TN	Wind River Modular	Industry	Participating Stakeholder
TN	East Tennessee Local Workforce Development Board	Govt WF	Participating Stakeholder/Community Advisory Board
VA	Virginia Housing (DHCD)	NP Housing	Industrial Advisory Board Member
VA	DPR Construction	Industry	Industrial Advisory Board Member
VA	Emmons Design	Industry	Industrial Advisory Board Member
VA	Modular Building Institute	Industry	Industrial Advisory Board Member
VA	VA Dept. of Housing and Community Development	Govt Housing	Industrial Advisory Board Member
VA	Holt Weston Consultancy	Industry	Industrial Advisory Board Member
VA	Virginia Western Community College	Education	Industrial Advisory Board Member
VA	Eagle Construction	Industry	Participating Stakeholder
VA	Lenowisco Planning District Commission	Economic Development District	Participating Stakeholder
VA	Cumberland Plateau PDC	Govt WF	Participating Stakeholder
VA	Virginia Coalfield Economic Development Authority	Govt WF	Participating Stakeholder
VA	Van Metre B.A.S.E.	Industry	Participating Stakeholder
VA	Mount Rogers Planning District Commission	Govt WF	Participating Stakeholder

VA	People Inc	Nonprofit	Participating Stakeholder/Community Advisory Board
VA	Mount Rogers Regional Partnership	Govt WF	Participating Stakeholder/Community Advisory Board
VA	New River Valley Regional Commission	Govt WF	Participating Stakeholder/Community Advisory Board
VA	New River Community College	Education	Participating Stakeholder/Community Advisory Board
VA	Virginia Tech	Education	Technical Partner/Convening Partner
WV	Marshall	Education	Convening Partner
WV	Bluefield EDA	Economic Development	Convening Partner/Community Advisory Board
WV	WVU Extension	Govt Education	Industrial Advisory Board Member/Community Advisory Board
WV	Eastern WV Community & Technical College	Education	Participating Stakeholder
WV	New River Community and Technical College	Education	Participating Stakeholder
WV	Bluefield University	Education	Participating Stakeholder
WV	ADL Ventures	Industry	Technical Partner
WV	Community Colleges of Appalachia	Nonprofit Education	Technical Partner/Community Advisory Board

## Appendix B

	Bluefield, WV	Huntington, WV	Knoxville, TN	Marietta, OH	Morgantown, NC	Pittsburgh, PA	Prestonsburg, KY
Invited (attended)	22 (22)	17 (17)	25 (25)	14 (14)	18 (18)	17 (17)	16 (16)

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