

Review

Prefabricated and Modularized Residential Construction: A Review of Present Status, Opportunities, and Future Challenges

Sunai Kim

Department of Civil Engineering, California State Polytechnic University, Pomona, CA 91768, USA;
sunaikim@cpp.edu

Abstract

Many countries worldwide are facing a housing crisis, marked by a shortage of affordable housing. To respond to this growing crisis, prefabricated residential construction is gaining popularity due to cost savings in mass production, faster construction times, improved quality control, and sustainability considerations. This study provides a critical review of the available literature within the prefabricated and modular residential construction industry to assess its present status and to identify opportunities and challenges. The literature was categorized into the subfields of architecture, sustainability, structural, energy, environment, factory build, installation, policy, possibilities and challenges, and case studies. A detailed summary is provided for each subfield. This study aims to provide insights into the prefabricated and modular residential construction industry to fill the knowledge gap, discover possibilities, and address any challenges to create a clear pathway for implementation.

Keywords: prefabricated modular construction; offsite construction; mass production; factory-built housing; manufactured housing; residential single-family housing; accessory dwelling units; sustainable and affordable housing



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1. Introduction

Prefabricated residential construction consists of prefabricating building elements or modules in a factory and then transporting them to a construction site for assembly and connection to foundations and utilities. In recent years, this approach has gained significant popularity due to its advantages over traditional methods. Some of the advantages of prefabricated residential construction include optimized designs that consider energy efficiency, lower carbon emissions, water conservation, economy of mass production due to streamlined and standardized construction processes, faster construction times and reduced site management costs, improved quality control, better acoustic and thermal insulation from structural insulated panels (SIPs), reduced waste, controlled and safer working conditions, decreased on-site labor requirements, less disturbance to the neighborhoods during construction, and the ability to disassemble and reuse the modules. Furthermore, the accelerated pace of construction can respond to the significant shortage of housing supply, address the affordability gap, or provide temporary housing for post-emergency circumstances such as earthquakes, wildfires, and hurricanes. Although there are numerous advantages, there are also challenges and barriers that need to be addressed. Some of these include the high cost of newly developed sustainable materials; offsite competitors; potential negative perceptions of prefabricated housing; regulations and tariffs; building

code gaps and inconsistencies; a lack of industry knowledge on prefabricated design, construction, and regulatory processes; and potential incompatible procurement approaches.

This paper seeks to contribute towards addressing the knowledge gap of the prefabricated modular residential housing field by providing a comprehensive and qualitative literature review. This paper uniquely contributes to the existing body of literature by integrating the historical context (U.S.), policy (U.S.), current market data (U.S.), and scholarly research (worldwide) across diverse disciplines of the prefabricated and modular residential housing. Future research is needed to expand this knowledge to a global context.

First, this paper defines the terms prefabricated, modular, manufactured, and mobile homes and presents the general permit requirements in the United States. Also, market trends for the past 30 years and current market conditions are reported for the United States. Next, the research methodology is introduced for conducting a literature review of prefabricated and modularized residential construction, and its subfields' summaries are systematically presented. The opportunities and challenges are discussed both for researchers and industry practitioners; specific examples are provided for the United States. Lastly, the conclusions are presented.

2. Background

Definitions: Prefabricated construction is an umbrella term that refers to the general process where a building element or the building is manufactured at a factory prior to its final assembly [1–3]. One example of a prefabricated element is structural insulated panels (SIPs). SIPs consist of an insulating foam core between an exterior sheathing (typically a shear wall) and an interior sheathing. They are delivered for on-site assembly and provide a high-performance structural system for residential construction. Modular construction refers to a structure that is built in contained units. The units are mostly completed at the factory (see Figure 1). A modular construction is typically prefabricated, but prefabricated construction does not necessarily have to be modular. A modular home is generally installed on permanent foundations. Typical uses for these homes are either single-family residences (SFRs) or accessory dwelling units (ADUs) where the homeowner owns the land. Because they are on permanent foundations, they require a building permit and are subject to local zoning and building code requirements.

Parameters	Prefabricated (Factory-Built) Single Family House Construction			
	1. Components	2. Elemental or Planar Systems	3. Modular Systems	4. Complete Building Systems
Examples of Construction Technologies	• Timber roof trusses • Cladding panels	• Structural steel frames • Timber framing • Light steel framing • Structural Insulated Panels (SIPs)	• Prefabricated pods (bathrooms, kitchens, etc)	• Fully modular buildings

Parameters	4. Complete Building Systems	
	Modular Home	Manufactured Home (after 1976) Mobile Home (before 1976)
Examples	Single Family Residence (SFR) Accessory Dwelling Unit (ADU)	Inside a community
Land	Typically owned by homeowner	Typically owned by developers (merchant / production builders)
Structure	Factory built	Factory built
Structural Permit	HUD/HCD requirements	HUD/HCD requirements
Delivery	Delivered to site	Delivered to site

Figure 1. Types of prefabricated residential construction, definitions, and examples [3].

The distinction between modular home, manufactured home, and mobile home comes from the U.S. Census and Department of Housing and Urban Development (HUD). Manufactured homes are typically in communities where the developer owns the land. Manufactured homes and mobile homes refer to the same units but, according to HUD, a factory-built home after 15 June 1976 is a manufactured home, whereas a factory-built home prior to 15 June 1976 is a mobile home. Thus, modular home, manufactured home,

and mobile home all refer to homes that were built at a factory. They are designed to be transported to a site for assembly and permanent installation. Trailers are designed to be towed behind a vehicle and only provide temporary housing and are outside the scope of this paper [4].

In this paper, the terms prefabricated construction and modular construction are used interchangeably. See Figure 1 for a visual taxonomy.

Structural Permits for Prefabricated Housing: The U.S. Department of Housing and Urban Development (HUD) is the federal agency that sets standards for the construction of prefabricated homes in the United States. Each state has a State Administrative Agency (SAA) for HUD. In California, the SAA is the California Department of Housing and Community Development (HCD). HCD regulates the construction and standards of manufactured homes, modular homes, and other factory-built housing structures where concealed manufacturing processes cannot be inspected before installation. The permitting process for all factory-built housing components and systems includes plan approval, inspections at the factory, and an insignia issued by HCD [5]. There are various types of structural systems for prefabricated modular homes in the current market.

Building Permit: All residential construction on permanent foundations must apply for a separate permit through the local governing jurisdiction and to connect to existing utilities.

Size of Modules and Transportation: Each state has a governing agency that issues a permit to operate or move a vehicle to deliver the modules that are oversized or overweight. For example, in California, the California Department of Transportation [6] has discretionary authority to issue a special permit to operate or move a vehicle where the size or weight exceeds the maximum limitations as specified in the California Vehicle Code. The single trip permit is for loads greater than 8'-6" wide, 14'-0" high, and over 80,000 pounds. The permit application process lays out the trip route, potential restrictions on travel times, dimensional limitations (widths and heights), and weight limitations. Depending on the size of the vehicle, pilot car(s) may be required, and height limitations are to verify adequate clearance under the bridges along the highways and roadways.

Market Share: From the U.S. Census data between 1994 and 2023, the number of new single-family houses completed were examined between site-built versus prefabricated (panelized, modular, and manufactured) construction (See Table 1). From this table, prefabricated construction (panelized, modular, and manufactured) numbers and trends were plotted on Figures 2 and 3. For manufactured homes, the number was in decline between 1999 and 2010, but it has been slowly and generally increasing since then. For the U.S. residential construction market share as of 2023, manufactured homes constitute 8.2%, modular homes 1.4%, and panelized construction 1.1%. In all, prefabricated new single-family homes constitute approximately 10% of the market share; it has been consistently between 10% and 15% since 2003 [7].

Table 1. Number of single-family houses completed ^{1,2,3} or shipped ⁴ in United States, in thousands [7].

Year	Total	Site-Built ¹		Panelized ²		Modular ³		Manufactured ⁴	
1994	1466	1093	74.6%	38	2.6%	30	2.0%	304	20.7%
1995	1406	1001	71.3%	35	2.5%	29	2.1%	340	24.2%
1996	1492	1059	71.0%	37	2.5%	32	2.1%	363	24.4%
1997	1471	1046	71.2%	40	2.7%	30	2.0%	354	24.1%
1998	1534	1082	70.6%	44	2.9%	34	2.2%	373	24.3%

Table 1. Cont.

Year	Total	Site-Built ¹		Panelized ²		Modular ³		Manufactured ⁴	
1999	1620	1197	73.9%	40	2.5%	34	2.1%	348	21.5%
2000	1493	1163	77.9%	40	2.7%	39	2.6%	250	16.8%
2001	1450	1184	81.7%	42	2.9%	30	2.1%	193	13.3%
2002	1494	1246	83.4%	46	3.1%	33	2.2%	168	11.3%
2003	1519	1313	86.5%	41	2.7%	33	2.2%	131	8.6%
2004	1664	1454	87.4%	42	2.5%	36	2.2%	131	7.9%
2005	1783	1565	87.8%	44	2.5%	26	1.5%	147	8.2%
2006	1772	1579	89.1%	40	2.3%	35	2.0%	117	6.6%
2007	1316	1166	88.7%	31	2.4%	22	1.7%	96	7.3%
2008	902	779	86.5%	23	2.6%	17	1.9%	82	9.1%
2009	571	497	87.2%	11	1.9%	12	2.1%	50	8.7%
2010	548	473	86.5%	12	2.2%	12	2.2%	50	9.1%
2011	500	427	85.6%	10	2.0%	10	2.0%	52	10.4%
2012	538	465	86.6%	8	1.5%	9	1.7%	55	10.2%
2013	630	548	87.1%	11	1.7%	10	1.6%	60	9.6%
2014	684	601	88.0%	10	1.5%	8	1.2%	64	9.4%
2015	721	628	87.3%	11	1.5%	10	1.4%	71	9.8%
2016	821	713	86.9%	15	1.8%	11	1.3%	81	9.9%
2017	889	769	86.6%	12	1.4%	14	1.6%	93	10.5%
2018	939	812	86.6%	12	1.3%	17	1.8%	97	10.3%
2019	999	879	88.1%	11	1.1%	13	1.3%	95	9.5%
2020	1007	884	87.8%	11	1.1%	17	1.7%	94	9.4%
2021	1077	946	87.9%	10	0.9%	14	1.3%	106	9.8%
2022	1137	997	87.8%	12	1.1%	14	1.2%	113	9.9%
2023	1089	972	89.3%	12	1.1%	15	1.4%	89	8.2%

¹—Number of site-built single-family houses: completed; ²—Number of panelized single-family houses: completed; ³—Number of modular single-family houses: completed; ⁴—Number of manufactured single-family houses: shipped.

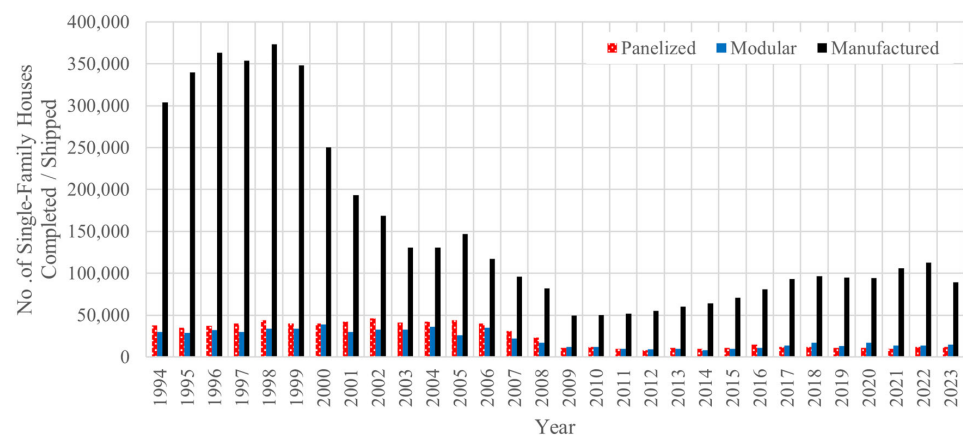


Figure 2. Number of prefabricated single-family houses completed or shipped in United States [7].

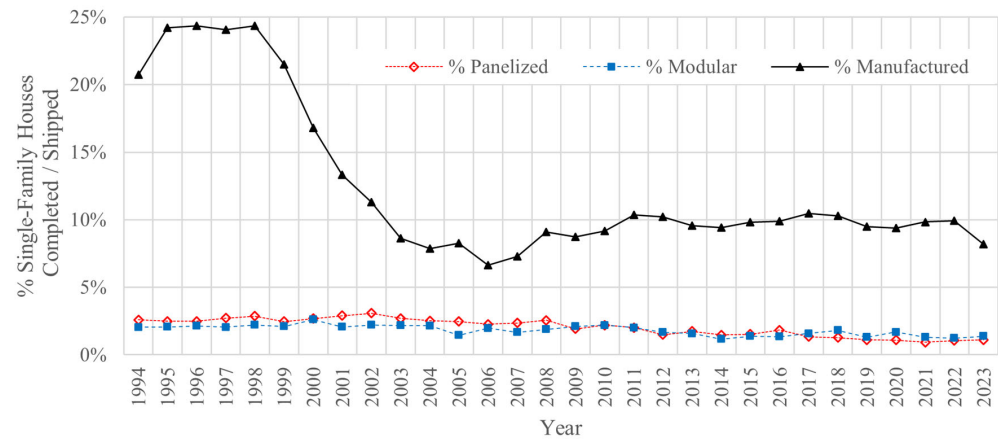


Figure 3. Percentage of prefabricated single-family houses completed or shipped in United States [7].

3. Research Methodology

A thorough literature review was conducted on prefabricated and modular single-family house construction. Database queries were run on ScienceDirect using the keywords “prefabricated modular manufactured residential construction.” With this search, 680 research articles were found in English. The subject areas were limited to Engineering, Energy, Environmental Science, Business, Management and Accounting, Decision Sciences, Material Sciences, and Computer Sciences. The subject areas of Earth and Planetary Sciences, Social Sciences, and Arts and Humanities were removed. Out of these, the dates were limited to 2010 to current (2025), as the number of journal articles were small prior to 2010. Also, conference proceedings were excluded from the literature review. In all, 428 research articles were found in ScienceDirect (see Figure 4). The current year is excluded in the plot.

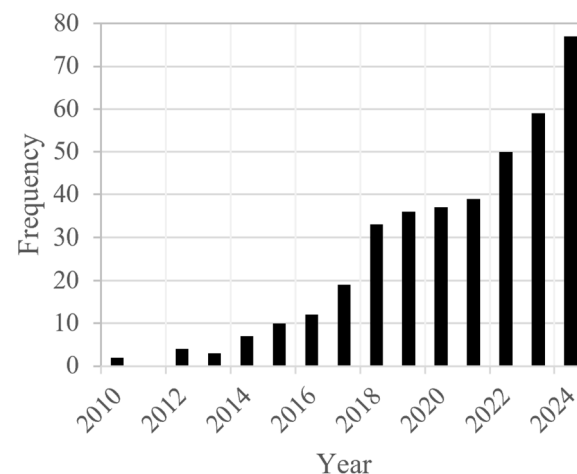


Figure 4. Frequency of research articles for a keyword search of “prefabricated modular manufactured residential construction” through ScienceDirect, between 2010 and 2024 (accessed 5 November 2025).

Using a similar methodology, database queries were run on SCOPUS using keywords “prefabricated” OR “modular” OR “manufactured” AND “residential construction.” This search returned 520 research articles written in English. The subject areas were limited to Engineering, Environmental Science, Energy, Business, Management and Accounting, Materials Science, Computer Science, Mathematics, Economics, Econometrics and Finance, Multidisciplinary, and Decision Sciences. The subject areas of Social Sciences, Physics and Astronomy, Arts and Humanities, Earth and Planetary Sciences, Chemical Engineering, Medicine, Agricultural and Biological Sciences, Chemistry, Pharmacology, Toxicology, and Pharmaceuticals, Psychology, and Health Professions were removed. The entire range of

dates were kept from 1970 to current. Also, conference proceedings were excluded from the literature review. Coincidentally, the same number of 428 research articles were found in SCOPUS (see Figure 5). The current year is excluded from the plot. As SCOPUS is the largest citation database of research literature with a wide variety of peer-reviewed journals, this was utilized as the main data source. Any duplicate articles were reviewed and removed. For inclusion criteria, quality assessment was conducted through reviewing the impact factor of the journal along with the number of citations. Lastly, abstracts were reviewed and categorized to examine the current state of prefabricated single-family house residential construction industry, and to identify research gaps, opportunities, and challenges.

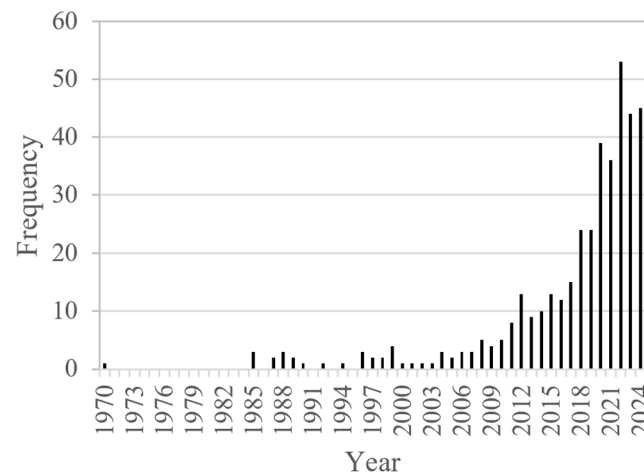


Figure 5. Frequency of research articles for a keyword search of “prefabricated” OR “modular” OR “manufactured” AND “residential construction.” through SCOPUS, between 1970 and 2024 (accessed 5 November 2025).

4. Overview of Prefabricated and Modularized Residential Construction and Its Subfields

To understand the current state of prefabricated and modularized construction, the research articles found were sorted into eight categories, namely, (1) architecture, (2) sustainability, (3) structural, (4) energy or environment, (5) factory build, (6) installation, (7) policy, or possibilities and challenges, and (8) case studies (see Table 2). Qualitative summaries are provided in each section, but quantitative synthesis such as a meta-analysis of the research articles is outside the scope of this study.

Although the research articles have been categorized, many topics have interdependencies and various disciplines usually work together for the final construction project. For example, optimized dimensions not only affect architecture, but also structural (length of gravity or lateral members), factory build (minimizing waste and optimizing productivity), and field installations (modular dimensions impact delivery permits and methods). Material selection also has numerous overlapping effects, including architecture (color, texture, and function), sustainability (sourcing and carbon emissions), structural (material strengths, if used as a structural member), energy (insulation), factory build (familiarity with installations and productivity), and policy (receiving permits). Another example would be in the selection of the structural system. Whether the structural module is constructed from timber, mass timber, cold-formed steel, structural steel, or concrete will affect sustainability, factory build, and field installation (delivery and connections to foundations). These examples are shown in Table 3.

Table 2. Prefabricated and modularized residential construction and its subfields.

1. Architecture	2. Sustainability	3. Structural	4. Energy/Environment
[a] Automated design [b] Active and passive design [c] Optimized design considerations • Modular configurations • Layout designs • Minimize LCA • Minimize energy • Minimize structural waste	[a] Assessment framework [b] Life cycle analysis (LCA) • Materials • Components • Systems • LCA Methods • Design strategies to lower LCA [c] LCA comparisons • Components • Systems	[a] Components • Gravity components/frames • Floors • Walls • 3D printing of concrete [b] Systems • Failure assessment • Structural performance [c] Connections • Structural • Non-structural [d] Existing building assessment	[a] Energy • Efficiency • Cooling/Heating • Performance • Design strategies to lower energy • Wall/envelope components [b] Environmental hazards • Air quality • Climate change • Contaminant exposure • Fire performance
5. Factory Build	6. Installation	7. Policy, Possibilities, and Challenges	8. Case Studies
[a] Supply chain [b] Working conditions [c] QAQC • Quality evaluation • Monitoring damage [d] Waste management [e] Optimization in productivity [f] Scheduling [g] Cost [h] Modular bathroom pods	[a] Assembly • Crane use • Safety • Foundations [b] Delivery optimization [c] Disassembly • End of life	[a] Policies • Europe • Asia • USA • Australia [b] Possibilities and Challenges • Possibilities • Challenges • Economic viability • Buyer preferences • Current practices	[a] Various countries • Europe • Asia • USA/Canada [b] Other • Post-disaster housing • Homeless housing • Senior housing • Temporary housing • Container homes • Net-zero buildings

Table 3. Literature review—Examples of topical interdependencies.

Optimized Dimensions	Material Selection	Structural System
1. Architecture 3. Structural 5. Factory Build 6. Installations	1. Architecture 2. Sustainability 3. Structural 4. Energy/Environment 5. Factory Build 6. Policy	2. Sustainability 5. Factory Build 6. Installation

4.1. Architecture

Although the architectural design considerations, such as site and location, esthetics, space and composition, functionality, acoustics, and scalability are important in all construction projects, in this paper, only the design concerns that are specific to prefabricated and modular designs are presented, within the scope of the literature review methodology.

- a. **Automated design:** To maximize opportunities for cost-effective design, a few studies were found that aimed to automate some of the manual processes in design. In a study by Pibal et al. [8], an algorithm-aided Building Information Modeling (BIM) approach with Revit, Dynamo, and Excel workflow was utilized within the design processes to optimize the manual processes. In another study by Alwisy et al. [9], a 2D computer-aided design (CAD) drawings were utilized to automatically generate BIM models, as well as shop drawings for the wood-framed panels. Automated processes can potentially reduce the design cost, improve layout accuracy, and enhance productivity.

- b. **Active and passive design:** A case-study of an energy-efficient resident building, the TDART house in Morocco, was evaluated for active and passive solar systems along with bioclimatic design to achieve a net-positive energy [10]. The key strategies included a cool roof, optimized orientation, natural ventilation, and insulation. The house's energy performance across lighting, heating, cooling, and hygrothermal behavior was evaluated. The study measured that (1) the heating and cooling demands were reduced by 40.27% and 29.79%, respectively, (2) the house resulted in net-positive energy balance, and (3) the occupants confirmed satisfaction. The case study indicated possible replication and scalability in other areas such as North America's hot climates. In another study in the southeastern Mediterranean climate [11], the authors noted that cooling and heating comprised the greatest proportion of the total energy consumption (73%). Thus, the study aimed to develop passive cooling retrofit design strategies for modular buildings to improve occupants' thermal comfort and reduce the overheating risk. After conducting building retrofits with ventilation and passive shading systems, an approximate 81% reduction in cooling consumption was achieved. Since mass production of residential houses is possible with modular construction, utilizing energy saving or passive designs could be very beneficial.
- c. **Optimized design considerations:** To generate various automated layout designs [12], a study by Wei et al. [13] incorporated design rules and parameters, both from the current building codes and inputs by the user, in BIM. This approach was found to generate fast design layouts with constructability evaluations. To optimize the modular configurations, a study by Liang and Yu [14] presented the design of prefabricated houses based on the optimization theory, modular function, modular design, and modular replacement. Another study [15] examined the optimum module configuration based on crane selection and scheduling methods. It introduced a new parameter called "modular suitability indicator" to accomplish a near optimum selection of modular configuration for an efficient delivery. Other optimized design considerations are covered in the following sub-sections: Section 4.2b (minimizing LCA), Section 4.4a (minimizing energy), and Section 4.5d (minimizing structural waste).

4.2. Sustainability

- a. **Assessment framework:** There are various sustainability metrics utilized to monitor progress, such as the United Nations Sustainable Development Goals. Some of these metrics include measuring the carbon footprint, impact to global biodiversity, economic impacts, and social impacts. Some of the benchmark sustainability frameworks such as Leadership in Energy and Environmental Design (LEED) mainly address the environmental aspects of buildings and do not address economic or social aspects. Thus, a study by Kamali et al. developed and ranked suitable life cycle sustainability performance criteria for modular buildings through a comprehensive literature review and expert interviews [16]. In several studies, a holistic approach was utilized to assess sustainability from various dimensions [17], including economic, environmental and social, accessibility, adaptability, health and comfort, impact on the neighborhood, maintenance and maintainability, safety, and security [18].
- b. **Life cycle analysis:** The life cycle analysis assessment (LCA) studies can largely be categorized into materials LCA [19], components LCA (such as slabs or wall panels [20–24]), or systems LCA [25–28]. There were studies that conducted LCA utilizing a BIM-based approach [29–34], and design strategies were presented for reducing embodied carbon in construction projects [35].
- c. **LCA comparisons:** There were numerous studies that compared the LCA of pre-fabrication methods to conventional methods [36–42]. The results were mixed;

some concluded that neither option is the absolute option, but optimal designs, a decrease in materials, and incorporating mass production can reduce the material and energy consumption [38]. One of the studies compared LCA and the cost of two engineered wood products: cross-laminated timber (CLT) versus glued-laminated timber (GLT) [43].

4.3. Structural

- a. **Components:** There are many new developments in modular construction gravity components such as new flooring or wall systems. For new flooring, there are various composite systems such as timber–steel [44,45], timber–concrete [46,47], hollow cellular panels [48], and composite concrete and expanded polystyrene (RC-EPS slabs) [49]. For new developments in walls or panels, there were prefabricated cross-laminated timber using Australian Radiata Pine [50], composite steel walls [51], infill walls using traditional materials [52], straw bale wall panels [53], prefabricated hybrid steel walls [54], and glass fiber-reinforced rigid polyurethane foam (PUF) and Magnesium Oxide (MgO) boards [55]. Furthermore, the three-dimensional (3D) printing of concrete for modular construction was examined [56–58].
- b. **Systems:** A few different types of failure mechanisms were studied on prefabricated structural systems including multi-family buildings under gas explosions [59] and progressive failure of large-panel buildings [60]. Structural performance was tested in prefabricated buildings constructed of various materials including timber [61,62], cold-formed steel [63,64], and hybrid light steel panel and modular systems [65]. There were also other experimental tests conducted for vibrations in lightweight steel floors [66] and for deformations in multistory large-timber-panel buildings [62].
- c. **Connections:** There were a few experiments that conducted structural performance of inter-module connections using concrete-filled steel tubular columns [67], glued-in multiple steel rod connections in CLT [68], and CLT-panel-to-foundation-angle-bracket connections [69]. For non-structural performance, a seal-sealing joint was tested for airtightness and thermal bridging effects [70].
- d. **Existing building assessment:** For retrofit projects, some were related to (1) occupancy change: for example, a timber residential building that was converted into a shop, nurse, or office [71]; (2) the retrofit of reinforced concrete buildings with prefabricated timber panels [72], and the retrofit of reinforced concrete or unreinforced masonry buildings with textile-reinforced concrete panels; and (3) modernization projects for large-panel construction built in 1970s and 1980s in Central European countries [73].

4.4. Energy/Environment

- a. **Energy:** Energy efficiency was examined for various project locations (1) in Hong Kong for the operational phase of a residential building [74] and (2) for prefabricated buildings in China [75]. Also, energy efficiency was examined for various materials, including phase-change materials in the walls [76], timber buildings [77] and utilizing recycled materials [78].

There were several studies on heating and cooling [79] including topics of ventilative cooling [80] and reducing thermal bridging [81]. Thermal performance was documented in several studies [82,83] and airtightness in wooden prefabricated walls was presented in a study by Piggot-Navarrete et al. [84]. An energy-driven design of lightweight steel-framed modular construction was studied by Rodrigues et al. [85].

- b. **Environmental hazards:** In a paper by Kubeckova et al. [86], the air quality of renovated residential buildings, constructed between 1950 and 1990 using panel con-

struction, was examined in the Czech Republic and Europe. Although the systematic renovations of these buildings led to energy savings, the study reported that this has also contributed to the hygienic damage of housing units and an unhealthy interior microclimate. Thus, this paper examines the interaction between indoor air quality and renovated residential panel buildings.

The next set of papers consider the impact of climate change on future energy demands [87,88], overheating [89], and new construction [90]. There are also studies of radiation exposure to prefabricated modular construction [91,92]. Lastly, the effects of fire hazards were analyzed, including (1) recovery time after a wildfire [93], (2) fire performance of a bearing light gauge steel frame (LSF) wall system [94], (3) heat release and flame propagation of glass fiber-reinforced polymer (GFRP) composite facades [95], and (4) fire performance of organoclay/glass fiber-reinforced polymer composites [96].

4.5. Factory Build

- a. **Supply chain:** In the Kitchener/Waterloo region of Canada, one study developed a framework to source more reclaimed construction materials. Applying their framework into a multi-residential building design to source reclaimed window and door components, the framework selected 35% reclaimed construction materials and 65% new materials [97]. There are other studies that document the viability of CLT sourcing in the United Kingdom [98], as well as procurement options in specific countries, such as Australia [99] and New Zealand [100,101].
- b. **Working conditions:** Skilled labor availability is an important part of prefabricated and modular residential construction. Two types of studies were identified: one that identified the issues of worker availability and another that analyzed multi-worker performance. A study conducted in New Zealand stated that the demand for housing has outgrown the availability of skilled workers; the study aimed to identify these issues within the prefabricated residential constructor sector [102]. In another study [103], a new methodology was developed to model a complex multi-worker physical process to obtain ergonomic and/or performance analysis.
- c. **Quality Assurance–Quality Control:** There are a few studies that evaluated the quality of the prefabricated modular construction [104,105] and monitored damage [106,107] to improve structural stability and optimize the building maintenance management, resulting in reduced economic and environmental costs for renovations.
- d. **Waste management:** Generating waste from construction and demolition is a critical problem, as this is disposed of in landfills. A few studies aimed to reduce waste and to increase waste recycling. Seeboon conducted a study with concrete and masonry unit buildings [108] to determine how much construction and demolition waste (CDW) was generated in the measurements of blocks. By adjusting the floor layout and the building dimensions, the CDW of 16.29% reduced 6.59% in cut-off waste. Another study has quantified construction waste in the early design of Spanish residential buildings utilizing BIM [109] to increase waste recycling. Lastly, a case study in China found that the construction waste of prefabricated systems was reduced when compared with conventionally built systems [110].
- e. **Optimization in productivity:** Effects of productivity on the assembly line of prefabricated and modular buildings can result in significant financial savings. Studies have documented optimizing productivity (1) in component assemblies, such as doors [111]; (2) through scheduling [112]; (3) stacking sequence of pre-cast concrete slab [113] or lean approach to prefabricated wall stacking, sequencing, and locating [114]; (4) logistics in operation (manufacturing, storage, and

assembly) [115]; or (5) through automation in operations [116]. There was also a case study that compared prefabricated construction productivity to that of conventional construction [117,118], and a study in China that combined the advantages of prefabricated construction with traditional methods [119].

- f. **Scheduling:** Similarly, the effects of good scheduling can result in substantial financial savings. A study by Gao et al. studied a residential building project with precast components: by facilitating dynamic planning, scheduling, optimization, and progress monitoring [120], they reported improved efficiency and effectiveness of project execution. Another study [121] aimed to develop a task-based expert system for progress scheduling for the reinforced concrete construction of modular multistory buildings.
- g. **Cost:** The prefabricated costs were generally reported as lower and specific savings were reported in materials [28,78], time [70,117,122], labor, waste [110], and energy or operational costs [10,11,72,78]. Some studies reported cost savings from the use of specific components such as lightweight concrete with recycled materials of granulated expanded glass aggregates (GEGAs) [122] or prefabricated ultra-shallow and lightweight flooring system [21]. There were other studies that reported a higher cost with other advantages. In a case study of a prefabricated modular residential building conducted in South Korea, it was reported that the direct construction cost of the modular construction was 8% more expensive compared to conventional reinforced concrete construction [123] but had reduced environmental impacts.
- h. **Modular bathroom pods:** Prefabricated bathroom pods offer several advantages including time and cost savings, streamlining the construction process and improved quality control. A study in Melbourne, Australia [124], examined these concepts through a semi-modular flexible solution for constructing a residential bathroom “wet” wall in high-rise buildings, where the walls were assembled at a factory, and later installed in the building. The study noted efficiencies in time, labor, and materials, compared to conventional construction. On the other hand, a study in the United Kingdom (U.K.) described the challenges of adopting prefabricated bathrooms [125,126]. This study stated that the lack of use in the U.K. is due to the perception that the maintenance is difficult and expensive. This study conducted cost comparisons of precast concrete modules, glass-reinforced polyester (GRP) modules, and conventional bathrooms. Their results showed that the GRP modules required the lowest maintenance costs, while conventional bathrooms were significantly more expensive to maintain. Another use for prefabricated bathrooms was in rural areas, where finding the best Mechanical, Electrical, and Plumbing (MEP) systems was difficult. A study was conducted in a rural and isolated region in Nunavik, Quebec; they found that a modularized MEP system demonstrated a reduction in installation cost and an increase in local job creation [127].

4.6. Installation

- a. **Assembly:** Once the prefabricated modular structures are constructed at a factory, they are delivered for on-site assembly. At this stage, studies were found in (1) erection or assembly methods, (2) guidelines for hybrid modular buildings that allow module interchangeability and fast plug-in and plug-out methods, (3) site layouts for hoisting efficiency, (4) jobsite safety, and (5) foundations.

To effectively assemble the prefabricated modular buildings, a study in Tehran, Iran [128], examined various production and erection methods that reduced the production and erection time and cost. A study by Di Pasquale et al. aimed to define guidelines and considerations for hybrid modular buildings, where interchangeable and fast plug-in and

plug-out modular systems can be installed next to a permanent building [129]. Another study explored construction site layout plans that optimized safety, transportation cost, and hoisting efficiency [130]. Jobsite safety was explored using various perspectives, including safety management [131], management factors on unsafe behaviors [132], and assessing injury risks [133]. Research on foundations was obtained on the topics of prefabricated concrete foundations [134,135], carbon emission-based foundation options for prefabricated construction [136], base-isolated foundations [137], and integrated strip foundation systems that are designed to be handled on site by one person [138].

- b. **Delivery optimization:** In prefabricated construction, transportation is essential in linking a factory to a project's jobsite. In these projects, transportation is often considered a fixed-cost, but a study by Ahn and Al-Hussein [139] developed a GPS-data-based prediction model to estimate the number of trailers and duration.
- c. **Disassembly:** Although there is an emphasis on circularity principles in prefabricated design, there is a lack of written guidance for the disassembly or recycling of the construction materials. A study by Torres et al. [140] deconstructed the disassembly actions, identified the level of difficulty, and classified the recovered materials into three categories: reusable, recyclable, and waste. They found that the lack of design criteria or information for disassembly significantly limited the system's circularity, as it prioritizes assembly speed and energy performance. This study aimed to establish a design of lightweight timber-framed panel design toward systems more aligned with circularity principles. In another study [141], the authors discussed ways of repurposing precast modules in new layouts with the "design for disassembly" concept.

4.7. Policy, Possibilities, and Challenges

- a. **Policies:** To build prefabricated homes, various policies should be implemented to reach housing, affordability, and sustainability goals. Various papers described the current policies, initiatives, or ways to implement guidelines in Europe [142], such as the United Nations' Waste Framework Directive aiming at reuse instead of recycling [143], Asia [144–147], the United States [148], and Australia [149].
- b. **Possibilities and challenges:** A study by Kirscheke and Sietko explored the potential of prefabricated construction in Poland and Germany [150], while various papers indicated that education or enablers need to be implemented to realize the potential of prefabricated construction in Egypt [151], China [152], Malaysia [153], and Hong Kong [154].

Conversely, some papers discussed other barriers to the adoption of prefabricated construction such as the knowledge gap and undesirability in developing countries [155], Malaysia [156], Egypt [157], Australia [158], and China [159]. In developing countries, the top three adoption barriers for prefabricated construction were cost, coordination, and standards. There were also technical and practical barriers, inflexibility and supply chain barriers, abilities and awareness barriers, and societal and desire-related barriers [155]. Another study identified infrastructure limitations, economic inequalities, and resource constraints as major barriers to the adoption of prefabricated construction in Egypt [157].

Some papers addressed both the possibilities and challenges in Australia [160,161].

One study by Mandoki and Orr discussed buyer preferences in Hungary among young adults [162]. To examine Hungarian young adults' (aged between 18 and 40) attitude towards buying prefabricated buildings and living in environments with reduced diversity, 100 people were surveyed. Their results showed that the former aversion towards industrialized housing solutions no longer existed among young adults in Hungary. They were only negative about having to see dwellings identical to theirs on a regular basis.

Thus, the researchers found non-uniform standardization to be a suitable tool to provide affordable housing in Hungary.

A study by Viriezky et al. explored the viability of prefabricated construction in Indonesia [163]. Another study discussed the challenges in opening factories in sub-Saharan Africa [164], such as a lack of sufficient development and participation from regional contractors. To boost prefabrication construction industry in sub-Saharan Africa, the study identified significant factors influencing the establishment of prefabrication factories. Chinese and international experiences were leveraged to encourage international knowledge transfer. Lastly, a study by Karthikeyan et al. [165] described India's current practices in prefabricated versus conventional construction.

4.8. Case Studies

- a. **Europe:** There were various case studies conducted on prefabricated housing including new and existing projects in London [166], the Soviet Union [167], Finland [168], and Italy [169].
- b. **Asia:** In Asia, there were case studies reported from China [170,171], Malaysia [172], and South Korea on rental housing development [173].
- c. **Canada:** A case study was reported from Quebec, Canada [174].
- d. **Other:** Other case studies consisted of (1) post-disaster housing, including earthquakes [175,176]; (2) senior affordable housing [177]; (3) temporary housing for refugees [178] and migrant workers in China [179]; (4) tiny portable housing in the Netherlands [180]; (5) container homes [181]; and (6) net-zero buildings [182,183].

5. Opportunities and Challenges

So far, this paper has presented the current status of prefabricated modular construction through a systematic literature review. Now, the aforementioned section will be further summarized with discussions of emerging trends, future opportunities, and challenges.

5.1. Emerging Trends

Mass Timber: Currently, there are emerging trends in mass timber within the construction industry; it is being used for taller building designs, and the material has been advocated for its focus on sustainability such as carbon sequestration. Furthermore, there have been advancements in digital design and prefabrication using Computer Numerical Control (CNC) technologies, that facilitate the use of mass timber in mass production.

There are also innovations in new mass timber materials, such as transparent mass timber. This is created by removing or modifying the lignin in wood and replacing it with a polymer, so that the material allows light to pass through. There are also new mass timber hybrid systems, such as post-tensioned timber or systems that combine mass timber with steel or reinforced concrete to leverage the strengths of each material.

For additional resources, TallWood Design Institute (TDI) is a partnership between Oregon State University (OSU) and the University of Oregon (UO) that focuses on mass timber and wood products building solution initiatives, education, and research collaborations; many new initiatives can be found there. Moreover, Mass Timber+ is an Offsite Construction conference in the United States that has a primary focus on mass timber and hybrid solutions.

AI in the Construction Industry: The use of artificial intelligence (AI) in the construction industry is also an emerging field. A study conducted by Abioye et al. [184] defined its application areas within the construction industry including health and safety, scheduling, cost estimation, legal (contracts and conflict management), supply chain and logistics, site monitoring and performance evaluation, material management, offsite assembly,

plant and equipment management, project planning, knowledge management, design, risk management, temporary structures, bids/tenders, energy management, and sustainability.

5.2. Opportunities

Modular Connections: As new materials, components, and systems are developed for prefabricated modular homes, new connections are also needed. There are connections (1) between the modules and (2) between the modules and the foundations. Since many contractors lack experience working with new materials and prefabricated elements or buildings, there is a need to develop connections that are simple and easy for installation and can meet load-carrying capacity and structural performance under appropriate loads.

Lack of Research: As shown in Table 2 and Section 4, some areas of prefabricated modular housing such as transportation did not yield many research articles. Some potential topics for this area include modular delivery methods including various types of truck availability, single-use weather wrap materials for the modules, optimized routes, contractors' preferred delivery methods versus sustainable options, availability of sustainable trucking options, and compatibility with permits.

Commercialization of Intellectual Property: The new developments in prefabricated building materials, components, systems, and accessories (automated blinds or home integration systems) shape and promote new startup opportunities to commercialize the developing intellectual property. For the entrepreneurs in the U.S., there are many startup incubators throughout the country to accelerate the commercialization of new technology and job creation.

Entrepreneurship: For large-scale entrepreneurs in the U.S., there is currently funding available to develop manufacturing factories through the Department of Energy Loan Programs Office (DOE LPO) Title 17 Clean Energy Financing. The DOE LPO provides access to debt capital for high-impact energy and manufacturing processes. There are two applications: (1) Part I: Concept and Viability, where the evaluations will focus on whether the applicant is able to achieve sufficient sales of its products to sustain long-term existence; and (2) Part II: Additional Resources and Due Diligence, where the business plan and financial plans will be evaluated.

5.3. Challenges

Adopting prefabricated modular houses into the residential construction sector will require a balance of demand, positive perception, and effective policy to implement these projects at scale. Below are several challenges that will need to be addressed during implementation.

Lack of knowledge and skillsets: One of the most fundamental barriers to prefabricated modular construction is that it is not well understood. From developers to tradespeople, with key professionals like architects, engineers, and regulators, and with home buyers, there is a general lack of awareness and technical background to design, finance, check, and construct these homes. Some of the challenges that can arise are potential incompatible procurement approaches and delays in the design, review, and approval of projects.

Policy: To effectively adopt prefabricated modular construction at mass scale, a streamlined regulatory approval will be needed, including clear building codes, streamlined plan approvals and inspections, and guidelines for the foundations.

Perception: There is a potential that people may view prefabricated homes as having lower quality, durability, and lower resale values than conventional homes. More research will need to be conducted to understand the current perception and efforts will need to be made to potentially enhance the perception of prefabricated homes.

5.4. Limitations

The author recognizes that there are important aspects of prefabricated modular homes that were not addressed in this paper, including but not limited to home integration systems, photovoltaic and energy storage systems, or other aspects of sustainability such as water conservation, due to the limitations in the keyword search. For example, photovoltaic and energy storage systems will likely appear in a “residential construction” search, but not in a “prefabricated modular manufactured residential construction” search. Thus, a future study that incorporates these topics together would be recommended. Furthermore, Social Sciences and Humanities were excluded from this literature review, but in a future study, this would potentially offer further insight into perception challenges. Also, there are many noteworthy conference papers that document the advancements in prefabricated and modular housing, such as a small-mass timber prototype house [185], that were not included in this literature review.

5.5. Future Work

Global Comparisons: A comparative study of foreign policies as well as current design and construction practices in various regions, such as Europe, Asia, Australia, the U.S., and so forth, will greatly help the implementation of prefabricated modular residential housing internationally.

Quantitative Analysis: A meta-analysis of the sections mentioned in Table 2, such as LCA results in carbon emissions, prefabricated construction cost savings, time savings, energy performance, and cost, will be helpful in quantifying the average percentage reductions across the vast literature.

6. Conclusions

This study contributes to the existing body of prefabricated and modular residential construction literature by integrating its historical background, current market data, policy, and scholarly research. Despite the rising popularity of prefabricated and modular construction, the literature on this construction method has not been synthesized for a comprehensive summary.

First, a thorough literature review of the prefabricated and modular residential construction was conducted. A database search was conducted using SCOPUS, from 1970 to the present (2025). Trends in the literature were described. The sub-fields were identified as (1) architecture; (2) sustainability; (3) structural; (4) energy or environment; (5) factory build; (6) installation; (7) policy, possibilities and challenges; and (8) case studies, to organize and to present the qualitative summaries.

Next, the historical and current market trends in the new single-family house industry were analyzed between 1994 and 2023, for site-built versus prefabricated (panelized, modular, and manufactured) construction in the United States. Since 2003, the prefabricated new single-family house industry has consistently captured between 10% and 15% of the U.S. market share. The regulatory processes to receive building permits through the U.S. Department of Housing and Urban Development (HUD) was also presented. The emerging fields within the construction industry were acknowledged as mass timber and the use of artificial intelligence, as they are penetrating the prefabricated and modular housing industry. The opportunities were noted for new materials, components, systems, and connections, as well as the areas that returned a smaller number of articles and needed further research, such as delivery methods and optimizations. There is an immense opportunity to commercialize intellectual property as well as entrepreneurship opportunities in mass production. The three main challenges were noted: the potential lack of awareness or knowledge in this field among the stakeholders including designers, tradespeople, developers, and regulators,

as well as home buyers; a lack of streamlined policy; and possible negative perceptions. The incorporation of prefabricated modular houses into the residential construction sector will require a balance of demand, positive perception, and effective policy that will define a pathway for implementation.

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