

Review Article

Floating house for climate resilience: A systematic review of design platforms, hydrostatics, and stability

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Article information	Abstract
Received: February 3, 2026 Revision: June 10, 2026 Accepted: June 15, 2026	Rising sea levels, increasingly frequent coastal flooding, and rapid shoreline urbanization demand housing that can adapt safely to changing water levels. This study aims to systematically review the literature on floating and amphibious housing, with particular emphasis on how platform typologies, hydrostatic behaviour, and stability performance influence residential habitability and climate resilience. Using a PRISMA-style systematic review approach, peer-reviewed English-language publications published between 2016 and 2025 were identified from Scopus and Web of Science. A total of 286 records were retrieved, screened, and assessed for eligibility, yielding 34 studies for the final synthesis. The findings are organized into four interconnected domains: platform typologies, materials, and modular design strategies; geometry-hydrostatics-buoyancy relationships; hydrodynamic response and mooring systems; and governance readiness, public acceptance, and service autonomy. The review shows that pontoon-based systems remain the most cost-effective and widely used option, but they often require additional motion-control measures and carefully designed shore interfaces to maintain comfort under wave and current exposure. Catamaran, semi-submersible, and amphibious hybrid systems generally offer better dynamic performance, though they entail greater technical complexity, higher costs, and greater regulatory demands. Overall, the review demonstrates that floating housing should be evaluated as a socio-technical system in which stability is not only a safety requirement but also a key determinant of long-term livability, scalability, and implementation feasibility.
Keywords Amphibious architecture; Climate resilience; Coastal adaptation; Floating housing; Hydrostatics and stability	

1. Introduction

Accelerating sea level rise and an increasing frequency of coastal flooding require new forms of climate resilient housing, and in this regard, floating and amphibious dwellings have been identified as effective types of resilient housing, as they can move with the water: rising with the increased flood levels and then returning to their original position as waters recede. This ability helps prevent structural damage and reduce the displacement of people (Ghani & Hidayati, 2024; Niamir & Pachauri, 2023), which is not simply an exercise in architectural design speculation, but rather a practical response to the destabilizing effects of anthropogenic climate change, seeking to maintain safe, usable, and long-lasting homes in highly vulnerable coastal areas (Ameh et al., 2024; Rosso et al., 2020). However, there are significant challenges in the large-scale practical application of floating

architecture, which include high upfront construction costs, the absence of consistent design and safety standards, and limited real-world testing of material performance in the context of complex wave and current conditions (Adithya & Manoj, 2021; Rosso et al., 2020), as well as institutional and political challenges, such as fragmented municipal responsibilities, unclear legal frameworks, and a deep-seated attachment to traditional ground-based housing models (Meng et al., 2020; Piątek & Wojnowska-Heciak, 2020).

Technical reliability alone is insufficient to enable floating and amphibious housing to move from experimental projects to widely accepted solutions, because planning systems, policies, and design processes need to be responsive to them, and they must also engage with local communities (Luccioni et al., 2024; Niamir & Pachauri, 2023; Suntoro et al., 2025). Climate resilience can be defined as the ability of a system to resist, adapt to, and recover from long-term and sudden climate-related stresses, and in the case of floating residential architecture, this resilience is achieved through: buoyant foundations that enable the structure to float; flexible mooring systems that allow controlled movement; and modular platforms that can maintain habitable conditions under changing water levels (Rosso et al., 2020). Moreover, architectural resilience in this context means maintaining safety, comfort, and a degree of independence during environmental disruptions, thereby protecting the physical infrastructure of housing and the social and spatial continuity of daily life (Paneliya & Suhane, 2025), which is therefore crucial for the success of floating and amphibious housing.

Existing flood mitigation practices (e.g., static elevation, embankments, levees) are increasingly criticized for their inability to address the unpredictability and long-term progression of sea-level rise, and they also have other limitations, such as limiting land use and displacing floodwater to other areas, which increase downstream risk via hydrodynamic displacement effects (Piątek & Wojnowska-Heciak, 2020). In contrast, floating and amphibious housing offer a more inherently adaptive alternative because, rather than attempting to hold water back, environmental variability is built directly into the design, allowing homes to rise and fall with changing water levels without compromising safety or daily usability (Paneliya & Suhane, 2025).

However, floating housing can only be successful if it combines robust hydrodynamic engineering with human-centered architectural design, which requires that stability metrics (e.g., metacentric height, righting-arm characteristics, buoyant equilibrium) must directly inform space planning to allow residents to conduct daily activities without excessive motion, discomfort, or disorientation (Patil & Karmakar, 2025).

Although literature on floating and amphibious housing has grown rapidly in recent years, much of it remains concentrated in single-case studies, pilot projects, or discipline-specific analyses that offer limited comparability across contexts (Rosso et al., 2020; Zhang et al., 2021). This makes the present review especially timely. The urgency no longer lies only in identifying whether floating housing can work in isolated settings, but in understanding how different platform typologies, hydrostatic properties, hydrodynamic constraints, and governance conditions interact to determine real-world residential performance (Patil & Karmakar, 2025; Paneliya & Suhane, 2025). Such a synthesis is increasingly needed because climate-driven coastal risks are intensifying, experimental projects are beginning to inform policy and planning discussions, and the growing diversity of technical and socio-institutional approaches makes it difficult to derive transferable design knowledge from case-specific evidence alone (Ameh et al., 2024; Meng et al., 2020; Niamir & Pachauri, 2023; Suntoro et al., 2025). For these reasons, a systematic review is necessary at this stage to consolidate fragmented findings into a more holistic and comparable framework for evaluating the habitability, feasibility, and scalability of floating housing (Luccioni et al., 2024; Rowell et al., 2024).

The strong interdependence between structural performance and residential habitability necessitates an integrated design approach in which platform behavior, vibration control, and spatial layout are considered together (Patil & Karmakar, 2025; Szymczak-Graczyk, 2020). Although research on floating and amphibious housing has expanded in recent years, important analytical gaps remain, particularly the lack of integrative frameworks linking platform typologies, hydrostatic

behavior, and dynamic stability to real-world residential performance across different regulatory and environmental contexts (Zhang et al., 2021). In addition, long-term evidence on how floating housing interacts with broader social and ecological systems remains limited (Rowell et al., 2024).

To frame this integrative perspective, the Graphical Abstract presents floating housing as a climate-resilient residential system shaped by four interconnected domains: platform typologies and modular strategies; hydrostatics, buoyancy, and stability; hydrodynamic response and mooring systems; and governance, public acceptance, and service autonomy. It therefore serves not only as a visual summary but also as a conceptual guide to the multi-scalar relationships examined in this review.

Accordingly, this systematic review clarifies the relationships among platform design, hydrostatic mechanics, and residential habitability, identifies key knowledge gaps, and outlines a future research agenda for scalable climate-resilient floating urbanism.

2. Methods

2.1 Search strategy

A systematic literature review (SLR) was used as the research methodology to ensure the transparency, methodological rigor, and reproducibility of the research (Baweja, 2025; Yahia et al., 2024), and this study applied a synthesis of qualitative and quantitative mapping approaches to explore the interplay between engineering performance and architectural habitability of floating and amphibious housing. Two prominent academic databases (Scopus and Web of Science) were selected for this research because they provide comprehensive and reliable coverage of architecture, engineering, and climate change adaptation. The search focused on peer-reviewed English-language journal articles published from 2016 to 2025 and covered both the technical and socio-environmental dimensions of floating residential systems. A multi-stage Boolean search strategy was used to achieve high precision and thematic relevance (Ameh et al., 2024; Naseri et al., 2024).

Keyword combinations included:

Foundational descriptors: "floating housing" OR "amphibious housing" OR "floating structures."

Climate-relevance connectors: ("climate resilience" OR "flood adaptation") AND ("urban design" OR "sustainable architecture")

Technical specificity: ("buoyancy" AND "stability") OR ("hydrodynamics" AND "amphibious architecture")

Contextual filters: ("design" OR "engineering performance") AND ("flood-prone areas" OR "coastal architecture")

The search was conducted between October and December 2025, yielding a dataset that reflects both the evolution and the current state of scholarship on floating residential adaptation strategies.

2.2 Eligibility criteria

To ensure conceptual cohesion and methodological robustness, a dual-layered eligibility protocol was applied, encompassing both inclusion and exclusion thresholds (Choorapulakkal et al., 2024; Dhanuskar, 2024).

Inclusion Criteria:

Articles must explicitly examine floating or amphibious housing systems in relation to residential function.

Eligible studies include empirical investigations or theoretical contributions focused on engineering metrics, platform design, hydrostatic stability, or occupant-centered habitability.

Sources must be peer-reviewed, written in English, and published within the 2016 - 2025 timeframe to ensure currency and relevance.

Exclusion Criteria:

Literature centered exclusively on offshore or marine engineering applications without architectural or residential relevance.

Grey literature, such as blogs, opinion pieces, and non-peer-reviewed publications, was excluded to maintain academic integrity. This exclusion was intended to preserve source quality, methodological transparency, and comparability across the reviewed studies. However, because floating housing remains an emerging practice-oriented field, this decision may have limited the inclusion of recent implementation evidence from pilot projects, municipal reports, technical documentation, and other practice-based sources not yet represented in peer-reviewed journals.

Future reviews may, therefore, adopt a mixed-evidence approach that incorporates validated grey literature, including municipal reports, technical design documents, post-occupancy evaluations, and monitored pilot-project records, where these sources provide transparent methods and verifiable implementation data. Such an approach would help capture emerging practice-based evidence while preserving the methodological boundary of the present review, which is restricted to peer-reviewed academic publications.

Studies lacking abstracts or published prior to 2016 were disregarded due to potential obsolescence in technical and climatic relevance (Storbjörk & Hjerpe, 2022).

This eligibility schema ensured the analytical coherence of the final dataset and aligned it with the interdisciplinary scope of the SLR.

2.3 Screening and selection process

Adhering rigorously to PRISMA protocols, the screening and selection process followed a structured four-stage progression (Adeola & Peters, 2025; Raza et al., 2025):

- 1) Identification: An initial corpus of 286 publications was retrieved across Scopus and Web of Science using the Boolean search syntax.
- 2) Deduplication: Redundant entries ($n = 25$) were eliminated through DOI and title-based metadata comparison.
- 3) Screening: Titles and abstracts of the remaining 261 unique entries were systematically reviewed for relevance to floating or amphibious residential design.
- 4) Eligibility and Inclusion: Full-text assessments were conducted for 261 shortlisted articles, from which 34 studies met all inclusion criteria and were admitted into the final review synthesis.

The multi-step process is shown in **Figure 1** in a PRISMA flow diagram that details the process from initial record identification, through screening and eligibility checks, to the final set of studies included in the review, and by applying this comprehensive screening pipeline based on SLR and PRISMA protocols, the study provides a robust and transparent evidence base to investigate the interaction between hydrostatics, platform design, and structural stability in the new domain of climate-resilient floating housing

3. Theoretical background

3.1 Hydrostatic and stability principles in floating residential architecture

In terms of the design of floating residential platforms, hydrostatics- the study of the behavior of submerged or partially submerged bodies at equilibrium- is the most dominant, and the most relevant concept in this field is buoyancy, which refers to the upward force exerted by displaced water. The buoyant force must counteract dead load (the weight of the structure itself) and live load (generated by the occupants, furniture, and other changes in the environment) to maintain adequate freeboard and prevent excessive immersion (Cahyono, 2024), because this is crucial for the overall stability of the platform. **Figure 2** gives a concise summary of the most important theoretical elements of hydrostatic stability for floating platforms and shows how they directly relate to a house's real-world performance, which illustrates that the vertical distance between the center of gravity (CG) and the center of buoyancy (CB) defines the metacentric height (GM), where the metacenter (M) acts as

a reference point to determine if the system is in stable equilibrium. The righting arm (GZ), which is the horizontal distance between CG and CB when the platform is heeled, defines the magnitude of the restoring moment when the structure is subjected to a sideways force, and these concepts are not esoteric naval-architecture abstractions, but directly determine how a floating house responds to real-world disturbances such as waves, occupants' movement, and wind loads. Moreover, lower CG and well-optimized GM and GZ values make the platform more resistant to undesirable rolling or tilting, which in turn impacts how safe, comfortable, and regulation-compliant the dwelling feels in practice. In summary, this framework suggests that floating residential systems must be evaluated for not only the capacity to float, but also the capacity to maintain everyday habitation under a range of changing dynamic conditions.

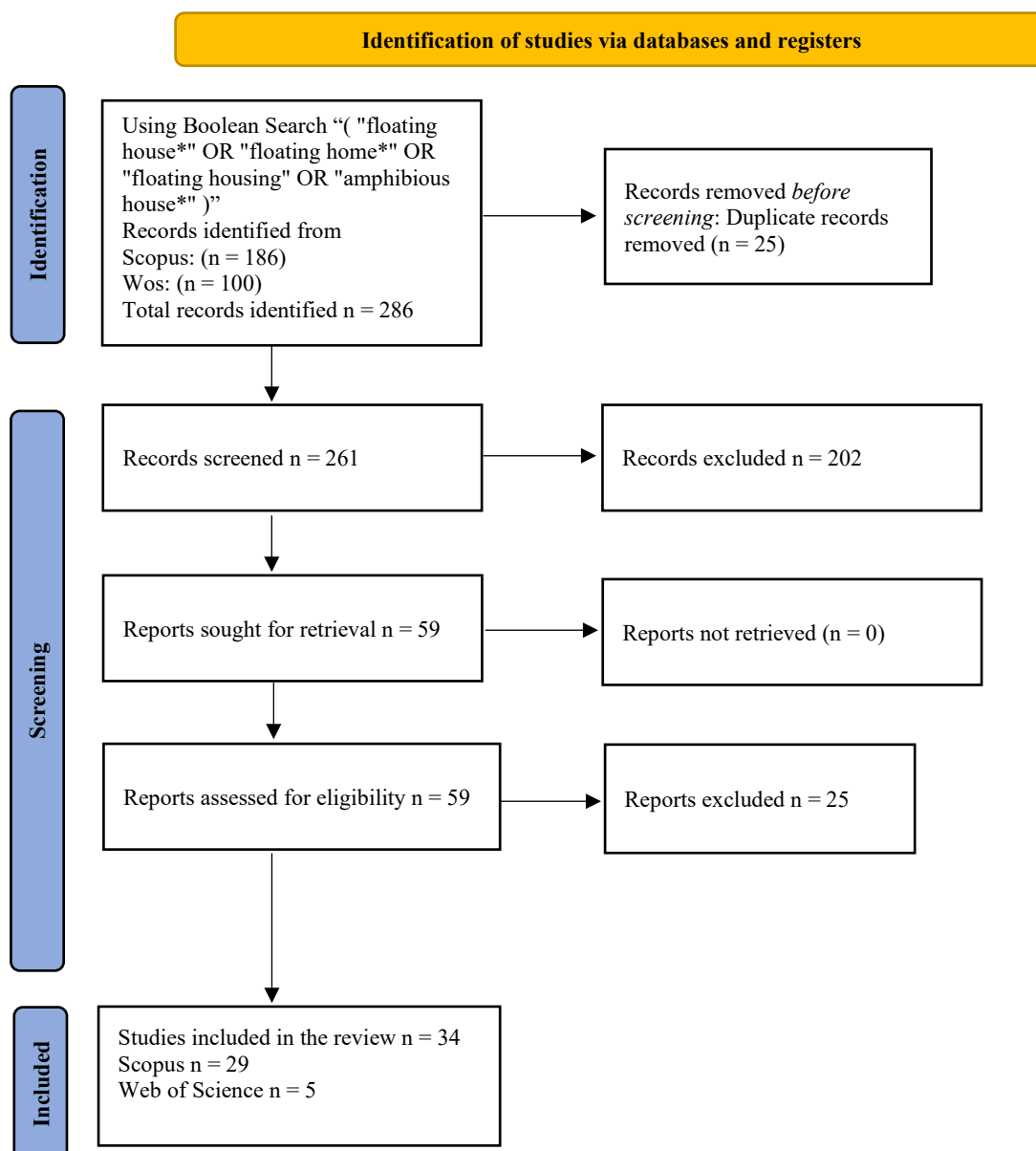


Figure 1 PRISMA flow diagram showing the identification, deduplication, screening, eligibility assessment, and final inclusion of studies in the systematic review. A total of 286 records were identified from Scopus and Web of Science, 25 duplicates were removed, 261 unique records were screened, and 34 studies were included in the final synthesis.

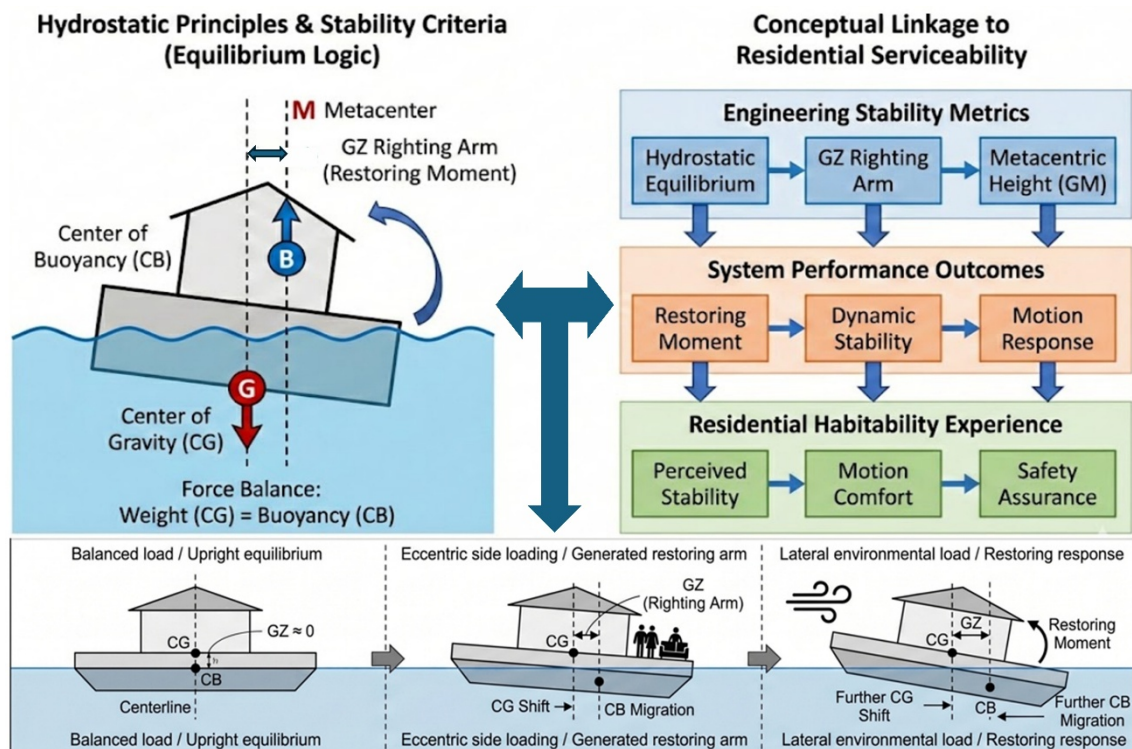


Figure 2 Conceptual linkage between hydrostatic parameters, center of gravity (CG), center of buoyancy (CB), metacenter (M), and righting arm (GZ), and their influence on residential stability, comfort in floating housing systems, and a schematic illustrating how CG, CB, and GZ evolve under balanced, eccentric, and laterally forced loading conditions to clarify the restoring mechanism during heel. Illustrative schematic only; not to scale.

Figure 2 has also been expanded with a supplementary sequential schematic illustrating how the relationship between center of gravity (CG), center of buoyancy (CB), and righting arm (GZ) evolves under simplified loading scenarios. In addition to the initial equilibrium condition, the revised figure now shows eccentric side loading and laterally forced heel to clarify how changes in load distribution or external forcing shift CB, generate GZ, and produce restoring action. This addition makes the concept of righting arm more intuitive for non-specialist readers by linking hydrostatic stability to physically recognizable residential loading situations (Ameh et al., 2024; Cahyono, 2024; Zheng et al., 2025).

Displacement, the volume of water displaced by the structure, is proportional to the maximum weight that can be safely supported by a floating platform, which requires a carefully managed weight distribution in a floating house, to ensure that the platform remains level in the water and does not develop an unwanted trim (bow-stern tilt) or heel (sideways tilt). The relationship between the center of gravity (CG) and center of buoyancy (CB) is particularly important in determining how the structure responds to changes in loading, because a lower CG generally increases stability, while the CB changes in response to changes in the submerged shape of the structure. The two together determine whether and how the platform will return to an upright position after it is disturbed (Cahyono, 2024), and several important stability parameters are used to characterize and design for this behavior. The metacentric height (GM), which is the distance between the CG and the metacenter, is a basic measure of initial stability, and higher GM values generally indicate that the platform is less likely to roll or pitch when subjected to side forces such as waves or wind (Ameh et al., 2024), while the righting arm (GZ), which is the horizontal distance between the CG and the vertical line through the CB when the structure heels, is the lever arm of the restoring moment generated by buoyancy (Cahyono, 2024). Angle of vanishing stability (AVS), the heel angle beyond which the platform can

no longer right itself and will capsize, is another important parameter, because it provides information on how resistant a floating dwelling is to extreme disturbances (Ameh et al., 2024).

Although classical hydrostatic parameters such as GM and GZ remain fundamental for the preliminary assessment of floating residential stability, their practical relevance must ultimately be tested against field performance under real operating conditions. Published long-term in-situ datasets for residential floating housing are still limited, but recent monitoring studies on analogous floating structures demonstrate the kind of empirical validation that is needed. Long-term on-site observations of a semi-submersible-type very large floating structure recorded waves, structural responses, connector forces, and mooring-line forces continuously for more than 1.5 years, showing the value of sustained monitoring for validating behaviour predictions under changing environmental loads (Wu et al., 2021). Likewise, measurement data from the full-scale TetraSpar prototype have been used to reconstruct structural states and fatigue-relevant loads under operational conditions, illustrating how real-time sensing can connect predicted structural behaviour with actual in-service response (Branlard et al., 2024). Real-time safety assessment studies on in-service floating platforms further show that monitored structural response data can support condition-based evaluation under time-varying loads (Li et al., 2024). For floating housing, these findings reinforce that buoyant equilibrium, GM, and GZ should be interpreted not only as design parameters but also as performance variables that require validation against long-term measurements of motion, load transfer, and serviceability in real environments (Cahyono, 2024; Ameh et al., 2024; Tsao et al., 2025).

Despite these advances in monitoring analogous floating structures, a major evidence gap remains for residential applications. No long-term open-access dataset for residential floating-house monitoring currently exists. This absence limits the ability to calibrate hydrostatic and serviceability models against real occupancy patterns, seasonal water-level variation, wave exposure, mooring loads, and resident comfort over time. Future floating-housing research should, therefore, prioritize longitudinal field monitoring that links platform motion, load transfer, hydrostatic stability, and post-occupancy experience under real environmental conditions.

3.2 Platform typologies and the geometry hydrostatics interface

Floating housing platforms can be generally grouped into a few main types, each having the hydrostatic and geometric logic that makes it suitable for a variety of water and climate conditions:

- Pontoon platforms are built on large, shallow floating elements having a high waterplane area, which gives the structure high initial stability and an impression of relative steadiness in calm or light conditions. However, high waterplane area also makes the structure more sensitive to waves and increases vertical and lateral motions, therefore requiring robust mooring and anchoring systems to control horizontal motions (Bachynski & Eliassen, 2019).
- Catamaran platforms, on the other hand, are built on two parallel hulls separated by a wide beam, and the separation between the hulls and the length-to-beam (L/B) ratio give very good transverse stability, which effectively reduces roll and provides good comfort in semi-dynamic water conditions, such as sheltered bays or estuaries with moderate wave activity (Barooni et al., 2022).
- Semi-submersible platforms distribute buoyancy on columns or pontoons located deeper below the water surface, and the low center of gravity and small waterplane area give favorable values of metacentric height (GM) and righting arm (GZ) that strongly dampen pitch and heave motions, making them suitable for high-exposure or wave-active sites where motion control is critical for habitability (Yang et al., 2020).

Although semi-submersible platforms generally provide superior motion control because their reduced waterplane area and lower center of gravity help dampen pitch and heave, these benefits are usually achieved through more complex structural and operational arrangements. In practice, semi-submersible systems often rely on multiple submerged columns, connecting pontoons or bracings, carefully managed ballast distribution, and more demanding mooring and installation requirements, which together increase fabrication complexity, structural analysis needs, and maintenance burden

(Edwards et al., 2023; Ghigo et al., 2020; Ivanov et al., 2023; Yang et al., 2020). Recent technical studies also show that platform performance in such systems depends on design choices that must simultaneously satisfy strength, manufacturability, and cost constraints rather than hydrodynamic efficiency alone (Ivanov et al., 2023; Wang et al., 2025). These limitations are especially important in the context of affordable mass housing, where shallow-water deployability, ease of transport and assembly, modular repair, and low-cost replication are often more critical than maximizing offshore-style motion performance. More broadly, the wider floating-structure literature indicates that complex floating foundations require standardized design solutions, advanced installation strategies, and robust mooring systems before they can become scalable and economically viable in practice (Hong et al., 2024; Jiang, 2025). For this reason, while semi-submersible logic is highly valuable in exposed or wave-active environments, its translation into affordable, large-scale residential housing remains constrained by technical complexity and cost.

- Moreover, amphibious systems combine land-based and floating performance and, under normal conditions, sit on the ground and act like regular houses but, during flooding, float on buoyant elements. The performance of these systems is governed by hydrostatic behavior when afloat and by soil-structure interaction when on the ground, so their design should account for foundations, guiding posts, or piles, as well as buoyant capacity, resulting in a more complex and multifaceted engineering problem (Bayati et al., 2020).

A key set of geometric ratios and coefficients applies to all types of platforms, and it governs hydrostatic performance. The length-to-beam (L/B) ratio is particularly important because it influences both stability and hydrodynamic resistance. In general, higher L/B ratios produce better maneuverability and less drag, but less roll stiffness and greater “tender” behavior in lateral motions (Yu et al., 2020), while the center of buoyancy coefficient (CB) is used to trace the migration of the center of buoyancy with varying loading conditions, which is crucial for accurate predictions of dynamic equilibrium and for guaranteeing that the platform can safely withstand variable occupancy and environmental loads (Yang et al., 2020). The waterplane area coefficient (CW) governs the interaction between the platform and the wave action in the vertical and rolling directions, as it affects roll damping and heave response and, hence, CW directly influences not only motion behavior under wave loads but also daily user comfort and the long-term structural durability of floating dwellings (Santo et al., 2017).

3.3 Stability beyond compliance: Toward habitability

Traditionally, stability concerns in floating houses have been confined to regulatory safety standards and mechanical performance in extreme loading conditions but, according to codes and standards, minimum allowable limits have been defined for parameters like metacentric height (GM), righting arm (GZ) and angle of vanishing stability (AVS) to reduce the risk of capsize or structural failure in events such as storm surges and high, wind-driven waves (Dorrell et al., 2022; Ghigo et al., 2020). However, this compliance-driven perspective does not meet the demands of daily residential use, because stability should be considered a critical habitability factor and a determinant of occupant wellbeing, and even minor, technically safe motions can be disorienting, disrupt daily activities, and undermine the perception of home livability. Engineering-based assessments, therefore, need to be supplemented with spatial and experiential criteria, which might include design responses such as motion-dampening technologies, floor plan layouts that concentrate heavier, more frequently occupied spaces closer to the center of rotation, and comfort-oriented performance thresholds that reflect residents' subjective perceptions and tolerances of motion. A comfort-oriented interpretation of stability also requires indicative serviceability thresholds rather than compliance-only safety criteria. Recent floating-structure serviceability studies suggest that the onset of human discomfort is commonly associated with frequency-weighted vertical accelerations of approximately 0.315 - 0.63 m/s², while caution becomes relevant at around 0.25 m/s² for 24 h exposure and around 0.5 m/s² for 4 - 8 h exposure (Jeong et al., 2025). With respect to inclination, approximately 1.5° is suitable for

spaces that require near land-like flatness, around 2.0° is more appropriate for general human activity, whereas $3 - 6^\circ$ corresponds more closely to workability or topside operability than to everyday residential comfort (Jeong et al., 2025). For floating housing, these values should be interpreted as preliminary habitability references rather than universal standards, but they help clarify that a dwelling may remain structurally safe while still failing to provide acceptable day-to-day comfort (Dorrell et al., 2022; Ghigo et al., 2020; Wang et al., 2021).

To facilitate comparison of these comfort-oriented criteria, **Table 1** summarizes indicative serviceability references for inclination and vertical acceleration in floating residential structures. These values should be interpreted as preliminary design references rather than universal residential standards, because acceptable comfort depends on exposure duration, wave climate, platform typology, occupant sensitivity, and post-occupancy conditions.

Table 1 Indicative comfort-oriented serviceability references for floating housing.

Serviceability indicator	Indicative reference range	Design implications for floating housing
Near-flat residential inclination	$\leq 1.5^\circ$	Preferred for spaces requiring land-like flatness, such as bedrooms, resting areas, kitchens, and other comfort-sensitive zones.
General residential inclination (tilt)	Around $\leq 2.0^\circ$	Suitable as an indicative upper range for ordinary daily activities, provided that motion frequency and duration remain acceptable.
Workability or short-term operability inclination	$3 - 6^\circ$	More relevant to operational or workability conditions than everyday residential comfort; should not be treated as a normal target for habitable spaces.
Preferred vertical acceleration for routine comfort	$< 0.315 \text{ m/s}^2$	Helps minimize routine discomfort, disorientation, and motion-related disturbance during daily residential use.
Discomfort onset/caution range (Moderate caution)	$0.315 - 0.63 \text{ m/s}^2$	May remain structurally acceptable but can reduce comfort, especially under repeated or prolonged exposure.
Duration-sensitive caution threshold	Approximately 0.25 m/s^2 for 24 h exposure; approximately 0.5 m/s^2 for 4 - 8 h exposure	Indicates that comfort assessment should consider exposure duration, not only peak acceleration values.

Note. These values are indicative serviceability references, not universal residential standards. They should be calibrated against local wave conditions, platform motion characteristics, exposure duration, user sensitivity, and post-occupancy monitoring data (Dorrell et al., 2022; Ghigo et al., 2020; Wang et al., 2021; Jeong et al., 2025).

The spatial implications of stability can also be clarified through the relationship between motion and the center of rotation. In rigid-body terms, locations closer to the instantaneous center of rotation experience lower local dynamic motion than those farther away, meaning the comfort profile of a floating dwelling is unevenly distributed across the plan (Patryniak et al., 2023; 2025). By extension, heavy furniture, storage mass, beds, seating, and other frequently occupied activity zones should, where feasible, be placed closer to the lower-motion core, while circulation areas and less motion-sensitive functions can be located nearer the edges of the platform. At the same time, such layout decisions must remain compatible with overall center-of-gravity management and hydrostatic

balance (Cahyono, 2024; Wang et al., 2021). This relationship is illustrated in **Figure 3**, which visually translates the uneven distribution of motion across the floor plan into a comfort-oriented spatial layout strategy. In architectural terms, the center-of-rotation concept can be translated into a zoning strategy for floating dwellings. Bedrooms, seating areas, storage zones, and heavy furniture should preferably be placed within the low-motion core, where local dynamic movement is relatively smaller and comfort-sensitive activities can be better protected. Kitchen and dining areas may occupy medium-motion zones, provided that their placement remains compatible with weight distribution and center-of-gravity control, while circulation areas, terraces, service spaces, and other less motion-sensitive functions can be located closer to the platform periphery (Cahyono, 2024; Wang et al., 2021; Patryniak et al., 2023; 2025). This perspective reinforces the idea that residential comfort on floating platforms is not only a function of global stability indices, but also of how internal space is organized relative to the structure's motion pattern. In summary, this approach reframes stability not only as a structural or regulatory requirement but as a fundamental aspect of residential performance in fluctuating aquatic environments.

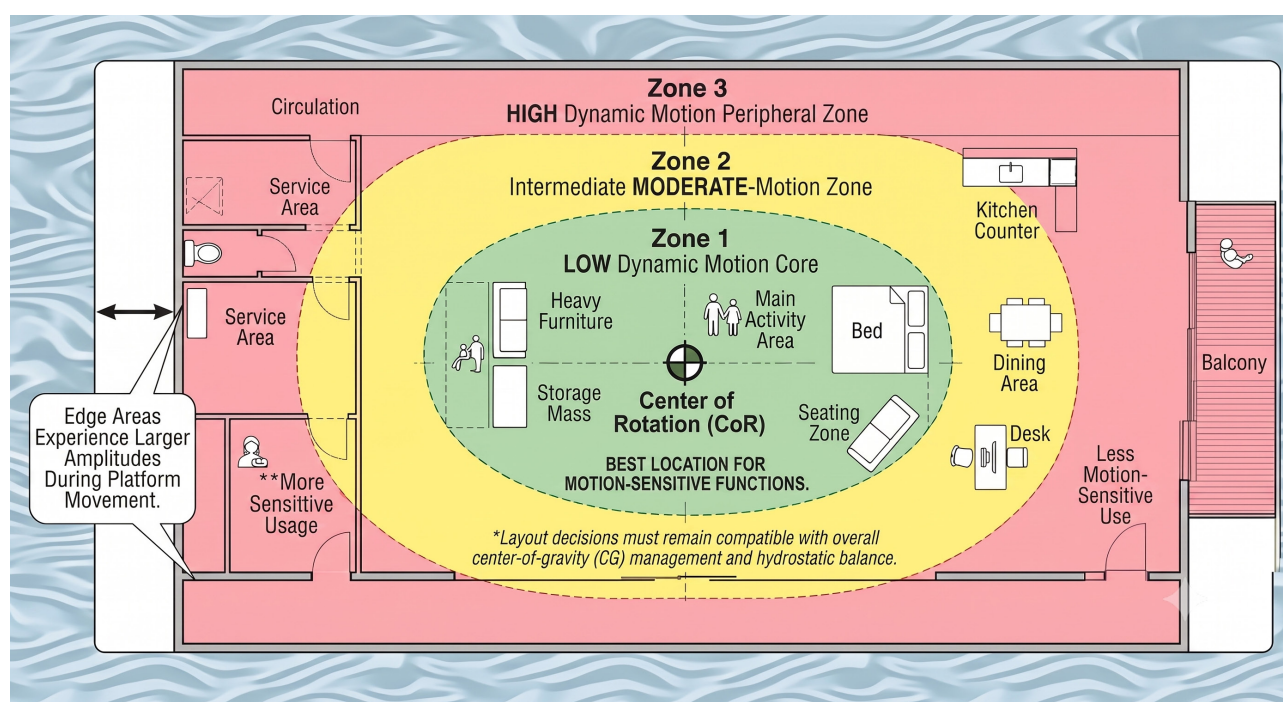


Figure 3 Center of rotation and comfort-oriented spatial planning in a floating dwelling. Low-motion areas near the center are better suited to heavy furniture and key activity zones, while peripheral areas are better suited to circulation or less-movement-sensitive uses.

3.4 Normative challenges: Regulation, perception, and ecological risk

The institutionalization of floating housing is also hindered by unresolved regulatory and sociocultural tensions, particularly a regulatory vacuum: most national building codes are designed for land-based construction and lack clear criteria for evaluating buoyant or amphibious dwellings. The legal uncertainty delays or prevents permitting, discourages investors, and results in a patchwork of isolated, one-off, or experimental projects rather than integrated, scalable development.

Concrete country examples help clarify that regulatory integration is possible, although uneven. The Netherlands remains the clearest case in which floating housing has moved beyond isolated experimentation and has been accommodated through the interaction of water management, spatial planning, property law, and project-level permitting, enabling realized developments such as

IJburg, Maasbommel, and Schoonschip (Huebner, 2025; Lin et al., 2022). In contrast, Sweden illustrates a more partial form of integration: floating districts have entered municipal planning and waterfront development debates, yet national support mechanisms and regulatory consistency remain insufficient for broad upscaling (Storbjörk & Hjerpe, 2022). These contrasting cases suggest that the central issue is not whether floating housing can be regulated at all, but whether countries can align land-use planning, legal classification, water governance, and permitting routines in ways that make implementation both predictable and scalable.

To make these regulatory differences easier to compare, **Table 2** summarizes two contrasting examples discussed in this review. The Netherlands represents a relatively mature regulatory setting in which floating housing has been integrated through the interaction of water management, spatial planning, property law, and project-level permitting. Sweden, by contrast, illustrates an emerging or partially integrated setting, where floating districts have entered municipal planning debates but continue to face regulatory ambiguity, limited national support, and difficulties in scaling beyond pilot projects (Huebner, 2025; Lin et al., 2022; Storbjörk & Hjerpe, 2022).

Table 2 Comparative regulatory integration of floating housing in selected country contexts.

Country	Regulatory status	Example project/context	Main lesson
Netherlands	Mature / relatively advanced	IJburg, Maasbommel, and Schoonschip	Floating housing can be integrated through coordinated water management, spatial planning, property law, and project-level permitting, allowing projects to move beyond isolated experimentation.
Sweden	Emerging / partial integration	Pilot floating districts and waterfront development debates	Floating housing has entered municipal planning discussions, but regulatory ambiguity, limited national support, and fragmented implementation routines continue to constrain broader upscaling.

Note. The comparison is indicative rather than exhaustive and is intended to show how different levels of regulatory integration affect the scalability of floating housing.

Meanwhile, public acceptance is also inconsistent and contested. In some contexts, floating homes are regarded as modern, climate-resilient solutions; however, in others, they are dismissed as visually incongruous, environmentally harmful, or socially exclusive, and objectors lament the aesthetic fit and landscape transformation, gentrification, increasing property prices, and loss of public access to waterfronts (Faraggiana et al., 2024; Shi et al., 2023). Ecological concerns are also legitimate because the placement of floating platforms in vulnerable water bodies may exacerbate biofouling, localized declines in water quality, shading-induced shifts in aquatic vegetation, and disruption of benthic habitats.

Ecological mitigation for benthic environments can be translated into a simple design sequence: siting → shading control → eco-mooring → monitoring, as illustrated in **Figure 4**. First, careful siting should avoid sensitive shallow-water zones, submerged vegetation, and benthic habitats that are vulnerable to persistent shading or altered hydrodynamics. Second, shading control should be addressed through limited platform coverage, module spacing, edge openings, and hydrodynamically open configurations that help preserve light penetration, water circulation, and oxygen exchange. Third, eco-mooring strategies should minimize seabed abrasion, anchor footprint,

trenching, and unnecessary disturbance of bottom habitats. Finally, long-term monitoring should evaluate water quality, biofouling, aquatic vegetation, seabed condition, and benthic recovery to enable adaptive management over time (Danovaro et al., 2024; de Lima et al., 2022; Kingma et al., 2024; Tamis et al., 2021).

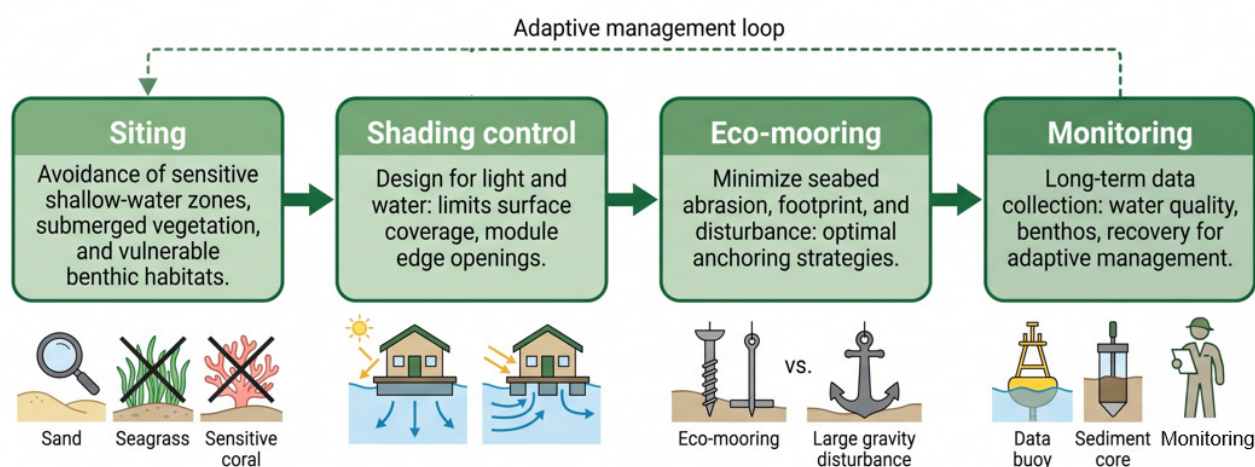


Figure 4 Design-oriented benthic ecology mitigation flow for floating housing projects. The sequence links siting, shading control, eco-mooring, and monitoring to reduce disturbance to aquatic bottom environments and support adaptive ecological management.

Preventing benthic impacts requires more than post hoc monitoring; it must be embedded in design from the outset. The first strategy is careful siting, especially avoiding ecologically sensitive shallow-water zones, submerged vegetation, and other benthic habitats that are highly vulnerable to persistent shading or altered hydrodynamics (Danovaro et al., 2024; Tamis et al., 2021). A second strategy concerns platform configuration: limiting surface coverage, maintaining spacing between modules, and incorporating edge openings or other hydrodynamically open arrangements can help preserve light penetration, water circulation, and oxygen exchange beneath the structure (de Lima et al., 2022; Tamis et al., 2021). Third, anchor and mooring systems should be configured to minimize seabed abrasion, trenching, and unnecessary footprint expansion. Fourth, material choices and anti-biofouling treatments should prioritize low-toxicity solutions and manageable maintenance regimes to reduce unintended ecological stress. Finally, where underwater structural elements are unavoidable, nature-inclusive detailing such as greater substrate heterogeneity, roughness variation, or ecologically informed habitat-forming add-ons may reduce habitat simplification and improve benthic performance relative to smooth, uniform surfaces (Kingma et al., 2024). Together, these strategies suggest that floating housing should be designed not only to avoid structural failure and maintain habitability, but also to minimize chronic disturbance to the aquatic bottom environment.

Without proper ecological impact assessment, monitoring, and adaptive management, floating urbanism may only aggravate the vulnerabilities it seeks to address; therefore, for floating housing to coalesce as a recognized and legitimate architectural and infrastructural type, technical optimization must be paralleled by an unequivocal ethical and institutional framework that integrates engineering performance, human-centered design, environmental care, and inclusive governance, and translates these into a context-sensitive regulatory system that can guide safe, equitable and ecologically responsible implementation.

4. Review of findings

4.1 Platform typologies and modular design pathways

The following section provides a critical review of 11 peer-reviewed articles that examine the relationship between architectural and engineering design decisions and the performance of floating

and amphibious housing platforms. An analysis of the empirical data summarized in **Table 3** indicates that the platform typology, material systems, and modular design strategies are highly variable because each platform configuration responds to specific hydrological risks, regulatory conditions, and socio-technical constraints.

Figure 5 illustrates a visual taxonomy of the five dominant platform types that emerge from the literature: (a) pontoon, (b) catamaran, (c) semi-submersible, (d) amphibious, and (e) vernacular raft-based systems, with each of the five platform types predicated on a unique spatial-structural logic. For example, pontoons depend on wide beam dispersion, catamarans rely on dual parallel hulls for stability, semi-submersibles on deeply submerged buoyant columns, and amphibious hybrids on vertically adaptive foundations that transition between land and water support. While the specific solutions are quite diverse, modularity is a common design principle: platforms are often conceptualized as assemblages of repeatable buoyant units or scalable segments that can be configured to accommodate different site profiles and occupancy scenarios, and this modular logic facilitates prefabrication, simplifies transport and assembly, and enables floating dwellings to be adapted over time to changing hydrological regimes or evolving household needs. **Figure 5** also highlights the fact that typological selection is fundamentally contextual, shaped by regional material availability, local construction cultures, governance capacity, and the intensity and frequency of flood exposure. Understanding these interdependencies between typology and modularity is critical in determining which designs are best suited and most resilient in different socio-ecological contexts, because platform typology acts not only as a structural solution, but also as a strategic framework for adaptive, scalable forms of urbanism on water. **Figure 5** has also been expanded with a compact comparative parameter panel to clarify the technical implications of each typology.

To improve cross-typological comparability, the technical parameter panel in **Figure 5** has been standardized using the same qualitative descriptors for all platform types: L/B ratio, waterplane-area tendency, initial stability, motion sensitivity, and relative cost level. Because the reviewed studies do not report comparable numerical values for each typology, these parameters are expressed qualitatively using descriptors such as low, medium, high, narrow, moderate, and wide. This approach allows pontoon, catamaran, semi-submersible, amphibious hybrid, and vernacular raft-based systems to be compared consistently without implying universal numerical design values. The panel should, therefore, be interpreted as a typological synthesis that links platform form with hydrostatic behavior, motion response, and implementation complexity (Cahyono, 2024; Yang et al., 2020; Yu et al., 2020).

Rather than presenting the five platform categories only as formal or modular variants, the revised figure now summarizes indicative tendencies in parameters such as L/B ratio, waterplane area/coefficient, dominant stability mechanism, and expected motion response. This addition helps connect the visual typology more directly with the hydrostatic discussion developed in Section 3.2, while avoiding overgeneralized numerical values for platform types whose exact proportions vary across case studies (Cahyono, 2024; Yang et al., 2020; Yu et al., 2020).

The first feature that is common to all the studies reviewed here is the absolute dominance of pontoon-based platforms, which remain the most common typology for rural as well as urban floating housing. Thus, for example, Nekooie et al. (2017; 2018) describe expanded polystyrene system (EPS)-filled lightweight concrete pontoons in Malaysia and, more broadly, Southeast Asia, and use multi-criteria morphological analysis to optimize these systems for amphibious operation; in a similar low-cost direction, Adi et al. (2017) design platforms using modular plastic barrels- 232 units per dwelling, each providing ca. 549.814 N of buoyant force- to create economically realistic solutions for low-income coastal communities. A closely related but materially different approach is described by Asrasal et al. (2019), who use modular PVC pipe pontoons (3 cm diameter) connected by bolts to achieve a total buoyant capacity of 648.792 N that is sufficient to safely support a structural load of 555,887.5 N, which is also reported by Prihatmaji and Nugraha (2018), revealing the benefits of EPS specifically, as its high buoyancy-to-weight ratio makes it a promising substitute for traditional bamboo floats in a range of river-based housing typologies. Typological diversity is as much the

product of vernacular building knowledge as engineered pontoons, because Arifin et al. (2019) describe how timber-based floating houses on Lake Tempe cluster, disperse and reconfigure seasonally in response to water level changes, creating a form of spatial fluidity that is tightly coupled to hydrological rhythms, while Puspitasari et al. (2019) describe the climatic performance of Rumah Rakit, or traditional raft houses, which integrate structural form, material choice, and microclimatic responsiveness into a coherent system. Consequently, these examples suggest that typology is not just a structural solution but also a medium for socio-cultural resilience and environmental learning, embedding local practices, climatic intelligence, and adaptive patterns of use into the design of floating housing.

FLOATING PLATFORM TYPOLOGIES AND MODULAR DESIGN LOGIC

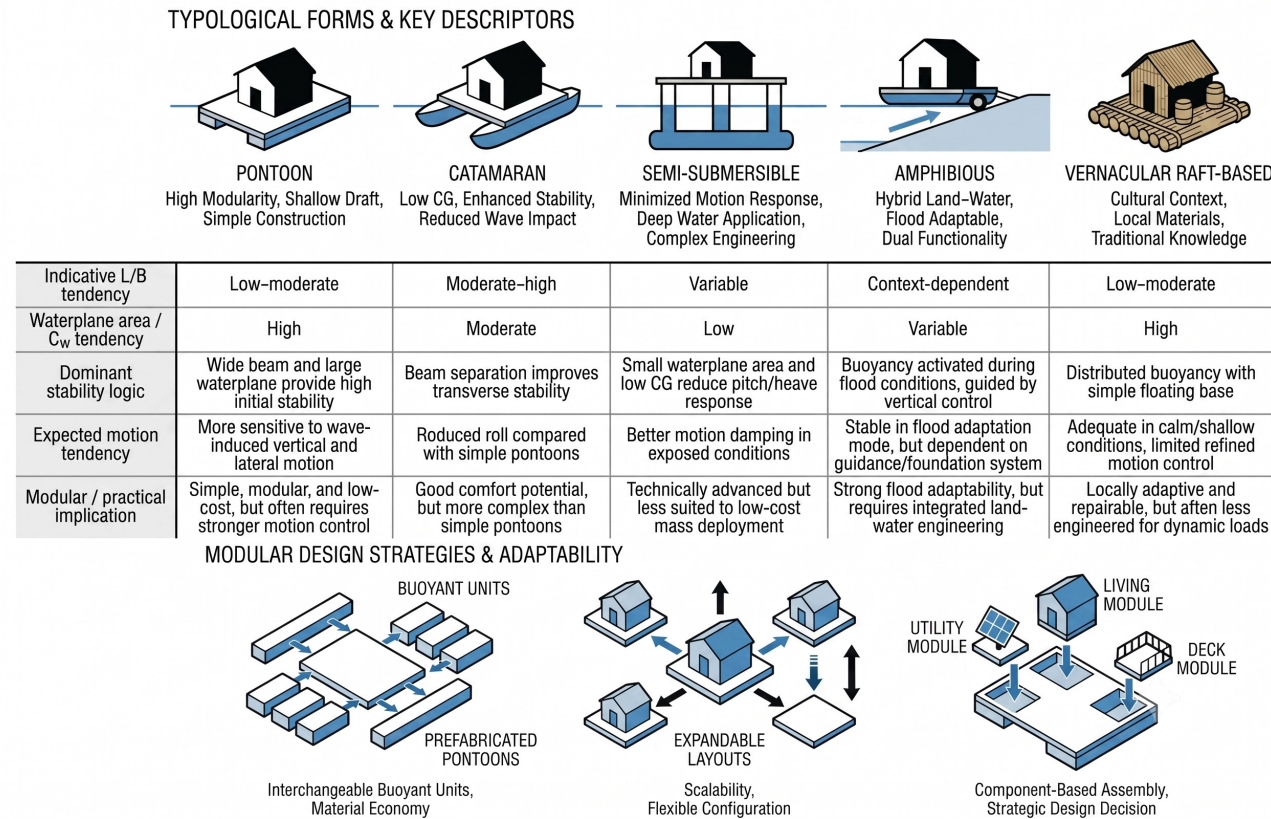


Figure 5 Representative typologies of floating and amphibious housing platforms- pontoon, catamaran, semi-submersible, amphibious hybrid, and vernacular raft- are illustrated together with associated modular design strategies and a compact comparative panel of indicative hydrostatic and geometric descriptors, including L/B tendency, waterplane-area tendency, stability logic, and expected motion behavior.

The modular theme is further expanded by Kizilova (2019), who proposes floating shell modules for networked autonomy in extreme environments, and conceptualizes modularity as both a structural tactic and a systemic condition affecting structural, spatial and infrastructural layers; this idea of systemic modularity is also reflected in Wang et al. (2020), whose comparative analysis of floating and land-based housing in Hong Kong indicates that, if properly integrated, modular systems can maintain functional equivalence with conventional housing in terms of layout, services and everyday usability.

From a policy perspective, Storbjörk and Hjerpe (2018) evaluate pilot floating districts in Sweden and, while confirming the structural robustness of pontoon platforms, they argue that technical success is not sufficient because, without being firmly integrated in planning systems, regulations, and institutional routines, even mature technologies will fail to scale up beyond demonstration projects.

Altogether, the corpus points to modular construction as a common denominator, since 63.6 % (7 of 11) of the studies explicitly describe modular design strategies, which include interlocking plastic barrels (Adi et al., 2017), precast EPS-filled pontoons (Nekooie et al., 2017), and connectable raft modules (Prihatmaji & Nugraha, 2018), all combining into adaptive assemblages that are easy to transport, repair, reconfigure, and incrementally expand.

Geographically, more than half of the cases (54.5 %) are located in Southeast Asia, which underscores the regional urgency and relevance of floating solutions in flood-prone environments, and consequently, Indonesia, Malaysia, and Vietnam in particular are the places where significant typological experimentation is happening, with hybrid floating-amphibious systems being intentionally adopted as a way to cope with increasingly unstable hydroclimatic conditions (Nekooie et al., 2018; Nguyen et al., 2025).

The strong concentration of cases in Southeast Asia also raises an important question of climatic transferability. The dominant typologies identified in this review, especially pontoons, raft-based systems, and amphibious hybrids, emerge largely from warm-water, flood-prone, and relatively shallow environments, where design priorities include buoyant adaptability, low-cost modularity, and seasonal hydrological flexibility (Arifin et al., 2024; Ngo & Le, 2022; Nguyen et al., 2025). For this reason, these typologies should not be interpreted as directly transferable to sub-Arctic or other cold-climate regions. In such settings, floating residential systems would face additional constraints, including ice loading, freeze-thaw exposure, snow accumulation, winterized service systems, and much stricter thermal and daylight performance requirements for housing (Huebner, 2025; Storbjörk & Hjerpe, 2022). The transferable value of the Southeast Asian cases, therefore, lies less in literal replication than in their underlying design logic modularity, buoyant redundancy, and adaptability to variable water levels, while the actual geometry, mooring layout, envelope specification, and material durability would need to be redefined for cold-region operation.

Future adaptation of floating housing for cold-climate or sub-Arctic regions should, therefore, be treated as a design-development agenda rather than as a directly established finding of the reviewed warm-water case studies. In such contexts, platform and envelope design would need to address insulated hulls or buoyant foundations, freeze-thaw-resistant materials, anti-icing protection for utilities, winterized water and wastewater systems, roof structures designed for snow accumulation, and mooring or guide systems capable of tolerating ice action and seasonal freezing. These requirements suggest that the transferable value of Southeast Asian and other warm-climate examples lies mainly in their modularity, buoyant redundancy, and adaptive logic, while their material specification, thermal envelope, service infrastructure, and restraint systems must be locally redesigned and validated for colder operating environments (Huebner, 2025; Storbjörk & Hjerpe, 2022).

Collectively, these studies reconceptualize platform typology as a composite decision shaped by engineering principles, material ecology, modular reasoning, and institutional context. The synthesis affirms that buoyancy is but one dimension in a broader matrix of climatic, social, and infrastructural performance criteria.

4.2 Geometry and hydrostatics: buoyancy, stability, and vertical control

This section discusses the impacts of geometric design parameters on structural and hydrostatic performance of floating and amphibious housing systems based on nine empirical studies summarized in **Table 4**; the interaction between spatial geometry, sectional form, and major

hydrostatic coefficients is discussed in relation to the control of buoyant response, metacentric stability, and overall architectural feasibility under dynamic loading conditions.

Table 3 Platform typologies, materials, and modular design pathways in floating and amphibious housing.

Platform Typology	Primary Platform Material / System	Design or Modularity Strategy	Intended Hazard / Context	Key Platform-Related Findings	References
Floating house + green farming	Floating floors; raised/floating structural systems	Integration of housing with VAC and aquaponics; adaptive rural model	Sea-level rise; climate change; epidemics (Vietnam)	Floating floors and hybrid housing–farming systems enhance self-service capacity and climate adaptability in low-lying coastal districts	(Ngo & Le, 2022)
Vernacular lake floating house	Timber-based traditional floating structure	Dynamic grouping and reconfiguration based on tides and wind	Seasonal lake-level variation (Indonesia)	Local typologies demonstrate adaptive spatial configurations and mobility responding to hydrological conditions	(Arifin et al., 2024)
Floating house (urban context)	General floating platform (unspecified)	Value-based functional decomposition and comparison with land housing	Land scarcity; coastal urban development (Hong Kong)	Floating houses show competitive functional value despite structural and living constraints when assessed holistically	(X. Wang et al., 2023)
Experimental floating housing districts	Pontoon-based floating houses	Small-scale, prototype-led experimentation	Urban climate adaptation; flooding (Sweden)	Platform robustness alone does not guarantee upscaling; integration with urban systems is critical	(Storbjörk & Hjerpe, 2022)
Simple floating house	Plastic barrel pontoons	Modular barrel-based platform sizing by buoyancy and cost	Coastal settlements; low-income housing	Plastic barrels can provide sufficient buoyancy at low cost, enabling basic floating-house platforms	(Adi et al., 2020)
Amphibious house	Lightweight concrete pontoons	Precast modular buoyant elements	River flooding (Malaysia)	Concrete pontoon platforms designed for buoyancy and stability can support amphibious housing under flood loads	(Nekooie et al., 2017)
Floating house	PVC pipe pontoons	Modular pipe-based platform with bolted connections	Coastal areas; land scarcity	PVC pipe platforms provide adequate buoyant force exceeding structural weight, with defined cost implications	(Asrasal et al., 2018)

Table 3 (continued) Platform typologies, materials, and modular design pathways in floating and amphibious housing.

Platform Typology	Primary Platform Material / System	Design or Modularity Strategy	Intended Hazard / Context	Key Platform-Related Findings	References
Amphibious house	EPS-filled lightweight concrete bucket pontoons	Morphological optimization using multi-criteria decision making	Floodplain protection (SE Asia)	EPS–concrete pontoon morphology identified as optimal across technical, environmental, and economic criteria	(Nekooie et al., 2018)
Vernacular river floating house (Rumah Rakit)	Timber raft-based platform	Climate-responsive architectural tectonics	Riverine flooding; microclimate adaptation (Indonesia)	Platform form and construction are tightly coupled with local climate knowledge and long-term resilience	(Puspitasari et al., 2018)
Traditional raft house (Lanting)	EPS pontoon modules	Substitution of bamboo floats with prefabricated EPS modules	Riverine housing decline; material scarcity (Indonesia)	EPS pontoons outperform traditional float materials in load capacity and durability for floating houses	(Prihatmaji & Nugraha, 2019)
Autonomous floating module	Modular floating shell structure	Connectable autonomous modules forming networks	Extreme/aquatic environments	Platform design emphasizes modularity, scalability, and autonomy at the layout, system, and shell levels	(Kizilova, 2020)

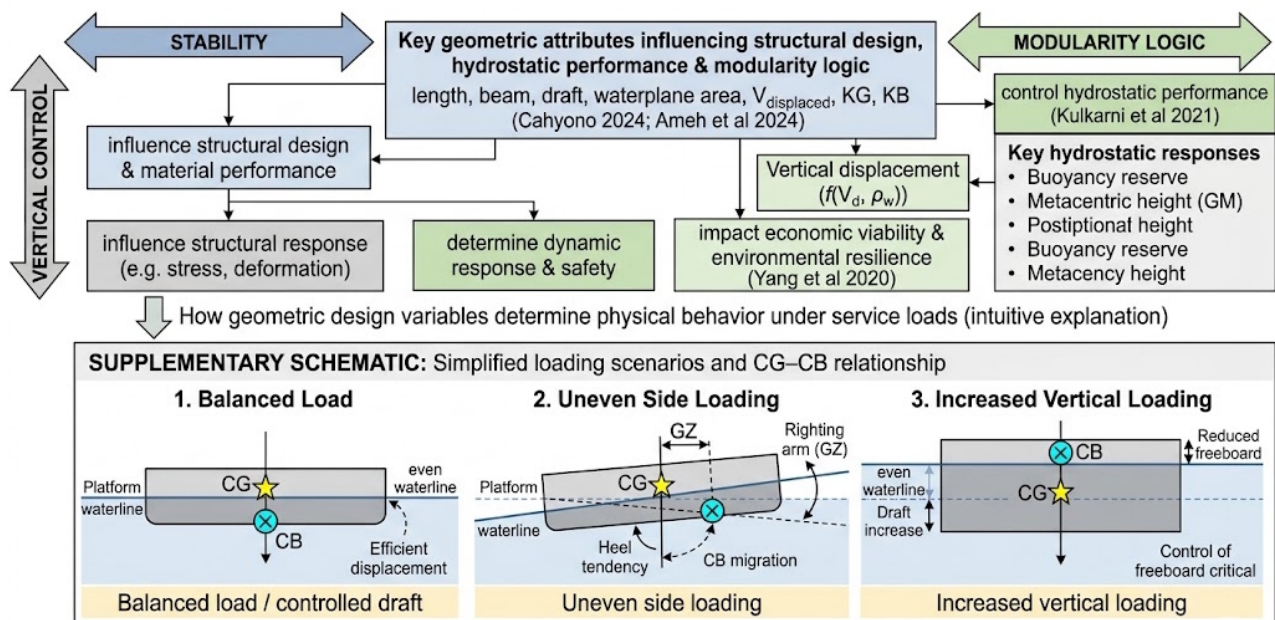


Figure 6 Conceptual pathway showing how geometric attributes such as length, beam, draft, and waterplane area influence hydrostatic responses, including buoyancy reserve, metacentric height, and vertical displacement, together with simplified loading scenarios illustrating the relationship between center of gravity (CG), center of buoyancy (CB), and platform response under service loads.

This section examines the impact of geometric design parameters on the structural and hydrostatic performance of floating and amphibious housing, based on the nine empirically based studies listed in **Table 4**; the analysis is organized around how spatial geometry, sectional form, and key hydrostatic coefficients collectively affect the buoyant response, metacentric stability, and architectural feasibility of platforms under different loading conditions. **Figure 6** illustrates the conceptual pathway of interaction between geometric design parameters and hydrostatic outcomes in floating structures, and input variables are placed on the left side of the diagram to stress their fundamental role as design drivers. These geometric variables determine reserve buoyancy, metacentric height (GM), and the magnitude of vertical displacement under applied loads and, in turn, determine higher-level performance indicators including static stability, load capacity, and safety margin, because the diagram shows that this geometry-performance linkage is mediated primarily through proportional relationships (not absolute dimensions) and, hence, why design sensitivity and ratio tuning are critical to achieving desirable stability. By condensing this sequence, **Figure 6** reinforces the central argument that platform geometry is not a secondary structural detail but a primary determinant of hydrostatic reliability, and also explains why inconsistent geometric assumptions between case studies (e.g., different L/B ratios or submerged volumes) strongly skew cross-study comparisons.

Figure 6 has also been expanded with a supplementary schematic panel illustrating the relationship between the center of gravity (CG) and the center of buoyancy (CB) under simplified loading scenarios. This addition is intended to make the concept of vertical control more intuitive by showing how changes in load distribution alter draft, heel, and the relative position of CG and CB, thereby affecting buoyant response and stability. In this way, the figure links geometric variables not only to abstract hydrostatic outputs, but also to the physical behavior of the platform under service loading (Ameh et al., 2024; Cahyono, 2024).

Hence, geometry should be treated as a first-order design decision in the hydrostatic logic of floating residential architecture. Cahyono (2024) has developed a comprehensive analytical model of an EPS-concrete hybrid platform (6.12×5.12×0.68 m) to simulate buoyant behavior under standard residential loading, and the platform generates a buoyant force of 18,246.6 kg, a surplus load capacity of 3,647.62 kg, and an overall safety factor of 2.59. Stability indices further confirm a strong static equilibrium, including a Fa/G ratio of 3.01 and a metacentric height of 16.531 m, while the model also shows the decrease in performance as draft increases, indicating the need to control vertical displacement throughout the lifespan of the dwelling.

A second analytical strand focuses on the interaction between geometry and material systems, and Adi et al. (2017) model a platform composed of 232 plastic barrels, each providing 549.814 N of uplift; although this solution is volumetrically bulky, it represents an affordable modular strategy that can be easily replicated in low-income coastal settlements. In a subsequent comparative study, Adi et al. (2020) compare EPS panels (2×1×0.5 m) with PVC rods (10-inch × 4 m), and demonstrate that the EPS configuration delivers much greater uplift (0.9 tons vs. 0.2 tons) and stability margins (+3.61 m vs. +3.23 m); therefore, the results reinforce the superior buoyancy-to-volume efficiency of EPS-based systems, and demonstrate the importance of matching geometry and material properties for load capacity and stability in floating residential platforms.

Nekooie et al. (2018) also build on this by employing multi-criteria decision-making to optimize the shape of EPS-filled bucket pontoons under concurrent environmental, economic, and technical criteria and, in combination with Nekooie et al. (2017), which presents a new drag coefficient for floodplain-scale testing, Nekooie et al. (2018) expand the scope of hydrostatics beyond preservation of vertical equilibrium, to lateral resistance and the estimation of flood-induced loads. More recent studies focus on active methods to control vertical displacement, and Nguyen et al. (2025) describe a vertical lift system in which only the floor slab is elevated using commercial rails within a fixed frame, which keeps the building envelope largely stationary.

By minimizing the volume of floating elements and mechanically transmitting vertical loads, this system decouples flotation from structural displacement, and reduces the risk of lateral instability. Yin (2017) offers a complementary perspective, through an analysis of Tuned Liquid Column Dampers (TLCDs) embedded within a floating box configuration, which shows that liquid columns tuned via fluid-structure resonance can reduce angular displacement under wave action through built-in dynamic stabilization. At the urban/infrastructure scale, Tsao et al. (2024) utilize digital twin techniques to simulate pile-supported floating cities using Reduced and High Order Models (ROM/HOM), which incorporate time-domain hydrodynamics, storm surge and sea-level rise scenarios, and their findings highlight the interrelatedness of platform geometry, natural frequencies and environmental forcing, and the need to manage these relationships at the district or city scale, rather than solely at the level of individual dwellings.

The reviewed studies demonstrate a clear preference for EPS and EPS-based composites, which are used in seven of the nine cases studied (77.8 %), due to their buoyancy-to-mass ratio and adaptability to diverse morphologies, and more than half of the studies (55.5 %) also employ some form of optimization framework, suggesting a move away from simple buoyancy checks, towards predictive, performance-led hydrostatic design. In conclusion, the evidence suggests that hydrostatic performance in floating housing is not only dependent on displaced volume, but also on the combined effects of spatial geometry, material configuration, and active/passive motion control systems and, therefore, supports the argument for an integrated design methodology which combines hydrodynamic modeling, architectural design, and structural engineering for climate-resilient floating infrastructure.

Table 4 Geometry and hydrostatics: Buoyancy, metacentric stability, and vertical control in floating/amphibious housing.

Hydrostatic / Geometry Focus	Key Geometric Inputs Reported	Core Hydrostatic Variables Used	Stability / Control Metric(s)	Method / Evidence Basis	Key Hydrostatic-Stability Takeaway (from abstract)	References
EPS platform with lightweight concrete cover (floating house substructure)	Platform size 6.12×5.12×0.6 m; sinking height as response variable	Buoyant force (Fa) vs total weight (G); center of gravity vs center of buoyancy	Fa/G stability ratio; metacentrum height (m); safety factor (SF)	Platform stability test + analytical evaluation	Fa = 18,246.6 kg supports extra 3,647.62 kg (SF 2.59); Fa/G = 3.01 (>1.2); metacentrum height 16.531 (>0) → stable; SF decreases with increased sinking height	(Cahyono, 2024)
Plastic-barrel platform buoyancy sizing (simple floating house)	Count of barrels as discrete buoyant units (platform modularity)	Buoyancy (Fa) estimation for barrels; load-bearing capacity concept	Floating feasibility threshold: Fa must exceed the structural load	Analytical sizing + cost estimation	Plastic barrels provide calculable buoyancy and cost basis for platform sizing; study reports Fa = 549.814 N and 232 barrels needed for a unit platform (cost quantified)	(Adi et al., 2020)
PVC-pipe platform stability and cost planning	Platform assembled from PVC pipes; bolted connection (3 cm diameter)	Floating force (Fa) vs structure weight; buoyant force exceedance	Float feasibility and platform stability via Fa-G comparison	Analytical weight, buoyancy, and cost plan	Total structure weight 555,887.5 N; floating force 648.792 N; bolted connection system specified; cost planning provided → demonstrates geometry/material choice changes buoyancy margin	(Asrasal et al., 2018)

Table 4 (continued) Geometry and hydrostatics: Buoyancy, metacentric stability, and vertical control in floating/amphibious housing.

Hydrostatic / Geometry Focus	Key Geometric Inputs Reported	Core Hydrostatic Variables Used	Stability / Control Metric(s)	Method / Evidence Basis	Key Hydrostatic-Stability Takeaway (from abstract)	References
Comparative uplift and stability of EPS vs PVC platforms (floating buildings)	PVC pipe size/length 10-inch diameter, 4 m; EPS sheet dimensions 2×1×0.5 m	Uplift capacity as a hydrostatic support indicator	Stability levels reported as “spectrum” values for each platform	Comparative analytical assessment (uplift-stability-cost)	Uplift: PVC 0.2 ton/rod, EPS 0.9 ton/sheet; stability “spectrum”: PVC +3.23 m, EPS +3.61 m; EPS achieves high uplift at markedly lower cost for the same load class	(Adi et al., 2020)
Amphibious-house buoyant-component morphology selection	Pontoon “bucket system” (pontoons) with EPS block inside lightweight concrete	Buoyancy and platform suitability are treated within multi-criteria sustainability classes	“Optimal morphology” decision outcome (technology-environment-economy-social)	Multi-attribute decision-making (criteria-based selection)	Identifies lightweight concrete pontoons with internal EPS blocks as the most applicable buoyant morphology for amphibious houses in floodplain contexts	(Nekooie et al., 2018)
Amphibious-house flood-force interaction (implications for stability design)	1/25 scaled floodplain model (scaled geometry; amphibious house as body)	Drag force formulation for flood loading on a floating/amphibious body	Drag coefficient equation (force prediction for stability design)	Experimental method + new drag-coefficient equation	Develops a new equation for the drag coefficient and validates it with sensitivity analysis, improving force prediction inputs for amphibious-house stability and guidance design	(Nekooie et al., 2017)
Vertical lift “piston house” for flood adaptation (reduced lateral instability)	Floor rises within structural frame; uses underfloor space for buoyant material; guiding rails	Buoyancy capacity; vertical displacement behavior; load transfer through rails	Vertical displacement stability; reduced lateral instability; buoyant-force requirement minimization	Conceptual development + simplified numerical simulations	Shows feasibility of lifting only the floor to limit lateral instability while meeting buoyancy capacity; indicates commercially available rail components can provide effective vertical control under flood conditions	(Nguyen et al., 2025)
Pitching suppression for a floating rectangular box structure (relevant to housing platforms)	Floating rectangular box (generic platform geometry)	Coupled fluid-structure interaction model (TLCD-floating body)	Pitching motion reduction via optimal TLCD parameters	Mathematical modeling + numerical optimization	Demonstrates that TLCD can efficiently suppress the pitching of a floating box, suggesting add-on motion-control options for improving dynamic stability in floating-housing platform forms	(Yin, 2017)
Time-domain digital-twin evaluation for floating-city systems (housing modules on adjustable platforms)	Floating houses on adjustable pile-supported platforms; breakwater-protected area	Dynamic response analysis in the time domain using models + real-time data assimilation	Natural frequencies as structural characteristics; response-performance indicators	Digital twin concept + ROM/HOM simulation approach	Integrates environmental drivers (storm surge, SLR) with structural dynamics to evaluate long-term performance; highlights the role of tuned liquid dampers and breakwaters in operational stability	(Tsao et al., 2025)

4.3 Hydrodynamic response and mooring systems

This section focuses on the performance of floating and amphibious housing under wave and water-level conditions, with emphasis on hydrodynamic response and mooring system design, drawing on the empirical and numerical results from the six core studies listed in **Table 6**. The influence of wave-induced forces, anchoring configurations, and water level variations on platform motion, structural stability, and day-to-day habitability is discussed because the studies support the notion that hydrodynamic design is not an add-on feature or a purely naval-technical problem, but an essential part of the architectural concept and the engineering approach of floating housing.

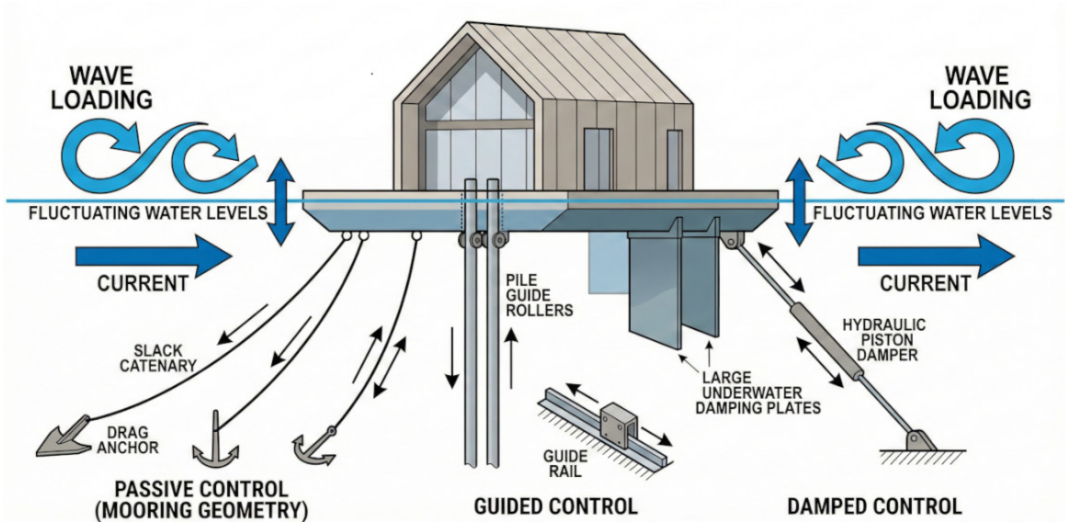


Figure 7 Hydrodynamic forces acting on floating housing structures, including wave pressure, current flow, and fluctuating water levels, alongside schematic representations of mooring and control systems such as flexible lines, guide rails, vertical piles, and passive damping elements, illustrate the interaction between environmental loads and constraint strategies.

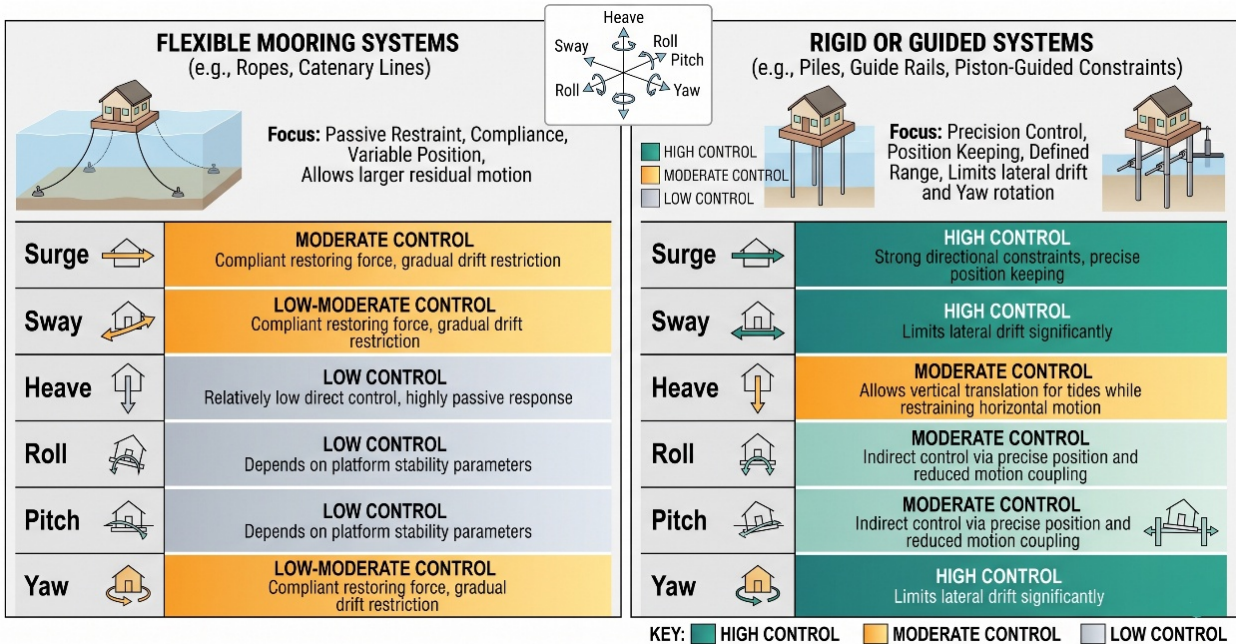


Figure 8 Comparison of flexible mooring and rigid/guided restraint systems in controlling the principal degrees of freedom of floating-house movement. Flexible systems allow greater residual motion, whereas rigid/guided systems provide stronger directional control, especially for lateral drift and yaw.

To clarify the implications of the restraint strategy for residential performance, a new comparative diagram (**Figure 8**) has been added, showing the relative effectiveness of flexible versus rigid/guided systems in controlling the principal degrees of freedom of floating-house motion. In general, flexible mooring systems provide compliant restoring action and are effective for limiting large-scale drift, but they still allow residual surge, sway, yaw, and some rotational motion. Rigid or guided systems such as piles, guide rails, and piston-guided mechanisms impose stronger directional constraints, especially on lateral translation and drift, but do so with higher structural specificity and more concentrated load transfer (Miszewska & Niedostatkiwicz, 2019; Nguyen et al., 2025; Tsao et al., 2025). This comparison, presented in the caption of **Figure 7**, reinforces that restraint selection is not only a structural decision but also a serviceability decision that affects comfort, accessibility, and perceived stability.

To complement the comparison between flexible and rigid or guided restraint systems, **Table 5** summarizes three representative mooring and guidance strategies for floating housing: flexible rope or catenary systems, guided piles, and rail or piston-based systems. The comparison is intended as a qualitative design aid rather than a universal selection rule, because the suitability of each system depends on water depth, wave climate, tidal range, seabed conditions, accessibility requirements, and maintenance capacity. In general, flexible systems are more appropriate for calm sheltered waters, guided piles are suitable for tidal zones and controlled waterways, while rail or piston systems are more relevant for urban waterfronts and amphibious housing sites where controlled vertical movement and reduced lateral drift are required (Miszewska & Niedostatkiwicz, 2019; Nguyen et al., 2025; Tsao et al., 2025).

Table 5 Comparative mooring and guidance strategies for floating housing.

Mooring/guidance type	Main advantage	Main limitation	Best site application
Flexible rope / catenary line (Miszewska & Niedostatkiwicz, 2019; Yang et al., 2025)	Relatively low cost, simple installation, and adaptable to moderate water-level variation	Allows greater residual surge, sway, yaw, and low-amplitude motion, which may reduce residential comfort without additional damping or optimized layout	Calm sheltered waters, canals, protected basins, and low-energy waterfronts
Guided pile (Miszewska & Niedostatkiwicz, 2019; Tsao et al., 2025)	Provides stronger directional control, limits lateral drift, and improves station keeping under fluctuating water levels	Requires more site-specific structural design, pile installation, and careful load-transfer assessment; may be less flexible where seabed or permitting constraints are significant	Tidal zones, controlled waterways, flood-prone river edges, and sheltered urban waterfronts
Rail/piston system (Nguyen et al., 2025)	Enables controlled vertical movement, reduces lateral instability, and can integrate the restraint system into the building structure	Technically more complex, maintenance-intensive, and dependent on precise guide components and structural alignment	Urban waterfronts, amphibious housing sites, and locations requiring vertical flood adaptation with limited horizontal movement

Note. This comparison is conceptual and should be calibrated against site-specific hydrodynamic conditions, tidal range, water depth, seabed properties, accessibility requirements, and long-term serviceability targets. Motion-control devices and damping-enhanced mooring may be combined with these systems where residential comfort requires stricter control of low-frequency motion and acceleration (Jeong et al., 2025; Yin, 2017; Yang et al., 2025).

This section critically examines the performance of floating and amphibious housing under real water conditions with a focus on hydrodynamic response and mooring design. The six studies included in the review (**Table 6**) all reinforce the idea that wave climate, currents, and water-level fluctuations must be considered primary design inputs rather than secondary considerations, as they directly affect platform motion, structural reliability, and everyday habitability. A clear and conceptual representation of this hydrodynamic context is given in **Figure 7**, showing waves, currents, and water level changes as directional loads on a floating platform, causing oscillation, drifting and rotation motion and, in tandem, the restraint systems are classified into two main categories: passive systems, including flexible mooring lines and pile anchoring; and guided or semi-active systems, including vertical guide rails and tuned damping devices. These are not only portrayed as structural safeguards, but also as mechanisms to protect resident comfort by limiting unwanted movement and tilt; therefore, the figure also serves to reiterate that hydrodynamic design is fundamentally related to spatial usability and habitability and lends support to the argument that mooring has transformed from a static and auxiliary add-on to an integrated and adaptive component of residential performance. In an increasingly turbulent climate and aquatic environment, the capacity to predict and control hydrodynamic behavior becomes a critical factor in the long-term sustainability of floating housing.

Some of the reviewed papers suggest key methodological and technical advancements in the field, and Nekooie et al. (2017) formulate a drag coefficient equation for amphibious housing through experiments based on a 1:25 floodplain scale model, for which they use parametric sensitivity analysis to validate, and show that this equation considerably improves the accuracy of lateral force prediction and provides a more robust basis for sizing and calibrating mooring systems in high-velocity flood conditions. Yin (2017) employs a systems dynamics perspective by installing Tuned Liquid Column Dampers (TLCDs) inside a floating box-type platform and, when properly tuned, the TLCDs show significant reductions in pitch and angular displacement under wave action and represent a discreet means of enhancing equilibrium and indoor comfort without substantial architectural concessions. On a larger scale, Tsao et al. (2024) apply digital twin techniques to simulate pile-moored modular districts, using a combination of Reduced Order and High Order Models to simulate hydrodynamics, mooring-line tensions, resonance effects, and water-level variations under storm surge and sea-level rise scenarios, and their findings show how real-time data and digital twins can support more adaptive mooring design and long-term resilience planning at the neighborhood or city scale. Overall, these contributions demonstrate that hydrodynamic and mooring design decisions are now closely intertwined with residential performance, as they not only determine whether a floating structure will remain safe in extreme conditions but also whether it will remain comfortable, usable, and acceptable to inhabitants under normal conditions.

Although the reviewed studies provide important insights into wave-induced loads, restraint strategies, and platform response, long-term field evidence on mooring performance under actual extreme-weather conditions remains limited. This is a significant gap because mooring reliability in service depends not only on ultimate resistance, but also on gradual changes in stiffness, pretension, fatigue accumulation, and repeated environmental loading over time (Gräfe et al., 2024; Rui et al., 2024). Recent design studies increasingly assess mooring behavior across operational, extreme, and accidental limit states, but these approaches still require validation against long-duration monitoring under real storm and surge conditions (Bian et al., 2025; Tsao et al., 2025). For floating housing, this means that confidence in long-term residential deployment will depend on sustained in-situ monitoring of mooring loads, platform motions, and serviceability during both normal and extreme events.

Hydrodynamic behavior in relation to mooring layout is more specifically addressed by Miszewska and Niedostatkiwicz (2019), who experimentally investigate tank testing of pontoons moored in longitudinal and transverse orientations, and they demonstrate that a symmetrical multi-

point mooring layout at 45° to the dominant wave direction is optimal for minimizing dynamic instability and spreading loads more evenly across the platform. Nguyen et al. (2025) then extend the discussion into the field of amphibious housing through a piston-house typology, in which mooring is redefined as a vertical guidance system using rails rather than flexible lines; thus, turning anchorage into an integral part of the building's architecture rather than a separate add-on engineering system, because in this model, rail-guided movement eliminates lateral drift while allowing a controlled buoyant rise. From a planning perspective, Storbjörk and Hjerpe (2022) argue that hydrodynamic control constitutes a systemic problem rather than a purely technical detail and, based on fieldwork in Swedish floating districts, they argue that hydrodynamic and mooring simulations need to be integrated early in the urban planning and development process, and that regulatory coherence and coordination between municipal actors are essential preconditions for the successful deployment of floating infrastructure. Across the six core studies, all of them (100 %) explicitly address hydrodynamic forces either through physical tank testing or numerical simulation, and two-thirds (66.7 %) go on to discuss mooring strategies in detail, consequently highlighting the importance of hydrodynamic considerations in floating infrastructure design.

For floating housing, mooring should be understood not only as a station-keeping system but also as a serviceability device that shapes everyday motion comfort. A platform may remain structurally safe yet still generate repeated low-amplitude surge, sway, roll, or pitch motions that disturb sleep, movement, and long-term residential acceptance. Mitigating such micro-motions requires more than increasing line strength; it involves optimizing mooring geometry, maintaining directional symmetry where possible, tuning line stiffness and damping and, when necessary, combining the mooring system with supplementary motion-control devices (Miszewska & Niedostatkiewicz, 2019; Nguyen et al., 2025; Yin, 2017). Recent serviceability studies on human-activity-oriented floating structures further reinforce the need to manage low-frequency accelerations and inclination levels with explicit reference to comfort rather than equipment-only criteria (Jeong et al., 2025). Likewise, damping-enhanced mooring concepts demonstrate that motion reduction and cable load reduction can be pursued simultaneously, suggesting a more integrated approach to both safety and comfort (Yang et al., 2025). In this sense, micro-motion mitigation should be treated as a core objective of residential mooring design, rather than merely an optional refinement.

Half of the studies present some kind of sophisticated control concept, such as TLCD dampers, digital twins, or piston-guided systems, which collectively point towards a broader disciplinary transition from basic, reactive anchoring to predictive and fully integrated hydrodynamic design, therefore underscoring that hydrodynamic stability and mooring reliability are not tangential concerns, but rather foundational to structural safety, occupant comfort, and long-term urban resilience. As such, hydrodynamic thinking must be embedded in the initial architectural brief and early design stages rather than retrofitted as a risk-mitigation measure, as this approach enables more effective and efficient integration of hydrodynamic considerations into the design process, ultimately contributing to the development of more resilient and sustainable floating infrastructure.

4.4 Governance, public acceptance, and service autonomy in floating housing

This section presents a critical review of governance arrangements, public acceptance, and infrastructural autonomy in floating and amphibious housing, based on eight empirical studies summarized in **Table 7**, which jointly reveal that regulatory fragmentation, socio-political conflict, and institutional inaction continue to limit the diffusion of floating residential typologies. Moreover, they demonstrate that, even where floating housing is technically and economically feasible, it will not progress beyond the pilot phase without the support of coherent regulatory regimes and broad public acceptance, because technical solutions alone will not mainstream floating housing, but must be matched by clear governance structures, inclusive planning processes, and acceptable models of ownership, access, and environmental stewardship.

Table 6 Hydrodynamic response and mooring design for floating and amphibious housing.

Hydrodynamic Focus	Mooring / Stability Strategy	Method / Model Type	Environmental Conditions Simulated	Key Hydrodynamic-Mooring Insight	References
Amphibious houses' drag coefficient under floodplain interaction	Anchored model tested at 1/25 scale	Scaled floodplain model test + drag formulation	Floodplain lateral water force and velocity variation	Drag coefficient equation validated by test and sensitivity analysis; improves hydrodynamic stability prediction	(Nekooie et al., 2017)
Pitched motion control for a floating platform via TLCD	Passive motion damping; no mooring modeled	Numerical model + optimization	Wave-induced pitching motion	TLCD dampers reduce angular displacement under pitching; enhance platform stability and comfort	(Yin, 2017)
Floating modular urban platform dynamics (digital twin)	Adjustable platforms moored on piles	Digital twin; Reduced Order Model (ROM) + High Order Model (HOM)	Storm surge; sea-level rise; wave interaction	Real-time digital twin model captures wave dynamics and mooring response under storm conditions	(Tsao et al., 2025)
Pontoon platform mooring system performance	Longitudinal and transverse mooring at various angles	Experimental model simulation	Wave and wind action in the canal context	Symmetrical multi-point mooring reduces instability; the 45-degree configuration is most effective	(Miszewska & Niedostatkiewicz, 2019)
Amphibious piston-house platform mooring	Rail-guided vertical motion control	Conceptual design + platform dynamics analysis	Flood-level variation	Rail system replaces mooring lines; guides vertical motion; reduces lateral instability	(Nguyen et al., 2025)
Floating housing planning and mooring strategy (Sweden pilot districts)	Planning guidance on mooring and anchorage	Empirical field study (urban planning context)	Urban water fluctuation; seasonal variation	Planning should integrate mooring and hydrodynamic modeling early in the floating-housing strategy	(Storbjörk & Hjerpe, 2022)

This section provides a critical examination of the governance, social acceptance, and infrastructure autonomy factors that shape the sustainability of floating and amphibious housing, based on eight empirical studies summarized in **Table 7**. Collectively, they demonstrate that regulatory fragmentation, socio-political contestation, and institutional inertia remain significant barriers to the mainstreaming of floating housing, even where the relevant engineering solutions are mature, which implies that technical feasibility is a necessary but not sufficient condition for the up-scaling of floating housing; in the absence of regulatory coherence and public legitimacy, it will remain confined to pilot projects and niche developments. **Figure 9** visualizes the broader socio-regulatory ecosystem in which floating housing is planned and implemented, and positions the floating dwelling not only as a technical object, but as the point of intersection of multiple interacting systems, around which are four domains: regulation, public acceptance, environmental stewardship, and infrastructure autonomy, with bidirectional arrows representing how these elements co-evolve; for example, clear and predictable policy frameworks can engender public trust, while organized

community engagement and advocacy can, in turn, stimulate regulatory innovation, and environmental requirements inform technical standards for construction and operation, just as the demonstrated feasibility of off-grid or microgrid systems can influence the willingness of authorities to recognize and support autonomous floating districts. This ecosystem framing thus underscores the primary argument that the success or failure of floating housing depends as much on institutional coordination and civic legitimacy as on structural stability and hydrostatic performance, because the figure also points to a recurring gap in the literature: while there is rapid progress in technical solutions for autonomy, such as solar-based microgrids, water-recycling systems and decentralized waste treatment, their integration at scale is hindered by fragmented governance systems and uneven social readiness. Consequently, the figure supports a shift from compliance-oriented governance, with its narrow focus on risk and code conformity, toward a more integrative and participatory model of floating urbanism.

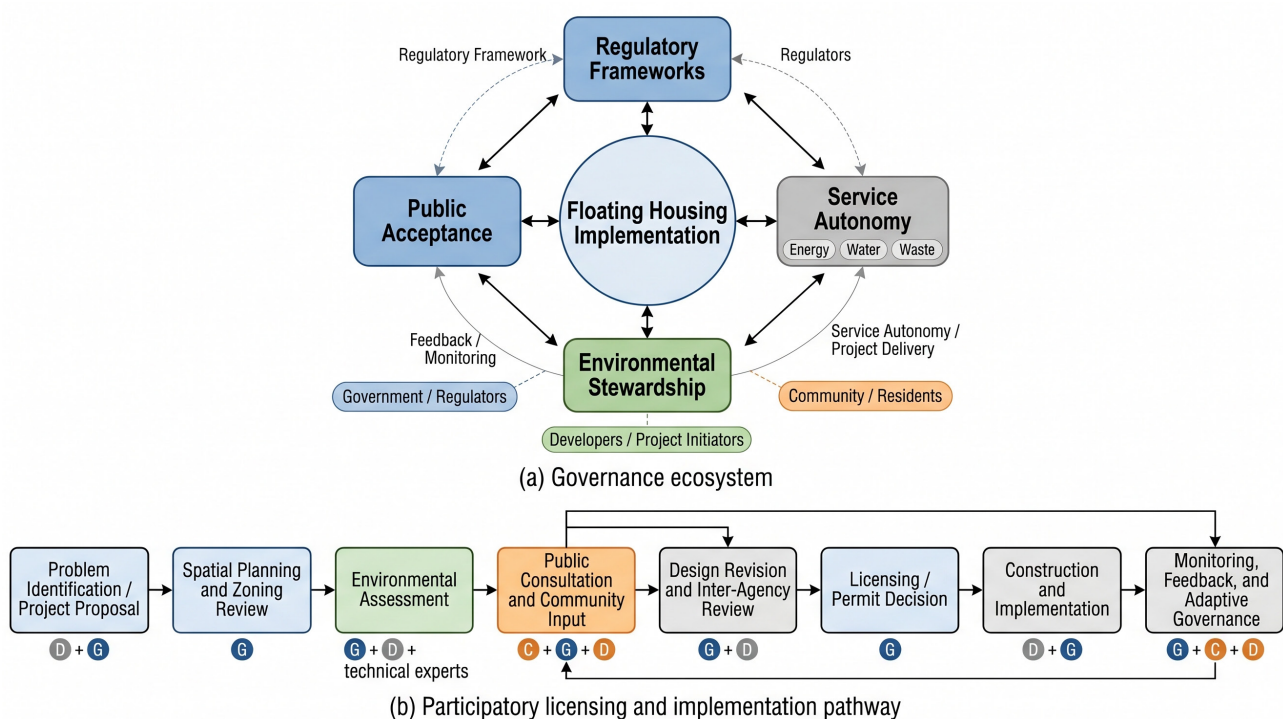


Figure 9 Governance dimensions of floating housing implementation. (a) Governance ecosystem linking regulatory frameworks, public acceptance, environmental stewardship, and service autonomy around floating housing implementation. (b) Simplified participatory licensing and implementation pathway showing how government, developers, and community stakeholders interact across proposal, assessment, consultation, permitting, implementation, and adaptive monitoring stages.

Figure 9 has also been expanded to include a supplementary participatory-governance panel to clarify how implementation depends on interactions among public authorities, project developers, and community stakeholders. This addition makes the figure more applicable to policymaking by showing that social acceptance is not merely an outcome of implementation, but an active part of consultation, design refinement, and long-term governance (Rosso et al., 2020; Storbjörk & Hjerpe, 2022; Suntoro et al., 2025).

To increase the practical relevance of the governance discussion, **Figure 9** has also been expanded with a simplified process-flow panel showing a licensing and partnership pathway for

floating housing implementation. The added panel clarifies how project proposal, spatial and environmental assessment, public consultation, inter-agency review, licensing, implementation, and monitoring are linked, and how developers, public authorities, and communities interact across these steps (Faraggiana et al., 2024; Shi et al., 2023; Storbjörk & Hjerpe, 2022).

Empirically, Rosso et al. (2020) present a comparative survey of public perceptions of floating architecture in five European cities, and show that residents tend to appreciate its design innovation and perceived livability gains, but are skeptical about environmental impacts and the risk that floating developments may become exclusive enclaves, which is why they argue for participatory planning processes and targeted, place-based public engagement to secure a social license to operate. Moreover, Faraggiana et al. (2024) analyze the Dutch governance context and identify a tension between strict ecological protection requirements and the pressures of urban densification, and through stakeholder interviews they show that practitioners see the need for governance frameworks that are both standardized and flexible: robust enough to ensure environmental and procedural accountability, yet adaptive enough to support experimentation and incremental scaling of floating housing. Therefore, collectively, these studies suggest that the development of floating housing from a novel experiment to a legitimate and climate-resilient housing type requires governance models that integrate engineering performance, human-centered design, environmental responsibility, and inclusive decision-making processes into a comprehensive, context-sensitive regulatory framework.

Shi et al. (2023) carry out a cross-jurisdictional policy review, concluding that most extant planning systems lack transparent zoning categories, consistent permitting pathways, and strong environmental oversight procedures for floating and amphibious housing, and they advocate for vertically integrated governance structures linking municipal, regional, and national authorities to avoid piecemeal regulation. This is reinforced by Storbjörk and Hjerpe (2022), who document how slow regulatory responses and legal ambiguity in Swedish pilot districts create delays, uncertainty, and stalled projects, and they emphasize the need to embed regulatory considerations at the outset of project development to prevent administrative gridlock. Turning to technological systems, Paneliya and Suhane (2025) map autonomous service strategies for energy, water, and waste in floating housing, and demonstrate that off-grid solutions, such as photovoltaic generation, rainwater harvesting, and bio-digester-based sanitation, can greatly enhance resilience and reduce dependence on vulnerable centralized networks, while Suntoro et al. (2025) expand on this perspective through a case study of modular microgrids in delta regions of Indonesia, showing that local communities support these systems because they offer both economic advantages and environmental benefits.

In terms of modeling, Luccioni et al. (2024) propose a framework that considers governance readiness and public trust to be as important as engineering performance, and their multi-criteria transition model identifies regulatory transparency and social legitimacy as key leverage points for scaling up floating housing. Niamir and Pachauri (2023) use climate-adaptation scenario modeling to examine when floating housing becomes a viable adaptation pathway, and their results indicate that large-scale diffusion is realistic only under conditions of strong governance and targeted, supportive policy measures, findings consistent with those of other studies. Across the reviewed work, every study (100 %) engages in some depth with governance or institutional readiness, and of these six (75 %) explicitly discuss public perception and community acceptance, while four studies (50 %) evaluate the feasibility of autonomous infrastructure and service systems, and together, these proportions support the conclusion that governance and civic engagement are not peripheral to design and engineering, but fundamental to real-world deployment. The literature situates floating housing at the intersection of climate-responsive architecture, decentralized infrastructure innovation, and evolving governance; therefore, moving the concept into the mainstream will not only require sophisticated structural and hydrostatic solutions but also institutional realignment, participatory decision-making processes, and policy frameworks that allow for innovation while protecting equity and environmental integrity.

Table 7 Governance, regulatory readiness, public acceptance, and service autonomy in floating and amphibious housing.

Governance / Policy Focus	Public Acceptance Dimension	Infrastructure / Autonomy Strategy	Method / Evidence Type	Key Insight (from Abstract)	References
Public perceptions of floating urban architecture in 5 European cities	Perception of aesthetics, livability, and acceptability	Indirect; focuses on social license and image	Survey and interview-based comparative study	Public perception of floating housing varies; strong aesthetics/livability scores; some resistance due to elitism/environmental concerns	(Rosso et al., 2020)
Regulatory governance and stakeholder perspectives in Dutch floating projects	Stakeholder tension around urban density vs. ecological risk	Not infrastructure-focused; governance framework emphasis	Interview-based stakeholder analysis	Standardization needed; flexibility also crucial; regulatory innovation required for broader adoption	(Faraggiana et al., 2024)
International policy review of floating housing frameworks	Not direct focus; implies lack of public engagement mechanisms	Legal zoning, permitting, building code deficiencies	Policy and planning review across jurisdictions	Regulatory gaps persist across most cases; coordinated governance needed across levels	(Shi et al., 2023)
Regulatory experience from pilot floating districts (Sweden)	Mixed institutional support: legal ambiguity causes friction	Mooring/zoning policies discussed; no autonomy detail	Empirical urban planning study	Regulatory inertia and vague legal classification inhibit upscaling; early coordination critical	(Storbjörk & Hjerpe, 2022)
Floating-housing system autonomy (energy, water, waste)	Not primary focus	Off-grid systems: solar, filtration, waste digestion	Engineering system performance review	Service autonomy enhances resilience and reduces grid dependency; technical maturity present	(Paneliya & Suhane, 2025)
Floating-microgrid performance in delta communities	Community support; social compatibility	Microgrid infrastructure; modular deployment	Empirical case study with community metrics	Floating microgrids are cost-effective, scalable, and supported by local users	(Suntoro et al., 2025)
Multidimensional transition model for floating housing	Public trust modeled as part of system viability	Integrated socio-technical modeling	Multi-criteria modeling (tech–gov–social)	Governance and public trust are as important as engineering quality in floating-housing success	(Luccioni et al., 2024)
Urban adaptation policy scenarios and floating housing roles	Policy acceptance key to scenario viability	Not focused on technical systems; scenario-level governance	Policy modeling and simulation	Without supportive governance scenarios, floating housing remains marginal in adaptation portfolios	(Niamir & Pachauri, 2023)

5. Discussion

The integration of the empirical and theoretical literature on platform typologies, hydrostatics, hydrodynamics, and governance demonstrates that floating housing is a deeply complex, multi-system response to climate-related spatial pressures, and it is not a question of structural engineering or urban design in isolation, but rather a delicate interplay of technical precision, architectural flexibility, regulatory preparedness, and community buy-in. As discussed in Section 4.1, platform typology is, at its core, a trade-off between affordability, buildability, and mechanical performance, because pontoon-based systems remain dominant, as they are relatively inexpensive, modular, and simple to build, but their hydrodynamic limitations, especially their strong response to lateral wave action, can erode day-to-day comfort and perceived stability. However, more advanced typologies, such as semi-submersible and catamaran platforms, are much better at controlling dynamic motions and improving occupant comfort, but they require more capital, more specialized design knowledge and, typically, more complex regulatory negotiation, which is consistent with Edwards et al. (2023), who find that greater levels of comfort and motion control almost always come at the expense of added design complexity and financial cost.

To clarify the comparative implementation implications of platform selection, **Figure 10** includes a simplified relative-cost panel, while **Table 8** summarizes the main cost drivers and design implications of the three dominant engineered typologies. This comparison should be interpreted as a qualitative synthesis rather than a universal cost ranking, because actual implementation costs depend on local material availability, fabrication capacity, water depth, wave exposure, transport logistics, regulatory requirements, and long-term maintenance regimes.

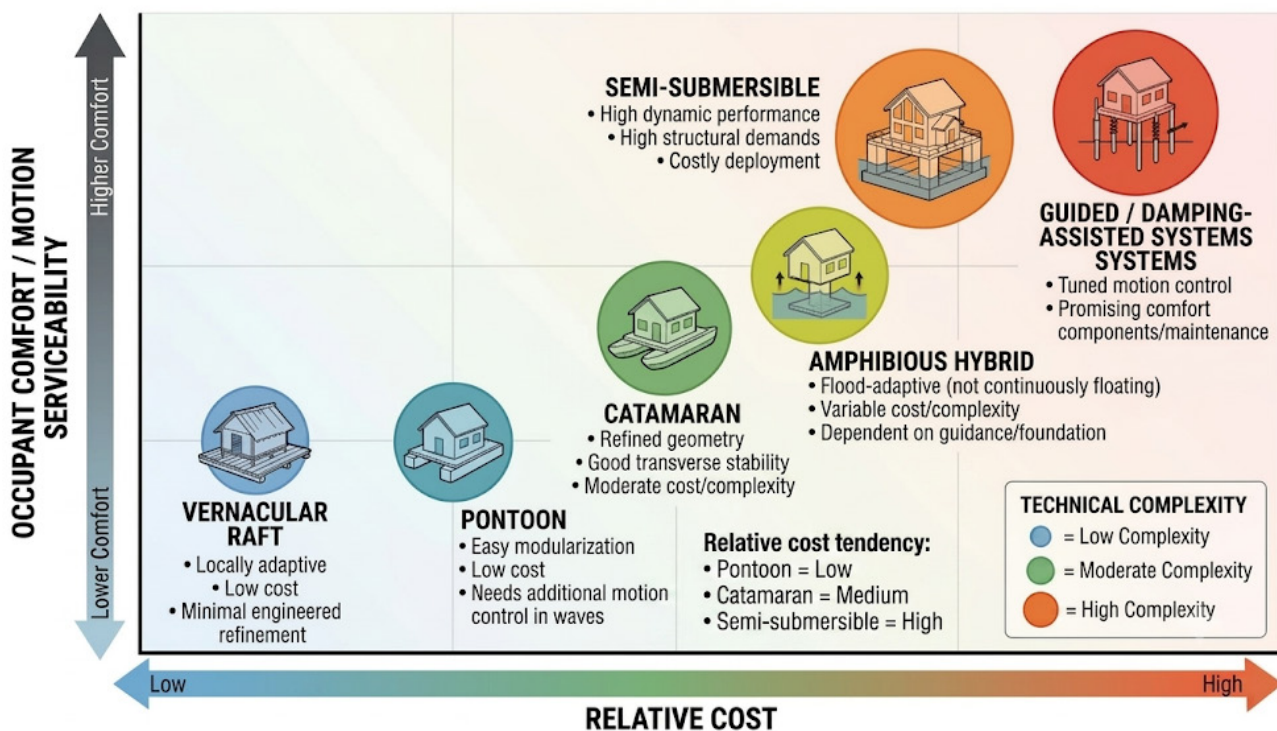


Figure 10 Comparative trade-offs among floating-housing platform typologies in terms of relative cost, technical complexity, and expected occupant comfort. The added panel summarizes the qualitative cost tendency of the three dominant engineered typologies: pontoon = low, catamaran = medium, and semi-submersible = high. These categories are indicative rather than universal, as actual costs depend on local materials, fabrication capacity, environmental exposure, regulatory requirements, and maintenance regimes.

Table 8 Qualitative cost logic and implementation implications of major floating-housing platform typologies.

Platform typology	Relative cost tendency	Main cost drivers	Implementation implication
Pontoon	Low	Simple geometry, modular fabrication, commonly available materials, and relatively straightforward installation	Pontoon platforms are generally the most cost-effective and modular floating housing option. However, they often require additional motion-control measures, robust mooring systems, and carefully designed shore interfaces to maintain residential comfort under wave and current exposure.
Catamaran	Medium	Dual-hull configuration, wider beam requirements, higher fabrication precision, and more complex structural detailing than simple pontoon systems	Catamaran platforms can improve transverse stability and reduce roll sensitivity. However, they require greater spatial coordination, more precise fabrication, and stronger structural integration, which may increase construction and site-adaptation costs.
Semi-submersible	High	Submerged columns or pontoons, ballast control, advanced mooring design, demanding installation procedures, and higher maintenance requirements	Semi-submersible platforms can provide better motion control in exposed or wave-active environments. However, their technical complexity and higher implementation burden make them less suitable for affordable mass housing unless standardized, simplified, and locally adaptable design solutions are developed.

To make the comparative implications of the review more explicit, a synthesis matrix has been added to summarize the principal trade-offs between platform typologies in terms of relative cost, technical complexity, and likely comfort performance. This relationship is further illustrated in **Figure 10**, which visually maps the comparative position of each typology and translates the discussion into a design-oriented decision aid. The matrix is not intended as a universal ranking, since actual outcomes remain context-dependent, but as a comparative guide derived from the reviewed literature. In broad terms, pontoon-based systems remain attractive because of their simplicity, modularity, and lower cost, yet they often require additional motion-control strategies to maintain acceptable comfort under wave and current exposure (Adi et al., 2020; Cahyono, 2024). By contrast, catamaran, semi-submersible, and guided or damping-assisted concepts generally offer better motion behavior and improved habitability, but do so at the cost of greater technical complexity, more demanding installation and maintenance requirements, and higher implementation burdens (Edwards et al., 2023; Nguyen et al., 2025; Tsao et al., 2025). Framed in this way, the selection of a floating-housing typology becomes less a matter of identifying a universally superior option than of aligning platform logic with budget constraints, environmental exposure, and desired serviceability outcomes (Wang et al., 2023).

While Section 4.2 highlights the importance of hydrostatics and geometry in informing these typological choices, studies by Cahyono (2024) and Adi et al. (2020) strengthen the argument for the relevance of stability indicators, such as metacentric height, righting arm behavior, and Fa/G ratios, for understanding how a platform will operate in service, while also highlighting methodological inconsistencies in the field. Moreover, Imani et al. (2020), Zhou et al. (2017), and Nwaoha and Idubor, (2019) all point to the effect of geometric assumptions, modeling approaches, and parameter definitions in limiting the accumulation of knowledge, because much of the research relies on

simulations that are, while sophisticated, not always well calibrated against real-world measurements and, therefore, Pavlidis and Rowe (2021) warn that the difference between modeled performance and in-situ behavior can lead to overly optimistic expectations of stability and comfort when platforms are actually exposed to wave climates, changing water levels, and user behavior.

The role of hydrodynamics and mooring, discussed in Section 4.3, adds a crucial further dimension to this, along with new techniques such as TLCDs (Yin, 2017), piston-rail amphibious systems (Nguyen et al., 2025), and digital-twin-based wave–structure interaction models (Tsao et al., 2025). All suggest a future of predictive, adaptive motion control over passive resistance. At the same time, the fact that most of these systems remain at the prototype or pilot scale raises acute questions over the ease of deployment, maintenance, and financing of such systems in actual housing projects because, as Formosa et al. (2023) and Abdelaty (2025) argue, there is a desperate need for long-term monitoring data on the actual performance of floating structures under variable hydrological stresses if these concepts are to be translated from theoretical potential to proven practice.

Section 4.4 makes clear that governance and service autonomy are no less decisive, since regulatory fragmentation, slow-moving institutions, and the lack of clear zoning and permitting categories continue to impede implementation (Shi et al., 2023; Storbjörk & Hjerpe, 2022), while public skepticism, frequently related to concerns over elitism, waterfront privatization, or ecological impacts can undermine the social license of floating projects (Faraggiana et al., 2024; Rosso et al., 2020). Overcoming these challenges will require more than technical guidelines and will demand coordinated policy design and genuine co-production with affected communities; therefore, autonomy in energy, water, and waste management is increasingly seen as a baseline requirement for resilience, especially in flood-prone or weakly serviced areas. Case studies by Paneliya and Suhane (2025) and Suntoro et al. (2025) demonstrate how decentralized infrastructure (solar microgrids, rainwater harvesting, bio-digestive sanitation) serves both as an engineering strategy and as a political intervention that reduces dependency on vulnerable centralized systems; however, as Luccioni et al. (2024) show, the performance of these autonomous systems depends just as much on governance capacity and public confidence as on technological robustness.

Consequently, the literature shows that there is no single “correct” design logic, policy model, or engineering recipe that can universally guarantee successful floating housing but, instead, each project emerges from context-specific negotiations between hydrodynamic conditions, platform typology, resident expectations, and the strength of local governance. Moreover, the persistent lack of integrative frameworks capable of reconciling these dimensions in a comparable manner constitutes a critical barrier to cross-context synthesis and to scaling floating housing as a mainstream climate adaptation strategy.

With respect to future research, five distinct priorities are evident, and first, methodological standardization is a pressing concern because studies must define, adopt, and apply consistent, reproducible criteria for assessing platform stability, hydrostatic performance, and occupant comfort across both simulation-based analyses and empirical case studies (Imani et al., 2020; Telfar-Barnard et al., 2017). Without shared metrics, there is little scope for comparative analysis or cumulative learning and, therefore, second, real-world performance monitoring is required, which involves conducting longitudinal research to record the actual performance of floating and amphibious dwellings across time in diverse climatic settings, with a focus on durability, adaptability, and resident satisfaction (Kucharczyk-Brus, 2020), as this type of evidence is crucial in order to validate the often overly optimistic results yielded by numerical models. Third, there is an obvious policy-related agenda for cross-scalar policy mapping and, moreover, the fourth research priority concerns the integration of participatory design in the architectural and planning process, which is crucial for making sure that floating housing designs are in line with cultural practices, everyday routines, and social expectations, and this would improve acceptance and long-term legitimacy (Amal & Larasati, 2025). The fifth research priority is the synchronization of technology and governance, as the development of new materials, smart infrastructures, and autonomous service systems requires

adaptive, inclusive governance frameworks that can guide their deployment, regulate their risks, and distribute their benefits in an equitable manner (Storbjörk & Hjerpe, 2022) and, consequently, these priorities show that floating housing is not a single technological solution but a plural and ongoing project that spans architecture, ecology, and politics. The future of the floating housing will thus depend not only on innovative platforms or advanced engineering, but also on the capacity of institutions, communities, and professionals to work together to co-create new ways of living with water.

6. Conclusions

This systematic literature review synthesizes the current state of knowledge on floating and amphibious housing as an adaptation to sea-level rise and increased flood risk, combining insights from engineering, architectural, and governance-oriented research. The review's organization around four key themes, including platform typologies, geometry-driven hydrostatics, hydrodynamic response and mooring, and socio-regulatory readiness, reveals how technical design decisions simultaneously condition residential habitability and determine whether such schemes can be realized. Findings demonstrate that the performance of floating housing cannot be assessed based on buoyancy or stability thresholds alone, because platform geometry, material selection, and modular construction strategies combine to determine hydrostatic efficiency and reserve buoyancy, while hydrodynamic forces and constraint systems, such as moorings, guide rails, and pile-supported arrangements, are essential to both structural safety and everyday comfort. Moreover, new technologies, including motion-damping, guided vertical-lift systems, data-driven monitoring, and control, hint at the emergence of more predictive and adaptive design cultures; however, these innovations have been only partially tested in full-scale, long-term applications, raising important questions about their robustness and scalability in the field.

From a policy perspective, addressing the current legal vacuum will require more than acknowledging floating housing as an experimental adaptation option. Governments need to establish clear legal classification pathways for floating and amphibious dwellings, integrate them into spatial planning and zoning systems, and align building, water, and environmental regulations through coordinated inter-agency permitting. In parallel, implementation frameworks should require site-specific hydrodynamic, ecological, and residential serviceability assessments, supported by post-occupancy monitoring and periodic regulatory review. Such measures would help shift floating housing from isolated pilot projects toward a more predictable and governable climate-adaptation pathway.

Equally important is the question of accessibility. If floating housing is to serve low-income and climate-vulnerable communities rather than remain an elite pilot typology, its implementation will need business and funding models that actively address affordability. Promising directions include modular and prefabricated production to reduce capital costs, public support through climate-adaptation and affordable-housing funding streams, concessional finance, and community-based, cooperative, or mixed-income delivery models that spread risk while protecting long-term affordability. Although these approaches should be understood as emerging policy directions rather than universally standardized models, they indicate that the future of floating housing depends not only on engineering feasibility but also on whether implementation pathways can be made socially inclusive and financially accessible.

Equally important are the institutional conditions under which floating housing is planned and regulated, and the fragmented regulatory frameworks, ambiguous legal classifications, and weak interagency coordination that are common in many cities typically confine projects to pilot or demonstration scale and prevent them from scaling up into mainstream solutions. Public acceptance is not only a matter of safety perceptions, but also of questions around equity, visual and cultural fit, environmental impact, and trust in the reliability of everyday services; in this context, autonomous systems for energy, water, and waste not only become critical levers of resilience, especially in flood-

prone or poorly serviced areas, but they also introduce new governance challenges around standards, oversight and accountability. Together, the review suggests that floating housing should be understood as a socio-technical system rather than as a standalone engineering object, because progress in this field depends on three main developments: first, standardized and comparable assessment frameworks that link stability and motion criteria directly to residential serviceability; second, long-term empirical monitoring of real-world performance and user experience; and third, governance models that can integrate engineering rigor with architectural quality, environmental care, and participatory legitimacy. Consequently, if hydrostatic precision, stability and motion control, and regulatory readiness can be brought into alignment, floating housing can move beyond experimental adaptation and become a credible, scalable component of climate-resilient urban futures.

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Declaration of competing interest

The authors certify that there are no financial conflicts of interest or personal relationships that could have influenced the study reported in this paper.

Declaration of generative AI in scientific writing

The authors used NotebookLM (Google) to synthesize relevant journal articles and conference papers, Grammarly for language editing, and Canva and Gemini (Google) to develop and refine all figures in the manuscript. The authors remain fully responsible for all stages of the research and manuscript preparation. All final edits, interpretations, arguments, findings, and conclusions are solely those of the authors. The authors confirm that this AI-use statement is accurate and truthful and accept full responsibility for the content of the submitted and published work, including the accuracy, completeness, and correctness of all references.

CRedit contribution statement

Eko Sasmito Hadi: Conceptualization, Methodology, Visualization, Writing- Original draft preparation. Writing- Reviewing and Editing. **Untung Budiarto:** Data curation, Writing, Original draft preparation. **Seykha Rafita Fathan:** Investigation, Supervision, Software. **Nicholas Saputra Ambarita:** Writing- Reviewing and Editing. **Muhammad Raafie Caesar Putra Hadi:** Resources, Visualization, Project administration. **Ahmad Fauzan Zakki:** Resources, Visualization, Project administration. **Samuel:** Resources, Visualization, Project administration. **Good Rindo:** Resources, Visualization, Project administration. **Deddy Chrismianto:** Writing- Reviewing and Editing. All authors have read and approved the final manuscript.

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