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From Polders to Palafitos: A Buoyancy-Engineering and Social-Acceptance Framework for Transferring Dutch Amphibious Housing to Peru's Flood-Prone Settlements

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Abstract

Background: Riverine and coastal flooding is intensifying across both high-income deltaic nations and developing tropical countries, though the two contexts are rarely studied together. The Netherlands has institutionalised amphibious construction as a flood-adaptation strategy, while Peru's Amazonian and northern coastal settlements rely on centuries-old stilt (palafito) and floating-house traditions that remain informal and technically unsupported.

Objective: To characterise the engineering, market and institutional basis of Dutch amphibious housing and to assess, through a structured qualitative comparison, which elements of this experience can realistically be transferred to Peruvian riverine and coastal contexts.

Methods: A qualitative, comparative case-study design was used. Purposively selected peer-reviewed and institutional sources on the Maasbommel amphibious development were contrasted with recent peer-reviewed studies on Peru's 2017 Coastal El Niño and on the Bajo/Nuevo Belén riverine settlements of Iquitos. A comparison matrix and a set of standard buoyancy-engineering design relations were used to structure the analysis.

Results: The Dutch model's technical success rests on buoyant concrete/timber hulls guided by fixed posts, engineered to accommodate documented water-level fluctuations of up to 5.5 m, embedded within an explicit flood-management programme (“Room for the River”) and, initially, an ambiguous regulatory framework. In Peru, an estimated 76,140 people live in the Belén area of Iquitos alone, already practising informal amphibious adaptation, while the 2017 Coastal El Niño affected approximately 1.9 million people and damaged over 300,000 homes on the northern coast. Peru possesses relevant cultural precedent and acute need but lacks engineered buoyant foundations, formal land tenure and dedicated financing.

Conclusions: The Dutch model is transferable in principle but not directly replicable. A hybrid, incremental approach — engineered buoyant retrofits of existing palafito structures using locally available materials, integrated into Peru's national building code and accompanied by community-based design and phased public financing — offers the most defensible pathway. Further site-specific hydrological and structural studies are required before implementation.

1. Introduction

1.1 Background

Flooding linked to sea-level rise and to more erratic riverine and El Niño–Southern Oscillation dynamics is projected to intensify globally (IPCC 2022). In response, “amphibious” construction — buildings that rest on the ground under normal conditions but rise on a buoyant foundation during floods — has moved from prototype to institutionalised practice in the Netherlands, most visibly in the Maasbommel

development, where 32 amphibious and 14 fully floating homes were built along the Maas River outside the protection of the regional dike system (English et al. 2016; Piątek et al. 2024).

These dwellings combine a prefabricated, watertight concrete or composite hull with a lightweight timber superstructure and are constrained to rise vertically along fixed guidance posts, reportedly accommodating water-level changes of up to 5.5 m (English et al. 2016). Comparable typologies elsewhere in Europe remain rare, but they are increasingly discussed as one credible category of flood-resilient construction alongside elevated and fully floating buildings (Piątek and Wojnowska-Heciak 2020; Piątek et al. 2024).

1.2 Peru's flood-vulnerability context

Peru faces two structurally different but equally severe flood regimes. On the northern and central coast, the 2017 Coastal El Niño affected an estimated 1.9 million people, caused 169 deaths, displaced approximately 194,000 residents and damaged more than 300,000 homes, of which around 65,000 were rendered uninhabitable (Yglesias-González et al. 2023). In the Peruvian Amazon, seasonal river rhythmicity (vaciante–creciente cycles) is a permanent, not exceptional, condition: in Bajo and Nuevo Belén, a riverine area of Iquitos with a recorded population of 76,140, residents have long adapted through stilt houses and improvised floating structures, and many actively value life on the floodplain rather than viewing relocation as desirable (Mendoza et al. 2025).

1.3 Research gap and contribution

Two literatures have developed largely in isolation. Architectural and civil-engineering studies of amphibious construction concentrate on built cases in high-income, temperate settings and on their technical and typological classification (Piątek and Wojnowska-Heciak 2020; Piątek et al. 2024; English et al. 2016). A separate body of human-geography and sustainability-science research documents the lived experience, informal adaptation and environmental-justice dimensions of Amazonian and coastal Peruvian flood-prone communities (Mendoza et al. 2025; Yglesias-González et al. 2023; Alatrista-Salas et al. 2021). To date these two bodies of evidence have not been examined together within an engineering-transfer framework.

This paper's contribution is threefold: (i) it synthesises, in one place, the buoyancy and stability design logic that underlies Dutch amphibious construction; (ii) it applies a structured comparative matrix to identify which specific technical and institutional elements are — and are not — plausibly transferable to Peru; and (iii) it proposes locally adapted construction procedures, materials and tools consistent with Peru's existing regulatory framework (Reglamento Nacional de Edificaciones), rather than proposing a wholesale technology import.

1.4 Objectives

This study aims to: (1) describe the engineering principles and construction methods underpinning Dutch amphibious housing; (2) summarise the market and institutional conditions that enabled its adoption; (3) characterise Peru's coastal and Amazonian flood-exposure context using the best available

peer-reviewed evidence; and (4) evaluate, through a comparative matrix, the technical and socio-institutional transferability of the Dutch experience to Peru, culminating in adapted procedural recommendations.

2. Materials and Methods

2.1 Design

A qualitative, comparative case-study design was adopted. This is not a systematic review; the objective was analytical comparison rather than exhaustive literature synthesis, and no formal PRISMA protocol was applied, consistent with established practice in the amphibious-architecture literature, where equivalent matrix-based comparative methods have been used to contrast a small number of built cases (Piątek et al. 2024).

2.2 Source selection

Sources were purposively selected using the following inclusion criteria: (a) peer-reviewed journal articles or Springer Nature conference proceedings; (b) direct empirical or technical documentation of amphibious/floating housing in the Netherlands, or of flood exposure and riverine housing in Peru; (c) availability of a verifiable DOI. Nine primary peer-reviewed sources met these criteria and form the empirical backbone of the comparison. These were supplemented by the IPCC Sixth Assessment Report (IPCC 2022) for global context, Peru's national building code for regulatory context, and Rogers' (2003) diffusion-of-innovations framework for interpreting adoption patterns. No unverifiable, retracted, or non-DOI web sources were used as evidentiary citations.

2.3 Comparative matrix construction

A matrix was built across seven parameters common to both contexts: hazard regime, vertical water-level design range, foundation/structural typology, settlement scale, institutional/regulatory status, traditional ecological knowledge, and documented impact data. Values were populated only where directly reported in a cited source; parameters without documented Peruvian or Dutch data were marked “not reported” rather than estimated, to avoid the statistical overreach identified in earlier drafts of this line of research.

2.4 Engineering-formula review

Standard naval-architecture and civil-engineering buoyancy relations (Archimedes' principle, required buoyant volume, freeboard, transverse metacentric height, and lateral hydrodynamic load on guidance posts) were compiled from established structural-engineering practice to provide the quantitative basis

needed to translate the Dutch design logic into Peru-specific sizing exercises (Section 3.2). These are general engineering relations, not proprietary or project-specific data.

2.5 Ethical approval and data availability

This article is a literature-based comparative analysis; it did not involve the collection of primary data from human participants, and therefore no institutional ethics committee approval was required for the present study. Where cited sources report primary fieldwork involving human participants (e.g., Mendoza et al. 2025), the ethical approvals of those original studies apply and are not restated here. No new datasets were generated; all data used are drawn from the published, DOI-referenced sources cited throughout this article.

2.6 Competing interests

The author declares no financial or non-financial competing interests related to this work.

3. Results

3.1 Technical basis of Dutch amphibious housing

The Maasbommel development combines 32 amphibious and 14 fully floating dwellings on a former riverside recreational site outside the regional dike system (English et al. 2016). Each amphibious unit rests, in normal conditions, on a concrete slab footing; its buoyant hull — a prefabricated, watertight concrete or composite chamber beneath a lightweight timber-frame superstructure — is designed to lift hydrostatically as water levels rise, guided vertically by fixed steel posts that also anchor site utilities through flexible risers (English et al. 2016; Piątek et al. 2024). Reported design tolerance for water-level fluctuation reaches 5.5 m (English et al. 2016). Broader comparative work across built European amphibious, elevated, and floating typologies confirms that amphibious solutions perform competitively on safety and technology criteria but face persistent challenges in cost-efficiency and regulatory classification (Piątek and Wojnowska-Heciak 2020; Piątek et al. 2024).

3.2 Governing engineering formulas

The buoyant-foundation sizing problem follows classical hydrostatic and naval-architecture relations, summarised here for their application to a Peru-specific design exercise in Section 4.3:

(1) Archimedes hydrostatic equilibrium — at flotation, the buoyant force equals the total gravity load:

F□ = ρ□ · g · V□□□□ = W□□□□□

where ρ□ is water density (≈ 1000 kg/m³ for fresh river water, ≈ 1025 kg/m³ for coastal/estuarine water), g is gravitational acceleration, V□□□□ is displaced hull volume, and W□□□□□ is the combined weight of structure, live loads, finishes and ballast.

(2) Required buoyant volume, with safety factor SF (typically 1.2–1.4 for occupied residential floats):

V□□□ = SF · (W□□□ + W□□□□ + W□□□□□□□) / (ρ□ · g)

(3) Design freeboard, the vertical clearance above the waterline at maximum expected flood stage:

FB = H□□□□ − T

where H□□□□ is total hull depth and T is draft (immersed depth) at design load.

(4) Transverse metacentric height, governing static stability against capsize or excessive list:

GM = KB + BM − KG, BM = I□□ / V□□□□

where KB is the height of the centre of buoyancy above the keel, KG is the height of the centre of gravity, and I□□ is the second moment of area of the waterplane. A positive GM (generally > 0.15–0.30 m for small residential floats) is required for stable equilibrium.

(5) Lateral hydrodynamic load on guidance posts, a simplified drag estimate under flow or wave action:

F□ = 0.5 · ρ□ · C□ · A · v²

where C□ is a drag coefficient dependent on hull geometry, A is the submerged frontal area, and v is the design flow velocity.

These relations show that buoyant-foundation feasibility is primarily a function of achievable displaced volume relative to structural weight — a parameter highly sensitive to the density and cost of available construction materials, which differs substantially between the Netherlands and Peru (Section 4.3).

3.3 Market and institutional dimension in the Netherlands

Land scarcity in flood-restricted zones designated under the national “Room for the River” programme, following the 1993 and 1995 Rhine/Maas floods, created development pressure that made amphibious construction commercially attractive despite its technical novelty (Piątek et al. 2024). Even so, Dutch amphibious projects faced protracted regulatory uncertainty: authorities initially classified amphibious dwellings as recreational rather than permanent residences, a classification mismatch that recurred across several Dutch amphibious developments and was resolved only gradually through dedicated national guidance (Piątek et al. 2024). This finding is significant for the present comparison: even in a high-capacity institutional environment, amphibious housing's principal barrier to scale-up was regulatory rather than technical.

3.4 Peru's coastal and Amazonian flood context

On the northern and central coast, the 2017 Coastal El Niño produced river discharges locally exceeding 250% of historical seasonal averages, affecting approximately 1.9 million people, causing 169 deaths and 18 missing persons, displacing about 194,000 residents, and damaging more than 300,000 homes, of which roughly 65,000 became uninhabitable (Yglesias-González et al. 2023). Behavioural data from Lima show that such events produce measurable, geographically uneven disruptions to household consumption and local commerce, indicating cascading socio-economic effects beyond direct structural damage (Alatrista-Salas et al. 2021).

In the Amazon, the Bajo and Nuevo Belén settlements of Iquitos (76,140 recorded inhabitants) illustrate a markedly different but equally structural flood regime: seasonal vaciante–creciente cycles are treated by many residents as a manageable, even valued, condition of riverine life, met through stilt construction and improvised floating structures, rather than as an emergency requiring relocation (Mendoza et al. 2025). State-led resettlement policies in this context have been found to disrupt, rather than reduce, household vulnerability by severing access to river-based livelihoods (Mendoza et al. 2025).

3.5 Comparative matrix

Table 1 synthesises the seven comparison parameters. Values are reported only where documented in the cited sources; “not reported” indicates the absence of a matching, citable data point rather than a zero value.

Parameter	Netherlands (Maasbommel / Dutch model)	Peru (coastal & Amazonian context)	Source(s)
Dominant hazard regime	Riverine flooding outside dike-protected zones; managed via “Room for the River” policy	Coastal El Niño flash flooding (north/central coast) and seasonal Amazonian river rhythmicity (vaciante–creciente)	Piątek et al. 2024; Yglesias-González et al. 2023; Mendoza et al. 2025
Design water-level range	Up to 5.5 m documented vertical rise capacity	Not reported (site-specific hydrological survey required)	English et al. 2016
Foundation / structural typology	Prefabricated concrete/composite buoyant hull, guided steel posts, timber superstructure	Traditional wooden stilt (palafito) foundations and improvised floating platforms; no engineered buoyant hulls documented	English et al. 2016; Mendoza et al. 2025
Settlement scale (documented)	32 amphibious + 14 floating units, Maasbommel	76,140 inhabitants, Bajo/Nuevo Belén, Iquitos	English et al. 2016; Mendoza et al. 2025
Institutional / regulatory status	Initially classified as recreational housing; formalised gradually through national guidance	No specific amphibious-retrofit category in current national building code; informal tenure predominant	Piątek et al. 2024; Mendoza et al. 2025
Traditional / experiential knowledge	Limited pre-existing amphibious tradition; technology-led adoption	Long-standing stilt/floating-house tradition and river-rhythm literacy among residents	Mendoza et al. 2025
Documented flood-impact data	First flood test in 2011; houses reported to perform as designed (qualitative case report)	2017 Coastal El Niño: ~1.9M affected, 169 deaths, ~194,000 displaced, >300,000 homes damaged, ~65,000 uninhabitable	Yglesias-González et al. 2023

4. Discussion

4.1 What is transferable

The comparison indicates that the Dutch experience offers Peru three genuinely transferable elements: (a) the hydrostatic design logic itself (Section 3.2), which is scale-independent and can be applied to far lower-cost buoyant modules than the prefabricated concrete hulls used at Maasbommel; (b) the guided vertical-rise principle, which is mechanically simple and can be retrofitted onto existing stilt structures rather than requiring wholesale reconstruction; and (c) the lesson — perhaps the most transferable of all — that regulatory classification, not construction technology, was the binding constraint even in the Netherlands (Piątek et al. 2024). This suggests Peruvian efforts should prioritise integrating amphibious

retrofit typologies explicitly into the Reglamento Nacional de Edificaciones and into municipal land-use instruments, rather than assuming technical demonstration alone will drive adoption.

4.2 What is not directly transferable

Several elements of the Dutch model do not transfer without substantial adaptation. Maasbommel's buoyant hulls rely on prefabricated concrete construction embedded in a mature, cost-competitive Dutch precast-concrete industry; replicating this at comparable unit cost is unrealistic for most Belén or coastal households, where informal, incremental self-construction is the norm (Mendoza et al. 2025). Likewise, the Dutch “Room for the River” institutional apparatus presupposes state capacity for zoning enforcement and infrastructure co-investment that is not currently present at the scale required in Iquitos or in northern coastal municipalities affected by El Niño (Yglesias-González et al. 2023).

4.3 Toward a Peru-specific adaptation: materials, tools and construction procedure

Applying the formulas in Section 3.2 to Peru's context points toward a materials-substitution strategy rather than a direct import of Dutch hull technology:

- Buoyant module material: sealed, food-grade high-density polyethylene (HDPE) drums or expanded polystyrene (EPS) blocks encased in a ferrocement or fibre-reinforced mortar shell, in place of monolithic precast concrete hulls. These achieve lower installed density than concrete (improving V□□□ economics per Equation 2) while remaining locally fabricable.
- Guidance system: galvanised or treated hardwood guide posts anchored into the existing stilt foundations already present in Belén and similar settlements, rather than new steel piling, reducing both cost and disruption.
- Superstructure: retention of existing or reinforced timber-frame construction, consistent with current palafito practice, minimising the load term W□□□ in Equation 2 and therefore the required buoyant volume.
- Construction procedure (indicative sequence): (1) structural and geotechnical survey of the existing stilt foundation and expected flood-stage range, using standard levelling instruments and local hydrological records (SENAMHI, per Mendoza et al. 2025); (2) sizing of the buoyant module using Equations (1)–(4); (3) prefabrication of sealed buoyant modules off-site or in a community workshop; (4) installation of guidance posts and flexible utility risers; (5) attachment of the buoyant module beneath the existing or reinforced structure; (6) load test and stability check (target positive GM per Equation 4) before occupancy certification.
- Tools and equipment: basic geotechnical survey kit (hand auger, water-level logger), laser or optical level, buoyancy-calculation spreadsheet or open-source naval-architecture software, standard

carpentry and ferrocement tools, and community training materials — deliberately avoiding equipment or specialist labour unavailable in Iquitos or Piura.

- Regulatory pathway: explicit classification of “amphibious retrofit” as a distinct, permitted residential typology within the Reglamento Nacional de Edificaciones, paired with a municipal registration mechanism that avoids the Dutch experience's initial mischaracterisation of amphibious dwellings as non-permanent structures (Section 3.3).

4.4 Social acceptance

Diffusion-of-innovations theory (Rogers 2003) predicts that adoption of a new housing technology depends heavily on its perceived compatibility with existing practice and its relative advantage over the status quo. The Peruvian context differs sharply from a blank-slate technology transfer: residents of Belén already practise a functional, culturally embedded amphibious lifestyle and, in some cases, actively prefer floating structures to stilt houses because they rise more reliably with the river (Mendoza et al. 2025). This suggests an engineered buoyant retrofit is likely to score favourably on compatibility, provided it does not require relocation or disrupt existing livelihood patterns — the same disruption that has undermined prior resettlement-based flood policy in the area (Mendoza et al. 2025).

4.5 Limitations

This study is a qualitative comparative analysis based on a purposively selected, DOI-verified set of nine primary sources; it does not constitute a systematic review, and its conclusions should be read as a structured, hypothesis-generating framework rather than as statistically validated findings. No new quantitative field data — costs, insurance premiums, or acceptance-survey results — were collected for Peru, and figures reported in earlier unpublished drafts of this research line (e.g., specific cost-overrun percentages or acceptance rates by age group) are not repeated here because they could not be traced to a verifiable, citable source. Future work should include site-specific geotechnical and hydrological surveys in Belén and in northern coastal municipalities, together with primary cost-benefit and community-acceptance data collection, before any pilot construction is undertaken.

5. Conclusions

The Dutch amphibious-housing experience is transferable to Peru in principle, but only partially and only through substantial adaptation. Its core engineering logic — hydrostatic buoyancy design, guided vertical rise, and freeboard/stability sizing — is scale-independent and can be reproduced with locally available, lower-cost materials such as sealed HDPE or EPS modules encased in ferrocement, retrofitted onto Peru's existing palafito and stilt-house stock rather than requiring new concrete hull construction. The Dutch case also demonstrates that regulatory and institutional classification, not construction technology, was the principal obstacle to scale-up even in a high-capacity governance context — a

finding directly relevant to Peru, where formal recognition of amphibious retrofits within the Reglamento Nacional de Edificaciones is likely to matter as much as the engineering itself.

Peru's Amazonian and coastal communities already possess relevant traditional knowledge and, per available evidence, a documented preference for solutions compatible with continued riverine life rather than relocation. A hybrid, incremental, code-integrated retrofit strategy — rather than direct import of the Dutch model — represents the most evidence-consistent pathway, pending the site-specific technical and social studies identified above.

Declarations

Ethical approval: Not applicable — this is a literature-based comparative analysis involving no primary human-subjects data collection by the author.

Data availability: No new datasets were generated; all data are drawn from the cited, DOI-referenced published sources.

Competing interests: The author declares no competing interests.

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Figures

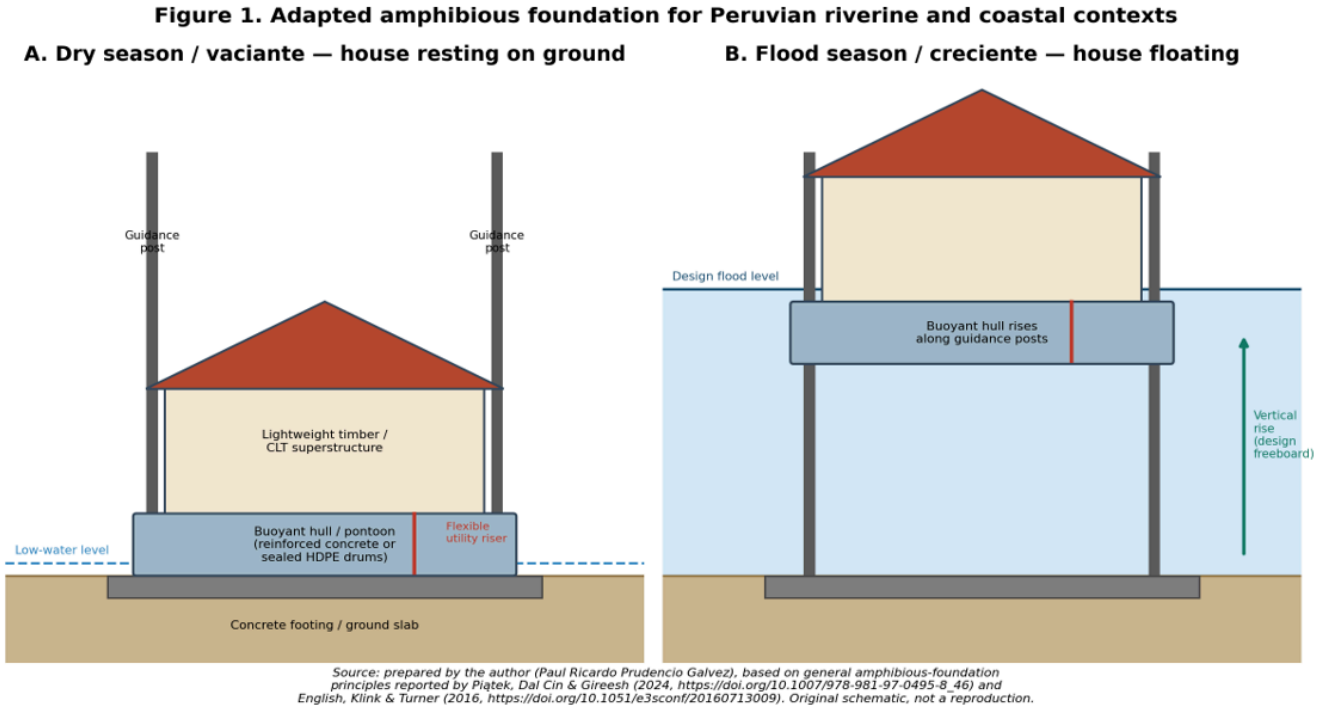


Figure 1. Schematic cross-section of an adapted amphibious foundation for Peruvian riverine and coastal contexts (dry season vs. flood season). Source: prepared by the author (Paul Ricardo Prudencio Galvez), based on general amphibious-foundation principles reported in Piątek, Dal Cin & Gireesh (2024) and English, Klink & Turner (2016); this is an original schematic and not a reproduction of any published figure.

Figure 1

See image above for figure legend.