

# Experimental Evaluation of a Sustainable Floating Shelter for Flood Resilience

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**Abstract**—Floods are among the most destructive natural disasters, causing extensive damage to infrastructure, disruption of essential services, and displacement of communities worldwide. Conventional flood management strategies primarily focus on evacuation and post-disaster recovery, offering limited support during sudden flood events where immediate access to safe temporary shelter is essential. This study presents the experimental evaluation of a sustainable floating shelter prototype developed to enhance flood resilience through a lightweight and environmentally responsible design approach. A laboratory-scale prototype was experimentally investigated under controlled conditions to evaluate its buoyancy characteristics, floating stability, load-bearing behaviour, and overall structural performance. The experimental observations were interpreted using established principles of fluid mechanics and floating body stability. The results demonstrated stable floating behaviour, positive restoring characteristics, and satisfactory structural performance under representative loading conditions, showing good agreement between theoretical predictions and experimental observations. The findings indicate that the proposed concept provides a feasible, sustainable, and cost-effective approach for temporary emergency shelter applications in flood-prone regions. The study establishes the engineering feasibility of sustainable floating shelter systems and provides a foundation for further research toward resilient flood-adaptive infrastructure.

**Index Terms**—Flood resilience, Floating shelter, Sustainable design, Buoyancy analysis, Stability assessment, Experimental evaluation, Emergency housing.

## I. INTRODUCTION

Flooding is one of the most frequent and destructive natural disasters, affecting millions of people worldwide, particularly in low-lying and densely populated regions. In recent decades, the frequency and severity of flood events have increased owing to rapid urbanization, inadequate drainage infrastructure, and changing climatic conditions. These factors have significantly increased the vulnerability of communities, resulting in substantial economic losses, damage to infrastructure, and threats to human safety during flood events [1]. Improving the resilience of communities against flood hazards has therefore

become a key objective of sustainable disaster management strategies [2]. Conventional flood management strategies primarily emphasize structural protection measures, evacuation planning, and post-disaster rehabilitation. Although these approaches play an important role in disaster risk reduction, they often provide limited protection during the initial stages of flooding when immediate access to safe temporary shelter is essential. This limitation has encouraged the development of adaptive shelter systems capable of remaining functional under varying water levels while improving the resilience of affected communities. Several engineering approaches have been proposed to enhance flood resilience, including elevated buildings, amphibious housing, and floating structural systems. Among these, floating structures have gained considerable attention because they adapt to rising water levels rather than resisting them, thereby minimizing structural damage and improving occupant safety [4]. Previous investigations have demonstrated the feasibility of amphibious housing as an adaptive solution for flood-prone regions [3]. Experimental studies have also confirmed that lightweight floating platforms can provide satisfactory buoyancy and stability for flood-resilient applications [5]. Floating and amphibious housing concepts have also been investigated for adapting to fluctuating water levels [6], [7]. In addition, biomimetic design principles have been explored to improve the adaptability of amphibious structures [8], while studies conducted in vulnerable low-lying regions have highlighted the potential of floating architectural concepts for mitigating flood impacts [9]. Despite these advancements, many existing floating shelter systems are intended for permanent installations and frequently involve specialized construction techniques, relatively high implementation costs, or location-specific infrastructure. Such limitations reduce their suitability for rapid deployment during emergency situations. Furthermore, comparatively few experimental investigations have focused on sustainable, lightweight, and modular floating shelter concepts that can be developed using readily available

resources while maintaining satisfactory buoyancy and stability. To address these limitations, the present study experimentally evaluates a laboratory-scale sustainable floating shelter prototype intended for temporary flood-resilient applications. The investigation focuses on assessing key engineering performance parameters, including buoyancy behaviour, floating stability, load-bearing capability, and overall structural performance under controlled loading conditions. The experimental observations are interpreted using established principles of fluid mechanics to evaluate the feasibility of the proposed concept without disclosing proprietary implementation details. The outcomes of this study contribute to the advancement of sustainable flood-resilient shelter technologies and provide a foundation for future research and technological development in emergency flood management.

## II. MATERIALS AND METHODS

The present study adopts an experimental approach to evaluate the floating performance of a laboratory-scale sustainable floating shelter prototype developed for temporary flood-resilient applications. The investigation was carried out under controlled laboratory conditions to examine the engineering feasibility of the proposed concept based on the principles of buoyancy and floating body stability. The overall methodology adopted in this study is illustrated in Fig. 1.

### A. Prototype Development

A laboratory-scale prototype was developed to investigate the feasibility of a sustainable floating shelter system intended for temporary use during flood events. The prototype was designed to provide adequate buoyancy, structural stability, and load-bearing capability while maintaining a lightweight and modular configuration suitable for laboratory-scale experimentation. The primary objective of the prototype was to experimentally validate the engineering behaviour of the proposed floating concept under representative loading conditions. To protect ongoing intellectual property development, detailed construction features and proprietary implementation aspects are intentionally not disclosed in this paper.

### B. Experimental Setup

The experimental investigation was conducted under controlled conditions using a water reservoir to simulate floating behaviour. The prototype was positioned on the water surface and allowed to attain stable equilibrium before testing. Representative external loads were then applied incrementally to simulate practical service conditions. At each loading stage, the floating response of the prototype was carefully observed and the corresponding measurements were recorded. The laboratory-scale experimental setup used in the present investigation is shown in Fig. 2.

### C. Performance Evaluation

The floating performance of the prototype was assessed using engineering parameters that govern the behaviour of floating structures. The selected performance indicators include immersion depth, displaced water volume, buoyant

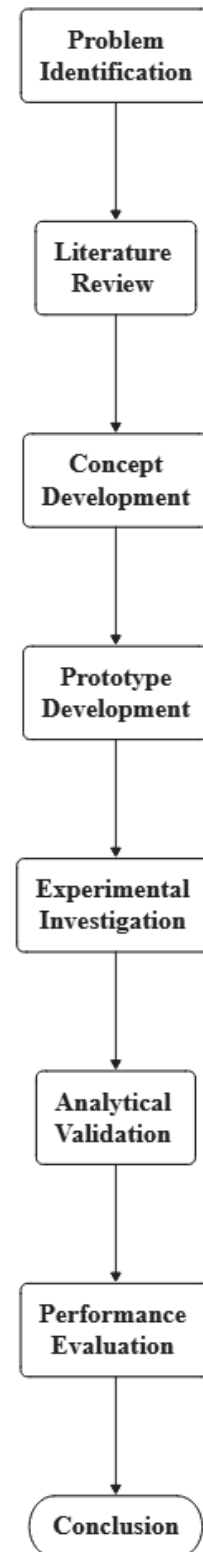


Fig. 1. Research methodology adopted for the experimental investigation.



Fig. 2. Laboratory-scale floating shelter prototype during experimental evaluation under controlled conditions.

force, floating stability, load-bearing behaviour, and freeboard. These parameters collectively provide an assessment of the operational safety and structural response of the prototype under different loading conditions.

#### D. Analytical Assessment

The experimental observations were interpreted using established principles of fluid mechanics. Buoyancy was evaluated according to Archimedes' principle, while stability characteristics were assessed using conventional floating body stability relationships. The analytical assessment enabled comparison between theoretical predictions and experimentally observed behaviour, thereby validating the engineering performance of the proposed floating shelter concept.

#### E. Testing Procedure

The prototype was initially allowed to float under its self-weight, after which external loads were applied gradually in successive stages. For each loading condition, the corresponding floating response was observed and relevant performance parameters were measured. Throughout the investigation, the prototype was monitored to ensure stable equilibrium and consistent experimental conditions. The recorded observations were subsequently analysed to evaluate buoyancy characteristics, floating stability, and overall structural performance under representative loading conditions.

### III. THEORETICAL BACKGROUND

The floating behaviour of the prototype was evaluated using established principles of fluid mechanics and floating body stability. Theoretical calculations were performed to interpret the experimental observations and verify the performance of the floating shelter under different loading conditions.

#### A. Buoyant Force

According to Archimedes' principle, the buoyant force acting on a floating body is equal to the weight of the fluid displaced by the submerged portion of the structure [10]. The buoyant force is expressed as

$$F_b = \rho g V \quad (1)$$

where,

- $F_b$  = Buoyant force (N)
- $\rho$  = Density of water ( $\text{kg/m}^3$ )
- $g$  = Acceleration due to gravity ( $\text{m/s}^2$ )
- $V$  = Volume of displaced water ( $\text{m}^3$ )

The calculated buoyant force was compared with the experimentally observed floating response to evaluate the load-supporting capability of the prototype.

#### B. Floating Stability

The stability of the floating prototype was assessed using the concept of metacentric height, which is commonly used to determine the equilibrium characteristics of floating bodies [11]. A positive metacentric height indicates stable equilibrium.

$$GM = BM - BG \quad (2)$$

where,

- $GM$  = Metacentric height (m)
- $BM$  = Distance between centre of buoyancy and metacentre
- $BG$  = Distance between centre of buoyancy and centre of gravity

The metacentric height was used to evaluate the stability of the prototype under different loading conditions.

#### C. Factor of Safety

The structural safety of the floating prototype was assessed using the factor of safety, which represents the ratio between the maximum safe load capacity and the applied load.

$$FoS = \frac{W_{max}}{W_{applied}} \quad (3)$$

where,

- $FoS$  = Factor of Safety
- $W_{max}$  = Maximum safe load capacity
- $W_{applied}$  = Applied load

A factor of safety greater than unity indicates that the structure remains within the safe operating range.

#### D. Freeboard

Freeboard is defined as the vertical distance between the water surface and the upper surface of the floating platform. Adequate freeboard is essential to prevent water ingress and maintain operational safety.

$$f = H - h \quad (4)$$

where,

- $f$  = Freeboard (m)
- $H$  = Height of floating platform (m)
- $h$  = Depth of immersion (m)

The freeboard values obtained experimentally were compared with analytical predictions to evaluate the floating performance of the prototype.

Figure 3 illustrates the fundamental stability parameters considered in the present investigation.

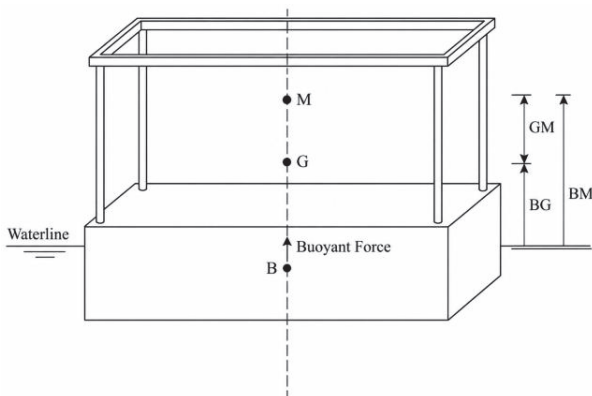


Fig. 3. Schematic representation of the stability parameters of a floating body.

## IV. RESULTS AND DISCUSSION

The floating performance of the laboratory-scale prototype was evaluated under representative loading conditions to investigate its buoyancy characteristics, floating stability, and overall structural behaviour. The experimentally measured parameters are summarized in Table I.

The experimental results indicate that the prototype maintained stable equilibrium throughout the investigation. As the applied load increased, the depth of immersion increased correspondingly, resulting in greater water displacement and a proportional increase in buoyant force. The observed behaviour agrees well with Archimedes' principle and confirms the expected response of a floating body subjected to incremental loading.

TABLE I

EXPERIMENTAL OBSERVATIONS UNDER REPRESENTATIVE LOADING CONDITIONS

Loading Condition	Immersion Depth (m)	Displaced Volume (m <sup>3</sup> )	Buoyant Force (N)
Condition 1	0.118	0.236	2315
Condition 2	0.150	0.300	2943
Condition 3	0.214	0.428	4199
Condition 4	0.284	0.568	5572

#### A. Buoyancy Behaviour

Figure 4 illustrates the relationship between immersion depth and displaced water volume. A nearly linear trend is observed, indicating a predictable buoyancy response throughout the experimental investigation. This behaviour confirms that the prototype maintained adequate buoyant support under all investigated loading conditions.

The relationship between displaced volume and buoyant force is presented in Fig. 5. The experimentally observed buoyant force increased proportionally with displaced water volume, demonstrating close agreement with theoretical predictions derived from Archimedes' principle.

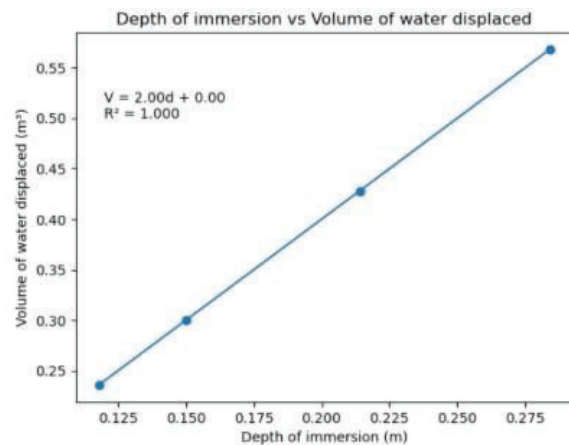


Fig. 4. Relationship between immersion depth and displaced water volume under representative loading conditions.

#### B. Floating Stability

The stability assessment confirmed that the prototype remained in stable equilibrium throughout the investigation. Positive restoring characteristics were observed under all loading conditions, indicating satisfactory floating stability. No significant structural deformation or excessive inclination was observed during the experimental investigation, demonstrating the capability of the floating system to maintain equilibrium under representative loading conditions.

#### C. Freeboard Assessment

Adequate freeboard was maintained throughout the experimental investigation despite the increase in immersion depth under higher loading conditions. The reduction in freeboard

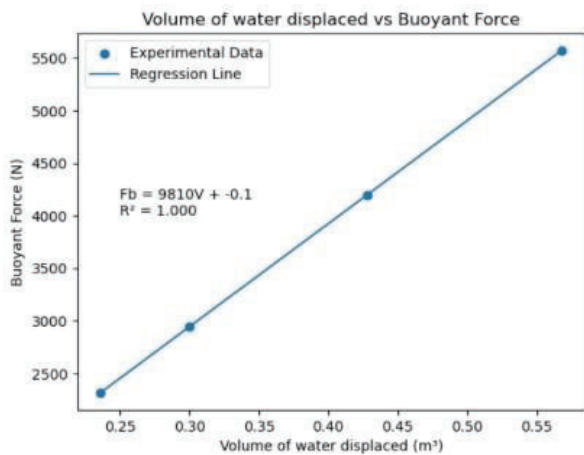


Fig. 5. Variation of buoyant force with displaced water volume.

followed the expected behaviour of floating bodies and remained within acceptable limits for safe operation under the investigated conditions.

#### D. Discussion

The experimental observations demonstrate that the proposed floating shelter concept satisfies the fundamental engineering requirements of buoyancy, stability, and load-supporting capability for temporary flood-resilient applications. The close agreement between theoretical calculations and experimental observations validates the analytical approach adopted in the present study.

Compared with previously reported floating shelter concepts [3], [5], [8], the present investigation demonstrates that laboratory-scale sustainable floating systems can achieve reliable floating performance using a simplified structural configuration suitable for further technological development. The findings establish a foundation for future optimization and full-scale implementation while providing flexibility for future design refinement.

#### V. CONCLUSION

This study presented the experimental evaluation of a laboratory-scale sustainable floating shelter prototype developed for temporary flood-resilient applications. The floating performance of the prototype was investigated under representative loading conditions to assess its buoyancy characteristics, stability, load-bearing behaviour, and freeboard. The experimental observations demonstrated stable floating performance throughout the investigation, with results showing good agreement with the theoretical predictions based on established principles of fluid mechanics.

The analytical and experimental evaluations confirmed that the prototype maintained positive floating stability and satisfactory buoyancy under the investigated loading conditions. The observed floating behaviour indicates that the proposed

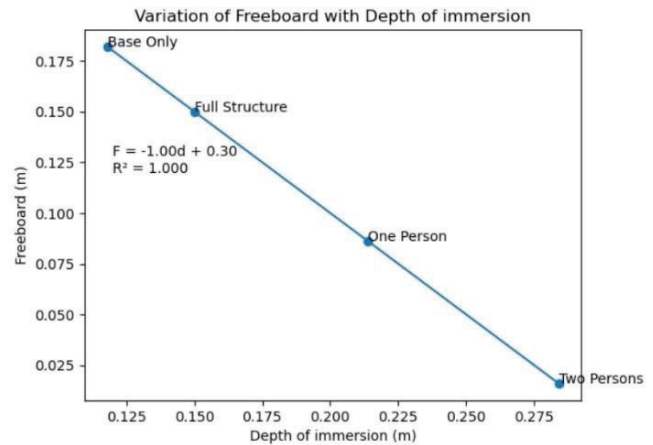


Fig. 6. Variation of freeboard under representative loading conditions.

concept has the potential to serve as a sustainable and adaptable temporary shelter solution for flood-prone regions while supporting environmentally responsible engineering practices.

The present investigation was limited to laboratory-scale experimentation under controlled static conditions. The effects of environmental factors such as wave action, flowing water, wind loading, and long-term durability were not considered and therefore require further investigation before large-scale implementation.

Accordingly, the findings should be interpreted as an initial proof of concept rather than a comprehensive assessment of full-scale operational performance. Future work will focus on the optimisation of the structural configuration, evaluation under dynamic environmental conditions, and validation through full-scale field testing. Additional studies may also investigate the integration of renewable energy systems, smart monitoring technologies, and modular deployment strategies to enhance the applicability of sustainable floating shelter systems for disaster resilience.

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## REFERENCES

- [1] R. Fenner, E. O'Donnell, S. Ahilan, D. Dawson, L. Kapetas, and V. Krivtsov, "Achieving urban flood resilience in an uncertain future," *Water*, vol. 11, no. 5, 1082, 2019.
- [2] Y. Y. Haimes, "On the definition of resilience in systems," *Risk Analysis*, vol. 29, no. 4, pp. 498–501, 2009.
- [3] O. Basak and S. A. Chowdhury, "Flood resilient amphibious housing: Barriers and prospects," *Architecture and Civil Engineering*, 2021.
- [4] R. White, "Innovative flood-resilient architecture: Designs and materials for the 21st century," *Sustainability*, vol. 14, no. 7, 2022.
- [5] F. Handayani, H. P. Adi, and S. I. Wahyudi, "Mathematical analysis and experimental testing of floating building platform prototypes made from expanded polystyrene system and lightweight concrete," *IOP Conference Series: Earth and Environmental Science*, vol. 698, no. 1, p. 012008, 2021.
- [6] A. Ambica and K. Venkatraman, "Floating architecture: A design on hydrophilic floating house for fluctuating water level," *Indian Journal of Science and Technology*, vol. 8, no. 32, 2015.
- [7] V. M. Varkey and P. M. Philip, "Flood risk mitigation through self-floating amphibious houses – modelling, analysis, and design," *Materials Today: Proceedings*, vol. 65, pp. 442–447, 2022.
- [8] H. Ameh, L. Badarnah, and J. Lamond, "Amphibious Architecture: A Biomimetic Design Approach to Flood Resilience," *Sustainability*, vol. 16, no. 3, 1069, 2024.
- [9] N. Nelson, "Envisaging the scope of amphibious architecture in below sea level regions of Kuttanad," *Journal of Emerging Technologies and Innovative Research*, vol. 8, no. 6, 2021.
- [10] F. M. White, *Fluid Mechanics*, 8th ed., New York: McGraw-Hill Education, 2016.
- [11] E. V. Lewis, *Principles of Naval Architecture*, Jersey City: Society of Naval Architects and Marine Engineers, 1988.