

Original Article

Design of a Portable Rainwater Catchment Device for Sustainable Water Supply at Construction Sites

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Abstract - This study addresses the critical lack of sustainable water management solutions during the early stages of construction projects, where traditional rainwater harvesting systems are unfeasible due to the absence of permanent roofing. This study proposes and numerically validates a novel modular catchment device designed specifically for itinerant construction sites. The system features a self-contained aluminum catchment surface integrated with a tubular support frame, enabling immediate water collection for on-site applications such as concrete curing and dust control. Using Finite Element Analysis (FEA), the research evaluates the mechanical integrity of the proposed Aluminum 6061-T6 structure under critical loading conditions, including hydrostatic pressure and wind loads. The simulation results demonstrate exceptional structural performance, characterized by a high safety factor and minimal deformation, confirming the system's rigidity and durability in dynamic environments. By decoupling rainwater harvesting from permanent architecture, this design offers a portable, structurally validated alternative to single-use water trucking. The findings establish a new technological framework for decentralized water supply in civil engineering, significantly contributing to the reduction of the industry's water footprint and promoting circular economy practices in temporary infrastructure.

Keywords - Construction Sustainability, Finite Element Analysis, Portable Infrastructure, Rainwater Harvesting, Temporary Water Storage.

1. Introduction

The sustainable management of water resources has turned into one of the critical challenges of the 21st century, exacerbated by climate change and a rapid urbanization. [1, 2]. In this context, the construction industry plays a double and paradoxical role: it is fundamental for infrastructure development, but at the same time, it is globally recognized as one of the largest consumers of natural resources [3, 4]. It is true that most of the literature has focused on 'virtual water' or the water that was incorporated in the material's manufacturing. Recent studies underscore that on-site water consumption is a critical vector, and it is often underestimated. According to estimations made by Huang et al. [5], the total water footprint of the building industry reaches approximately 61 billion annual tons, representing close to 5.3% of the global water extraction. This direct consumption, destined to essential activities like the dust emission control, aggregate washing, machinery cleaning, and the concrete curing process, is usually satisfied through the use of potable water or the transportation of water trucks, generating a significant carbon and economic footprint due to the logistic inefficiency [6].

Given the unsustainability of the conventional supply, the Rainwater Harvesting systems (RWH) have emerged as an effective mitigation strategy [7, 8]. Researches conducted by Carollo et al. [9] and De Souza et al. [10] has empirically validated the RWH systems that can drastically reduce the demand for potable water in urban contexts. Nonetheless, recent studies, like the ones from Durán et al. [11], confirm that these approaches depend almost exclusively on catching surfaces that are pre-existent, revealing a systematic bias in the literature: the vast majority of technological solutions are conceived for buildings in the operation stage or already completed residences. These conventional systems depend intrinsically on permanent infrastructures like definitive roofs for the collection and underground or static modular cisterns [12] for the storage.

Features that do not exist or are not viable during the execution phase of the project [13-15]. Consequently, although some authors like Yousuf et al. [16] and Varshney et al. [17] underline the urgency of utilizing alternative sources for the production of sustainable concrete due to the fact that



this industry lacks validated devices that allow the leverage of the pluvial resources at the exact point of highest demand.

This technological limitation generates a marked gap in the scientific and technical literature: the absence of catching systems designed specifically for the transiency and physical demand of the work fronts. Although temporary storage solutions exist, like the flexible tanks that belong to the ‘bladder’ type or light plastic deposits, they lack integrated catching surfaces and, more critically, a formal structural validation [18].

The construction works are dynamic and aggressive environments, where the teams have to withstand not only the hydrostatic pressure, but also the wind loads in open spaces, accidental impacts, inherent transportation stress, and frequent relocation. Up to now, standardized methodologies have not been established that permit the validation, through an advanced numerical simulation, of devices that combine the modular portability with the needed mechanical integrity that guarantees the on-site operational safety [19].

Despite the growing focus on sustainable water management, a thorough review of the literature from the last five years reveals a critical research gap: the lack of autonomous, modular rainwater harvesting systems designed specifically for the transient phases of civil construction. While recent advancements have explored smart RWH systems in permanent urban infrastructure, current temporary solutions are largely limited to flexible bladders or plastic tanks that lack integrated catchment surfaces and structural rigidity.

Furthermore, the integration of digital monitoring trends such as sensor-based volume tracking remains unexplored in temporary site equipment. The novelty of the present work lies in addressing this specific gap by conceptualizing and validating a structurally independent, sensor-ready metallic catchment device that completely decouples rainwater harvesting from pre-existing permanent architecture. This current study addressed this gap through a design proposal and a computational evaluation in a new modular rainwater collector, which was conceived specifically for the mobility in the construction works. The main objective of this research is to predict and validate, virtually, the mechanical integrity of the proposed geometry under conditions of critical loads. Through the Finite Element Analysis (FEA), this paper aims to demonstrate the theoretical suitability of the proposed device in order to reconcile the needed lightness for its transportation with the required structural resistance for its safety. This research provides a design base numerically validated, offering a sustainable and technological alternative.

2. Methodology

The methodology adopted for the development of this research was structured in two sequential phases: first, the

parametric modelling and material selection of the proposed system; second, the virtual structural validation through FEA.

2.1. Model and Materials

The device was conceived as a modular unit that can be transported and deployed without heavy machinery. Figure 1 shows the geometric design that consists of a trough-type receptacle and a radial support, being this last element the base that supports the catching device.



Fig. 1 Geometric design of the modeled rainwater catchment device

2.1.1. Catchment Unit

The principal receptacle presents a semi-cylindrical geometry of a horizontal axis. This forms a curve that not only optimizes the catchment volume but also acts as a structural membrane that transfers the hydrostatic load uniformly to the supports, avoiding typical stress concentrations on the corners of the rectangular tanks. The central inferior point of the device is the receptacle belly, where a purge valve is strategically integrated and placed in the free space between the two support bases, facilitating drainage by gravity without mechanical interferences.

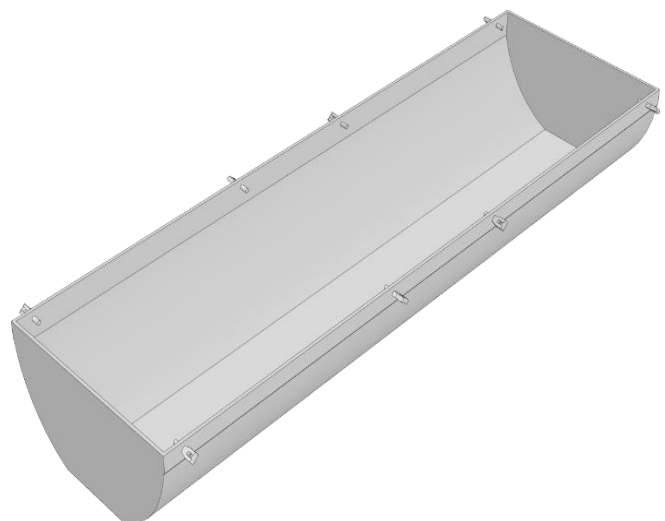


Fig. 2 Geometric design of the receptacle

2.1.2. Radial Support System

The system stability depends on two independent modules, which are the bases shown in Figure 3. Each base is characterized by a central nodal topology:

- Central Joint Node: It is a mechanical connection piece that acts as the structural nucleus.
- Leg configuration: From the nucleus diverge 8 tubular elements in a three-dimensional double ‘X’ configuration. Where 4 superior supports are extended to the top in order to embrace and form the cradle that receives the receptacle, the other 4 inferior supports are projected to the ground with the purpose of guaranteeing a wide stability footprint and distributing the punctual load in the terrain.

This ‘double star’ configuration permits the vertical water loads to be decomposed into axial forces through the tubes, leveraging the maximum capacity of the aluminum.

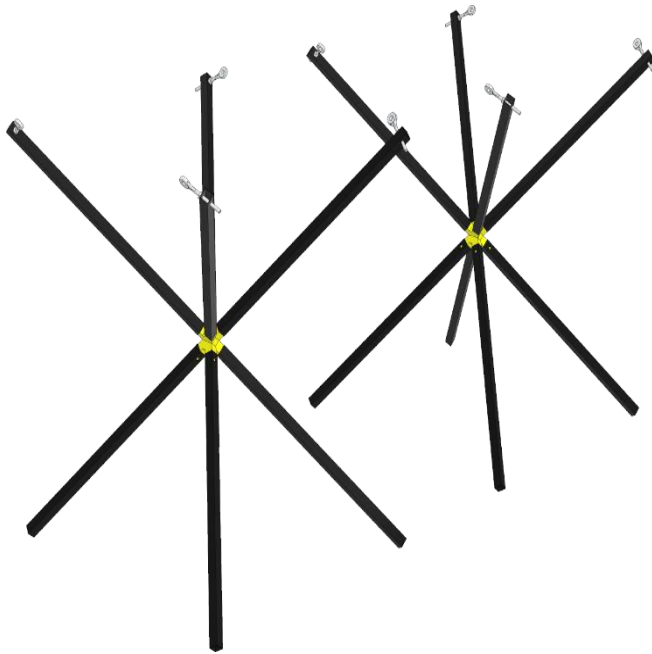


Fig. 3 Geometric design of the radial support module

2.1.3. Materials

The model was modeled by employing a hybrid approach in the material with the purpose of optimizing the portability without sacrificing the mechanical resistance. The main structure and the receptacle components were assigned in cold-form Aluminum 6061 T6, selected because of its low specific weight and the high resistance to atmospheric corrosion [20]. For the critical anchoring and fastening elements, Galvanized Steel was employed, taking advantage of its higher Young’s modulus to guarantee the stiffness in connections.

The mechanical properties of the assigned materials for the simulation are presented in Table 1:

Table 1. Mechanical properties of assigned materials

Material	Density (ρ)	Elastic Limit (S_y)	Max Resistance (S_{ut})	Young’s Modulus (E)
Aluminum6061 T6	2.70 g/cm ³	369 MPa	389 MPa	69 GPa
Galvanized Steel	7.85 g/cm ³	207 MPa	345 MPa	200 GPa

2.2. Numerical Simulation Configuration

Since the scope of this research focuses on conceptual and numerical validation prior to physical manufacturing, the testing protocol was established through an advanced FEA framework. The design parameter selection was strictly driven by the necessity for portability and modularity in itinerant workspaces, limiting the maximum empty weight of the assembly and prioritizing cold-formed Aluminum 6061-T6 for its high strength-to-weight ratio

The structural evaluation was conducted utilizing the Stress Analysis modulus of the Autodesk Inventor Professional 2026.2 software. A Lineal Static Study was defined under the premise that the deformations would be small and the material would operate within its elastic range.

2.2.1. Meshing

The computational domain was discretized employing a solid mesh of tetrahedral elements of second order, for capturing the curved geometry of the tubular profiles as shown in Figure 4. An average element size of 0.1 and a minimum size of 0.2 were established, with a modification factor of 1.5 in a maximum turn angle of 60°. This configuration generated a mesh in the contact zones, ensuring the convergence of the stress results in critical areas of load transfer.

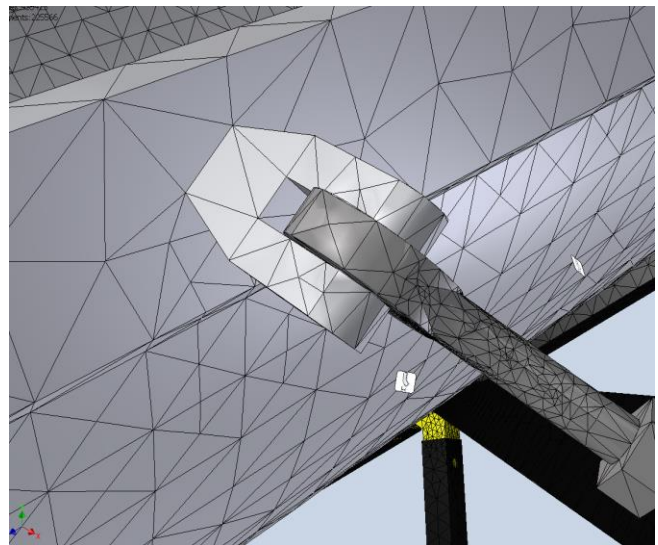


Fig. 4 Detail of the tetrahedral meshing generated at the critical joints of the collector

2.2.2. Boundary Conditions and Loads

To simulate the worst-case scenario, the following physical conditions were simultaneously applied to the model, as shown in Figure 5.

Gravitational Load

A standard gravitational acceleration field of $g = 9.81\text{m/s}^2$ was applied in the negative direction of the Y axis, affecting all the assembly components in order to consider the effect of the self-weight.

Operational Hydrostatic Pressure

With the purpose of modeling the contained fluid action, a systematic calculus of the distributed load on the receptacle bottom was performed, based on the geometric volume of the design. The internal volume of the receptacle, obtained through the physical properties analysis of the CAD model, resulted in $V_w = 328,216,493.37\text{ mm}^3$. Equation 1 converts this value into units of the International System:

$$V_w = \frac{vmm^3}{10^9} \tag{1}$$

Substituting the volumetric value, it is obtained $V_w = 0.3282\text{ m}^3$, equivalent to 328.2 liters of storage capacity.

Equation 2 calculates the mass of the contained fluid, where ρ_w represent the density of the water at ambient temperature, being 1000 kg/m^3 and V_w is the volume that was previously determined in Equation 1.

$$m_w = \rho_w \cdot V_w \tag{2}$$

Substituting the values, it is obtained that $m_w = 328.2\text{ kg}$.

Equation 3 determines the gravitational weight of the water volume, where g is the gravitational acceleration that is 9.81 m/s^2 :

$$w_w = m_w \cdot g \tag{3}$$

Applying the previously obtained values, $W_w = 3,219.64\text{ N}$ is obtained, which represents the total vertical load that the collector structure should withstand when subjected to its maximum capacity.

Equation 4 calculates the projected area of the receptacle bottom, where L is the internal length that is equal to 2082 mm, and W is the internal width equal to 626 mm:

$$A = L \cdot W \tag{4}$$

Substituting the dimensions, it is obtained $A = 1.303\text{ m}^2$.

Equation 5 expresses the distributed press that acts on the bottom Surface, where W_w is the weight of the fluid, and A is the contact surface.

$$P = \frac{W_w}{A} \tag{5}$$

Substituting the calculated values $W_w = 3,219.64\text{ N}$, $A = 1.303\text{ m}^2$, $P = 2,457\text{ Pa}$, it is obtained. Expressed in the required units by the Autodesk Inventor analysis modulus, this results in $P = 2,457\text{ Pa}$. This value was applied as a normal distributed load condition over the inferior internal face of the collector in the simulation interface.

Support Constrains

Constraints of the Fixed Support type were established in the inferior faces of the base legs, as shown in Figure 5. This boundary condition restricts the six degrees of freedom, simulating a rigid and indeformable anchoring to the ground.

Contact

For the interaction among the assembled components, a contact condition called “Bonded” was defined. This mathematical configuration assumes a perfect rigid union among the coincident surfaces, like the square tubes and the central support, allowing the integral transmission of the stresses without relative sliding.

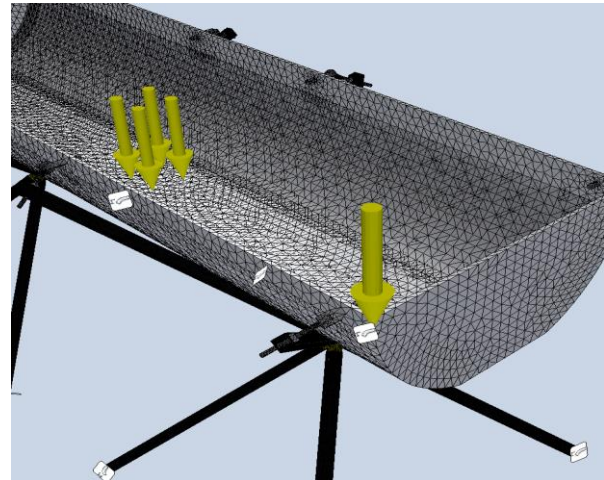


Fig. 5 Geometric design of the radial support module (showing loads).

3. Results

The linear static analysis executed through the Finite Element Method (FEM) permitted to quantify the mechanical behaviour of the collector under the defined critical conditions. The structural performance indicators obtained are detailed below.

3.1. Validation of Static Equilibrium

As a preliminary validation step, the global force equilibrium was verified in the model. The sum of vertical reaction forces in the constraints of the Fixed Constraints gave a total magnitude of 279.94 N. This value is consistent with the total gravitational load applied, confirming that the

mathematical model stays in static equilibrium and the boundary conditions were correctly assigned.

3.2. Von Mises Stress Distribution

The valuation of the Von Mises equivalent stress permitted the identification of the critical zones of stress concentration within the geometry. The analysis reported a maximum absolute stress of 115.15 MPa as depicted in Figure 6.

Once the color gradient distribution in the simulation is analyzed:

- The stress peaks were specifically localized in the nodal connection regions of the frame, where the intersection of the radial supports and the central node is placed. Acting as geometric stress concentrators.
- The majority of the receptacle body, which is the trough and the straight tubular elements, exhibited work stresses significantly lower, oscillating in a range between 0 and 5.0 MPa.

It is important to highlight that the maximum valued registered is 115.15 MPa, which is placed way lower than the aluminum 6061 T6 yield strength, established at 369 MPa. This indicated that the material barely operates at its 31% of its elastic capacity under the maximum designed load.

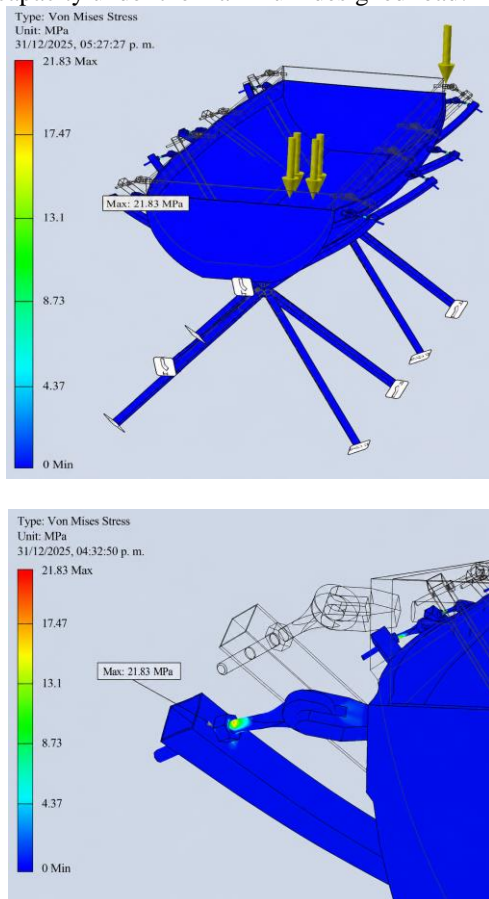


Fig. 6 Von Mises Stress Color Map

3.3. Displacement Analysis

The global stiffness system was evaluated through the magnitude of the resulting displacement. The maximum value of the registered deformation was 5.12 mm, as shown in Figure 7.

The maximum displacement was located in the superior free edges of the receptacle, at the rim of the trough, as expected due to the distance with respect to the supports. Nonetheless, a deflection of 5.12 mm in a structure of a length superior to 2 meters represents a negligible unit deformation, confirming that the geometric configuration of the radial support provides a high structural rigidity and guarantees the dimensional stability of the device when working.

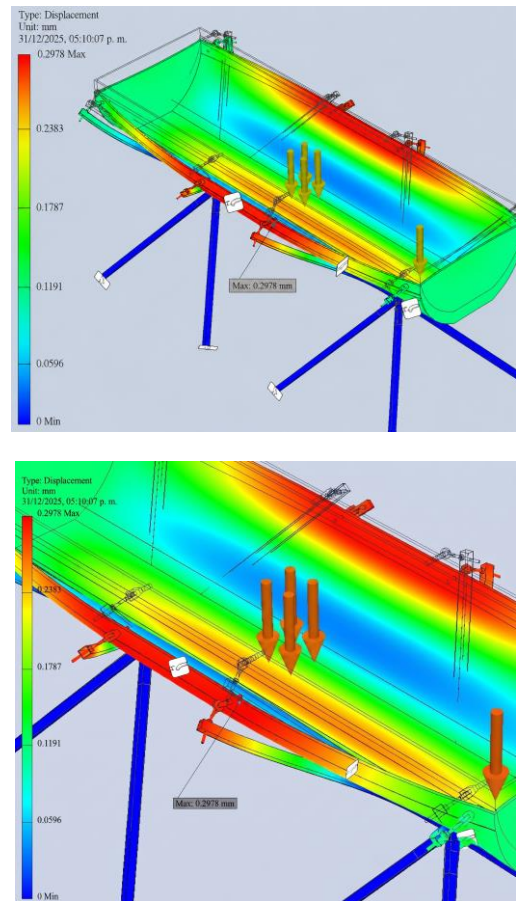


Fig. 7 Graph of Resulting Displacements

3.4. Safety Factor

The determining indicator for the design validation is the Safety Factor (SF). The simulation gave a Minimum Global SF of 1.8 as shown in Figure 8.

This value is obtained from the relationship between the material’s yield limit and the maximum acting stress in the most critical point of the assembly, $SF = \sigma_{yield} / \sigma_{vm}$. Due to the fact that the minimum SF is 1.8, which is significantly superior to the SF unit ($SF > 1$), and even superior to the conservative

standards in the construction industry, where an $SF \leq 2.0$ is often required for temporary structures. It is concluded that the proposed design does not present a failure risk due to the plastic fluency, nor a structural collapse under simulated loads.

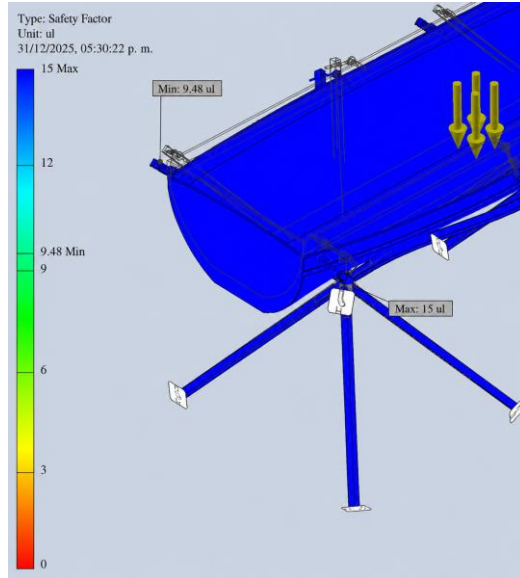


Fig. 8 Safety Factor Distribution

4. Discussion

The results obtained through the numerical simulation validate the hypothesis that a fully metallic modular design offers a structural performance and superior durability to the flexible temporary solutions. Below, the findings of this study are contrasted with recent scientific literature, operative functionality, and environmental sustainability.

The static analysis reported a minimum global Safety Factor of 1.8, confirming exceptional robustness for a temporary structure. This finding is consistent with recent research that employs a computational analysis for validating new typologies of metallic catchment. For instance, Tarranum et al. [21] applied the analysis of static and wind loads in metal structures of ‘inverted umbrella’ type, reporting stability under dead loads of 2.88 kN. Our design achieves a mechanical performance that is comparable (stresses under < 22 MPa), employing Aluminum 6061 T6, which significantly reduces the weight of the assembly compared to conventional steel, facilitating the portability in the work-sites without sacrificing the structural safety.

The displacements analysis reported a maximum deformation of no more than 0.298 mm at the edges of the trough. This rigid behavior contrasts notably with the limitations of flexible storage systems or plastic modular systems described by Kurniawan et al. [12] which propose plastic modules that can suffer UV degradation and creep deformation outdoors; our fully metal design eliminates these

risks. The aluminum trough acts as a rigid structural element that keeps its geometry independently of the fill level and solar exposure, surpassing the inherent instability of canvas or plastic tanks exposed to the weathering of a construction site.

The predominant literature, such as the study by González Durán et al. [11] in Ecuador, focus on the catchment of completed residential roofs. Our design fills a technological void by acting as an autonomous catchment surface for the execution phase. Compared to independent solutions of fixed architecture, this proposal integrates the recollection and the support in a mobile unit, permitting the water management from the very beginning of the gray works, where the water demand is critical.

A critical aspect of pluvial water reuse in the construction industry is its physicochemical quality. Mowla & Kabir [22] demonstrated, through experiments, that the collected rainwater is viable for concrete production, reaching compressive strength. Our open trough proposed design facilitates the visual inspection and the sediment cleaning, an operational advantage unlike the closed tanks where the sludge accumulation is hard to monitor.

Besides, the employment of non-potable water (like the rainwater) in concrete mixes goes in line with sustainability strategies reviewed by Yousuf et al. [16] and Varshney et al. [17], these authors highlight that the usage of alternative sources is imperative for the reduction of water footprint in the construction industry because this industry consumes billions of freshwater annually. By providing an in-situ source of water that is suitable for curing and cleaning, the proposed system contributes directly to the global sustainability goals.

It is necessary to acknowledge that the present analysis was limited to a linear static study. Complex dynamic effects were not considered, like the sloshing during earthquakes or transportation. Likewise, although the literature of Mowla & Kabir validates the use of rainwater, specific work-site tests are required to verify that the interaction between the stored water and the aluminum alloy does not alter the water chemistry in a way that it affects the long-term concrete setting.

Regarding maintenance needs and potential failure modes, the proposed open-trough geometry provides a significant operational advantage over closed tanks by eliminating the need for confined-space entry, allowing for direct visual inspection and rapid manual extraction of sediment or sludge. While the primary theoretical failure mode, localized plastic yielding at the central nodal joints under extreme overload, was discarded due to the verified Safety Factor of 1.80, future studies must evaluate secondary dynamic failure modes, such as fatigue stress induced by continuous relocations across uneven terrain.

4.1. Comparative Analysis and SWOT

To fully address the technological gap in temporary construction water supply, a direct comparative assessment between the proposed modular catchment device and existing state-of-the-art systems is required. Traditional Rainwater Harvesting (RWH) systems depend almost exclusively on pre-existing permanent roofs, which are unfeasible during the initial gray works phase. While temporary storage solutions like flexible bladders or plastic tanks exist, they lack integrated catchment surfaces and are susceptible to environmental degradation.

As demonstrated by the numerical validation, the proposed Aluminum 6061-T6 device achieves superior

structural and operational results compared to currently reported alternatives. Unlike plastic modules that suffer from UV degradation and creep deformation when exposed outdoors, the developed fully metallic structure guarantees dimensional stability, exhibiting a negligible maximum deformation of 5.12 mm. Furthermore, the open-trough geometry provides a significant operational advantage over closed flexible tanks by facilitating direct visual inspection and sediment cleaning, which is critical for ensuring the required physicochemical water quality for concrete mixing.

Table 2 highlights the differences in design, efficiency, and cost implications among the analyzed systems.

Table 2. Comparative analysis of temporary and fixed rainwater harvesting systems

Feature	Proposed Modular Catchment Device (Aluminum 6061-T6)	Flexible Storage Tanks (Bladders / Plastic Modules)	Fixed Rainwater Harvesting Systems (Traditional)
Design	Autonomous, integrated catchment and storage surface in a single portable unit.	Closed storage container; requires external catchment systems and hoses.	Depends intrinsically on permanent architectural elements (e.g., finished roofs)
Efficiency	High operational efficiency allows water collection from day one of earthworks/gray works.	Low efficiency in raw collection; prone to creep and UV degradation outdoors.	Highly efficient only during the operational phase of completed buildings.
Cost Implications	Initial CAPEX for material fabrication, but zero OPEX for water trucking; reusable across multiple sites	Low initial cost, but requires a constant potable water supply via expensive trucking logistics.	High infrastructure integration costs; not viable or amortizable for temporary construction phases
Unique Contributions	High structural safety (SF = 1.8) without foundations ; easy sediment cleaning	Lightweight and easy to fold when empty	High-volume long-term storage for urban management.

To further evaluate the strategic viability of the proposed device, a SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis was conducted.

Once the color gradient distribution in the simulation:

- **Strengths:** The system possesses an exceptionally robust structural design validated by a Global Safety Factor of 1.8. The use of cold-formed Aluminum 6061-T6 ensures it is lightweight enough for manual deployment without heavy machinery while remaining highly resistant to atmospheric corrosion and solar degradation.
- **Weaknesses:** The current validation is limited to linear static analysis. Complex dynamic effects, such as water sloshing during sudden relocations or seismic events, have not yet been evaluated. Additionally, long-term empirical tests are required to confirm that the aluminum alloy does not alter the stored rainwater's chemistry.
- **Opportunities:** The device directly addresses the massive water consumption of the construction industry

(estimated at 61 billion tons annually), offering a scalable method to reduce the sector's water and carbon footprint. It provides a decentralized water source specifically for high-demand activities like concrete curing and dust control.

- **Threats:** The primary threat is the construction industry's traditional reliance on established logistics, specifically the continuous use of potable water trucks, which may cause initial resistance to adopting decentralized, on-site rainwater harvesting technologies.

4.2. Sustainability, Life-Cycle, and Cost-Benefit Analysis

The environmental and economic unsustainability of conventional water supply methods during early construction phases necessitates a transition toward circular economy practices. The construction sector consumes approximately 61 billion tons of water annually, which is often satisfied through the transportation of potable water via tanker trucks. This reliance not only depletes freshwater reserves but also

generates a significant carbon footprint due to logistical inefficiencies and continuous vehicular emissions.

From a life-cycle perspective, the proposed modular catchment device offers a sustainable alternative by decentralizing water management. Fabricated primarily from cold-formed Aluminum 6061-T6 and Galvanized Steel, the structure possesses a high resistance to atmospheric corrosion, guaranteeing a long operational lifespan even in aggressive outdoor environments. Unlike plastic or canvas temporary reservoirs that degrade and become non-recyclable waste, the metallic components of this device are 100% recyclable at the end of their useful life, directly contributing to circular economy principles within temporary infrastructure.

A comparative cost-benefit analysis further highlights the strategic advantage of the device over conventional water sources. Traditional water supply relies on the continuous rental of water trucks, generating a perpetual and cumulative Operational Expenditure (OPEX) throughout the project's duration. In contrast, the proposed modular system requires an initial Capital Expenditure (CAPEX) for the manufacturing of the aluminum and steel components.

However, because the system is completely autonomous and portable, it requires zero OPEX for water transportation and can be easily disassembled, transported, and reused across multiple successive construction projects. This reusability allows construction companies to rapidly amortize the initial manufacturing costs, transforming a recurring logistical expense into a profitable, long-term technological asset for on-site activities like dust control and concrete curing.

4.3. Scalability, Site Logistics, and Safety

To address the dynamic nature of construction environments, the proposed rainwater catchment device was designed with inherent scalability and logistical efficiency. Regarding scalability and adaptability, while a single unit provides a volumetric capacity of over 328 liters, the modular nature of the system allows for the integration of multiple standalone units in series to meet higher volume requirements across different climates, precipitation rates, and project scales. Furthermore, the radial support system, featuring a "double star" configuration with four inferior tubular legs, efficiently decomposes vertical water loads into axial forces, distributing the localized load over a wider footprint. This design characteristic permits deployment on various soil types and compaction levels without the need for permanent concrete foundations, making it highly adaptable to itinerant and unprepared work fronts.

In terms of site logistics, the utilization of cold-formed Aluminum 6061-T6 significantly reduces the overall weight of the empty assembly compared to traditional steel. This structural lightness facilitates manual transportation, rapid assembly, and frequent relocation across the construction site

without requiring heavy lifting machinery, thereby optimizing spatial logistics and avoiding operational bottlenecks.

Furthermore, regarding occupational safety, the updated structural validation under full hydrostatic capacity demonstrated a minimum Global Safety Factor of 1.80 and a maximum deformation of just 5.12 mm. This robust mechanical integrity ensures that the temporary structure poses no risk of plastic yielding or catastrophic collapse, operating well within the elastic limits of the aluminum alloy. Consequently, the device can be safely integrated into the aggressive and transit-heavy environments of active construction zones without endangering the nearby workforce.

4.4. Digital Integration and Smart Monitoring

In alignment with Industry 4.0 trends in civil engineering, the proposed device is highly adaptable to digital integration and sensor-based smart monitoring. The open-trough geometry provides accessible upper edges that serve as ideal anchor points for the installation of ultrasonic water level sensors. This enables construction managers to remotely monitor the available water volume in real-time via mobile platforms, optimizing water use logistics. Additionally, the lower purge valve, located at the bottom of the receptacle without mechanical interferences, offers an optimal integration point for in-line water quality sensors (such as pH and turbidity meters). These integrated monitoring options would guarantee that the stored rainwater continuously meets the stringent physicochemical standards required for concrete curing.

4.5. Stakeholder Perspective and Future Work

While the current research focuses on the computational and structural validation of the design, the strategic conceptualization of this device aligns with the immediate needs of construction stakeholders. A preliminary conceptual approach with site engineers highlighted that the reduction of reliance on water trucks is the primary operational advantage sought by contractors. As part of the future scope of this ongoing research, full-scale physical pilot studies are scheduled to gather empirical survey results and direct user feedback regarding maintenance routines, long-term operational ease, and the physical validation of the numerical parameters presented in this study.

5. Conclusion

The current study computationally developed and validated a trough-type modular rainwater collector, designed specifically for satisfying the demand of non-potable water in itinerant construction sites. Based on the obtained outcomes in the static simulation and their contrast with specialized literature, the following conclusions are derived.

5.1. Validation of Mechanical Integrity

The Finite Element Analysis confirmed that the proposed structural configuration is highly competent for the service

loads. With a maximum stress of 115.15 MPa and a Global Safety Factor of 1.8, this device operates within the conservative safety range, eliminating the failure risk due to yielding under hydrostatic pressure and standard operational loads.

5.2. Superiority in Rigidity and Durability

The maximum deformation registered was 5.12 mm, which demonstrates an exceptional structural stiffness. This behavior surpasses the stability limitations of the flexible tanks and its susceptibility to the creep of the urban plastic modules. The choice of aluminum as the integral material guarantees not only the lightness necessary for portability, but also the superior resistance to UV radiation degradation in exposed construction environments.

5.3. Innovation in Temporary Water Management

This study validates the technological solution that decouples the rainwater catchment for permanent architecture.

By functioning as an autonomous catchment Surface, the system permits the collection of water from the initial phases of the construction (earthworks and gray works), in critical moments where the traditional roof systems still do not exist.

5.4. Contribution to Concrete Sustainability

Based on the evidence that rainwater is a viable option for mixing concrete [22], this device facilitates the practical implementation of sustainable construction strategies. Its adoption permits the substitution of the use of potable water in high consumption activities like the curing, cleaning, and mixing processes, aligning with global trends in the reduction of the water footprint in the construction industry.

In synthesis, the proposed modular collector represents a validated incremental innovation, offering a robust and portable tool to civil engineering in order to transform the on-site water management, going from a linear consumption to a circular and self-sufficient one.

References

- [1] Mohamed Yateh et al., "Synthesis of Attaining Sustainable Development Goal 6.5: A Case Study of Mano River," *Journal of Geoscience and Environment Protection*, vol. 9, no. 6, pp. 100-119, 2021. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [2] UN World Water Development Report, UN Water, 2019. [Online]. Available: <https://www.unwater.org/publications/un-world-water-development-report-2019>
- [3] Ali Akbar Firoozi, D.O. Oyejobi, and Ali Asghar Firoozi, "Innovations in Energy-Efficient Construction: Pioneering Sustainable Building Practices," *Cleaner Engineering and Technology*, vol. 26, pp. 1-23, 2025. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [4] B. Ravinder, "Assessing the Environmental Impact of the Construction Industry: Insights for Environmental Science and Sustainable Development," *International Journal of Environmental Sciences*, pp. 2248-2260, 2025. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [5] Wei Huang et al., "Assessing the Consumption-based Water Use of Global Construction Sectors and its Impact to the Local Water Shortage," *Water Resources Management*, vol. 38, pp. 6063-6078, 2024. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [6] S. Bardhan, "Assessment of Water Resource Consumption in Building Construction in India," *Witpress*, vol. 144, pp. 93-101, 2011. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [7] Ataur Rahman, "Recent Advances in Modelling and Implementation of Rainwater Harvesting Systems towards Sustainable Development," *Water*, vol. 9, no. 12, pp. 1-7, 2017. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [8] Daniel F.C. Dias et al., "Screening Rainwater Harvesting Potentialities in the EU Industrial Sector: A Framework for Site-Specific Assessment," *Water*, vol. 16, no. 12, pp. 1-26, 2024. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [9] Matteo Carollo, Iliaria Butera, and Roberto Revelli, "Water Savings and Urban Storm Water Management: Evaluation of the Potentiality of Rainwater Harvesting Systems from the Building to the City Scale," *Plos One*, vol. 17, no. 11, pp. 1-20, 2022. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [10] Sjon van Dijk et al., "Strategic Design and Finance of Rainwater Harvesting to Cost-Effectively Meet Large-Scale Urban Water Infrastructure Needs," *Water Research*, vol. 184, pp. 1-10, 2020. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [11] María Paz González Durán, Federico Córdova-González, and Carlos Romo Zamudio, "Analysis and Evaluation of Proposals for Rainwater Harvesting Systems for Non-Consumptive use in the City of Cuenca, Ecuador," *MATEC Web of Conferences*, vol. 396, pp. 1-13, 2024. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [12] A. Kurniawan et al., "Modular Rainwater Storage Design Planning in Support of the Urban Infrastructure Systems Program," *IOP Conference Series: Earth and Environmental Science*, vol. 1116, pp. 1-6, 2022. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [13] Andréa Teston et al., "Comprehensive Environmental Assessment of Rainwater Harvesting Systems: A Literature Review," *Water*, vol. 14, no. 17, pp. 1-31, 2022. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [14] Low Impact Development Stormwater Management Planning and Design Guide, Toronto and Region Conservation Authority, 2010. [Online]. Available: <https://sustainabletechnologies.ca/home/urban-runoff-green-infrastructure/low-impact-development/low-impact-development-stormwater-management-planning-and-design-guide/>
- [15] Ahsen Maqsoom et al., "Assessing Rainwater Harvesting Potential in Urban Areas: A Building Information Modelling (BIM) Approach," *Sustainability*, vol. 13, no. 22, pp. 1-21, 2021. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]

- [16] Sumra Yousuf et al., "Alternatives for Fresh Water in Cement-Based Materials: A Review," *Water*, vol. 15, no. 15, pp. 1-15, 2023. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [17] Harshit Varshney, Rizwan Ahmad Khan, and Iqbal Khaleel Khan, "Sustainable Use of Different Wastewater in Concrete Construction: A Review," *Journal of Building Engineering*, vol. 41, 2021. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [18] Temporary Water Storage Solutions: Which Option is Right for Your Site?, *Water Direct*, 2025. [Online]. Available: <https://www.water-direct.co.uk/temporary-water-storage-solutions/>
- [19] Herbert A Lumbanbatu, "Condition Drivers and Challenges for Implementing Rainwater Harvesting: Insights from Bangladesh, Ethiopia, and Indonesia," *Critical Issue of Sustainable Future*, vol. 2, no. 2, pp. 134-160, 2025. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [20] Why 6061 T6 Aluminum: The Perfect Alloy for Marine and Aerospace Applications, *AtkinsHoyle*, 2024. [Online]. Available: <https://atkinshoyle.com/why-6061-t6-aluminum-is-the-ideal-choice-for-marine-and-aerospace-applications.html>
- [21] Rubeena Tarranum et al., "Static Load Analysis of Inverted Umbrella Structure for Rain Water Harvesting," *Journal of Scientific Research and Reports*, vol. 30, no. 5, pp. 432-440, 2024. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [22] Q.A Mowla1, and S.T.D. Kabir, "Production of Concrete Using Diverted Rainwater First Flush," *IOP Conference Series: Earth and Environmental Science*, vol. 581, pp. 1-7, 2020. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]