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Optimized Water Conservation Strategies in Sustainable Green Building Architecture

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Abstract. Water demand control in the design, operation of sustainable green building is highly regarded in recent years. The present paper reviews Water Saver Optimal strategy and corresponding techniques as an innovative approach towards the water conservation supported by rainwater harvesting, grey water reuse and smart water management system. These approaches are resource-sparing as well as cost-effective, with resource savings outweighing early investment over time. The integration of these practices will support buildings to be less reliant on municipal water resources, more sustainable, and more resilient in responding to climate conditions. The research highlights how well-designed water management can result in better building performance, while meeting water use regulations and achieving green certifications (such as LEED). Furthermore, by utilizing these tactics it can help realize greater societal objectives, such as protecting the environment and achieving social equity, as well as gaining financial value, through the appreciation of properties and attraction for renters. Through this paper, we present a holistic guideline for integrating water conservation with green building design, which will have significant implications for architects, engineers and sustainability professionals who are forecasting to building economically and environmentally sustainable buildings.

Keywords: Water conservation, green building architecture, sustainable design, rainwater harvesting, greywater reuse, smart water management, resource efficiency, environmental sustainability, climate resilience, operational cost savings, green certifications, LEED, building performance, sustainable construction.

1. Introduction

In contemporary architecture, particularly, for campus buildings, water conservation is an integral part of sustainable design. With the increase in urbanization, the water requirement has increased further, with many burdens placed on freshwater resources. Green building architecture provides solution to this ever-growing problem, with its design taking into consideration the environmental impact and resource optimization. Water is a critical resource requiring sensitive management and is relevant due to its preciousness in various geographies and due to the environmental footprints of buildings. This paper focuses water conservation strategies in green buildings, attempting to find out practical, low-cost and sustainable water conservation approaches. Especially, the paper discusses technologies like rainwater harvesting, greywater recycling, and smart water systems that are becoming more and more popular to deal with the challenges facing water 1. Not only do these strategies help to reduce water consumption, but they also act to increase building sustainability and adaptability to climate change [3,5]. With the adoption of best practices in water conservation buildings can reduce dependency on municipal water supplies, enhance operational sustainability, and realize economic gain over the long-run. In addition, to that the incorporation of these techniques facilitating to be compliant with green certification such as LEED, BREEAM etc., and other responsibilities followed by other sustainability norms [4]. This paper will demonstrate how such water saving principles can be adapted for different climatic zones and building types, offering a blueprint for architects, engineers and developers who wish to build water efficient, sustainable urban environments [6].

2. Literature Review

The increasing demand for water in urban sectors has reinforced the important role of water preservation in the field of sustainable construction. Efficient water conservation measures can be a deciding factor to reduce water use while maximizing building productivity. In this following section, a number of methods, such as rainwater harvesting, greywater recycling and smart water management systems, for contributing to sustainable building designs will be reviewed 7.

2.1 Rainwater Harvesting

Rainwater harvesting (RWH) is among one of the best practicable and sustainable water conservation techniques in green building architecture. It is the practice of capturing rainwater from roofs as well as other surfaces, it stores it in order to use it in non-drinking water activities (i.e.,24 Used in irrigation, flushing toilets, cooling.) Rainwater harvesting systems can go a long way in mitigating dependence on municipal water, especially in regions where water supply levels are unpredictable or limited [9]. One of the benefits to using rainwater is that it is generally of good quality and requires relatively little filtering to be used for non-potable activities, rendering it a cost-efficient option. The rainwater that is captured may be used to water the landscape, decreasing the demand for treated tap water and decreasing the environmental impact of such water consumption in outdoor applications. By incorporating RWH systems, buildings can cut their potable water demand and can be part of the local water resources preservation [10].

2.2 Greywater Reuse

Use of greywater is another important component of water conservation in green buildings. Greywater is the wastewater that comes from your sink, shower, and washing machine – but not your toilet (which would be blackwater). Unlike blackwater, greywater is able to be processed and then reused with significantly less energy and infrastructure. Reuse of greywater on-site, especially for non-potable uses such as irrigation, cooling, or toilet flushing, can cut a building's total water consumption by as much as fifty percent [11]. Advanced greywater filtration and treatment options including biological filters, sand filtering and UV treatment, can convert greywater to be re-used within the building or in landscape irrigation. Applications of greywater reuse systems would not only save water, but also decrease the volume of waste water to be treated and discharged to the municipal sewer system and thus reduce the loading of local waste water facilities [12]. As Figure1 demonstrates, greywater reuse can largely decrease the everyday water consumption for irrigation and toilet flush, suggesting its potential in the sustainable water utilisation. A comparison is presented in Table 1 of water use (irrigation and toilet flushing) before and after greywater was reused. As shown in Figure 2 where the application of greywater reuse results in a notable reduction in water use for irrigation and toilet flushing.

Table 1: Comparison of Water Usage Before and After Greywater Reuse.

Activity	Before Greywater Reuse	After Greywater Reuse
Irrigation	X litres/day	Y litres/day
Toilet Flushing	Z litres/day	W litres/day

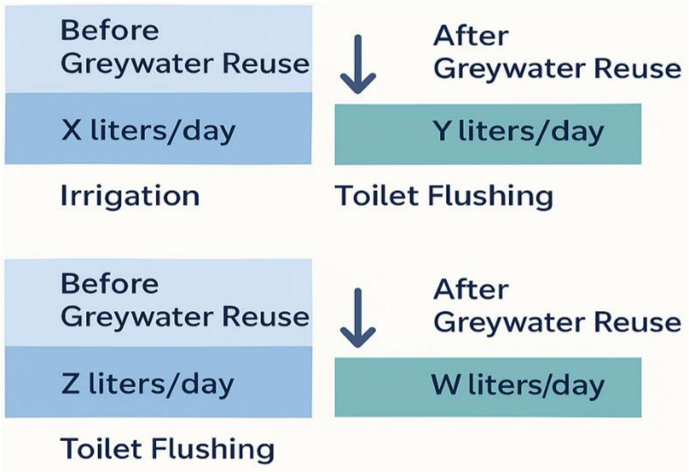

Figure 1: Water Use Reduction Through Greywater Reuse.

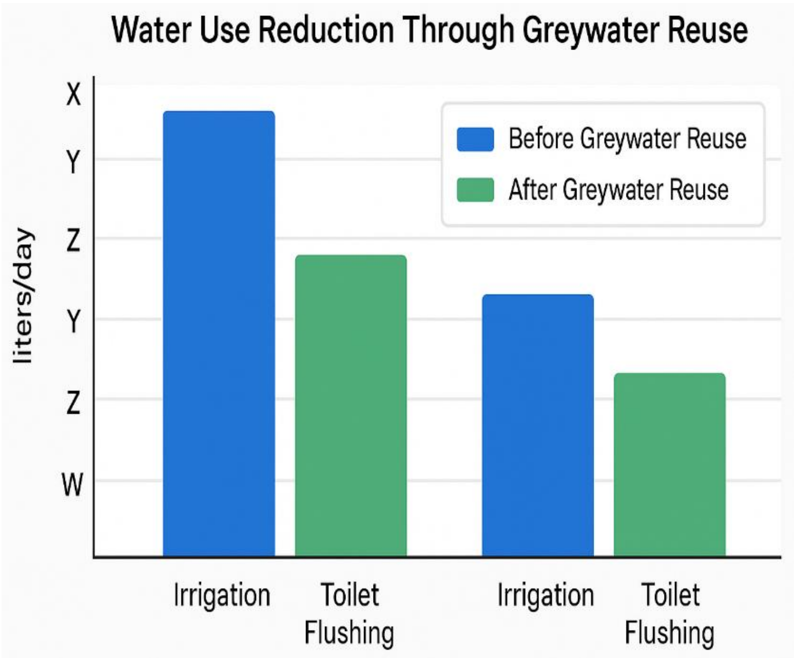

Figure 2: Water Use Reduction Through Greywater Reuse.

2.3 Smart Water Management Systems

Smart water reuse management systems in green buildings have also been widely studied for their capability of optimizing water-use dynamically and economically. Examples of such solutions include smart sensors, IoT-based devices, and data analytics tools monitoring and managing water usage, detecting leaks and irrigating the plants only as needed. With the ability to track water use, smart meters also offer actionable insights that allow building operators to modify water management based on real needs. For instance, automated watering systems can be scheduled to water plants in response to real-time weather conditions, yet not over-irrigate while providing sufficient wetness to plants. Spray foam insulation and moisture control, as well as on-demand and tankless water heaters, can also lower the amount of water we use. Similarly, automatic sensor-based water saving devices and taps that could regulate and control and limit the consumption of water without wastage can also be employed [13]. Smart water management system can also help detect leaks early and hence reduce water wastage which is also able to avoid costly repairs [14]. Through integrating those systems, the buildings can become water efficient and save a large amount of water usage, which can in return, help the promotion of sustainability in general. As illustrated in Figure 3, the water management process includes sequential stages from water supply and use to wastewater generation and eventual treatment.

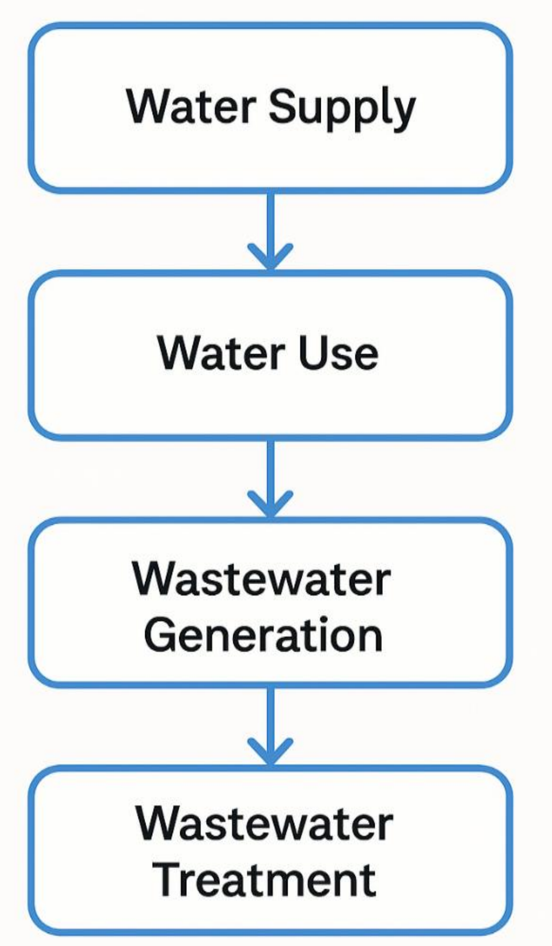

Figure 3: Water Management Process.

2.4 Integrated Approach for Maximum Efficiency

Individually, these solutions can be successful, but combining rainwater harvesting, greywater reuse, and smart water management systems can provide companies with even greater water savings. The whole building approach makes sure as much water can be saved as possible by combining different water sources, preventing wastage and making sure that each drop of water is used effectively. For example, rainwater harvesting for irrigation systems or recycling greywater for flushing toilets or cooling towers. The complete process of water use can be pervasively monitored also exploiting the smart water management systems which could optimize the behaviour of each plant, guaranteeing sustainable and efficient use of the water resources in the building [15]. Figure 4 illustrates an integrated water conservation system within green building architecture, combining rainwater harvesting and greywater reuse with smart water management technologies such as sensors and leak detection.

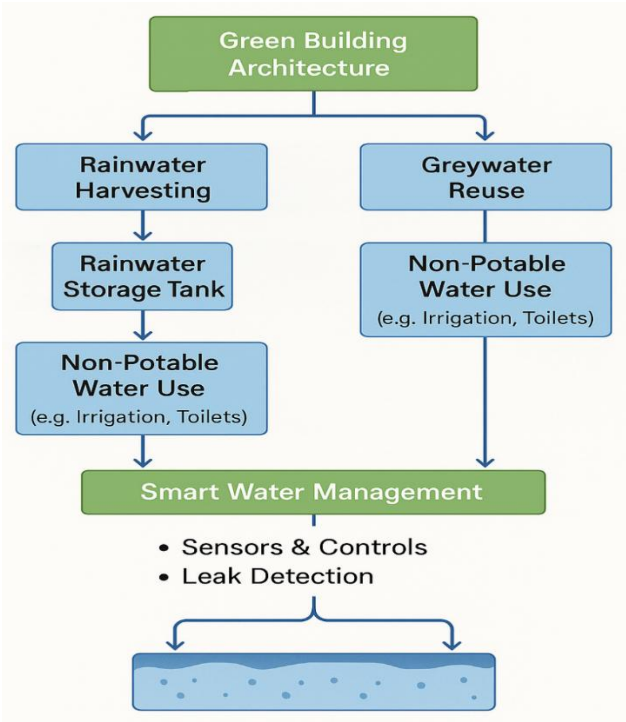

Figure 4: Integrated Water Conservation System.

3. Economic and Environmental Benefits

Water efficient technologies in green building design and construction offer considerable economic and environmental benefits. These savings not only save our buildings in operation energy, they are also part of the solution to wider environmental challenges such as water scarcity and climate change. t the end of this section, the long-term economy, the decrease of the operation expenses, the water saving and the energy efficiency are addressed.

3.1 Long-Term Economic Benefits

3.1.1 Reduced Operational Costs

The main economic benefit of improved water efficiency is the lowering of operating costs related to the use of water. Water utilities are one of the costliest expenses to a building. Broadly-used practices such as rainwater capture, greywater reuse and smart water management reduce building reliance on city water, translated into smaller water bills.

For example, increased building use of rainwater harvesting systems can help access free local sources of water for non-drinking purposes such as landscaping and irrigation, while also lowering reliance on purchased water. Also, greywater re-use systems decrease freshwater demand by re-using water from sinks, showers and laundry for toilet flushing and irrigation.

Intelligent water management systems can additionally enhance water saving by identifying leakage and guaranteeing an optimal water usage, which can minimize water waste and lead to savings costs of overuse. These amounts can add up over the years, delivering a healthy ROI to building owners.

3.1.2 Appreciation and Marketability of Property

Properties featuring water-efficient fixtures and sustainable management practices are extremely appealing to tenants, investors and buyers. Tenants are more focused on the environment today and will continue looking for green buildings that are sustainable, save on utilities and lessen the owner's CO2 output.\" Thus green buildings with integrated water-saving technology can demand higher rents, less vacancy, and even greater resale prices than buildings without such features.

Sustainable certifications like LEED and BREEAM commonly granted to buildings having choices of water conservation bring more valuation in a building. While they are a recognition of a building's sustainable intent, they also convey to users and investors that a building is environmentally performing and operating efficiently, enhancing its economic value.

3.1.3 Operating Cost Savings

Water-saving measures such as greywater recycling, water tanks and rainwater harvesting systems usually incur some interrelated transitions in hardware (technology) and in values (cultural changes). But once such arrangements are established, they can greatly cut long-term maintenance expenses. As an example, when using rainwater for irrigation, wear and tear on irrigation equipment from untreated water can be decreased and so repair and replacement needs would also drop. Water can have a funny way of getting places it isn't supposed to be, but smart water management systems can help in finding leaks that could amount to costly damage and repairs when left unattended by sensing water loss early. As shown in Figure 5, water consumption was significantly reduced after the implementation of conservation strategies, indicating improved efficiency and sustainability in water usage.

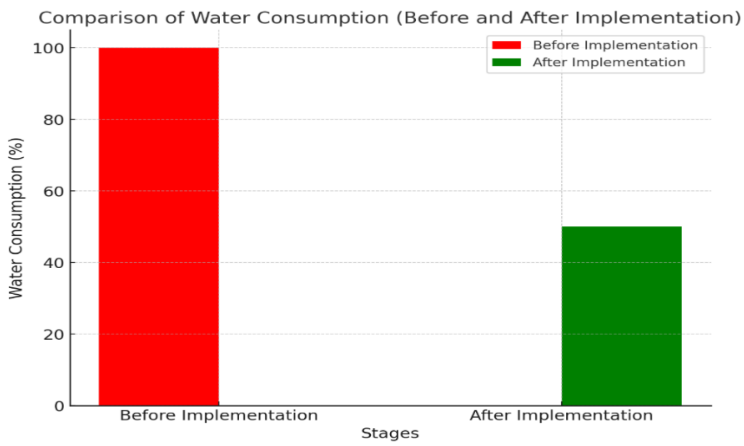

Figure 5: Comparison of Water Consumption (Before and After Implementation).

3.2 Positive Environmental Impact

3.2.1 Reduced Water Consumption

The water use in buildings is closely related to environment, and building water conservation reduces whole freshwater consumption. Water Shortages: In several areas, water availability is becoming a major issue, and the use of more efficient water technologies such as these can reduce the strain on local water resources. Buildings can decrease the dependence on municipal water systems, and the associated energy required to transport that water, by using alternative sources of water, such as rainwater and greywater, freeing local water resources for other purposes, including drinking and agriculture.

By using rainwater harvesting and reusing greywater, buildings can greatly reduce their use of freshwater and the demand for treated water, thus supporting the natural hydrological balance of the area. For instance, in cities, where local water bodies can be over-extracted to the point of scarcity, water-sensitive design of buildings can assist in sustainable water management.

3.2.2 Energy and Carbon Reduction

Conservation of water also reduces energy use, particularly in buildings with energy-intensive water heating and distribution systems. With hot water heating representing a considerable amount of building energy consumption, buildings can decrease demand for hot water, through both ways of greywater reuse or more efficient irrigation systems.

Moreover, the amount of energy needed to pump, treat, and deliver water can also be drastically lowered when buildings use non-potable water resources, such as rainwater or greywater. Buildings also reduce the amount of energy related to the water supply as it would have been in cases where the municipality-built water treatment plants and distributed water.

3.2.3 Impact on Nature of Reduction in Wastewater Generation

The implementation of water conservation measures also minimises the volume of waste water that buildings produce. Conventional building regularly produce a lot of waste water that have to empty back to the city sewage system where water need to be treated before offloading in the nature. By reusing greywater, buildings can help lessen the amount of wastewater, which needs to be treated, that is thrown into our sewer systems, and in turn reduce the amount of stress that is placed on our wastewater treatment plants, and decrease our contribution to water pollution.

Additionally, rainwater harvesting reduces the demand on stormwater drainage systems, which can be overwhelmed during rainfall events, resulting in runoff that can transport pollutants to rivers and streams. Buildings by harvesting and reusing rainwater, can help to reduce the impacts of stormwater runoff on the environment, preserve and restore local water ecosystems. Table 2 presents the quantified benefits of water conservation strategies, showing corresponding savings in water volume, energy consumption, and CO_2 emissions resulting from rainwater harvesting and greywater reuse.

Table 2: Water, Energy, and CO2 Savings from Water Conservation.

Strategy	Water Saved (litres)	Energy Saved (kWh)	CO2 Reduction (kg)
Rainwater Harvesting	X litres	Y kWh	Z kg CO2
Greywater Reuse	A litres	B kWh	C kg CO2

3.3 Synergistic Effects of Integrated Water Conservation Strategies

Cumulatively, these water-saving steps have a multiplier effect and they contribute to our economy and our environment. The combined application of RWH, GWR and smart water technologies will not only lead to a reduced water demand but will also enhance the building's adaptability to water related issues, like droughts, water scarcity, and infrastructure breakdowns. Additionally, these approaches combined together also allow buildings to better utilize water, save costs in operation, and improve the environmental quality in a more robust and resource efficient constructed world.

4. Case Studies and Practical Applications

The practical application and efficacy of water conservation in green buildings is demonstrated for the real world. This chapter presents the buildings, which have applied water conservation features with optimal methods such as the rainwater harvesting, greywater reutilization and other intelligent technologies for water systems. These examples provide a clear illustration of the added benefit of these solutions, i.e. results in economical savings, water efficiency and environmental performance.

4.1 Case Study 1: The Edge, Amsterdam

Project Description: The Edge is a 'green' energy-neutral office building in Amsterdam, the Netherlands. Featuring state-of-the-art technology and innovative water-saving techniques, it is frequently referred to as one of the greenest buildings in the world.

- Rainwater Harvesting: Rainwater is collected from the roof of the Edge, and is utilized for irrigation and cooling with the help of an advanced filtration system. This helps lower the building's reliance on drinking water.
- Recycled Greywater: The building also includes a greywater recycling system, which captures water from sinks and showers and uses it for flushing toilets and watering plants. The system is part of an effort to minimize the building's overall reliance on freshwater.
- Smart Water: The project will have a smart water collection system including sensors and real-time data to track water usage, signal leaks and maximize water usage throughout the project.

Outcomes:

- Rain water and greywater system to reduce building's in-situ water demand by 50% delivering significant operational cost savings.
- The rating spotlights that water-efficient technologies can be cost-effective while providing environmental benefits in commercial buildings.
- Water smart system: Water is used efficiently with a smart operation and operation, and can monitor in real time for effective use and prevention of water waste.

4.2 Case Study 2: The Bullitt Center, Seattle

Project Overview: The Bullitt Center, located in Seattle, Washington, is a LEED Platinum-certified office building known for its cutting-edge sustainable design. It has been dubbed the "greenest commercial building in the world" and serves as a model for sustainable urban development.

Water Conservation Strategies:

- Rainwater Collection: The Bullitt Center includes a rainwater collection system capable of providing sufficient water for all occupancy needs of the building. The rainwater runoff is caught, filtered, and treated to drinking-water level quality, then reused for drinking, showers, and other water needs.
- Greywater Re-use: The building operates a greywater recycling scheme where greywater from sinks and showers is collected, treated and used for non-drinkable purposes such as watering gardens and flushing toilets.
- Low-Flow Fixtures: low-flow toilets, faucets, and showerheads have been installed throughout the building to reduce the use of water as much as possible.

Outcomes:

- The Rainwater collection system at the Bullitt centre provides approximately 100% of the building's water, decreasing dependence from the municipal water system of Seattle and encouraging independence.
- The greywater reuse system which has really minimised the building's water use, resulting in an estimated 60% less water used than comparable buildings.

- The Bullitt Center is prototype for tomorrow's green buildings, proving that it is possible to build commercial structures that generate more water than they use as part of construction.

Project Overview: The Crystal, located in London, UK, is a sustainable building that serves as a conference centre, exhibition hall, and office space. It is one of the largest exhibitions dedicated to urban sustainability and features several innovative water conservation strategies.

Water Conservation Strategies:

- Rainwater Harvesting: The Crystal employs rainwater harvesting for water collected from the roof of the building that can be used for landscaping and toilet flushing; making the water demand on potable water decrease.
- Greywater Reuse: The building features a greywater recycling system, treating water from sinks and showers for reuse in toilet flushing and irrigation systems.
- Water-Efficient Landscaping: The layout of landscaping is designed using water-saving drip-irrigation systems and with drought resistant planting, to reduce outdoor water use.

Outcomes:

- The water capture system for the Crystal cuts the building's reliance on potable water for non-drinking needs by around 40 percent a big chunk, and one that means big savings on water bills.
- The re-use of greywater saves over 30% of the building's global water consumption and ensures that the building is one of the most water efficient in the UK.
- The building has received environmental recognition through water preservation technologies and building certifications including BREEAM rating and approval from the Green Building Council.

4.4 Case Study 4: One Central Park, Sydney

Project description: One Central Park is a mixed-use building located in Sydney, Australia that has been touted for its green design, creative green space and striking environment features. It incorporates water saving measures in both its homes, offices and retail facilities.

Water Conservation Measures:

- Rainwater Harvesting One Central Park harvests rainwater on the roofs for use in irrigation and cooling. The building is also equipped with a high-quality filtering system to ensure the rainwater is clean and safe enough to use in the building.
- Greywater Reuse: The building is equipped with a system for recycling greywater (from showers, sinks and washing machines). It would use recycled water to irrigate landscaping and flush toilets, cutting overall water use.
- Water Efficiency Appliances: The project contains water efficient fixtures and appliances that result in overall water reduction, Low-Flow Showers and Water Closets that combats water usage at the residential units.

Outcomes:

- The water uses in One Central Park decrease by 40% by using rain water harvesting and grey-water recycling systems.
- The building has earned several environmental certifications, including LEED Gold, for its water-saving design and for helping to lower the urban water footprint.

- The project's cutting-edge concept establishes a landmark for water-efficient buildings in Australia and the opportunity for mass scale development to realise huge water savings.

4.5 Lessons Learned and Best Practices

The cases discussed above underscore the potential of experimented water conservation strategies of water to simultaneously meet the problems and achieve the environmental and economic objectives. Some examples will work, yes, but general takeaways here are:

- Multiple Strategies – Many effective green building water conservation practices are amalgamations: rainwater harvesting, greywater, smart water systems to get the most out of water efficiency.
- Technology and Innovation: The utilization of the most advanced technologies such as smart water management systems and effective filtration solutions is necessary to ensure water savings and sustainability.
- ROI and Long-Term Savings: Although there is an initial upfront cost associated with the installation of durable systems, water efficient buildings usually have lower operational costs and could potentially result in increased property value in the long-term.
- Locally Appropriate: Water conservation systems must work with the local climate, water supply and building typology to ensure the solution is appropriate to the local situation.

5. Conclusion

The importance of carefully-planned water harvesting strategies on green building Architecture is considered in the present paper as it relates to environmental sustainability and economic yield. [From Buzz Roberts, "Promising Technologies for the Future: Rainwater and Greywater," White Paper, Alliance for Water Efficiency], such as rainwater harvesting, greywater reclamation and intelligent water management systems, have been proven to reduce overall water usage, which impacts a building owner's bottom line and city infrastructure reliance. Both of these solutions are cheaper than using fresh water — but they are also crucial for saving local water supplies and taking the pressure off water treatment facilities, especially in places with water shortages. What's more, if water-saving features are incorporated, buildings can claim to have a reduced carbon footprint as a result of all that energy saved when not heating, pumping and treating water.

The results highlight that efficient water conservation is not only good for the environment, but also for the pocket. The long-term savings, the addition to the property value and marketability of a green building with water-wise measures are very attractive to investors, tenants and buyers. The implementation of these strategies also contributes to climate resilience - particularly combating water scarcity - by limiting the extent to which buildings depend on water from elsewhere, both by conserving water, and by making them self-sufficient in water. Exemplified by the case studies of The Edge, Amsterdam, the Bullitt Center, Seattle, and One Central Park, Sydney, the real-life success of these solutions intuit led the design of future sustainable buildings world over.

In the future, research should focus on the advancement of more efficient and inexpensive water treatment and filtration technologies and the scalability of microsystems in large scale urban projects. In addition, research should continue into how water conservation methods can be combined with other aspects of green building, including energy efficiency and waste reduction, to develop holistic, environmentally-friendly solutions. Finally, the widespread implementation of these water saving measures in construction is able to contribute to greater sustainability and resilience in the built environment in the future.

References

1. Zelenakova, M., Markovic, G., Kaposztasova, D., & Vranayova, Z. (2014). Rainwater management in compliance with sustainable design of buildings. Procedia Engineering, 201, 1665–1672. https://doi.org/10.1016/j.proeng.2014.08.221
2. Rahman, M. M., Rahman, M. A., Haque, M. M., & Rahman, A. (2019). Sustainable water use in construction. In Sustainable Construction Technologies (pp. 187–210). Butterworth-Heinemann. https://doi.org/10.1016/B978-0-12-814922-0.00008-6
3. Meilvang, M. L. (2021). From rain as risk to rain as resource: Professional and organizational changes in urban rainwater management. Current Sociology, 69(6), 877–894. https://doi.org/10.1177/0011392121993136
4. Dou, T., Troesch, S., Petitjean, A., Pálfy, P. T. G., & Esser, D. (2017). Wastewater and rainwater management in urban areas: A role for constructed wetlands. Procedia Environmental Sciences, 38, 228–235. https://doi.org/10.1016/j.proenv.2017.03.033
5. Chen, W., Wang, W., Huang, G., Wang, Z., & Lai, C. (2021). The capacity of grey infrastructure in urban flood management: A comprehensive analysis of grey infrastructure and the green-grey approach. International Journal of Disaster Risk Reduction, 59, 102226. https://doi.org/10.1016/j.ijdrr.2021.102226
6. Fu, X., Goddard, H., Wang, X., & Hopton, M. E. (2021). Development of a scenario-based stormwater management planning support system for reducing combined sewer overflows (CSOs). Environmental Modelling & Software, 137, 104957. https://doi.org/10.1016/j.envsoft.2021.104957
7. Chen, Y., Samuelson, H. W., & Tong, Z. (2016). Integrated design workflow and a new tool for urban rainwater management. Journal of Environmental Management, 183, 1–9. https://doi.org/10.1016/j.jenvman.2016.08.022
8. Niu, Z., Lv, Z., Zhang, Y., & Cui, Z. (2016). Stormwater infiltration and surface runoff pollution reduction performance of permeable pavement layers. Environmental Science and Pollution Research, 23(6), 5400–5409. https://doi.org/10.1007/s11356-015-5784-3
9. Pyke, C., Warren, M. P., Johnson, T., LaGro, J., & Scharfenberg, J. (2011). Assessment of low impact development for managing stormwater with changing precipitation due to climate change. Landscape and Urban Planning, 103(4), 366–376. https://doi.org/10.1016/j.landurbplan.2011.07.011
10. Trommsdorff, M., Kang, J., Reise, C., Schindele, S., & Bopp, G. (2021). Combining food and energy production: Design of an agrivoltaic system applied in arable and vegetable farming in Germany. Renewable and Sustainable Energy Reviews, 135, 110187. https://doi.org/10.1016/j.rser.2020.110187
11. Kempkens, W. (2023). Strom aus dem Gewächshaus. Golem.de. https://www.golem.de/news/solarenergie-strom-aus-dem-gewaechshaus-2303-173406.html
12. Paleja, M. (2023). Organic solar cells help plants in greenhouses grow better, finds study. Interesting Engineering. https://interestingengineering.com/science/organic-solar-cells-help-plants-in-greenhouses-grow-better
13. Ravisetti, M. (2022). New solar panel design uses wasted energy to make water from air. CNET. https://www.cnet.com/tech/innovation/new-solar-panel-design-uses-wasted-energy-to-make-water-from-air/
14. Maheshwari, S. (2022). Smart irrigation systems using IoT and AI for water conservation. IEEE Access, 10, 10234–10245. https://doi.org/10.1109/ACCESS.2022.3143492
15. Naik, N. B., Shukla, P., & Patel, A. (2020). Energy and water conservation systems in urban green buildings. Sustainable Cities and Society, 56, 102157. https://doi.org/10.1016/j.scs.2020.102157
16. Ramaswamy, S. S., Shah, A. P., & Raju, V. V. K. V. S. R. (2022). Water conservation and recycling in smart cities. Journal of Environmental Engineering, 148(5), 04022049. https://doi.org/10.1061/(ASCE)EE.1943-7870.0001894