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Urban Sustainability Engineering: Design of a Rainwater Harvesting and Automated Irrigation System in a Community Garden

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Engenharia aplicada à Sustentabilidade Urbana: captação e automação da irrigação com águas pluviais em horta comunitária

RESUMO

Objetivo – Elaborar e implantar um sistema de captação e automação da irrigação com águas pluviais para canteiros de plantas alimentícias localizados em uma horta comunitária sob cobertura impermeável, reduzindo a dependência de irrigação manual realizada por voluntários e promovendo a gestão sustentável da água.
Metodologia – O estudo, de natureza aplicada e abordagem exploratória e experimental, envolveu levantamento bibliográfico e técnico sobre sistemas de captação de águas pluviais, automação de irrigação e agricultura urbana sustentável. O projeto foi desenvolvido com base em medições locais, testes de eficiência hidráulica e adequação dos componentes, resultando na instalação de um sistema automatizado de irrigação na *Horta das Flores*, localizada na zona leste de São Paulo.
Relevância – A proposta integra engenharia e sustentabilidade urbana, aplicando tecnologia acessível ao reaproveitamento de recursos hídricos em um contexto comunitário e educativo. A horta estudada constitui um espaço pedagógico**,** onde ocorrem eventos e ações de educação ambiental que abordam **os** Objetivos de Desenvolvimento Sustentável (ODS)**,** e este projeto fortaleceu ainda mais essa conexão com a Agenda 2030. Destaca-se pela replicabilidade em hortas urbanas de pequeno porte e pela contribuição direta aos ODS 2, 3, 4, 6, 11, 12 e 13.
Resultados – O sistema demonstrou viabilidade técnica e operacional, garantindo regularidade no fornecimento hídrico e redução do esforço humano. A avaliação em campo possibilitou aperfeiçoamentos hidráulicos e ajustes na automação, comprovando o potencial de otimização no uso da água e de promoção da eficiência no manejo hídrico urbano.
Contribuições metodológicas – O trabalho amplia a discussão sobre a aplicação de tecnologias sustentáveis e sistemas de automação em agricultura urbana, fornecendo subsídios técnicos e acadêmicos para a replicação de modelos semelhantes em outros contextos urbanos.
Contribuições sociais e ambientais – O projeto fortaleceu a integração entre universidade e comunidade, estimulando práticas de educação ambiental, participação social e corresponsabilidade na gestão da água. Ao promover o uso racional dos recursos hídricos e a produção local de alimentos, reforça a importância de soluções integradas para cidades mais sustentáveis.

PALAVRAS-CHAVE: Captação de água pluvial. Horta urbana. Sustentabilidade. ODS. Automação hidráulica.

Urban Sustainability Engineering: Design of a Rainwater Harvesting and Automated Irrigation System in a Community Garden

ABSTRACT

Objective – To design and implement a rainwater harvesting and irrigation automation system for food plant beds located in a community garden under an impermeable roof, reducing dependence on manual irrigation by volunteers and promoting sustainable water management.
Methodology – This applied research, with an exploratory and experimental approach, included bibliographic and technical surveys on rainwater harvesting systems, irrigation automation, and sustainable urban agriculture. The project was developed through field measurements, hydraulic efficiency tests, and component adjustments, resulting in the installation of an automated irrigation system at *Horta das Flores*, located in the eastern region of São Paulo, Brazil.
Relevance – The proposal integrates engineering, automation, and urban sustainability by applying accessible technology for rainwater reuse in a community and educational context. The studied garden functions as a pedagogical space, hosting events and educational activities on sustainability and the Sustainable Development Goals (SDGs)**,** thus reinforcing the connection with the 2030 Agenda. It stands out for its replicability in small-scale urban gardens and its direct contribution to SDGs 2, 3, 4, 6, 11, 12, and 13.

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Results – The system proved technically and operationally feasible, ensuring regular water supply and reducing manual effort. Field evaluation enabled hydraulic improvements and automation adjustments, confirming the potential for optimizing water use and increasing efficiency in urban water management.
Methodological contributions – The study broadens the debate on the application of sustainable technologies and automated systems in urban agriculture, providing technical and academic foundations for replication in other urban contexts.
Social and environmental contributions – The project strengthened the integration between university and community, encouraging environmental education, social participation, and shared water governance. By promoting rational water use and local food production, it reinforces the importance of integrated solutions for sustainable cities.

KEYWORDS: Rainwater harvesting. Urban garden. Sustainability. SDGs. Irrigation automation.

Ingeniería Aplicada a la Sostenibilidad Urbana: captación y automatización del riego con aguas pluviales en un huerto comunitário

RESUMEN

Objetivo – Elaborar e implementar un sistema de captación y automatización del riego con aguas pluviales para canteros de plantas alimenticias ubicados en un huerto comunitario bajo una cubierta impermeable, reduciendo la dependencia del riego manual realizado por voluntarios y promoviendo la gestión sostenible del agua.
Metodología – El estudio, de carácter aplicado y con enfoque exploratorio y experimental, incluyó una revisión bibliográfica y técnica sobre sistemas de captación de aguas pluviales, automatización del riego y agricultura urbana sostenible. El proyecto se desarrolló a partir de mediciones de campo y pruebas de eficiencia hidráulica, culminando con la instalación de un sistema automatizado en el huerto *Horta das Flores*, situado en la zona este de São Paulo, Brasil.
Relevancia – La propuesta integra ingeniería, automatización y sostenibilidad urbana mediante la aplicación de tecnología accesible para el aprovechamiento de recursos hídricos en un contexto comunitario y educativo. El huerto estudiado funciona como un espacio pedagógico, donde se realizan eventos y actividades de educación ambiental relacionados con los Objetivos de Desarrollo Sostenible (ODS), fortaleciendo así su conexión con la Agenda 2030. Se destaca por su potencial de replicación en huertos urbanos de pequeña escala y su contribución directa a los ODS 2, 3, 4, 6, 11, 12 y 13.
Resultados – El sistema demostró viabilidad técnica y operativa, garantizando la regularidad en el suministro de agua y reduciendo el esfuerzo manual. Las pruebas de campo permitieron mejoras hidráulicas y ajustes en la automatización, evidenciando su potencial de optimización del uso del agua y eficiencia en la gestión hídrica urbana.
Contribuciones metodológicas – El trabajo amplía la discusión sobre la aplicación de tecnologías sostenibles y sistemas automatizados en la agricultura urbana, aportando bases técnicas y académicas para su replicación en otros contextos urbanos.
Contribuciones sociales y ambientales – El proyecto fortaleció la integración entre la universidad y la comunidad, fomentando la educación ambiental, la participación social y la corresponsabilidad en la gestión del agua. Al promover el uso racional de los recursos hídricos y la producción local de alimentos, refuerza la importancia de soluciones integradas para ciudades más sostenibles.

PALABRAS CLAVE: Captación de agua de lluvia. Huerto urbano. Sostenibilidad. ODS. Automatización del riego

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1. INTRODUCTION

The accelerated pace of urbanization, combined with the impacts of climate change, has intensified pressure on water resources, compromising both the quantity and quality of water available for domestic, commercial, and public use (Li et al., 2020; Medeiros et al., 2024). The current urban sanitation system is still characterized by the intensive use of potable water, contributing to water scarcity and polluting water bodies – major obstacles to urban sustainability (Cohim and Kiperstok, 2008; Tundisi, 2014).

In this context, rainwater harvesting presents itself as a promising alternative to reduce pressure on public supply systems and increase urban water resilience (Gaitán and Teixeira, 2020; Batista et al., 2021). Recent studies demonstrate that rainwater harvesting and storage systems, when properly sized, can contribute to reducing potable water consumption, decreasing flooding, and mitigating climate impacts, while also providing safe alternatives for non-potable uses, such as irrigating green areas (Campisano et al., 2017).

The integration between rainwater harvesting and urban agriculture expands environmental and social co-benefits, linking environmental education, food security, and community participation (Thwaites et al., 2025). International and national experiences have shown that community and school gardens are effective instruments for promoting healthy eating, citizenship education, and ecological awareness (Golba et al., 2014; Santos; Silva, 2019; Nascimento et al., 2022). When associated with automated irrigation technologies powered by rainwater harvesting, these initiatives can maximize water use efficiency, reduce operating costs, and strengthen the links between environmental management and food security.

Recent reviews highlight that urban agriculture, when planned within the context of sustainability, contributes to the Sustainable Development Goals (SDGs) of the UN's 2030 Agenda. Among the SDGs, 2, 11, and 12 stand out, strengthening local food systems and the resilience of cities (Thwaites et al., 2025). In the context of small-scale food production, modeling studies indicate that rainwater harvesting can increase productivity and household water security, provided it is accompanied by good agronomic practices (Amos et al., 2021). Complementarily, critical syntheses on urban rainwater harvesting systems (RHS) highlight the multifunctional nature of these systems and the main barriers to adoption (capital cost, public perception, and quality uncertainties) (Ali et al., 2025).

The growing environmental awareness and the search for sustainable practices reinforce the need to adopt alternative water management technologies. As Capra (2006) points out, global problems cannot be understood in isolation, but rather as part of an interdependent system that integrates society and nature. In this way, it becomes essential to promote the dissemination of environmental knowledge and the construction of an ecological ethic that values sustainable practices, as proposed by Leff (2001). In this sense, academic spaces are configured as important environments for the development of socio-environmental practices. Among the numerous pedagogical activities, school gardens stand out as instruments of nutritional, environmental and civic education, enabling practical learning about sustainability and natural resource management (Golba; Serpe; Brun, 2014; Santos; Silva, 2019).

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In this context, this article aims to develop and implement a rainwater harvesting system for automated irrigation in food plant beds in an urban community garden. The proposal demonstrated technical, economic, and environmental viability, as well as its contribution as a sustainable and replicable alternative in urban contexts, aligned with the principles of sustainability and the SDGs of the 2030 Agenda (UN, 2015).

2. METODOLOGY

This study adopted an exploratory approach, with the purpose of providing an initial and systematic understanding of the phenomenon investigated, as proposed by Gil (2008). Simultaneously, an experimental approach was employed in a controlled environment, following the methodological principles described by Lakatos and Marconi (2003). The central focus of the research consisted of the development and implementation of a rainwater harvesting system, integrated with automated irrigation technologies, applied in a community urban garden.

The methodological path was structured in three main stages: theoretical-conceptual survey, dimensioning of the rainwater harvesting and storage system, and implementation of the automated irrigation system. In stage 1, a bibliographic and documentary research was carried out focused on the technical foundation of the project, especially regarding the sustainable use of water and automation technologies in irrigation. In stage 2, the sizing of the rainwater harvesting and storage system was carried out, including a study of the local rainfall regime, the available catchment area, and the water needs of the vegetable garden, based on hydraulic engineering principles. And in stage 3, the implementation of the automated irrigation system was carried out, based on the technical design developed by the team of engineers, authors of this article, considering the technical, economic, and environmental feasibility of the proposal.

For the second stage, essential parameters for sizing the hydraulic system were analyzed, including the definition of the reservoir volume, gutters, pipes, and filters, in accordance with the recommendations of ABNT NBR 15527:2007, which establishes criteria for the use of rainwater in urban areas. The project was developed considering the rainfall regime of the region, the catchment capacity, and the irrigation demand of the vegetable garden. The implementation of the system included the installation of storage tanks, gravity-fed piping, an auxiliary pump for booster pumping, and timers to automate the irrigation process, in addition to sprinklers strategically distributed in the delimited areas of the garden.

The third stage involved the execution of the implementation work, preceded by technical discussions, feasibility analyses, and project adjustments, based on the principles of civil engineering applied to urban sustainability. All phases prioritized the efficient reuse of rainwater, the reduction of dependence on manual irrigation, and the adoption of technically feasible solutions in urban contexts.

2.1 Study Area

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Located in Praça Alfredo Di Cunto, in the Mooca neighborhood, in the eastern region of the city of São Paulo (Figure 1), Horta das Flores community garden was established in 2004 by the Municipal Government through the Urban and Peri-urban Agriculture Program (PROAURP). Since then, the space has been maintained collectively and voluntarily by residents of Mooca and adjacent neighborhoods, with the support of undergraduate and graduate students, both in the conservation of the flowerbeds and in the offering of courses aimed at the community (Nascimento et al., 2023). The location of Horta das Flores highlights the insertion of green areas into the urban fabric, with access via the famous Radial Leste, Alcantara Machado Avenue, and next to the Bresser Viaduct.

The area for cultivating food plants is called a "greenhouse" by the managers, and it was reopened this year as part of the Sampa + Rural Program. Currently, this space has 10 plant beds, 7 of which are planted with unconventional food plants (PANC), totaling 60 m2 of cultivated area. This area is intended for education; that is, the cultivation has a pedagogical character. Figure 1A shows part of the area where the project was implemented, while Figures 1B and 1C show the PANC beds. This record is fundamental to understanding the accessibility of the space and its integration with the potential for articulation with environmental education and urban agriculture initiatives.

Figure 1. General view of Praça Alfredo Di Cunto, popularly known as Horta das Flores, east zone of the municipality of São Paulo, SP (1A). Next to it are images of the flowerbeds with unconventional food plants (PANC) being cultivated.

Source: Google Maps and Authors, 2025.

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3.2 Project Development

The automated rainwater harvesting and irrigation system was designed with the participation of engineers and professors from the Professional Master's Program in Civil Engineering at São Judas Tadeu University, ensuring the technical consistency of the proposal. During the design phase, meetings were held, the most suitable materials were evaluated, the executive feasibility of the proposal was assessed, and the structural conditions of the building were considered, taking into account the need for any civil reinforcements for the installation of the rainwater harvesting gutters.

The technical design of the system was based on fundamental premises: 1. the collection of rainwater through gutters strategically positioned along the roof and directed to the storage reservoir; and 2. the integration of an automated hydraulic pumping system, responsible for transferring water from the reservoir to the sprinklers, ensuring sufficient pressure and flow to meet the planned irrigation area. The automated control of the pumping sought to optimize water use by reducing waste and ensuring that the entire cultivated area of the garden was irrigated.

The sizing of the rainwater harvesting and reuse system was carried out based on an analysis of the specific needs of the urban garden where the project was implemented, taking into account the area available for collection, the physical constraints of the site, and the feasibility of implementation without the need for additional structural works. The system was designed to ensure hydraulic efficiency, ease of maintenance, and compatibility with available resources, following the guidelines of the ABNT NBR 5626 standard (ABNT, 2020), which deals with building cold water systems.

The hydraulic design was developed based on hydraulic principles, adopting the total flow method described in NBR 5626 (ABNT, 2020), since all sprinklers operate simultaneously, making the use of the weight method provided for in the same standard unsuitable. The unit head loss (J) was calculated according to the Fair-Whipple-Hsiao method for PVC or copper pipes, as presented by Fernández and Netto (2015), and is expressed by the equation:

$$J = 0{,}0008695.\frac{Q^{1,75}}{D^{4,75}} \quad (1)$$

where J is the unit head loss (m/m), Q corresponds to the flow rate (m³/s), and D is the internal diameter of the pipe (m). Considering the physical space constraints at the installation site, a motor-pump unit was chosen for pumping rainwater collected and stored in the reservoirs. The sizing of the motor-pump unit was carried out based on correlation charts between the total manometric head of the system (including head losses) and the power of commercially available pumps, ensuring efficiency and technical feasibility of the installation.

3.2.1 Technical visits

Located in Praça Alfredo Di Cunto, in the Mooca neighborhood, Horta das Flores was conceived with the purpose of constituting an accessible urban green space, for collective and voluntary use by residents of Mooca and adjacent neighborhoods. The site has had the support of undergraduate and graduate students from Universidade São Judas, both in the maintenance of the flowerbeds and in the provision of educational and extension activities aimed at the community (Nascimento et al., 2023).

In order to deepen the technical and spatial knowledge of the area, an initial reconnaissance visit was carried out, conducted by a group of students accompanied by specialist professors. In this stage, metric and photographic surveys were carried out, in addition to technical discussions in the field, aimed at analyzing the structural conditions and understanding the spatial organization of the land. During the visit, the general state of the physical facilities was observed, including lighting systems, material storage locations and logistics of daily activities, which were used to assist in decision-making.

3.2.2 Feasibility study

The feasibility study phase comprised three technical meetings, held with the objective of defining, reviewing, and approving the project, which received institutional funding from São Judas Tadeu University. These discussions allowed for the consolidation of the system's technical design, in accordance with the recommendations of Campisano et al. (2017), who highlight the importance of the correct calibration of hydraulic parameters and the planning of automation in urban rainwater harvesting projects. Furthermore, the interdisciplinary approach adopted reflects the guidelines of Ali et al. (2025), according to whom the success of rainwater harvesting systems depends on the involvement of multiple actors—technical, academic, and community—and the consideration of operational and social barriers during planning.

3.2.3 Purchasing materials

The process of acquiring the materials began after the completion of the executive project and the preparation of the quantitative survey of the materials needed for the execution of the implementation work. Given the need to obtain reference values, it was decided to carry out price mapping through e-commerce, a strategy that allowed for extensive market research in a short period of time.

Seven websites of stores specializing in construction materials were consulted, and their values were organized and compared in an electronic spreadsheet created in Microsoft Excel. The purpose of this spreadsheet was to perform a comparative cost analysis and calculate the average unit price of each item, ensuring transparency and technical basis for the decision-making process. After obtaining the total estimated value and the approval of the budget proposal in a meeting with the project team, it was decided to purchase all the materials from a

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single online store. This decision was motivated by administrative and financial issues of the proposing institution, in addition to favoring logistical optimization and delivery time.

During the execution phase, the need for additional acquisition of items not foreseen in the initial budget was identified, due to technical adjustments made in the field. The quotation procedure followed the same methodological criteria described previously. However, considering the urgency of supplying the materials, the team opted for direct purchase from a physical store, where the materials were available for immediate delivery, ensuring the continuity of implementation activities without compromising the schedule.

3.3 Project implementation

The mobilization for the project implementation occurred after the arrival of all necessary materials. The activities were conducted by a field engineer, responsible for technical monitoring, and two professionals with experience in civil engineering projects. The executing engineer made prior visits to the site to assess the structural conditions of the area, develop the activity schedule, and define the operational logistics of the work.

4. RESULTS AND DISCUSSION

The presentation of the results was structured in four complementary blocks: (I) technical visits and feasibility study; (II) project development, describing the system sizing, the selection of hydraulic components and the technical-economic decisions; (III) project execution, with emphasis on operational challenges, adjustments made in the field and the performance achieved; and (IV) project contributions to the SDGs, highlighting social, environmental and economic effects.

4.1 Technical visits and feasibility study

During the technical visits to the site, it was found that natural lighting is predominant, favored by the transparency of the plastic dome roof, which intensifies the incidence of solar radiation and, consequently, raises the internal temperature of the structure. The roof is supported by round wood pillars driven into the ground up to half its length, a solution that ensures structural stability and resistance to wind and other acting loads, characteristics that demonstrate the suitability of the infrastructure to local conditions.

In the first meeting, the conceptual proposal of the system was discussed and the preliminary planning of the actions was outlined. In addition to the technical aspects, operational feasibility indicators were considered, such as the availability of time of the participants, the compatibility of the schedules and the days of the week intended for monitoring the practical activities. In the second meeting, the engineering students presented the preliminary project to the specialist professor in the area, with the purpose of obtaining technical guidance and an advisory opinion for the improvement of the proposal. During the presentation, relevant questions arose, especially regarding the automation process of the irrigation system, an element that would directly impact both the hydraulic dimensioning and

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the definition of the bill of materials. The uncertainties focused on the need for a hydraulic booster pump to ensure adequate pressure and efficiency of the automated system. The feasibility of using two independent reservoirs, considered essential to guarantee the regularity of irrigation under different operating conditions, was also discussed.

In the third meeting, the project was presented to the coordinator of the Master's course, with the proposal to frame it as a university extension activity, given its social and environmental relevance to the local community. The technical descriptive report, the budget spreadsheet, and the cost estimate, covering materials, labor, and equipment, were presented. During this meeting, specific questions arose regarding the technical and financial feasibility of the system, which were promptly clarified based on the analyses carried out in the previous phase. After institutional validation, the funds were approved and released by the coordination, authorizing the effective start of activities. This stage concluded the planning and feasibility phase, initiating the logistical organization for the acquisition of materials and the preparation for implementation in the field.

4.2 Project Development

Based on the intake configuration, a rainwater harvesting strategy was adopted, consisting of galvanized metal gutters shaped along the edge to expand the collection area. These gutters, integrated with galvanized headwalls, direct the flow to the conveyance system. Auxiliary pipes connected to the gutters transport the water to the storage tanks (plastic drums), ensuring efficiency in water use and supplying the automated irrigation system. Figure 2 shows the design for gutter installation.

For rainwater collection, galvanized metal gutters were used, installed laterally to the greenhouse roof, to direct surface runoff of rainwater into the drainage piping. The choice of galvanized material is due to its resistance to oxidation and durability, important characteristics considering continuous exposure to the elements. The piping for conveyance and distribution consisted of brown, weldable PVC pipes and fittings with a nominal diameter of ¾”, using 90° elbows, tees, and couplings of the same standard, which allows for efficient fitting and the creation of joints/connections, ensuring watertightness and reducing the risk of leaks over time. The standardization of the fittings also facilitated system maintenance by reducing the complexity of any replacements.

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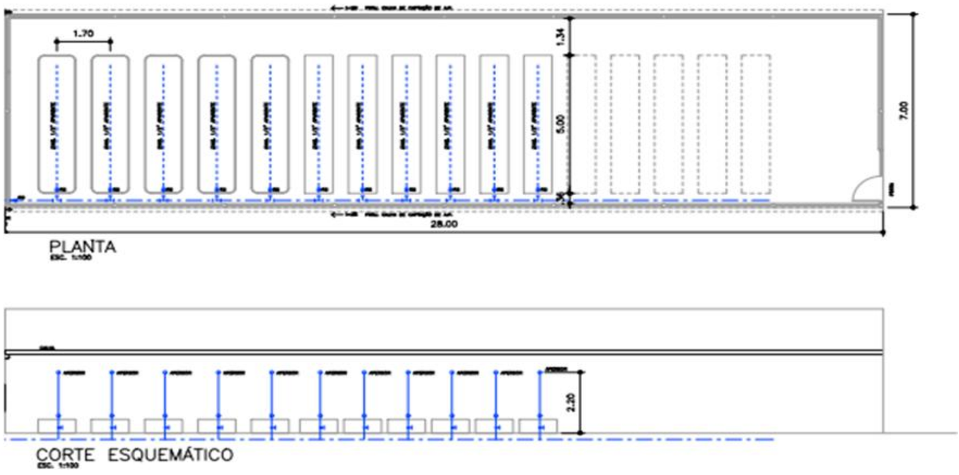
Figure 2. Project - floor plan for the installation of gutters for rainwater collection in Horta das Flores.



Source: Authors, 2025.

The irrigation system was designed around a 500-liter reservoir for rainwater storage, as well as a tank to serve as a water reserve compartment. Distribution occurs through ¾" pipes and hoses, sized to serve a 100-meter linear garden on flat terrain, equipped with 22 sprinklers. To ensure adequate pressure and flow, a hydraulic pump was specified (nominal pressure of 30 m.w.c. and nominal flow of 66 L/min), installed in a waterproof plastic box for protection against the elements and easy access for maintenance. This technical design is aligned with the recommendations of Li et al. (2020) and Amos et al. (2021), who emphasize the role of RHS (Rainwater Harvesting Systems) in increasing water use efficiency and urban water security.

The choice of reservoir capacity was made based on the availability of physical space for installation, since no adaptation or structural expansion works were planned. Thus, a reservoir compatible with the usable area was chosen, even without adopting more in-depth calculations based on the region's average rainfall. The decision prioritized the immediate applicability of the solution in the field, respecting the logistical limitations of the site. The storage system was integrated into an automated irrigation network, consisting of 22 sprinklers, strategically distributed to cover a total area of approximately 60m2. The distribution network included a small hydraulic pump, whose installation was essential to ensure the flow and pressure required for the full operation of the emitters, meeting the technical specifications of the sprinklers used.

The hydraulic line was complemented with a gate valve, check valve, and pressure regulating valve with a pressure gauge, ensuring operational control, system safety, and preventive maintenance. The operation is automated by means of a programmable timer, which controls the activation of the pump at predefined times, ensuring efficiency in water use and homogeneity in irrigation. Figure 3 shows the hydraulic design for irrigation.

Irrigation was automated using a low-cost, battery-powered timer, whose main advantage is the elimination of the need for an electrical connection, in addition to allowing simple and efficient programming of irrigation cycles. The equipment used comes from the factory with functionalities that allow the definition of schedules and frequencies, eliminating the need for additional programming or integration with complex control systems.

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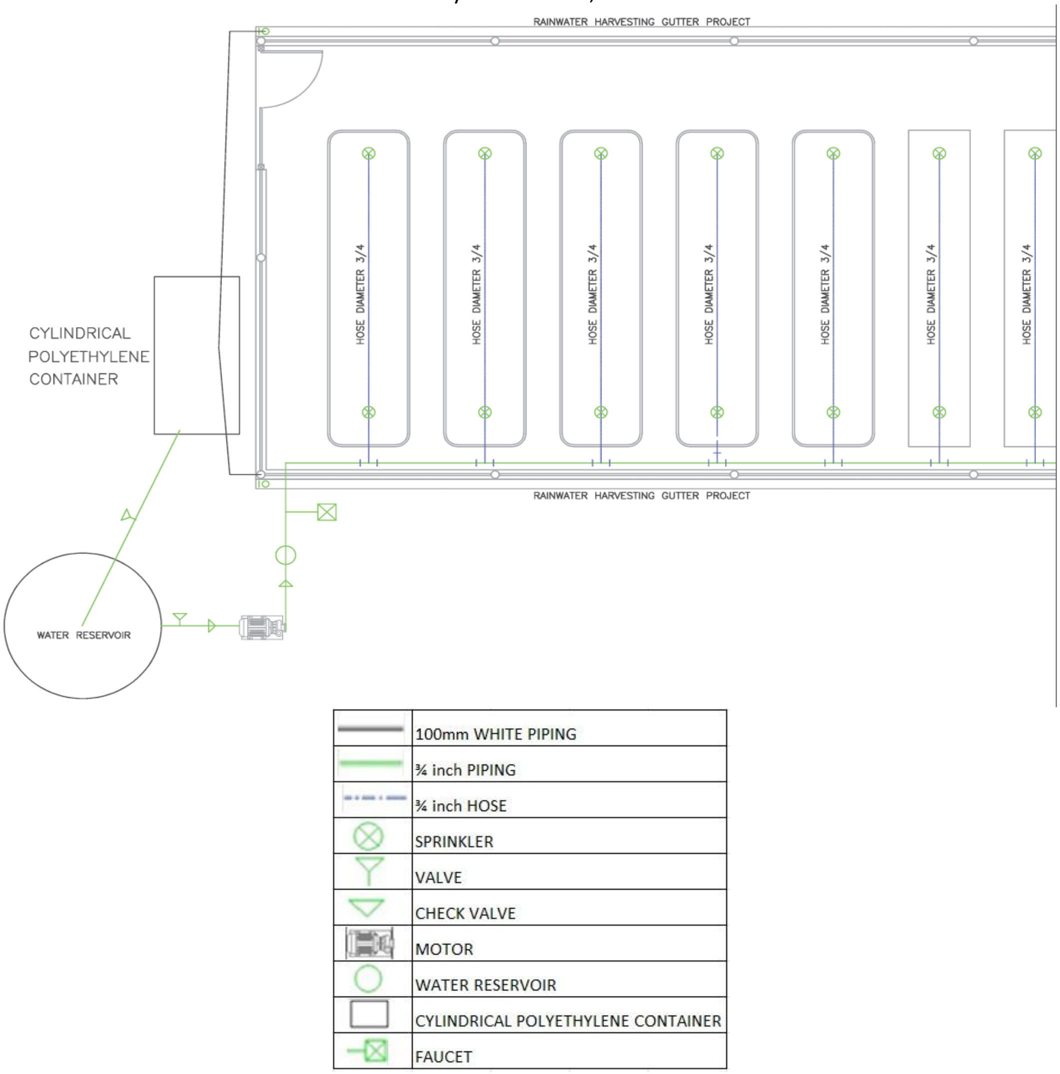
Figure 3. Hydraulic design for irrigation of edible plant beds for the Horta das Flores, Mooca neighborhood in the city of São Paulo, SP.



Source: Authors, 2025.

Regarding the economic viability of the project, an approximate cost of R$8,000.00 was initially estimated for the acquisition of the necessary materials, considering a prior budget based on market values and online purchases. However, during field execution, the need for adjustments was observed, mainly due to the incompatibility of connections acquired specifically with the pipes actually used, which generated the need for new purchases. In addition, the inclusion of the hydraulic pump, which proved indispensable for the proper performance of the system. These factors led to an increase of approximately R$1,500.00, raising the total cost of materials to around R$9,500.00.

Considering also the costs of specialized labor for the assembly and execution of the system, which was R$2,500.00, the total value of the implemented project was R$12,000.00. The costs remained within a viable budget for small-scale sustainable proposals. The final result demonstrated that the project presents technical and functional viability of the system, in addition to its relevance as a replicable alternative in urban contexts, with strong potential to contribute to sustainable urban agriculture practices and savings in potable water consumption.

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This strategy follows the low-cost and replicability approaches advocated by Thwaites et al. (2025), when proposing the integration between green infrastructure and urban agriculture as central elements of local sustainability.

4.3 Project implementation in the community garden.

The development of the implementation was structured in successive stages, according to the initial schedule of two working days, intended for the installation of gutters and pipes and the definition of the positioning of the water tanks (Figure 4A). During this preliminary phase, the executing engineer, together with the designers and creators, checked the material and verified the need to acquire additional materials, such as pipe connections, an electric float for pump protection, and compatible rainwater pipes, which had not been foreseen in the initial list. This finding reflects a recurring characteristic of experimental sustainable projects, in which adjustments occur due to the availability of local inputs, a condition highlighted by Ali et al. (2025) as one of the challenges to the implementation of rainwater harvesting systems.

The execution phase began with the organization and checking of all materials, previously mapped in the planning stage. This initial verification was essential to ensure the conformity of the inputs with the established technical specifications, preventing delays and inadequacies during installation. Subsequently, the field team began installing the collection gutters on the greenhouse roof, marking the start of the practical implementation of the rainwater harvesting system (Figure 4A). In parallel, with the support of the engineers responsible for the project and the technical executor, the assembly of the hydraulic system began, including the positioning of the pipes, the layout of the hydraulic system, and the alignment with the community garden beds.

During the execution, adjustments not foreseen in the original project were identified as necessary. One of the main challenges was adapting the gutter supports, since the greenhouse structure did not have adequate rigid covering for fixing. As a solution, the supports were fixed using metal strips and galvanized screws, ensuring adequate stability and mechanical resistance, according to the recommendations of Campisano et al. (2017), who highlight the importance of secure and oxidation-resistant fixing solutions in systems exposed to weather conditions.

During the assembly stages, incompatibilities between hydraulic components were also identified, requiring the acquisition of complementary materials, such as: an additional pressure gauge, installed next to the pump to control the operating pressure; additional connections and pipes (approximately 100 meters), necessary for the interconnection between the collectors and the reservoir (Figure 4B); adaptations to the sprinkler connections, whose acquired models did not have compatible technical specifications; and the inclusion of an electric safety float switch, intended to protect the pump against dry running (Figure 4D).

These adjustments were incorporated during execution, with continuous technical monitoring by the engineering team, which ensured the functionality and efficiency of the implemented system. After mapping the new demands, a meeting was held with the course coordinator to present the needs identified in the field. With the approval and release of

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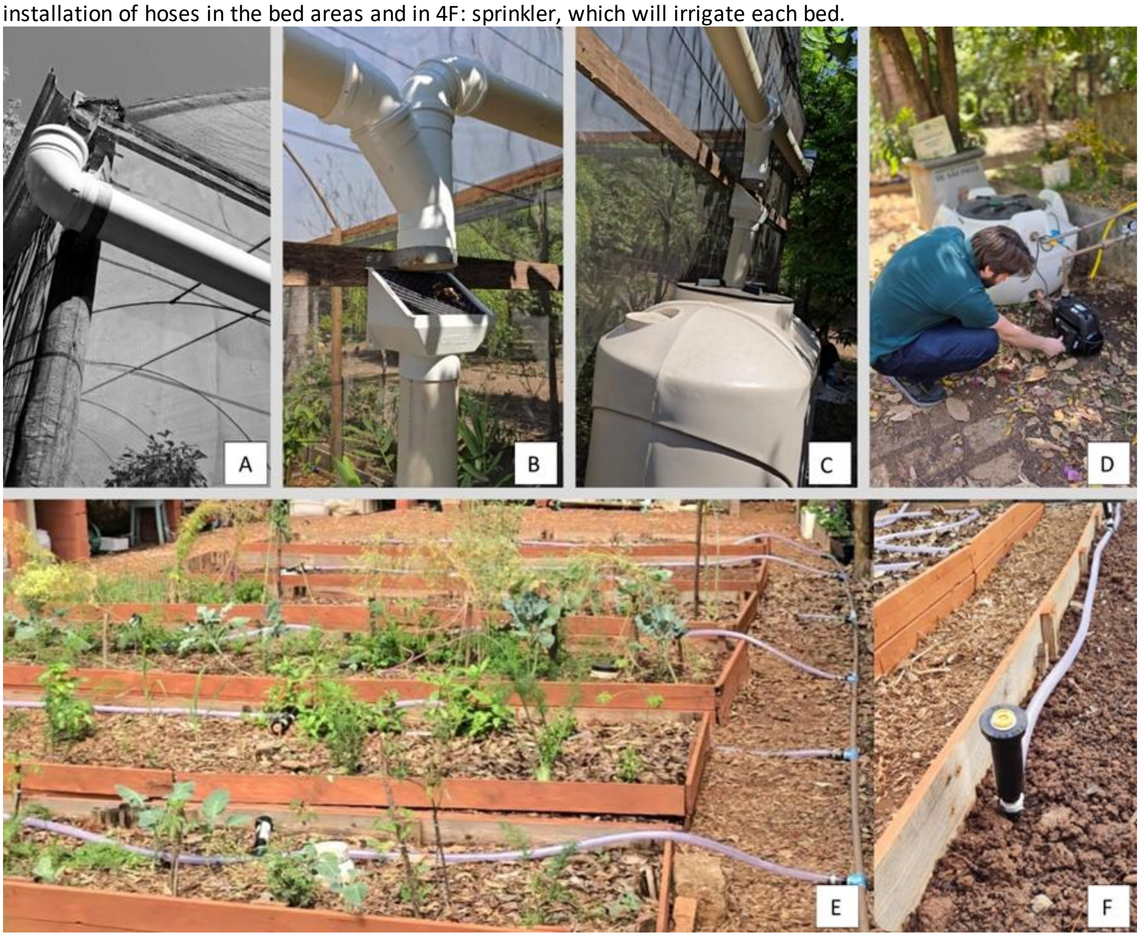
additional resources, it was possible to make the new acquisitions and continue with the final stage of the installation.

The following week, the team returned to the site to finalize the implementation of the complete hydraulic system, consisting of the main reservoir, hydraulic pump, suction and discharge connections, interconnecting hoses (Figure 4E) between the pump and the sprinklers (Figure 4F), and the electrical drive components. After the installation of all elements, operational and calibration tests of the system were carried out.

Figure 4. Images demonstrate the execution of the rainwater harvesting project at Horta das Flores for irrigating PANC (non-conventional food plants) beds. In 4A: gutter installation; 4B: junction of pipes from the side gutters of the greenhouse; 4C: collection reservoir; 4D: reservoir that will distribute water to the 10 beds and the pump; 4E: installation of hoses in the bed areas and in 4F: sprinkler, which will irrigate each bed.



Source: Authors, 2025.

As the execution period coincided with days of drought, the operational tests were carried out with water from the public network, used to simulate the supply of the reservoirs. The use of this experimental method made it possible to verify the performance of the system under controlled conditions, allowing the evaluation of pressure, flow rate and irrigation uniformity.

The images recorded during this stage illustrate the completed hydraulic installations at Horta das Flores, highlighting the strategic positioning of the gutters, reservoirs, and pipes, as well as the technical standard of the assembly, as shown in Figure 4. The implementation

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process, conducted with technical supervision and a formative character, reinforces the integration between teaching, research, and outreach, consolidating the project as an experience in engineering applied to urban sustainability.

Replacing the 80 mm rainwater pipe with 100 mm pipe, considered standard in civil works, ensured greater compatibility between connections, reduced localized head losses, and ease of maintenance. This decision is in line with the good practices of hydraulic performance and durability described by Campisano et al. (2017), who emphasize the importance of using standardized and corrosion-resistant materials in exposed systems.

On the first day of execution, the material check and the installation of the collection gutters were completed. However, the need for adjustments and the acquisition of new components required extending the schedule by two additional days to ensure the completion of the hydraulic assembly. This rescheduling demonstrates that applied projects, in which execution feeds back into the design process, are an essential dynamic in experimental and community contexts, as indicated by De Moraes and Rocha (2013) in their study on the adaptation of rainwater harvesting technologies in the Brazilian semi-arid region.

After the arrival of the new items, the team proceeded with connecting the pipes, configuring the pump, and installing the associated electrical system. Operational tests revealed insufficient flow in the more distant sprinklers, compromising irrigation uniformity and therefore the system's efficiency. The problem was attributed to the use of ¾" pipes, which increased the unit head loss, aggravated by the linear length of the network fed at only one end. This configuration resulted in significant differential pressures, effectively irrigating only 7 of the 10 plots.

These results find technical support in the literature. Campisano et al. (2017) point out that unidirectional feeding and undersized pipe diameters are critical factors that reduce the efficiency of RWH systems, especially when used under pressure. Classic alternatives, such as increasing pipe diameter, increasing pump power, and repositioning the feed point to the center of the system, were discussed by the team, with the aim of reducing total head losses. These solutions are in line with recommendations from Gaitán and Teixeira (2020), who indicate that localized hydraulic improvements, even if they involve additional costs, can result in substantial gains in performance and operational efficiency.

The proposal to reposition the reservoir to the center of the greenhouse was discarded due to the high internal temperatures, which could raise the temperature of the stored water, compromising the microbiological quality and thermal balance of the plants. This precaution is consistent with the concerns highlighted by Campisano et al. (2017) and Ali et al. (2025) regarding the degradation of water quality in catchment systems exposed to excessive heat or long periods of stagnation.

Due to thermal infeasibility and the costs associated with the complete replacement of the network, it was decided to replace the existing pump (38 m.w.c.) with a more powerful one (55 m.w.c.), maintaining the original layout of the pipes. However, this alternative also proved to be economically disadvantageous, given the cumulative increase in project costs during execution. This type of budgetary constraint is frequent in community water infrastructure projects, in which the balance between cost and performance must be constantly

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reassessed — a limitation also pointed out by Li et al. (2020) when discussing water scarcity in megacities and the need for low-cost, high-efficiency solutions.

During subsequent tests, it was found that the timer installed in-line reduced the pressure available to the sprinklers, preventing complete irrigation of the area. Removing the timer allowed for uniform water distribution across all plots, albeit at the cost of automation, which is one of the pillars of the project. This limitation highlights the importance of low hydraulic loss automation components, a guideline also highlighted by Ali et al. (2025) in the search for simplified and efficient technological solutions.

The final scenario achieved included the complete irrigation of the flowerbeds with the 38 m.c.a. pump, still without the restoration of automation. The next steps involve tests with external timers and hydraulic bypass, to enable automation without compromising system pressure. This experimental phase reinforces the need for empirical verification in the field, as highlighted by Amos et al. (2021), to validate irrigation models and identify efficiency conditions in different urban configurations.

To ensure the operational sustainability of the system, it is recommended to adopt preventive maintenance routines, including periodic cleaning of the gutters, inspection of the hydraulic system and the possibility of replenishing the reservoir from the public network during periods of drought. These measures are consistent with the good practices indicated by Gaitán and Teixeira (2020), who demonstrate that continuous maintenance is essential to preserve water efficiency and reservoir performance. Furthermore, educational practices of community monitoring and participatory management, as observed by De Moraes and Rocha (2013), can strengthen the link between the implemented system and the users, ensuring technical and social longevity to the project.

In summary, the execution of the project showed that the interaction between engineering, education and community is the main factor for the success of sustainable technologies in urban contexts. The practical-academic integration allowed technical adjustments to be discussed in the field, collaboratively, consolidating the system as a low-cost, replicable and pedagogically relevant prototype for cities seeking water and environmental resilience.

4.4 Project contributions to the SDGs

The implementation of urban gardens associated with rainwater harvesting systems directly aligns with the SDGs, promoting solutions that integrate environmental, social, and economic aspects. This type of initiative contributes to SDG 2 (Zero Hunger and Sustainable Agriculture), by encouraging the local production of fresh and healthy food, and to SDG 11 (Sustainable Cities and Communities), by improving urban spaces and strengthening community resilience practices.

The use of rainwater, through collection and storage technologies, is aligned with SDG 6 (Clean Water and Sanitation), as it encourages the rational use of water resources and reduces pressure on conventional supply systems. In addition, the integration between urban gardens and sustainable water management reinforces SDG 12 (Responsible Consumption and Production), by encouraging curricular practices based on efficiency and waste reduction.

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In this context, projects that combine food production and rainwater harvesting represent not only technical solutions, but also tools for socio-environmental education, raising awareness in urban communities about the importance of sustainability and contributing to the consolidation of the 2030 Agenda. Table 1 represents the thematic areas and SDGs linked to this project.

Literature recognizes urban agriculture as a vector for SDG 2 (Zero Hunger), SDG 11 (Sustainable Cities and Communities), and SDG 12 (Responsible Consumption and Production), strengthening local food systems, ecosystem services, and resilience (Thwaite et al., 2025). In São Paulo, urban gardens also contribute to sustainable drainage and environmental awareness (Souza et al., 2022). The incorporation of unconventional food plants (PANC) expands ecological and educational benefits, adhering to SDGs 2 and 15 (Rocha Silva et al., 2023).

Table 1. Contributions of the rainwater harvesting project in an urban garden, connecting to the SDGs.

Thematic axis	**Description**	**Related SDGs**
Integration between sustainable technologies and educational practices	It highlights the connection between rainwater harvesting systems and school gardens, promoting environmental education and citizenship.	SDG 4: Quality education; SDG 6: Clean water and sanitation.
Urban gardens and spaces as socio-environmental and multifunctional spaces.	Urban gardens are presented as places of inclusion, learning, food security, and environmental stewardship.	SDG 2: Zero hunger and sustainable agriculture; SDG 3: Good health and well-being; SDG 11: Sustainable cities and communities.
Urban social resilience	The integration of gardens and rainwater harvesting contributes to adaptation to urban climate change, as a nature-based solution.	SDG 13: Climate Action.
Systematization of replicable practices and models.	It proposes theoretical and practical guidelines for public policies and projects that can be replicated in schools and diverse urban contexts.	SDGs 4, 11 and 17: related to urban sustainability and education.
Interdisciplinary fields in applied sustainability	It reinforces the need to integrate engineering, education, ecology, and urban planning in sustainable approaches.	Interdisciplinary: SDGs 4, 6, 11, 13 and transversally to the others.

Source: Authors, 2025.

From the perspective of water management, local-scale harvesting and reuse support SDG 6 (Clean Water and Sanitation) and SDG 13 (Climate Action) by reducing pressure on conventional systems, increasing resilience to droughts, and raising awareness of rational use (Li et al., 2020; Medeiros et al., 2024). Finally, the most recent literature reinforces that the widespread adoption of RWH requires institutional support and social acceptance, dimensions that this project addresses through education, participation, and technological demonstration (Ali et al., 2025; Amos et al., 2021).

5. FINAL CONSIDERATIONS

The study demonstrated the technical feasibility and social relevance of rainwater harvesting and irrigation automation in a community garden under an impermeable roof, reducing the need for human resources. The educational nature of the space broadened the social impact, connecting the community and the university, as well as the SDGs. For the next stage, hydraulic and automation optimization, performance monitoring, and rainfall assessments are recommended, with monitoring of the rainfall regime.

The implementation of the rainwater harvesting and automated irrigation system presented some challenges that deserve highlighting. Among them, the need for prior structural assessment of the building for the installation of metal gutters stands out, ensuring the safety and durability of the system. Another relevant aspect refers to the protection of hydraulic and electrical equipment against inclement weather, which required the use of waterproof plastic boxes and additional preventive maintenance measures.

The proposed structure utilized the garden's translucent and waterproof roof as a catchment area, directing rainwater through galvanized gutters to a 500-liter reservoir, feeding an irrigation system with 22 sprinklers, operated by programmable automation. The solution allows for water conservation, optimizes garden maintenance, and reduces the need for manual operation, with an estimated investment of R$12,000.00, including materials and labor. In addition to its technical functionality, the results reinforce the importance of urban gardens as multifunctional spaces that promote health, education, food security, and social engagement. The execution of this project contributed to the SDGs, especially SDGs 2 (zero hunger), 3 (good health and well-being), 4 (quality education), 6 (clean water and sanitation), and 11 (sustainable cities and communities).

For future studies, it is recommended to monitor the local rainfall regime throughout the coming seasons in order to correlate the efficiency of the rainwater harvesting system with the variability of rainfall in the region. Adjustment and automation of the irrigation system, still in the calibration phase, are also necessary to optimize the use of stored water. Finally, the potential for replicating the system in other urban spaces, such as schools and community gardens, is highlighted, adapting the sizing according to the available area and local water demand. This perspective broadens the scope of the proposal, consolidating it as a sustainable practice with a strong contribution to the SDGs. The study offers theoretical and practical support for future initiatives aimed at integrating technology and innovation with sustainable practices.

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DECLARATIONS

CONTRIBUTION OF EACH AUTHOR

When describing each author's contribution to the manuscript, use the following criteria:

- **Conception and design of the study**: Ana Paula Branco do Nascimento and Thais Reis Rocha
- **Data curation**: Ramoel Serafini and Ana Paula Branco do Nascimento
- **Metodology**: Thais Reis Rocha and Rafael Silva de Araújo
- **Formal analysis**: Ana Paula Branco do Nascimento
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- **Review and final editing**: Ramoel Serafini and Ana Paula Branco do Nascimento
- **Supervision**: Ramoel Serafini
- **Acquisition of financing**: *Programa de Mestrado Profissional em Engenharia Civil da Universidade São Judas Tadeu.*

DECLARATION OF CONFLICTS OF INTEREST

We, **Ana Paula Branco do Nascimento,** , **Rafael Silva de Araújo, Thais Reis Rocha** and, **Ramoel Serafini**, declare that the manuscript entitled "**Engineering applied to Urban Sustainability: rainwater harvesting and irrigation automation in a community garden**":

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