Application of Modular Vertical Gardening Racks to Improve Vegetable Cultivation Skills among Urban Communities

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Abstract

Limited household land is one of the main constraints on vegetable cultivation in densely populated urban areas. This community service program aimed to introduce modular vertical gardening racks and improve the knowledge and practical skills of urban communities in cultivating short-cycle leafy vegetables. The program was conducted with residents of RT 007/RW 01, Bandulan, Sukun District, Malang City, in February 2026 and involved 30 participants. The activities consisted of a partner needs assessment, participatory rack fabrication, training in plant biology and cultivation techniques, installation, and four weeks of mentoring. The racks were designed using hollow-steel frames with bolted joints, three planting levels, and removable planting containers, allowing them to be easily assembled, relocated, maintained, and expanded according to the available space. Program outcomes were evaluated using pretest and posttest questionnaires, skill observation sheets, participant response questionnaires, and plant growth monitoring. The program produced eight modular vertical gardening racks equipped with 72 planting containers. The participants' mean knowledge score increased from 56.3 on the pretest to 84.7 on the posttest. Furthermore, 86.7% of the participants achieved the competent category in rack assembly and vegetable cultivation. At the end of the monitoring period, the plant survival rate reached 93.1%, supported by appropriate growing-medium preparation, watering practices, and light management. The program demonstrates that an interdisciplinary approach integrating manufacturing engineering and plant biology can provide practical, affordable, and replicable urban agriculture technology. Continuous mentoring and evaluation over several planting cycles are recommended to strengthen community independence and ensure program sustainability.

1. Introduction

Rapid urbanization reduces the availability of open land while increasing the need for accessible, fresh, and nutritious food. Urban agriculture has therefore developed as a strategy that combines household food production, environmental learning, social interaction, and the utilization of underused urban spaces (Wadumestrige Dona et al., 2021). A global synthesis shows that urban agriculture provides educational, ecological, social, economic, and health-related benefits. However, its implementation is often constrained by limited land availability, inadequate technical knowledge, insufficient initial facilities, and inconsistent maintenance (Wadumestrige Dona et al., 2021).

Evidence from various cities indicates that small-scale household gardens and community gardens can improve access to fresh vegetables and strengthen local food systems (Abdoellah et al., 2020; Ayerakwa et al., 2020; Modibedi et al., 2021; Payen et al., 2022). Urban gardening activities are also relevant as community learning spaces because participants acquire knowledge through direct practice, observation, and repeated plant maintenance. Community gardening interventions have been associated with increased environmental awareness and more sustainable lifestyle practices. Nevertheless, their long-term outcomes depend on community participation, access to appropriate facilities, and continuous mentoring (Milestad et al., 2020; Tharrey et al., 2020).

These conditions are also found in RT 007/RW 01, Bandulan Urban Village, Sukun District, Malang City. The area is characterized by relatively dense residential development, while the available household

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yards are generally narrow, paved, or used for other domestic activities. Such conditions make conventional horizontal cultivation difficult to implement because vegetable cultivation requires sufficient planting space, sunlight exposure, drainage, and accessibility for routine maintenance. Vertical gardening offers an alternative approach by arranging planting containers at several levels, thereby increasing the effective growing area without requiring a large ground footprint. Studies on vertical and building-integrated gardening have demonstrated the potential use of corridors, walls, rooftops, and compact structures for supplementary vegetable production (Dominici et al., 2022; Ogut et al., 2022; Shao et al., 2022; Song et al., 2022a, 2022b). However, the technology introduced to urban communities must remain affordable, easy to assemble, structurally stable, safe to use, and compatible with the residents' maintenance capacity.

The effectiveness of a vertical gardening program is not determined solely by the physical structure of the rack. Plant survival and growth are influenced by plant species, root-zone volume, growing media composition, sunlight exposure, drainage, watering frequency, nutrient availability, and pest management. Short-cycle leafy vegetables are appropriate for introductory community programs because their growth and development can be observed within a relatively short period. Locally familiar and underutilized edible species may also broaden household use and biodiversity benefits (da Cunha et al., 2020). Therefore, the cultivation component must be integrated with basic plant biology so that participants understand the relationships among roots, water, nutrients, leaves, light, and overall plant growth.

Based on the initial needs assessment, the residents of RT 007/RW 01, Bandulan Urban Village, experienced three main problems. First, the limited household space restricted opportunities for conventional vegetable cultivation. Second, residents had limited experience in designing and constructing stable planting racks suitable for narrow urban spaces. Third, their knowledge and skills related to seedling preparation, growing-media composition, transplanting, watering, and plant maintenance were inconsistent. Previous gardening activities in the area generally focused on distributing plants or planting containers without providing an integrated cultivation system and structured mentoring. Consequently, the community required an appropriate technology that could be fabricated locally, maintained easily, and operated independently.

This community service program integrated manufacturing engineering and plant biology. The manufacturing engineering component included needs-based design, material selection, measurement, cutting, joining, assembly, structural safety, corrosion protection, and rack maintainability. The plant biology component included vegetable selection, seed germination, growing-media preparation, transplanting, watering, light management, pest observation, and plant growth evaluation. The integration of these disciplines was expected to reduce the gap between providing a physical product and developing the knowledge and practical competence required by the community to operate and maintain the technology.

The objective of this community service program was to implement modular vertical gardening racks and improve the knowledge and practical skills of residents of RT 007/RW 01, Bandulan Urban Village, Sukun District, Malang City, in cultivating leafy vegetables on limited household land. The program outcomes were evaluated based on rack production and functionality, changes in participants' knowledge, observed practical competence, participant responses, and early plant growth performance.

2. Method

2.1. Partner and Program Setting

The program was implemented with an urban community group in RT 007/RW 01, Bandulan Urban Village, Sukun District, Malang City, East Java Province, in February 2026. The target participants consisted of 30 adult residents representing households with limited yard space. Participant selection was coordinated with the neighborhood community leader and prioritized residents who were willing to attend the entire training program, provide a small area with adequate sunlight exposure, and participate in routine plant maintenance.

Before the program was implemented, the community service team conducted field observations and semi-structured discussions with community representatives and prospective participants. These preliminary activities aimed to identify the availability and characteristics of planting spaces, preferred vegetable species, existing tools and materials, access to water, sunlight conditions, and participants' previous experience in vegetable cultivation. The results of the needs assessment were used as the basis for determining the rack dimensions, selecting suitable planting containers and vegetables, preparing the training materials, and designing the mentoring activities.

2.2. Program Design and Implementation Stages

The program used a participatory community empowerment approach. Participants were involved not only as recipients but also in the assembly, installation, planting, and maintenance process. The implementation consisted of five stages: needs assessment, technical preparation, training and demonstration, assisted practice, and monitoring-evaluation. Table 1 presents the activities and success indicators used in the program.

Table 1. Program stages, activities, and indicators

Stage	Main activities	Output/indicator
Needs assessment	Observation, partner discussion, mapping of space and resources	Partner problems, participant profile, and installation site identified
Technical preparation	Rack design, material procurement, cutting, drilling, trial assembly, and surface protection	Rack components fit properly and can be safely assembled
Training and demonstration	Introduction to vertical gardening, rack safety, plant biology, media preparation, and cultivation procedure	Participants understand the system and can explain key maintenance steps
Assisted practice	Rack assembly, container arrangement, seeding/transplanting, watering, and labeling	Participants demonstrate assembly and cultivation skills
Monitoring and evaluation	Pretest-posttest, skill observation, participant response, and four-week plant monitoring	Knowledge improvement, competent practice, functional racks, and plant survival

2.3. Modular Rack Design and Fabrication

The rack was designed as a three-level modular structure with an overall dimension of approximately 1500 mm in height, 1000 mm in width, and 450 mm in depth. The main frame used 20 × 20 × 1.2 mm hollow steel. Bolted connections were selected at the principal joints to allow disassembly, transportation, component replacement, and future expansion. Each level accommodated four removable planting containers, giving a total of twelve containers per rack. The lower frame was made wider than the upper planting zone, and diagonal bracing was provided to improve stability. Sharp edges were ground, exposed surfaces were coated with anti-rust paint, and the rack was installed on a flat surface away from vehicle and child circulation paths.

Fabrication involved measuring and marking, cutting frame members, drilling bolt holes, preparing braces and supports, trial assembly, dimensional inspection, deburring, and surface coating. The mechanical engineering team supervised tool safety and dimensional accuracy, while participants were introduced to basic manufacturing concepts, including material efficiency, interchangeability of components, load distribution, ease of maintenance, and safe operation. The rack was considered technically acceptable when it stood without visible rocking, all fasteners could be tightened, containers were securely supported, and water drainage did not accumulate on the frame.

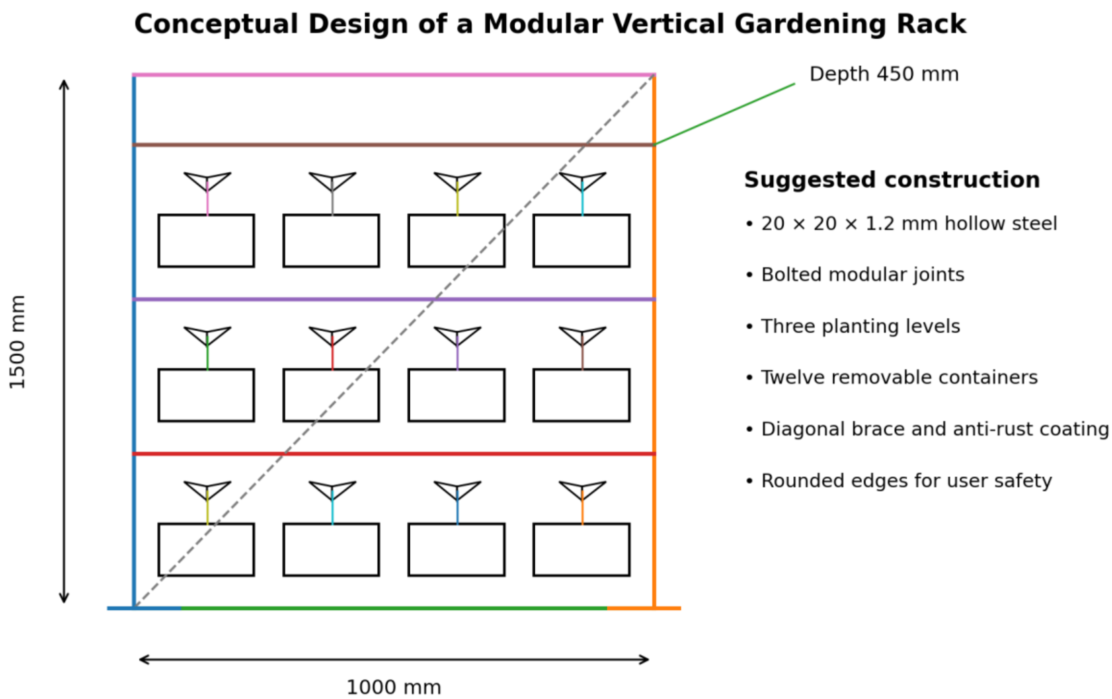

Figure 1. Conceptual design and suggested specifications of the modular vertical gardening rack

2.4. Vegetable Cultivation Training

The biological training emphasized the functions of roots, stems, and leaves; the role of water and mineral nutrients; the requirement for light in photosynthesis; and visible symptoms of water stress, nutrient deficiency, and pest damage. The selected crops were pak choi (*Brassica rapa subsp. chinensis*) and mustard greens (*Brassica juncea*) because they are familiar to households, have relatively short cultivation cycles, and can be grown in containers. Seeds were germinated in small trays for approximately 7-10 days and transplanted after producing two to three true leaves.

The growing medium consisted of topsoil, mature compost, and cocopeat at a volume ratio of 1:1:1. Containers were provided with drainage holes and arranged so that upper-level drainage did not directly damage the plants below. Participants practiced transplanting without damaging the roots, maintaining one healthy seedling per planting point, watering according to media moisture, rotating containers when light distribution was uneven, removing weeds, and inspecting leaves for pests. Monitoring was conducted once each week for four weeks using plant survival, plant height, and number of leaves as simple indicators.

2.5. Evaluation and Data Analysis

Evaluation covered four aspects. First, participant knowledge was assessed using a structured questionnaire administered before and after training. Second, practical competence was observed using a checklist covering rack assembly, growing-media preparation, transplanting, watering, and maintenance. Third, participant responses were collected using a five-point Likert-scale questionnaire. Fourth, plant growth was monitored weekly for four weeks. Knowledge scores were summarized using mean values and percentage improvement, calculated as ((posttest score - pretest score) / pretest score) × 100%. Practical competence, attendance, and plant survival were expressed as percentages, whereas plant height and leaf number were analyzed descriptively. Participants were categorized as competent when they completed at least 75% of the observed practical steps correctly.

3. Result and Discussion

3.1. Rack Production, Installation, and Functionality

The program produced eight modular vertical gardening racks with a total of 72 planting containers. Each rack was assembled in approximately 45 minutes by a small group of four participants under the supervision of the community service team. The bolted connection system enabled the rack components to be transported separately and assembled at the installation site using basic hand tools, including spanners, screwdrivers, and measuring devices. After installation, 87.5% of the racks, equivalent to seven of the eight units, met the predetermined functionality criteria without requiring additional structural correction. One rack required minor adjustments consisting of bolt retightening and frame leveling to improve its stability on an uneven surface.

The modular concept was appropriate for the partner community because residents had different amounts of available space and required structures that could be relocated or rearranged according to household conditions. Low-cost and do-it-yourself vertical greening systems are generally more accessible when their designs minimize the use of specialized components and encourage direct community participation (Dominici et al., 2022). Public intention to adopt micro-vertical farming is also influenced by perceived usefulness, ease of use, self-efficacy, and the availability of facilitating conditions (Shao et al., 2022). During the program, participants were directly involved in tightening fasteners, positioning planting containers, checking frame alignment, and evaluating structural stability. This practical involvement helped transform the rack from an unfamiliar technological product into a cultivation system that participants understood and were able to operate and maintain independently.

From a manufacturing perspective, the main practical advantages of the rack included component interchangeability, ease of assembly and repair, and reduced dependence on permanent welding at the partner site. Damaged or corroded components could be replaced individually without dismantling or reconstructing the entire structure. Nevertheless, bolted joints require periodic inspection because repeated relocation, vibration, uneven loading, and exposure to outdoor conditions may cause the fasteners to loosen. Therefore, the community maintenance checklist included monthly bolt inspections, observation of corrosion, cleaning of accumulated water and soil deposits, checking of frame alignment, and prevention of excessive or uneven loading. These maintenance procedures are important because the sustainability and safety of vertical greening structures depend not only on the initial design but also on consistent long-term inspection and maintenance (Dominici et al., 2022; Ogut et al., 2022).

3.2. Improvement in Participant Knowledge and Practical Skills

The knowledge and skill evaluation is summarized in Table 2. The participants' mean knowledge score increased from 56.3 before the training to 84.7 after the training, representing an improvement of 50.4%. The greatest improvement was observed in the topics of growing-media preparation and modular rack assembly, while the lowest improvement was recorded in pest identification and nutrient management, indicating the need for further mentoring in these areas. Practical observations showed that 86.7% of the participants, equivalent to 26 of the 30 participants, achieved the competent category in rack assembly and vegetable cultivation. The remaining 13.3%, equivalent to four participants, required additional guidance, particularly in seedling transplanting, watering adjustment, and early pest identification.

Table 2. Participant knowledge and practical competence

Evaluation indicator	Before activity	After activity	Change/achievement
Knowledge of vertical gardening	55.0	84.0	52.7% improvement
Knowledge of rack safety and maintenance	59.0	80.0	35.6% improvement
Knowledge of media, light, and watering	54.9	90.1	64.1% improvement
Ability to assemble rack components	Not assessed	86.7% competent	Practical achievement
Ability to prepare media and transplant seedlings	Not assessed	83.3% competent	Practical achievement

The combination of explanation, demonstration, and assisted practice was important because the program required participants to understand two related systems: the manufactured structure and the living plant. A rack that is technically stable will not generate vegetables when media, water, light, and plant health are poorly managed. Conversely, cultivation knowledge cannot be applied efficiently when containers are unstable or difficult to access. This finding supports the use of interdisciplinary community service rather than separate delivery of tools and agricultural information.

Community gardening research indicates that repeated participation and access to facilities can contribute to environmental awareness and sustainable practices (Milestad et al., 2020; Tharrey et al., 2020). In this activity, the posttest measured immediate learning; therefore, it should not be interpreted as proof of long-term behavior change. A follow-up evaluation after at least two planting cycles is needed to determine whether participants continue to use the rack, independently replace seedlings, manage pests, and share knowledge with other households.

3.3. Early Plant Growth and Maintenance

At the end of the four-week monitoring period, plant survival reached 94.4% for pak choi and 91.7% for mustard greens. These percentages were equivalent to 34 surviving pak choi plants and 33 surviving mustard green plants from 36 seedlings of each species, resulting in an overall survival rate of 93.1%. The mean plant height and number of leaves increased each week, as shown in Table 3. Plant losses were primarily associated with transplant shock during the first week and excessive moisture caused by inconsistent drainage in several planting containers. Uneven growth between rack levels was observed on the lower level of racks positioned close to residential walls, where the plants received less sunlight than those on the middle and upper levels. This finding indicates that periodic container rotation and adjustment of rack orientation are necessary when nearby buildings or walls produce partial shade.

Table 3. Four-week monitoring of pak choi and mustard greens

Indicator	Week 1	Week 2	Week 3	Week 4
Pak choi survival (%)	100.0	97.2	94.4	94.4
Pak choi height (cm)	5.8	9.6	14.2	19.1
Pak choi leaves (number)	3.8	5.6	7.4	9.1
Mustard green survival (%)	100.0	97.2	94.4	91.7
Mustard green height (cm)	6.2	10.8	16.5	22.7
Mustard green leaves (number)	4.0	5.9	7.8	9.7

The early growth results must be interpreted together with micro-site conditions. Vertical arrangements increase the use of limited space but can create differences in light exposure, airflow, and water distribution among levels. Experimental and modeling studies show that vertical and building-integrated gardening can contribute meaningful vegetable production when crop selection and sunlight availability are considered (Song et al., 2022a, 2022b). Urban agriculture productivity and environmental performance vary considerably according to growing system, crop, management, and environmental conditions (Hu et al., 2019; Payen et al., 2022; Wang et al., 2021). Simple spatial monitoring can also help identify micro-site differences among rack locations (Egerer et al., 2020). For this reason, the rack should be treated as an adaptable platform rather than a single fixed cultivation recipe.

The use of removable containers provided a practical biological advantage because each plant unit could be rotated, replaced, or isolated when pests were detected. The 1:1:1 soil-compost-cocopeat medium was selected to provide support, organic matter, and moisture retention while maintaining drainage. Nevertheless, the composition must be adjusted to locally available materials and verified by observing media compaction and water retention. Overwatering was emphasized as a risk because limited container volume can quickly become saturated and reduce root aeration.

3.4. Participant Response and Program Sustainability

Participant attendance reached 93.3%, and the mean response score was 4.6 out of 5. The highest-rated aspect was the practicality and space efficiency of the modular vertical gardening rack, while the lowest-rated aspect was the affordability of the initial material cost. Participants reported that the rack made the cultivation area more organized and reduced the ground area occupied by planting containers. The main concerns were the initial cost of materials, the need for routine watering during hot weather, and the possibility of corrosion when the rack was continuously exposed to rain.

To support program continuity, the partner community formed a maintenance group consisting of six residents and prepared a simple rotating duty schedule. Each rack was accompanied by a maintenance card containing information on the planting date, crop species, watering notes, weekly observations, and harvest date. This step was important because the benefits of community gardening are not generated by infrastructure alone. Long-term outcomes depend on access, active participation, shared responsibility, and practical solutions to routine maintenance barriers (Milestad et al., 2020). The maintenance card also transformed daily cultivation activities into simple records that could be used for future program evaluation and decision-making.

The program had several limitations. The monitoring period covered only one early cultivation cycle, the participants were limited to one community group, and the evaluation did not compare the modular racks with conventional ground-level planting containers. Plant yield, production cost, rack durability, corrosion development, and participant adoption should therefore be evaluated over a longer period. Future implementation may also compare alternative materials, including galvanized steel, reused polymer containers, or treated wood, while maintaining structural safety, durability, and suitability for food-crop cultivation.

4. Conclusion

The community service program integrated modular vertical gardening racks with plant biology and vegetable cultivation training for an urban community with limited land. The program produced eight functional modular racks and increased the participants' mean knowledge score from 56.3 before the training to 84.7 after the training, while 86.7% of participants achieved practical competence in rack assembly and vegetable cultivation. Early monitoring showed an overall plant survival rate of 93.1% and identified light distribution, watering consistency, drainage, and bolted-joint maintenance as key operational factors.

The modular design, bolted connection system, and removable planting containers provided flexibility for narrow urban spaces and enabled participants to understand the procedures for assembly, relocation, inspection, and routine maintenance. The program demonstrates that collaboration between manufacturing engineering and biology education can produce appropriate urban agriculture technology that is practical, affordable, maintainable, and replicable. Further monitoring over at least two planting cycles is recommended to evaluate harvest yield, production costs, rack durability, corrosion resistance, independent community management, and the potential for program replication in other densely populated urban communities.

Author Contributions

Novan Habiburrahman contributed to the conceptualization, mechanical design, fabrication supervision, methodology, investigation, visualization, and writing of the original draft. Novie Ary Priyanti contributed to the conceptualization, plant cultivation methodology, community training, data collection, biological analysis, and writing of the original draft. Aulia Rahman contributed to the mechanical design, material selection, fabrication, rack assembly supervision, investigation, and technical validation. Putra Dwiantoko contributed to manufacturing process planning, fabrication supervision, structural functionality testing, investigation, visualization, and technical validation. All authors contributed to project administration, community mentoring, data validation, writing-review and editing, and approval of the final manuscript. All authors have read and approved the final manuscript.

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Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the implementation, authorship, and publication of this article.

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