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OUTDOOR LIVING WALL SYSTEMS IN A DEVELOPING ECONOMY: A PROSPECT FOR SUPPLEMENTARY URBAN FOOD PRODUCTION?

REVIEW ARTICLE[1]

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ABSTRACT

Green wall systems have greatly advanced over the past few decades and hold important potential for the future in light of predicted urban population growth, densification, and climate change. This article provides a brief background to living walls, followed by a summary of the advantages and disadvantages of the four types of systems that are currently available in South Africa. It makes use of a case study review of three recently implemented edible living walls in Gauteng to reflect on the challenges currently experienced and the future potential benefits, with specific focus on system resilience, economic feasibility, and edible plant possibilities. Interviews were conducted with clients and client representatives, contractors and/or designers on each project. The findings suggest that living walls have indirect commercial value through customer experience and satisfaction, as well as educational value. Should the scale, economic feasibility and resilience of living wall systems be enhanced, they can improve urban food production. The article concludes that this could be achieved in the Global South by using simplistic technologies with lower cost living wall infrastructure systems.

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When deployed on a large scale, with climate-tolerant indigenous and edible plants in exterior systems, productivity will be improved.

ABSTRAK

Groen muur sisteme het in die laaste paar dekades aansienlik ontwikkel, en toon potensiaal om impakte van geprojekteerde populasiegroei, verdigting en klimaatsverandering te versag. Hierdie artikel gee 'n oorsig van groen mure, gevolg deur 'n opsomming van die voor- en nadele van die vier sisteme wat tans in Suid-Afrika beskikbaar is. Drie gevallestudies van onlangs voltooide stedelike projekte met groen mure, gefokus op eetbare plante in Gauteng, word vergelyk deur oor elke projek se voordele en uitdagings te besin, met spesifieke fokus op die sisteem se veerkragtigheid, ekonomiese vatbaarheid en oorlewingsukses van eetbare plantspesies wat gebruik is. Onderhoude is met kliënte, kontrakteurs en ontwerpers van elke projek gevoer. Die bevinding is dat groen mure indirekte kommersiële waarde het, gebaseer op die gebruiker se ervaring en waardering, asook opvoedkundige waarde. Indien geïmplementeer op 'n skaal waar ekonomiese vatbaarheid en omgewingsveerkragtigheid van die sisteme verbeter kan word, kan dit geskik wees vir stedelike voedselproduksie. Die gevolgtrekking is dat verhoogde voedselproduksie in Suid-Afrika gebaseer moet wees op die gebruik van ongekompliseerde tegnologie met meer bekostigbare infrastruktuursisteme. Wanneer eetbare, lokaal-aangepaste plantspesies op 'n groot skaal in ope-lug groen mure geïmplementeer word, kan produktiwiteit verhoog word.

Sleutelwoorde: Groen mure, klimaatsverandering, lewende mure vir voedselproduksie, lewende muur sisteme, stedelike voedselproduksie

1. INTRODUCTION

Initially sought after for their unusual aesthetics, living walls have proven to provide much-needed present-day urban ecosystem services and make a perceived value contribution to biodiversity (Collins, Schaafsma & Hudson, 2017: 121). A prime contemporary research focus is the potential of living walls to improve the urban microclimate through thermal insulation (Köhler, 2008: 423; Davis, Vallejo Espinosa & Ramirez, 2019: 243) and cooling by means of evapotranspiration, wind, or sun screening (Pérez, Rincón, Vila, González & Cabeza, 2011: 4854; Cameron, Taylor & Emmett, 2014: 198; Vosloo, 2016: 47).

A second forthcoming area of interest is urban small-scale, vertical outdoor food production (Nagle, Echols & Tamminga, 2017: 22), which is increasingly serving as an extension of rural food production (Eigenbrod & Gruda, 2015: 487). In inner cities with limited, expensive, or unsafe ground space, the extent of the latent area for façade greenery is almost double the footprint of buildings, with the prospect of offering more environmental benefits than green roofs (Köhler, 2008: 426).

As the performance of outdoor living walls depends on the local climate and socio-cultural needs and values, more context-specific system reviews are required (Medl, Stangl & Florineth, 2017: 237; Felix, Santos, Barroso & Silva, 2018: 806), which are specifically aimed at cost-competitive and logistically practical food production technology (Nagle *et al.*, 2017: 24), to which this article aims to contribute.

Climate change is predicted to pose significant challenges to people's dependence on the environment because of regional economic imbalances with limited diversified economies, inequalities, and poverty (Davis-Reddy & Vincent, 2017: 1). It is predicted that Africa will experience an increase in droughts and an intensification in hot extremes, as well as more frequent and longer heat waves (Engelbrecht, Adegoke, Bopape, Naidoo, Garland, Thatcher & McGregor et al. 2015: 2; Dosio, 2017: 493). In South Africa, this must be understood in relation to the expected acceleration in urbanisation, from 66.9% in 2019 to an anticipated 79.8% in 2050 (UN/DESA/PD, 2018).

Despite initiatives such as C40 Cities (2020) to promote climate action and combat the effects of climate change, urban greening does not have a high priority in southern African cities (Du Toit, Cilliers, Dallimer, Goddard, Guenat & Cornelius, 2018: 257; Schäffler & Swilling, 2013: 246). The capital City of Tshwane's Climate Action Plan 2050 considers important outcomes that include climate-smart urban planning and design (City of Tshwane, 2015). Innovative thinking in terms of greening and cooling is required from designers and planners to mitigate the forthcoming impacts of global warming. Such ambitions could include novel approaches to living walls, which also include urban food production based on local needs.

In 2017, hunger affected a total of 6.8 million South Africans and 1.7 million households (Stats SA, 2019: 14). Drought and climate variability played a major role in yield and caused a drop in agricultural production (Stats SA, 2019: 7). Besides undernourishment, nutritional adequacy is marginal, with the lowest consumed food group comprising vitamin A-rich fruit and vegetables (Labadarios, Steyn & Nel, 2011: 1). Food systems are required that provide safe and high-quality food that is economically and environmentally more affordable. However, locally, there is limited uptake of urban agriculture, as there is no dedicated national policy to guide the spatial planning community (Cilliers, Lategan, Cilliers & Stander, 2020). Urban small-scale, vertical food production, focused on sustainability, can play a role in this regard.

This article expands on former research (Medl *et al.*, 2017: 227; Nagle *et al.*, 2017: 22), by investigating the advances and current possibilities of building integrated living wall systems (LWSs), specifically for vertical urban food production, considering the South African context. Therefore, this article has the following objectives:

1. Introduce key criteria for sustainable LWSs.
2. Review the LWSs currently available in South Africa and reflect on the local potential and challenges they offer for urban food production.

3. Provide a local overview of LWSs in terms of their outdoor use and benefits in the past decade.
4. Present three case studies to consider the local prospects for edible living walls.

2. LITERATURE REVIEW

2.1 Living wall criteria for sustainability

Locally, LWSs have mainly been used as a novel attraction with indirect economic benefit, without exploiting the cooling and insulation potential they offer. This might change in future, as the country foresees an average temperature increase of three degrees (Dosio, 2017: 493). A greater current emphasis on smart cities and the green economy could also assist with this change in mindset to explore more LWS benefits.

Smart cities provide improved quality of life, economic feasibility, sustainability and liveability for their inhabitants, accomplished through solutions to development challenges (Maček, Ovin & Starc-Peceny, 2019: 110). Despite the potential of LWSs as part of smart cities to mitigate global challenges such as food security, sustainable cities and climate change, their economic feasibility and sustainability remain questionable, due to their high inset costs and maintenance requirements (Larcher, Battisti, Bianco, Giordano, Montacchini, Serra & Tedesco, 2018: 31; Ottelé, Perini, Fraaij, Haas & Raiteri, 2011: 3419; Perini & Rosasco, 2013: 120). A comprehensive understanding of urban LWS is therefore necessary to enhance their resilience.

The term ‘resilience’ has come into common usage, due to climate change and the required climate adaptation. Resilient systems are less vulnerable and can adapt to changes while retaining their systems operation (Panagopoulus, Jankovska & Dan, 2018: 56). Resilient systems strive for a balanced relationship between natural processes and human management. Living walls need to be environmentally resilient and address specific soil, light and water requirements, which can result in a restricted planting palette to handle the intensified stresses of the urban environment. Investigating appropriate plant selection is one important way to improve LWSs’ resilience. Comprehensive research has been conducted on the effects of LWSs on microclimate. Evapotranspiration of plants in LWSs has been found to contribute to the cooling of buildings and their direct environments (Davis & Hirmer 2015: 136, Pérez-Urrestarazu, Fernández-Cañero, Franco-Salas & Egea, 2015: 65; Price, Jones & Jefferson, 2015: 1). The selection of suitable plant species for living walls has been explored in terms of the species’ contribution to environmental cooling (Cameron, Taylor & Emmett, 2014: 198). However, less research has been done to determine species' tolerance (or resilience) of the urban environmental and local climatic conditions to ensure feasibility and sustainability, or to address food security.

Sustainable urban food production has the potential to mitigate social issues such as malnutrition, poverty and health; economic challenges that place pressure on arable land, and environmental challenges such as reduced transport emissions, energy and water resource use, reduction of organic waste, and climate change (Specht, Siebert, Hartmann, Freisinger, Sawicka, Werner *et al*., 2014: 33).

2.2 Living wall systems available in South Africa

Over the past few decades, designers have developed different living wall infrastructure systems to achieve improved technical solutions and benefits. LWSs are classified into continuous and modular systems (Manso & Castro-Gomes, 2014: 865). Continuous systems entail lightweight screens without a substrate for plant growth, while modular systems include substrates and comprise containers with specific dimensions, and varied composition, weight, and assembly methods (Manso & Castro-Gomes, 2014: 866).

Table 1: Comparison of living wall systems in terms of resilience, feasibility, and sustainability in the South African environment

Criterion	*Modular*	*Continuous systems*		
		Hydroponic	*Aquaponic*	*Aeroponic*
Low-technology requirements (limited reliance on resources such as electricity and water)	Yes, can function for a 24-hour period without water and electricity	No	No	No
Easy replacement of individual plants	Yes	Yes	Yes	Yes
Tolerates drought stress for a 24-hour period	Yes, due to soil medium	No, requires water	No, requires water	No, requires water
Effective control of disease	Yes, not a continuous system and, therefore, limits the spread of disease	No, continuous system	No, continuous system	No, continuous system
Locally produced systems are available	Yes	Yes	Yes	Yes

In South Africa, both local and imported products have been used in projects with living walls, with local products being more cost effective to the client and the environment. The four leading available vertical food-growing systems and their potential as built environment infrastructure applications are summarised in Table 1.

2.2.1 Modular systems

Modular LWSs entail growing plants in a growing medium. They consist of structures of specific dimensions that support elements such as trays, vessels, or bags (Manso & Castro-Gomes, 2014: 866). The elements can also be fixed directly to the vertical surface of the building (Manso & Castro-Gomes, 2014: 866).

There are four types of modular LWSs:

1. Trays consist of containers or modules attached to each other through an interlocking system to hold each individual plant and growing media. They are normally made of lightweight polymeric material, mounted onto a frame, fixed to the vertical surface, and linked to an irrigation system (Manso & Castro-Gomes, 2014: 865).
2. Vessels include containers with several plants that can be attached vertically to each other (Manso & Castro-Gomes, 2014: 866).
3. Planter tiles consist of tiles with pockets for individual plants and flat back edges glued or mechanically fixed to the vertical surface to serve as modular cladding (Manso & Castro-Gomes, 2014: 866).
4. Flexible bags are made of flexible polymeric material and are filled with the growing media. They are suitable for surfaces of different shapes such as curved or sloped walls (Manso & Castro-Gomes, 2014: 866).

Modular LWSs are currently the most widely used local systems, mainly because of the instant impact after installation. Plants can be pre-grown off-site in advance, and individual plants can be replaced with minimal effect on the aesthetics or adjacent plants because of the separate modules provided for each plant. A variety of imported products is nationally available. Locally manufactured systems include products such as Vicinity and Modiwall. In the Modiwall system, the growing medium is placed directly in modules, whereas in the Vicinity system, geotextile bags are used to contain the growing medium in hexagonal pots. Most of the products comprise a growing medium capacity that varies between 1 and 3 litres.

The Eco Green Wall (Figure 1) is a local patent established in 2019 that aims to address the challenges experienced with modular LWSs relating to cost and sustainability. Developed by Abrus Enterprises in 2018, the Eco Green Wall is based on the principle of vegetation-bearing architecture and focuses on outdoor applications. It comprises lightweight blocks of a locally developed recycled polystyrene aggregate and cement mixture. The result is a lightweight, fire-resistant system, with acoustic and thermal qualities and limited exposure of the growth medium to promote the moisture retention and durability of plants. Assembly is basic, with an interlocking system for the blocks, seed trays with a volume of 1.59 litres for the growth medium and plants, and two alternatives for irrigation: trunking with a wick or a drip irrigation system (Van der Walt, 2019: personal communication).

Figure 1: The Eco Green Wall has been custom-designed and manufactured in South Africa. It is a self-assembly system, which makes use of a commercially available low-cost soil tray and drip irrigation pipes that fit into the custom-made bricks. This allows for boundless size and shape assembly options.
Source: Images taken by the author, 2020

The growing medium is a vital component of modular LWSs, the composition of the growing medium needs to be adjusted to ensure optimised plant growth. The organic and inorganic compounds and nutrients are determined by weight and specific plant preferences (Manso & Castro-Gomes, 2014: 867). Effective moisture retention is critical, as it impacts on the performance and survival of plant species (Van der Walt, 2019: personal communication).

The Eco Green Wall offers local benefits such as improved resilience of the system to environmental changes, especially the harsh, dry climate of Gauteng, and circumstances such as electricity failures. Further improvement of modular LWSs is, however, necessary to increase the survival rate of plants and overall sustainability through the full life cycle of these walls. The following aspects must be considered, namely the reduction of the ecological footprint through materials selected for the supporting structure and elements; the identification of tolerant plant species, and the reduction of water usage, maintenance requirements and overall cost.

2.2.2 Hydroponics

Hydroponic living walls are based on the principles of a continuous LWS developed by Patrick Blanc in 1986 and regarded as the modern innovator of living walls. They entail systems with lightweight screens, where plants are grown without a substrate and are dependent on a permanent supply of water and nutrients (Manso & Castro-Gomes, 2014: 866). In the USA, hydroponics has become viable for commercial farming since 2004 (Quagrainie, Flores, Valladão & McClain*,* 2018: 1). Besides their more recent use for commercial farming, hydroponic systems have been actively used in South Africa for architectural green wall projects and were initially one of the most popular systems employed.

Although there are successful exterior examples, the lack of air humidity in large parts of South Africa, especially in Gauteng, where annual humidity averages 59% and it is below 50% in winter months (Weather and Climate, 2020), makes these systems particularly fragile and less effective. Even short-term electricity or system failure could lead to the perishing of plant species. Once under drought stress, the plants are also susceptible to attack from pests that could spread very quickly through the continuous system and often limited variety of species. Availability, quality, and pH of water are important factors determining the success of these systems, with crop yields easily affected by algae. The required foliar cleansing in indoor environments could further cause the spread of plant diseases in these systems. Although the hydroponic systems allow for easy plant replacement depending on accessibility, which is often required, it is not a sustainable proposition. Innovation is required to address the lack of resilience and sustainability of hydroponic systems, especially for low-humidity environments.

2.2.3 Aquaponics

In South Africa, aquaponics is an emerging practice (Mchunu, Lagerwall & Senzanje*,* 2018: 12) and entails the production of vegetables in combination with fish, using fish waste as the main nutrient source. These systems show merit in terms of food production, especially for leafy vegetables, but would be sensitive to pollution and vandalism, which makes them less viable as part of built environment projects. In addition, aquaponic systems are not yet a sustainable solution for urban environments in Gauteng, due to challenges such as water quality, harsh local climatic conditions, as well as complexity and limited knowledge about the systems. Obtaining the correct lighting levels and fish tank ratio, and balance between fish feed and the nutrient requirements of plants can be challenging and problematic (Mchunu *et al.,* 2018: 12), making these systems delicate in terms of water quality management. Food safety could pose a problem, as fish could be unsafe for human consumption if the system is not managed properly (Mchunu *et al.,* 2018: 16). Furthermore, climatic adjustments such as water temperature, which is important for metabolic processes, are needed for systems to ensure profitability. Information and know-how on these systems are lacking to assist users to achieve financial feasibility (Mchunu *et al.,* 2018: 12).

2.2.4 Aeroponics

Aeroponics is a more recent innovation, which entails a sealed soil-less cultivation system with a nutrient-rich solution sprayed by atomisers onto the exposed plant roots (Lakhiar, Gao, Syed, Chandio & Buttar, 2018: 339). This technology has been extensively explored in The Netherlands over the past five years and was introduced in South Africa by Impilo Projects in roughly 2017 (Van Niekerk, 2021: personal communication). The structure of aeroponic systems, which allows for complete measurement and control of moisture and nutrients provided to plants, makes this system easy to monitor, track and adjust.

The lightweight structure of these systems makes them effective to retrofit commercial buildings. The limited space required, high yields, quick results, low maintenance, water efficiency, reduced need for nutrients, mobility of the system and easy access to root inspection (Reyes, Montoya, Ledesma & Ramírez, 2012: 153; Nir, 1980: 147) make aeroponics a viable choice that comes at a cost. The system also needs consistent energy and water supply but permits economies in the use of fertilizers and water because of the re-use of the nutrient solution (Nir, 1980: 147). Despite its benefits, the suitability of aeroponics for low-key and low-cost urban environments is questionable. This is mainly due to its high cost, complex technology, high control, and the expertise required. The equipment includes high-pressure pumps, misters, and timers. Specific parameters for the nutrient concentration are essential for successful plant growth. Although maintenance is limited to cleaning and disinfecting the root chamber, the high moisture content in the root chamber makes this system vulnerable to bacterial growth (Reyes *et al*., 2012: 153). As in the case of hydroponic systems, these systems are equally fragile, with hardly any resilience in the dry local climate. Prevalent short-term water and electricity failures or a slight malfunction of the system can result in significant impacts on the plant condition.

The next section considers the local living wall examples implemented in Gauteng in the last decade, with a reflection on industry tendencies and change.

3. LIVING WALL TENDENCIES IN GAUTENG OVER THE PAST DECADE

In general, the local installation and popularity of LWSs have primarily been as embellishments and mostly used to enhance buildings' indoor environments. Secondly, LWSs have been associated with buildings seeking Green Star status rating and environmentally friendly branding such as the head offices of the Department of Environmental Affairs (installed in 2014) and the South African National Road Agency Limited (SANRAL) in Pretoria, with its green roof and façade (installed in 2012). Because of their public display and the increased availability of modular systems, LWSs have further become popular in private homes of those who desire and can afford these living artefacts.

In contrast to the use of LWSs for pure aesthetics or "green" branding, more sustainable systems and plant species have also been introduced that contribute to greater longevity, functional value, and use. This phenomenon has mainly manifested in three ways:

1. The use of local indigenous species for a local African identity.
2. The use of indigenous and diverse plant species to attract biodiversity.
3. The creation of edible vertical gardens for human consumption.

One of the first public green walls (or "green buildings") implemented in this spirit in South Africa was the Maropeng Visitor Centre (installed in 2006) at the Cradle of Humankind World Heritage Site. Designed by GAPP and MMA Architects, the concept of the "Tumulus" as an ancient burial mound and iconic entrance to the primitive origin of humankind created an innovative statement by covering the building completely with local veld grass. The native grass is a reference to visitors of something truly local and African, uniting the building with the landscape.

The University of Pretoria's Plant Sciences Building (installed in 2012), designed by kwpCREATE, is an exceptional project. Similar in design and function to the green wall system proposed by Chanampa, Rivas, Ojembarrena and Olivieri (2010), a local "man-made cliff" was created to provide a habitat for indigenous cremnophytic or cliff-dwelling plants (Vosloo, 2016: 43). The structure of the wall comprises a steel frame that supports a rock-filled gabion screen (Vosloo, 2016: 48), custom-designed for the building. The species were carefully selected from similar local natural habitats, and "dry wall" and "wet wall" systems were developed on two western aspect façades, respectively. The wall remains novel in terms of its design, habitat creation, diversity of species included, and the fact that the species are all indigenous, contributing to an African identity.

Figure 2: The veld wall of the Keyes Art Mile, Rosebank, has created a novel precedent where "wild" Egoli grassland species were planted in a Gro-Wall system retrofitted to a brick façade. The wall alleviates the sun's glare and heating produced on the northern and western façades and creates a unique ambience along the street that houses many art galleries.
Source: Images taken by Author, 2018

The recent "veld wall" at the Keyes Art Mile in Johannesburg (installed in 2018) (see Figure 2) has been an original example of a living wall that creates environmental awareness. The wall was designed for Tomorrow. co by the Fieldworks Design Group, with Dr Johan Wentzel in an advisory capacity to specify the planting palette. The wall, with a western to north-western aspect, consists of a Gro-Wall modular system retrofitted to a brick façade at the St. Theresa School. The veld wall displays flora from the Egoli granite grassland vegetation type that is threatened, mainly due to urban development. The wall includes close to 6 000 plants comprising 60 different species. Wild veld grasses and forbs, which have increasingly been seen in urban plant palettes, are placed in an unexpected vertical plane to create a novel architectural component. This mental contrast of ideas – wildness matched with architectural form and technology – creates the emphasis required for public awareness. The wall is innovative in that it uses wild native species in great diversity with the goal to make people aware of their unique local environmental context and identity (Taljaard, 2018: personal communication).

4. METHODOLOGY

The authors followed a qualitative exploratory case study research design to address the research question: Do living walls with edible plants offer value for consumers and developers in developing economies? Case studies are valuable to study phenomena in context and to evaluate and develop interventions (Baxter & Jack, 2008). For the three selected case studies, data collection occurred through site visits, personal observations and interviews with the owners or managers, landscape architects and/or landscape contractors responsible for their design and installation. The aim was to explore system resilience, economic sustainability, and edible plant palette potential. The data was analysed to obtain findings for each of these areas of interest, while conclusions were drawn by combining the findings for each case study.

5. CASE STUDIES

Three case studies were selected to consider the current use of living walls for edible plants in Gauteng. The South African Landscapers Institute (SALI) could provide a list of registered landscape construction companies specialising in roof and urban gardens in the Gauteng region. The authors contacted fourteen companies from the list of twenty-five to obtain the location and information of completed projects comprising edible plants in living walls. One SALI-registered company installed an edible living wall, and the authors were referred to four additional companies and suppliers not registered with SALI to follow up on three projects. Following this information, case studies were selected followed by site visits to all projects with edible living walls in Gauteng. Local explorations to expand the functional possibilities of living walls that have more recently delivered examples in food production were considered. Three recent developments in Johannesburg, Gauteng, with edible living walls include Doppio Zero @ Hobart, The Mix cocktail bar, Keyes Art Mile, and the Neighbourgoods Market greening project. The walls comprise leafy vegetables and herbs for inclusion in food dishes, drinks, and cocktails, and have set a trend in the local restaurant industry. However, they need further investigation for the deployment of large-scale urban food security.

5.1 Doppio Zero @ Hobart, Grove Shopping Centre (Bryanston, Johannesburg)

The Doppio Zero @ Hobart edible living wall (Figure 3), installed in January 2019, has theatrical value, according to the owner of the restaurant. Life Landscapes was responsible for the design and installation of edible plants in the wall for use in the kitchen (De Kock, 2019: personal communication). The living wall, comprising approximately 6 m^2 on a northern aspect, serves as a feature element at the entrance to the restaurant. The aspect enables maximum sun exposure, which is beneficial to herbs and leafy vegetables that require direct sun.

Figure 3: The edible green wall at Doppio Zero, making use of the Gro-Wall system for exterior conditions on a northern aspect
Source: Images taken by the author, 2019

The contractor chose the Atlantis Gro-Wall modular system, due to the instant impact and versatility of the product, which can expand horizontally and vertically in terms of size and shape. The growing medium volume for each individual pot in this system distinguishes it from other modular systems in terms of resilience against drought and pests. Life Landscapes listed the main challenges of LWSs as economic feasibility, due to high installation and management costs and ensuring that the physiological requirements of plants are met. Another challenge is human access to growing surfaces to maintain the plants and the system (Lockwood & Strydom, 2019: personal communication).

5.1.1 System resilience

The soil volume of 3 litres, together with the automated targeted drip irrigation, enhances the resilience of the plants in the living wall against drought. A canopy initially shading the living wall's sun-loving plant species led to some of the plant species struggling and dying. Life Landscapes resolved this, by requesting the client to remove the canopy. Maintenance is monitored on a consultation basis by the landscape contractor. The system is resilient, due to an appropriate growing medium, automated irrigation, sufficient natural light, and intermittent maintenance.

5.1.2 Economic efficiency

Since the product is imported, the currency exchange of the South African Rand makes the installation cost quite high at approximately R6 000 per m^2 (in 2019). All the plants in the living wall are for use in the restaurant's kitchen, which gives it some financial viability, combined with the favourable customer experience (De Kock, 2019: personal communication). The wall is an attraction and intrigues customers who show an interest in the different herbs. The chef harvests the herbs, and staff inform customers about the different herbs, for example different types of basil or mint, which adds an educational aspect. The cost of replacing the plants is negligible, although a bigger scale wall with a larger variety of species with higher yields would have improved the wall's economic feasibility (De Kock, 2019: personal communication). The living wall succeeds in meeting its client's aesthetic and functional objectives.

5.1.3 Edible plant palette possibilities

The owner found that edible living walls and rooftop gardens are widely used in the USA, and viewed this with great local potential, especially if implemented on a larger scale. Exotic edible plants that are used in the kitchen were specified as part of the planting palette and include lettuce (*Lactuca sativa*), mint (*Mentha spicata*), rocket (*Eruca vesicaria*), sweet basil (*Ocimum basilicum*), capers (*Capparis spinosa*), lavender (*Lavandula angustifolia*), spinach (*Spinacia oleracea*), parsley (*Petroselinum crispum*), garlic (*Allium sativum*), and celery (*Apium graveolens*) (De Kock, 2019: personal communication).

5.2 Mix cocktail bar, Mesh Club, Trumpet Building, Keyes Art Mile (Rosebank, Johannesburg)

The Mix cocktail bar at the Mesh Club comprises a local indigenous edible living wall (Figure 4). The living wall, installed by Landtech Projects in 2018, comprises indigenous plants with edible or aromatic qualities that can be used for the cocktail mixes in the bar, in line with the conservation strategy adopted by the Keyes Art Mile Development. The inspiration, according to the landscape architects, Fieldworks Design Group, was Monkey 47 dry gin, which comprises 47 botanicals from the Black Forest in Germany. This led to the mixologist (at the time) proposing that local fynbos and botanicals be included in this living wall for utilisation in the cocktails and kombucha served at this venue (Wilken, 2019: personal communication).

Two living walls, utilising the Vicinity modular system, form part of the northern aspect of the bar area. Each wall contains a custom-designed 3 x 30 x 30 mm steel angle frame, painted black, with a 12 mm treated marine ply and backboard painted black to accommodate the spatial parameters. The walls, each comprising an area of approximately 2 m^2, are on a covered balcony and therefore do not get direct sun exposure. Irrigation consists of a manual system, which makes use of a drip line and water trough at the bottom, filled by hand with a watering can.

Figure 4: The edible wall at the Mix cocktail bar, which makes use of the local Vicinity modular system with added artificial lighting for plant growth. The wall provides fresh herbs for use by the mixologist and for customers to experience and enjoy in their cocktails
Source: Images taken by the author, 2019

5.2.1 System resilience

Currently, challenges include over-harvesting and consequent artificial lighting sources required to improve low growth (Wilken, 2019: personal communication). The plants do not have enough time to regenerate after harvesting, resulting in species such as the wild mint (*Mentha longifolia*) dying back. The wild rosemary (*Eriocephalus africanus*) did not survive, due to overwatering, poor drainage, and insufficient light. Natural light would have increased the efficiency and resilience of the living wall and a larger variety of species with higher yields (Wilken, 2019: personal communication). Staff of the Mix cocktail bar maintain the living wall by watering it two to three times a week and switching on the grow light. The system is manually operated to reduce cost. However, the consistent maintenance poses a challenge (Cross, 2019: personal communication). Human reliance in terms of over- or under-watering, pruning, harvesting and light provision challenges the resilience of the system (Wilken, 2019: personal communication).

5.2.2 Economic efficiency

The approximate installation cost of the system was R6 500 per m^2 (in 2018). The owner states that the LWS adds value to the development. The living wall provides an upper-hand allure to customers over other venues. More is offered than simply the standard experience, while customers benefit from quality products through added flavour and awareness of fresh ingredients in their drinks (Cross, 2019: personal communication). The owner deems the wall financially viable, as it provides the kitchen with eight to ten different types of fresh herbs on the premises. Herbs and other species are also grown in pots on the balcony, but the living wall is more effective in saving horizontal space. In comparison, a horizontal area of 4 m^2 would be required for the number of herbs provided in the 2 m^2 living wall. Plants in the living wall are also outperforming those in pots. Maintenance and yields of some species such as the forest num-num (*Carissa bispinosa*) are a challenge. More plants are needed to ensure enough material for the kitchen (Cross, 2019: personal communication). The landscape architect deduces that the limited soil volumes and the resulting “bonsai” conditions in the modular wall pocket impact on the yields (Wilken, 2019: personal communication).

5.2.3 Edible plant palette possibilities

The fully indigenous planting palette achieves the objective of harvesting for use in making drinks and as garnish. The planting palette comprises forest num-num (*Carissa bispinosa*) for its edible fruits; several pelargonium species (*Pelargonium tomentosum, P. graveolens, P. quercifolium* and *P. odoratissimum*) for their scented, decorative leaves; wild rosemary (*Eriocephalus africanus*) for its scented leaves, as well as wild mint (*Mentha longifolia*) and daisy tea bush (*Athrixia elata)* to make kombucha. Asparagus ferns (*Asparagus setaceus* and *Asparagus plumosus*) are interplanted as fillers for their foliage, and large red iris (*Freesia grandiflora*) is planted for its flowers (Wilken, 2019: personal communication).

Natural light would have provided the opportunity for a wider planting palette, while a larger living wall would increase plant numbers that provide more harvesting potential.

5.3 The Neighbourgoods Market, Juta Street (Braamfontein, Johannesburg)

The greening strategy of the Neighbourgoods Market (Figure 5) was introduced in March 2020 as a marketing strategy to celebrate the Strongbow brand as a new market partner in the inner city. The project comprised temporary and permanent interventions to the space, including three pop-up structures as retrofit to the multi-storey building on the western façade of the second floor, with two living walls of 5.4 m^2 each. The objectives were, first, to advertise the brand by providing space for signage and a green backdrop to pop-up stands; secondly, to add value, by providing greening and softening the spaces used for the vibrant weekly market held in the parking area of the building, and, thirdly, to enhance layout legibility at the market level and from street level.

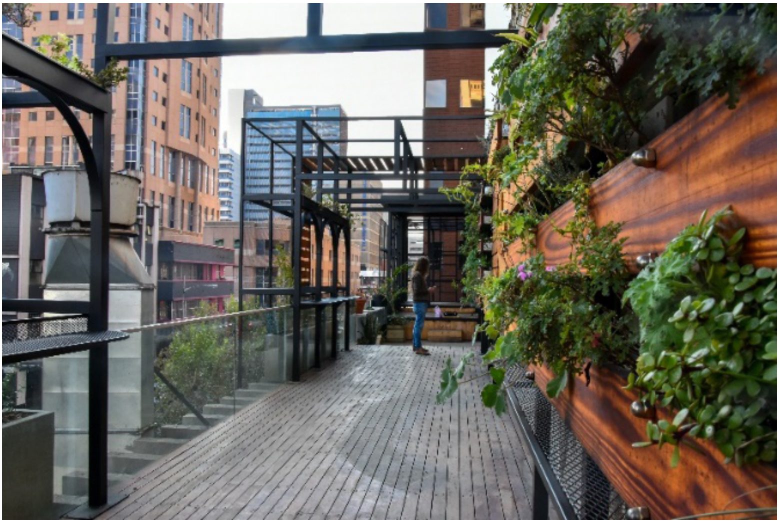

Figure 5: The greening strategy of the Neighbourgoods Market, with galvanised steel gutters fixed to steel frames and cladded with timber slats, bolted to the frames. The wall provides fresh herbs for use at the market and for customers to experience and enjoy in their ciders
Source: Images taken by the author, 2020

The landscape architects, Fieldworks Design Group, extended the brief to improve the microclimate and air quality, and add to the functionality of the wall, by introducing a mostly indigenous planting palette with diverse colours, textures, edible and fragrant qualities. The stands each comprise a black painted 76 x 76 mm square steel tubing frame, with an overhead plane of galvanised wire mesh with climbers planted in concrete pots (Figure 6). The living walls each contain five planted 125 x 100 mm galvanised steel gutters fixed to the steel frame and cladded with 38 x 152 mm SA pine timber slats, bolted onto the frames (Figure 7). The landscape architect selected the pine, treated with linseed oil to increase durability, together with the painted black steel and mesh, to strengthen the modern, masculine identity, retaining the link with the vernacular. Irrigation comprises an automated drip system at the top gutter of each wall, gravitating to the bottom gutters by means of staggered drainage holes spaced 500 mm apart, with irrigation running for 30 minutes three times a week (Wilken, 2020: personal communication).

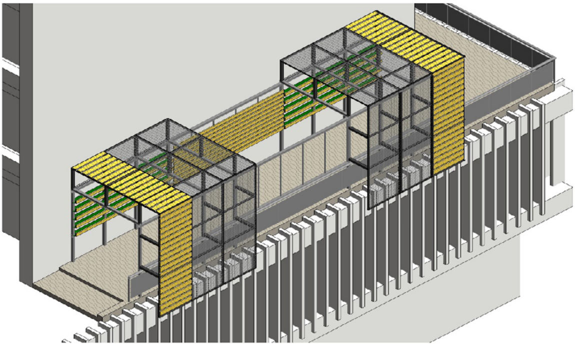

Figure 6: Isometric drawing of Neighbourgoods Market deck area, indicating two steel boxes with timber cladding, and timber-cladded galvanised steel gutters between the two frames
Source: Fieldworks Design Group, 2020

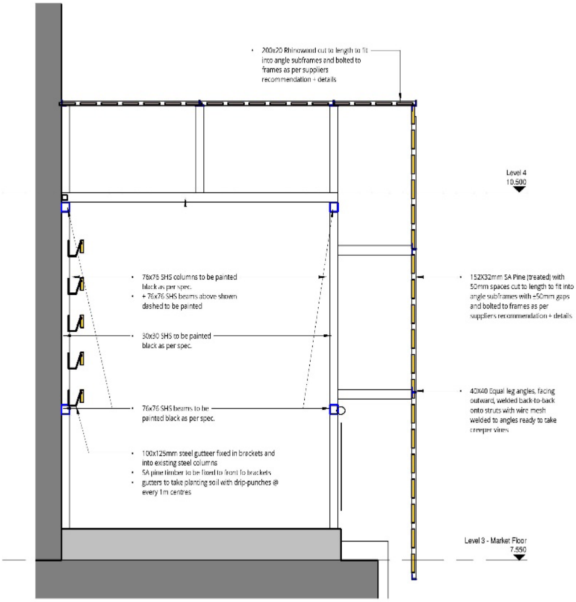

Figure 7: Section through market deck area, indicating five 125 x 100 mm galvanised steel gutters fixed to the steel frame and cladded with 38 x 152 mm SA pine timber slats, bolted onto the frame
Source: Fieldworks Design Group, 2020

5.3.1 System resilience

The mostly indigenous plant palette contains mainly low-maintenance, hardy, water-wise plants that will tolerate limited soil, the harsh micro-climate of the western façade, and heat generation from hard surfaces and containers. A three-month post-completion maintenance period is included in the contract, which was adjusted, due to the two-month COVID-19 hard lockdown period, during which landscape maintenance could not be performed. Due to the plants not yet being established at the time, roughly 10% to 15% of the plants died and had to be replaced. This demonstrates the resilience of the system. The uncertainty of long-term regular and quality maintenance is expected to take its toll on the LWS. However, all plants selected are fairly hardy and should be able to withstand climatic shifts and periods without attention once established.

Lack of consistent future maintenance and micro-climatic factors such as glare, elevation, and wind tunnels from surrounding buildings could impact on evaporation and result in windburn on plants. A third challenge entails the western aspect, which affects the soil in the planted gutters, causing it to dry out more rapidly. This was mitigated by adding a moisture retention agent in the form of hydrogel crystals to the potting soil and vermiculite mixture at a ratio of 4 kg per 1.5 m^3 potting soil. The support structures with the mesh and climbers as an overhead plane will further mitigate the glare and micro-climatic conditions (Wilken, 2020: personal communication).

5.3.2 Economic efficiency

The approximate installation cost of the system was R2 500 per m^2 (in 2020). The cost was reduced by design approaches such as the utilisation of gutters and irrigation, which entailed the use of gravity for water flow. The landscape architect states that the living wall is successful in the development because it attracts customers. During the COVID-19 lockdown, the weekly markets could unfortunately not continue.

5.3.3 Edible plant palette possibilities

The planting palette was selected to include edible and aromatic plants, which can be added to the ciders and drinks during markets. The planting palette includes the grass bulbine (*Bulbine abyssinica)*, forest num-num (*Carissa bispinosa),* chlorophytum *(Chlorophytum bowkerii*), star flower *(Hypoxis hemerocallidea),* creeping crassula (*Crassula spathulate)* for colour and aesthetics*,* wild rosemary *(Eriocephalus africanus),* wild mint *(Mentha longifolia*), sweet basil (*Ocimum basilicum)*, several pelargonium species (*Pelargonium graveolens* and *Pelargonium odoratissimum)* for their scented leaves, and the porkbush *(Portulacaria afra*) for its edible leaves (Wilken, 2020: personal communication).

6. DISCUSSION

6.1 System resilience

Automated irrigation and natural light sources reduce the risk of human inconsistencies. This improves the resilience of LWS, but heightens input cost. Modular systems, also recommended by Larcher *et al*. (2018: 31), are more durable in dry climates. The appropriate selection of the type, volume and agents of the growing medium plays a vital role in plant survival, ensuring effective moisture retention and optimal growth according to root expansion. The right exterior aspect and addressing the specific light quality and duration requirements of plant species in LWSs impact on plant performance. Local indigenous plants are often better adapted to local conditions such as direct sun exposure, air humidity levels and precipitation, and require less running costs and maintenance. The use of local species is supported by other studies (Larcher *et al*., 2018: 31; Medl *et al.,* 2017: 236), in order to enhance system resilience but was further found to create local environmental awareness and appreciation, while attracting customers through unique experiences. Adding artificial lights, gravity irrigation or structures to provide refuge against glare raises costs, but these design elements reduce the need for maintenance and improve the resilience of the systems.

6.2 Economic sustainability

Despite the potential of living walls, the constraints and challenges currently experienced entail the complex technologies involved, high installation costs, the resilience of plants in LWSs, and intensive maintenance requirements. Ottelé *et al*. (2011) concur that materials used, maintenance, nutrients and water needed generally make the sustainability of LWSs questionable. The use of renewable materials and environmentally friendly substrates could result in greater sustainability (Larcher *et al*., 2018).

Perini and Rosasco (2013) propose that economic sustainability could be increased through reduced installation costs, material choice, envelope design and ensuring benefits in terms of climate control for cities. Locally, LWSs have mainly been used as a novel attraction with indirect economic benefit, without exploitation of the cooling and insulation potential they offer. This might change in future, as the country foresees an average temperature increase of three degrees. However, Ottelé *et al*. (2011) determine that, apart from the 'direct' greening systems, the environmental burden of vertical greening systems generally exceeds their cooling benefits. Implementing measures to ensure more feasible LWSs would, therefore, mitigate the disadvantages and ecological footprint.

Another aspect of the economic sustainability that has not been much discussed is the real estate or marketing value of LWSs. Still a relative novelty in South Africa, LWSs have been used to attract customers through their instant aesthetics and by creating much-desired progressive-looking environments. All three case studies reviewed reflect the desire for ambiance and experience – visual and culinary – as a reason for the LWS installations or their owners' appreciation. In Canada, Peck, Callaghan, Kuhn and Bass (1999: 35) assumed that living walls increase the real estate value of a building by between 6% and 15%.

In concurrence with Perini and Rosasco (2013: 120), the economic sustainability of LWSs can be enhanced through reduced installation costs, as noted in the Neighbourgoods Market example. In Portugal, Félix *et al*. (2018: 803) designed a foldable green wall from re-usable material for assembly in wasted space that shows a careful adaptation to local needs and conditions. The authors recommend the use of locally produced systems to lower installation and embodied energy costs, and designs involving less sophisticated technology that reduce maintenance needs. Edible LWSs installed on a larger scale will increase yields, improving demand and profitability. Suman and Bhatnagar (2019) recommend that food security for low-income groups should focus on small and medium-sized entities and home garden initiatives. The versatility of modular systems saves space and provides for required expansion possibilities.

6.3 Edible plant possibilities

We propose that the economic efficiency of LWSs can be enhanced through the incorporation of edible plant species. Although vertical systems are already used in the commercial farming industry, these are typical indoor high-technology, high-cost systems. The outdoor study by Nagle *et al*. (2017: 33) in the USA, which makes use of common vegetables, showed a higher yield for leafy herbs and vegetables that outperformed their average productivity rate three to five times, although other vegetables under-performed. The small-scale LWS examples in the case studies included in this study – mainly focused on retail customers – indicate several common local and exotic species that are grown successfully (Table 2).

Limited research and experimental projects are available on edible living walls, and specifically local indigenous edible plants to grow in LWSs as recommended by several studies (Medl *et al.,* 2017: 236; Larcher *et al*., 2018: 31).

Table 2: Edible plant species grown successfully in living walls in Gauteng

Scientific name	*Common name*
Allium sativum	Garlic
Apium graveolens	Celery
*Athrixia elata**	Daisy tea bush
Capparis spinosa	Capers
*Carissa bispinosa**	Forest num-num
*Eriocephalus africanus**	Wild rosemary
Eruca vesicaria	Rocket
Lactuca sativa	Lettuce
Lavandula angustifolia	Lavender
*Mentha longifolia**	Wild mint
Mentha spicata	Spearmint
Ocimum basilicum	Sweet basil
*Pelargonium graveolens**	Rose-scented pelargonium
*Pelargonium odoratissimum**	Sweet-scented pelargonium
*Pelargonium quercifolium**	Oak-leaf pelargonium
*Pelargonium tomentosum**	Peppermint pelargonium
Petroselinum crispum	Parsley
*Portulacaria afra prostrata**	Porkbush
Spinacia oleracea	Spinach

* local indigenous species
Source: Wilken, 2019: personal communication

7. CONCLUSIONS

Living walls can make a significant contribution to cooling benefits, climate adaptation and urban food production in the Global South. Contextual studies such as this one inform the design and installation of systems in response to local cultural, socio-economic, and environmental conditions.

Living walls have had a great aesthetic appeal in South Africa, based on the sensory stimulation opportunities they provide. Local designers have fashioned several exceptional examples that produce unique urban habitats and a strong place identity through the use of indigenous, native, or edible species. Edible living walls are currently adding economic value to commercial restaurants and bars. Benefits include fresh produce and customer attraction.

From the three reviewed case studies, the authors conclude that LWSs are required that address local needs and conditions. Less complicated technologies need to be developed with designs that enable lower cost and larger scale applications. Local materials and products must get priority, and resources such as water and energy need to be used effectively, making automated systems favourable, but in need of more simplistic systems operated from renewable resources. Locally produced LWSs such as the Eco green wall and Vicinity modular systems show potential and need to be further explored to enhance benefits. Resource efficiency could be further achieved through plant selections and designs that are adapted to the local climate and the increased stresses of urban environments. This will aid the development of more economically efficient LWSs.

Incorporating urban agriculture through living walls to compact urban environments will enhance the auto-efficiency and well-being of communities and could make food production more cost-effective and sustainable. These food-production systems could, at the same time, contribute to many important, but seemingly less urgent ecosystem services. Living walls can create unique urban experiences, which are not limited to functional and economic value, but with the added ability to create awareness and educational value about the mutual dependence between urban nature and people. However, research is required to address the information gaps in South Africa in these areas.

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