Between Promise and Performance

Technology, Land, Energy, and Labor in the Agro-Industrial Greenhouse Cluster of Westland, The Netherlands

Abou Jaoude, Grace; Muñoz Sanz, Víctor

DOI
10.1080/10630732.2025.2498870

Publication date
2025

Document Version
Final published version

Published in
Journal of Urban Technology

Citation (APA)
Abou Jaoude, G., & Muñoz Sanz, V. (2025). Between Promise and Performance: Technology, Land, Energy, and Labor in the Agro-Industrial Greenhouse Cluster of Westland, The Netherlands. *Journal of Urban Technology*, *32*(5), 5-33. https://doi.org/10.1080/10630732.2025.2498870

Journal of Urban Technology

Routledge
Taylor & Francis Group

ISSN: 1063-0732 (Print) 1466-1853 (Online) Journal homepage: www.tandfonline.com/journals/cjut20

Between Promise and Performance: Technology, Land, Energy, and Labor in the Agro-Industrial Greenhouse Cluster of Westland, The Netherlands

Grace Abou Jaoude & Víctor Muñoz Sanz

To cite this article: Grace Abou Jaoude & Víctor Muñoz Sanz (2025) Between Promise and Performance: Technology, Land, Energy, and Labor in the Agro-Industrial Greenhouse Cluster of Westland, The Netherlands, Journal of Urban Technology, 32:5, 5-33, DOI: 10.1080/10630732.2025.2498870

To link to this article: https://doi.org/10.1080/10630732.2025.2498870

Published online: 16 Jun 2025.

JOURNAL OF URBAN TECHNOLOGY
2025, VOL. 32, NO. 5, 5–33
https://doi.org/10.1080/10630732.2025.2498870

Routledge
Taylor & Francis Group

Between Promise and Performance: Technology, Land, Energy, and Labor in the Agro-Industrial Greenhouse Cluster of Westland, The Netherlands

Grace Abou Jaoude [a,b] and Víctor Muñoz Sanz [a]

[a]Department of Urbanism, Faculty of Architecture and The Built Environment, Delft University of Technology, Delft, The Netherlands; [b]Institute for Sustainable Urbanism, Department of Architecture, Technical University of Braunschweig, Braunschweig, Germany

ABSTRACT
Controlled-environment horticulture is one of several automation technologies emerging as possible ways of guaranteeing the future of food production. However, studies on the implications of horticulture's infrastructuralization for urbanization remain limited in literature. This article presents an exploratory study that examines the Dutch agro-industrial cluster of Westland. We draw on semi-structured interviews to understand emerging networks and socio-technical systems and identify spatial and environmental outcomes of automation. Analysis around the themes of technology, land, energy, and labor revealed spatial tensions, limitations of technologies, capital concentration, and accelerating technological diffusion. We conclude that automation technologies affect scalability, increase the need for space, and call greenhouse's sustainability claims into question given the distinct disparities between an enclosed artificial and technologically intensive inside and a natural outside.

KEYWORDS
automation; digitalization; controlled environments; greenhouses; horticulture

Introduction

With rising social and ecological uncertainties, automation technologies in controlled environment agriculture (CEA) are increasingly seen as an imperative by corporate and public actors to meet future food requirements, increase food safety, reduce pressure on the ecosystem, and maximize return on investment (Broad, 2020; Maffezzoli et al., 2022; Sott et al., 2020). These socio-technical systems promise optimal performance, precise climate control, and improved decision-making, offering to protect against the turmoil of anthropogenic climate crisis, diminishing areas of arable land and fluctuations in the labor market (Giacomelli et al., 2008; Pekkeriet and van Henten, 2011). Given these advantages, automation is increasingly embraced in CEA not only to overcome

CONTACT Grace Abou Jaoude g.abou-jaoude@tu-braunschweig.de Institute for Sustainable Urbanism, Department of Architecture, Faculty of Architecture, Civil Engineering and Environmental Sciences, Technische Universität Braunschweig, Pockelsstraße 3, Braunschweig 38106, Germany

unpredictable climate variations but also to secure capital's reproduction (Lockhart and Marvin, 2020; Marvin et al., 2024). However, general attempts to systematically analyze the spatial and socio-environmental implications of automation technologies in controlled environments remain limited in urban studies literature, with few notable exceptions (Marvin and Rutherford, 2018; Muñoz Sanz et al., 2018; Lockhart and Marvin, 2020; Marvin et al., 2024; Rutherford and Marvin 2024).

This article investigates the horticultural cluster of Westland, the largest in the Netherlands and a historic testing ground of innovations. It depicts automation technologies currently in use in greenhouses and examines their relation to spatial and socio-ecological questions beyond the confines of horticulture production premises. The Netherlands has been at the forefront of adopting and globally supplying automation technologies for CEA. Correspondingly, Dutch CEA has been widely appraised, presented, and promoted in mainstream media as the mirror of how the future of food production could look like (Viviano, 2017; AMO and Koolhaas, 2020). To achieve high production levels and maintain their competitive advantage, greenhouses in the Netherlands sought for decades to specialize their production and expand their scale of operations. In parallel, these horticultural firms shifted to consumer driven production, implemented lean management practices, and employed labor-saving technologies to facilitate high quality production (Montero et al., 2011; Pekkeriet et al. 2015).

The study stems from an understanding of interdependencies between commodity flows, labor markets, resource extraction, power relations, urbanization processes, and automation technologies as what Moore (2015: 10) calls "products and producers of spatial configurations" conducive for capital accumulation. We examined several lines of enquiry, namely: (1) the range and variety of digital agriculture technologies adopted and their effects on greenhouse practices; (2) the reciprocal correlation between greenhouse scale and the uptake of digital technologies; (3) the primary beneficiaries of this adoption and its impacts on capital concentration; (4) the implications of adoption on labor, including processes of de- or reskilling within CEAs; and (5) the extent to which these technological shifts promote sustainable development, considering the broader social and environmental implications that extend beyond the enclosed artificial inside to influence local and global flows of production and distribution.

We traced material processes in Westland's greenhouses, with a focus on technology, land, energy, and labor to understand how they support horticulture firms and influence emerging networks and relations in space. Such flows of capital and material nature reinforce interdependencies between Westland's operational productive enclosures, which can be understood as spatial-temporal fixes (Marvin et al., 2024), infrastructures, and institutions and reveal networked forms of accumulation. To study those flows and the spatial products involved, we employed a mixed methods approach and consulted secondary sources to identify greenhouses that embraced automation technologies. In addition, we conducted 13 semi-structured interviews and fieldwork between November 2017 and November 2019. Insights at the interface of urban studies and horticulture were derived to systematically analyze how the adoption of automated technologies, which are typically concealed within private enclosures, reconfigure spatial logics.

The article is structured as follows. First, we position the trend towards digitalization and automation of indoor horticulture within existing theoretical debates on the infrastructuralization of controlled environments and digitalization of agriculture in the fields of geography and urban studies. After introducing the horticultural cluster of Westland, we describe the methodology used to study the area's horticulture firms. We expand on the findings by focusing on the themes of technology, land, energy, and labor to depict the assemblages of humans and machines and emphasize how Westland is shaped by profit-driven imperatives that are intended to guarantee the continuous accumulation of capital. These sections shed light on accumulation strategies, socio-ecological contradictions as well as "spatial dispositions" (Easterling, 2014) and logics that seem to contribute to the restructuring of urban space in Westland.

Analysis of the empirical material revealed how capital and its associated metabolizations are etched in Westland's infrastructure and accelerate technological diffusion. The mosaic of greenhouses, spatial infrastructures, technological components, and socio-ecological processes testify to capitalism's ecological dimension and the spatial restructuring of Westland and question the social and environmental sustainability of the model. The article poses the argument that investments to improve or establish infrastructures, greenhouses, and automation technologies are posited as what Ekers and Prudham (2017) called "socio-ecological fixes," that respond to accumulation exigencies and accelerate the circulation of capital. This research concludes that there is a decoupling between such developments which support Westland's competitive advantage and transnational outreach, and the purported local societal and environmental benefits of automation technologies.

On Digitally Controlled Environments in Agriculture

With intentions to shift from precision to decision systems, the digitalization of agriculture is transforming greenhouses into autonomous cyber-physical systems (Weltzien, 2016; Shepherd et al., 2018). Emerging digital technologies—from sensors and networked autonomous vehicles to robotics and cloud-computing systems—are increasingly integrated in agriculture. These capital-intensive systems generate massive amounts of data to drive management decisions and promise a high return on investment thereby drawing interest from firms, policymakers, and investors (Rotz et al., 2019). The adoption of automation technologies and the transition to digital agriculture are driven by various challenges, namely: (1) changing demographics, particularly the increasing global population and the rising demand for food, coupled with an aging population in advanced economies, which threatens productivity; (2) increasing resource scarcity, such as water; and (3) climate change variations that impact agriculture (Maffezzolli et al., 2022). In parallel, the adoption of digital technologies promises diverse benefits such as reducing resource input; enhancing process efficiency; reducing costs; optimizing productivity, production systems and value chains; improving product quality and food systems (i.e., ameliorating the safety and traceability of food) (Broad, 2020); attracting youth to the agriculture sector; and improving knowledge exchange (Chuang et al., 2020; Dawkins 2016). While the digitalization of agriculture firms is expected to generate higher yields with a better quality at lower expenses, various scholars have highlighted digital technologies' role in reducing employment and questioned their social implications (Shamshiri et al., 2018; Walter et al., 2017).

Different terms and concepts such as "precision agriculture," "smart farming," and "Agriculture 4.0" have recently proliferated in the literature and typically refer to different forms of digitalization of agriculture (Pauschinger et al., 2022; Rotz et al., 2019). The technological field is dominated by two types of platforms, as classified by Srnicek (2016): cloud platforms, involving subscription services of diverse software applications and data storage; and industrial platforms, providing the hardware enabling the transformation of conventional production processes. Generally, a range of digital technologies and cloud systems are employed such as the Internet of Things (IoT), big data, augmented reality, artificial intelligence, and machine learning and integrated in hardware systems (Maffezzoli et al., 2022; Shamshiri et al., 2018). Different forms of digital and hardware technologies are bundled, introduced or integrated into agriculture firms as a suite or combination of data-intensive automated smart systems. Given the significant investments required to deploy expensive decision support systems, interoperability is a growing concern among users. With the ongoing corporate monopolization as well as data ownership and siloing tendencies, there are increasing practices to restrict agricultural firms to a specific service provider or brand by programming systems to not accept data from different sources (Rotz et al., 2019).

While the digitalization of agriculture has been widely reported across environmental science and agriculture engineering (Klerkx et al., 2019; McCartney and Lesfrud, 2018; Shamshiri et al., 2018), technologically intensive processes and ongoing automation of indoor horticulture, as instruments of capital's reproduction, is gaining prominence in urban studies literature (Lockhart et al., 2023; Lockhart and Marvin, 2020; Marvin et al., 2024; Rutherford and Marvin 2024).

As defined by Marvin and Rutherford (2018: 1143) controlled environments are "enclosed and engineered socio-technical spaces that create specialized 'microclimates'[emphasis] that are specifically designed to provide the precise conditions for food production." These enclosures provide optimal microclimates where production drivers, including temperature, lighting, humidity, and nutrients are precisely regulated to achieve an entirely controlled growth environment.

Given the increasing urbanization and climatic turbulences, controlled environment horticulture promises increased food security and sustainable food production and is thus celebrated as the future of farming by cities, agritech firms, and corporate actors (Despommier 2011; Geilfus 2019). Indeed, self-proclaimed high-tech greenhouses are presented as innovative, reliable, and ideal technological visions that surpass climatic and contextual limitations bringing about transformative shifts in food production. These "technically mediated enclosures" (Marvin et al., 2024) offer to reduce CO_2 emissions, energy, water requirements, and pesticides, all while optimizing yield efficiency and increasing food security. CEA has become a global phenomenon, expanding rapidly—particularly in China—to ensure year-round production, support agricultural intensification and improve food systems, yet its environmental and socioeconomic implications remain underexplored (Dsouza et al., 2023; Tong et al., 2024).

Considering the increasing uptake of digital and automation systems, Giacomelli et al. (2008: 13) posited that CEA "should be considered as a technology platform." In a similar vein, Marvin and Rutherford (2018) noted that microclimatic enclosures appertain to selective actors and spaces and are less engaged with global sustainability or the collective good. Framed by narratives of infrastructuralization and standardization, the authors emphasized the significance of the context (and its specificities) in which these enclosures emerge. They discussed a novel condition where the inside, underpinned by automation technologies, becomes an optimal, artificial and scalable reconstruction of a distant outside ecosystem. While the inside sustains the production of optimized microclimates and enclaves, the direct outside is left subject to anthropogenic climate change. Rather than focusing on the schism between a reconstructed inside (in-situ) and a natural outside (ex-situ), Rutherford and Marvin (2024) called for examining the role of technology and infrastructure in sustaining, enabling and optimizing environments that surpass local constraints, disconnecting them from the hostile outside. Through geo-historical analysis, the authors sought to broaden relational geographies of circulation by focusing on climate control and revealed how these socio-technical processes reshape spatial conditions, practices, and capacities to support "more-than-human" environments.

While decision-makers and experts claim that technologies will improve economic performance and sustainability by enhancing input precision and overall greenhouse management, evidence regarding technologies' contribution to environmental sustainability remains lacking (Broad 2020; Goodman and Minner 2019; Knierim et al., 2019). A handful of studies have conducted life-cycle assessment (LCA) in heated (high-tech) and unheated greenhouse systems, as well as open-field production processes to understand the environmental implications of agriculture products, with some comparing energy, pesticide, and water consumption across different geographic contexts (Muñoz et al. 2008; van der Velden and Jansen, 2004). The carbon footprint assessment of butterhead lettuce cultivation in the Netherlands revealed that vertical farming's carbon footprint (8.177 kgCO2-eq kg^{-1}) was 16.7 times greater than open field (0.490 kgCO2-eq kg^{-1}), 6.8 times greater than soil-based greenhouse horticulture (1.211 kgCO2-eq kg^{-1}) and 5.6 times greater than hydroponic greenhouse horticulture (1.451 kgCO2-eq kg^{-1}) per kg of fresh weight produced (Blom et al., 2022). In a review of 36 LCA studies on the production of fresh tomatoes in greenhouses, Pineda et al. (2021) highlighted that in Northern Europe, where Venlo-type greenhouses made of glass and steel are common, energy demand varies, ranging from 600 to 2,500 MJ/m^2, with the majority of energy consumed for heating, ventilation, and irrigation, particularly during winter. In contrast, unheated greenhouses in the Mediterranean or warmer regions, which typically use plastic coverings, exhibit significantly lower energy requirements, ranging from 0.6 to 3.6 MJ/m^2. A comparison using data from the Ecoinvent 3.10 LCA database on tomato production for fresh consumption indicates that the Netherlands is the leading producer and exporter of tomatoes in heated greenhouses, with a yield of 483 t/ha and a global export share of 13.3 percent. The Netherlands also consumes 1014 m^3/ha of water for irrigation. Spain, ranking third in global exports with a 10.4 percent share, produces 165 t/ha of fresh tomatoes but has a larger water footprint compared to the Netherlands, using 4,748 m^3/ha for irrigation (Ecoinvent, 2024). Despite differences in environmental burdens, CEA—which originally involves the alteration of the natural environment to optimize plant growth and achieve higher yields (Jensen, 2002)—complements open-air systems by leveraging seasonal harvest variations. With the rising energy costs, this complementarity has become increasingly important as many Dutch suppliers source crops from Spain's Almeria and Murcia regions during the winter months (Tong et al., 2024). Capitalizing on the favorable climatic conditions to meet the demands in Europe throughout the year, many Dutch producers, such as AgroCare, have established semi-closed greenhouses in Tunisia and Morocco, despite local resistance and protests (Sijmonsma, 2023).

Enclosed structures are not necessarily impervious, isolated, or fixed; rather the inside (architecture and technologies) extends beyond the greenhouse structure to influence and reconfigure its immediate surrounding while forming part of social, environmental and socioeconomic networks that interact with broader scales, processes, and natures (Biehler and Simon, 2011; Easterling, 2014; Brenner and Katsikis, 2020). As a consequence of globalization, inputs that support greenhouse operations and that were initially provisioned through local resources are increasingly being sourced from different geographic locations. These distant interactions between diverse human, technical, and natural systems have socioeconomic and environmental implications that are often not accounted for (Tonini and Liu, 2017; Liu et al. 2013). Such global networks and their ensuing challenges require the consideration of different geographic locations and scales—beyond the confines of the greenhouse—to attain a better understanding of the flows and metabolic interactions. The complexity of socio-ecological flows and the networked forms of accumulation and infrastructures involved to maintain these technically mediated enclosures dictate that greenhouses are increasingly understood as spatial-temporal or socio-ecological fixes for food production (Ekers and Prudham, 2017; Marvin et al., 2024). Indeed, CEA is inherently infrastructural, and together with digital technologies, bypasses and reconfigures local environments and new contexts, transforming patterns of food production across different scales (Marvin and Rutherford, 2018; Marvin et al., 2024). Overall, CEA and their associated cloud and industrial platforms can potentially reconfigure patterns of urbanization, regulate space, and shift "the consumption, perception, and production of material urban space" (Bauriedl and Strüver, 2020: 270). Against this background, CEA that seek to fulfill the "promise of digital agriculture" (Shepherd et al., 2018) bring to the fore spatial questions that should be further explored by urban planners.

Automation technologies in CEA are profoundly political and are increasingly encouraged to sustain the accumulation of capital. Lockhart and Marvin (2020: 642) argued that automation technologies are adopted in controlled environments transforming the latter into "politically mediated spaces, embedded within broader social processes and uneven production of nature." Analyzing three cases in the city of Sheffield, the authors highlighted the ways in which fragile controlled environments are influenced by the context's political economy in an attempt to shape these areas into enclaves for reproduction and accumulation. From the perspective of agritech firms, Gardezi and Stock (2021) noted that the adoption and use of capital-intensive technologies, are intended to maintain capital accumulation and agritech's hegemony over food production systems. The adoption of automation technologies requires considerable investments and the "securitization of a site" to maintain optimal and completely secured artificial enclosures (Marvin et al., 2024). The concentration of corporate power and the high costs involved in adopting technologies has implied that numerous automated and digital systems mainly cater for the needs of large-scale, wealthy farmers—a phenomenon that profoundly affects small and mid-sized farmers (Rotz et al., 2019). Indeed, digital solutions in agriculture generally and CEA specifically seem to empower agritech suppliers and large-scale, family-owned horticulture holdings and exacerbate the disparities, digital divide, and economic polarization thereby hampering the participation of small and medium-sized firms or pushing them into debt to maintain their competitive advantage (CBS, 2016). The economies of scale along with capital accumulation further enable large capitalist firms to adopt and access automation technologies thus reducing their input costs and exacerbating unsustainable intensification practices (Tilman et al., 2002, Rotz et al., 2019). As a result, low-input small scale firms lag behind the technological race and become largely absent from data development areas. The large amounts of data generated by digital systems are not neutral; they rather reflect power relations, capital accumulation processes and bring to the fore questions regarding ownership, access, and control over data (Pauschinger et al., 2022).

Overall, there is a lack of empirical studies on these emergent socio-technical infrastructures and their role in shaping spatial, environmental, and economic processes. An evaluation of the technical functionalities of these systems is not enough to develop a holistic understanding; rather digital systems and automation technologies should be analyzed through the complex composition and interactions of actors and interests (Pauschinger et al., 2022). While emerging scholarship has explored the technical, social, economic, institutional, and ethical implications of digital technologies in agriculture (Carolan, 2018; Klerkx et al., 2019; Rotz et al., 2019), numerous gaps numerous gaps still warrant attention. These include the role of farmers… the role of farmers (particularly the focus on data-driven management in lieu of hands-on experience), the involvement of new actors in the agriculture sector due to digital opportunities (Carolan, 2020; Broad, 2020; Lioutas et al., 2019), the contribution of new technologies to the deskilling of laborers and the displacement of farm workers, as well as the marginalization of and discrimination against the digitally illiterate or non-adopters (Klerkx et al., 2019). In addition, the reciprocal processes between technologies and the context, particularly farm scale, farmer's role, division of labor, value chain, and knowledge systems are not well understood in urban studies literature.

In a similar vein, the effects of digitalization on value chain actors as well as on sustainability issues remain underexplored. Indeed, despite the pervasiveness of digital technologies, their contribution towards the transition to sustainability is not well addressed in literature (Klerkx et al., 2019; Kneirim et al., 2019). In that regard, empirical studies are further needed to reflect on these "socio-cyber-physical systems" to better conceptualize digital agriculture and sustainability goals (Lioutas et al., 2019; Lockhart and Marvin, 2020) and understand the metabolic processes and flows that bridge otherwise distant yet connected human and ecological realms to support CEA operations (Hull and Liu, 2018). Since the increasing diffusion of automation technologies conditions the spatial logics, materialities and processes of the urban context (Macrorie et al., 2019; Marvin et al., 2024), we explore the issue empirically by focusing on these socio-technical enclosures and artifacts and the ways they shift and produce patterns of urbanization while affecting labor, orchestrating material and resource flows at different scales, and accentuating the division between a technologically intensive inside and a natural outside.

Case Study: Westland

Westland, an agglomeration of several towns, is the Dutch epicenter of horticultural production. In 2004, Westland along with the neighboring Oostland was designated a Greenport. Greenports are defined as concentrated geographical clusters consisting of firms and institutes that support the Dutch horticulture sector (Mann et al., 2011).

Greenhouses occupy more than half of Westland's total area with less than 443 hectares available for their expansion (Compendium voor de Leefomgeving [CLO], 2020). Hosting the highest concentration of greenhouses compared to similar milieus, Westland embodies a large number of vegetable greenhouses (around 37 percent of total greenhouse area), ornamental and floriculture (approximately 32 percent), potted plants (approximately 27.4 percent), as well as seedling and seed (around 3.5 percent) greenhouses and companies (Jannink et al., 2015).

The success of Westland is attributed to its ideal climatic conditions and strategic location, given its proximity to the port of Rotterdam. Complementing greenhouses is a network of physical infrastructure that underpins the distribution of horticulture perishables - including auction houses (most notably Royal Flora Holland), wholesalers, cooperatives, fresh logistics services and agri-business parks for (re)packaging products. As an export-focused cluster, the Greenport (Westland and Oostland) contributes significantly to the national economy with an export value amounting to 5.4 billion euros annually (Greenport West-Holland, 2019a). The newly established Dutch Fresh Port, supports the Greenport and processes 25 percent of Dutch exports (Dutch Fresh Port, 2023).

Sustaining the competitiveness of the Greenport involves the improvement of accessibility to horticultural production areas, freight and agribusiness parks as well as auction facilities. The widening of roads and development of new infrastructure through provincial visions are intended to intricately connect the Greenport to transnational destinations and world markets. With the increasing complexity of distribution systems, many growers have established cooperatives and growers' organizations to evade procurement restrictions of auction houses and wholesalers as well as protect family firms. Others have opted to shorten the supply chain by selling directly to large retailers and supermarkets through fixed-price contracts (Porter et al., 2011). Perishables destined to overseas markets are shipped through containers from Rotterdam's Coolport or through refrigerated compartments at Schiphol airport. Perishables to intra-European markets are transported through refrigerated trucks to preserve their quality and increase shelf life.

Initially a center for grape production, the historical processes of land consolidation, labor displacement, and resource exhaustion in Westland are echoed through successive expansions of the greenhouse cluster as well as through the technological intensification and typological transformation of greenhouses. After World War II, the policies of Sicco Mansholt—the Minister of Agriculture in the post-war Dutch government materialized in the accretion of land parcels, development of new roads, as well as expansion and modernization of the horticulture cluster (Ijsselstijn and van Mil, 2016). Typological shifts in greenhouses reflected through changes that enhanced radiation and enabled growers in Westland to control temperature, sunlight, water, and fertilizer input—necessary components for superior plant growth. With time, small unheated hotbeds gradually gave way to commercial greenhouses with advanced machinery.

Nodal towns developed and the area witnessed additional scale expansions and modernization of the productive premises, particularly with the introduction of machinery and technical improvements. With its designation as a Greenport in 2004, the horticulture cluster acquired an industrial character. Greenhouses in Westland increasingly transformed into knowledge intensive firms that relied on biotech activities and

Information and Communication Technology (ICT) to enhance innovation and productivity in horticulture.

Further precise control and automation of the production processes have been witnessed recently. Bio-stimulants and biological control methods are increasingly used to suppress diseases and increase yields (Marcelis et al., 2019). In addition to biotechnological innovations, ICT tools driven by deep learning and big data improve efficiency by reducing resource use while maximizing yields (Belussi and Sedita, 2008; Hoste et al., 2017). The adoption of IoT enables the collection and exchange of real-time big data with service providers. As an innovative ecosystem, big data and blockchains are expected to drive further developments in the Greenport and support the development of data platforms (Greenport West-Holland, 2019b).

Methodology

To understand the implications of automation on the built environment, we used a mixed methods approach, where qualitative and quantitative data derived from literature, interviews, and spatial analysis were integrated. By means of expansive desk-based research and field visits, a range of documentary material was gathered from different greenhouse production organizations (e.g., potted plants, vegetables, and cut flower firms), horticulture exhibitions and social media platforms to trace the variety of digital agricultural technologies adopted and identify firms that embraced automation technologies. These include promotional brochures, journalistic coverage, reports, videos, etc. Following the collection of grey literature, purposive sampling was used to identify a list of relevant interviewees. A total of 13 semi-structured interviews were conducted: nine of which were with greenhouse representatives, three with high-tech firms and one with a freight firm representative between November 2017 and November 2019 (See Table 1). Our semi-structured interviews focused on the company's history, production processes, resources, and uptake of digital and automation technologies to understand the underlying spatial logics and the implications of socio-technical systems on the greenhouse scale, workers and their skills, as well as capital accumulation and resource input. We generated written summaries of the interviews and coded the summaries thematically around four recurrent themes namely technology, energy, labor, and space. Concurrent to interviews, we visited 15 greenhouses. Our observations

Table 1. Summary of greenhouse firms interviewed

No.	Greenhouse Name	Type of Crop	Number of Branches in Westland	Total Area (ha)
1	Schenkeveld Tomaten	Tomatoes	4	39.98
2	Ter Laak Orchids	Orchids	2	17.90
3	Lans Tomaten	Tomatoes	4	32.69
4	Prominent	Tomatoes	2	17.32
5	Maarel Orchids	Orchids	1	9.49
6	Opti Flor	Orchids	3	17.23
7	Vreugdenhil Young Plants B.V.	Seedlings	3	26.28
8	Deliflor Chrysanten	Chrysanthemums (Seedlings/ Cuttings)	1	7.23
9	Sion Orchids	Orchids	1	6.34

during those visits focused on the implications of technologies on greenhouse practices. We supplemented our findings with existing scholarship and open geo-spatial data on greenhouse age and size (Jannink et al., 2015; Publieke Dienstverlening Op de Kaart [PDOK], 2020) which were used to develop analytical drawings that helped us interpret the spatial dimension of the transition to automated forms of production in greenhouses.

Our approach has several limitations. Despite the small number of interviewees involved, the findings of the study contribute to a better understanding of the Westland horticulture cluster and the implications of technological intensification on the built environment. In addition, the sample mostly included large-scale production firms in order to depict the automated technologies used and understand their implications on space, resources, and labor. During our greenhouse visits, we were given a tour of the facilities; however, we could not engage in extensive periods of observation because of safety and hygienic reasons. The exact number of laborers and the energy requirements of individual firms were not revealed during interviews; rather representatives mostly discussed energy sources and provided approximate numbers of seasonal and permanent workers. Additionally, the precise number of greenhouses employing automated technologies is not conclusive due to the prevalent competitiveness between commercial greenhouses, which hampers access to firms and information. Instead, the number presented in this study is estimated through secondary sources.

Results

Technology and Automated Control Systems in Westland's CEA

Greenhouses adopted technologies to optimize production, scale-up operations, and reduce labor costs. Others tapped into technologies to manage large greenhouses and information, compensate for shortages of skilled labor, and maintain food safety. All greenhouses in our sample embraced mechanisms and layouts from industrial and systems engineering and adopted mechanical machines that substituted workers in simple tasks and robotics or high-tech mechatronics equipped with sensors to handle complex tasks. The scale and intensity of automation in these greenhouses is dependent on the crop type, greenhouse operational volume, and size. Common to all horticulture firms interviewed, the harvesting phase remains reliant on human labor. Whereas tasks such as transplanting, sorting, and packing are extensively automatized (See Figure 1).

Given the scale of their operations, each greenhouse interviewed adopted environmental control and energy efficiency systems including forced ventilation systems as well as a combination of automated retractable or permanent screens to control air humidity inside the greenhouse and enhance light transmission. With increasing pressures to reduce emissions, sensors and monitoring systems are employed to optimize greenhouse parameters and the efficient use of resources. Wireless sensor networks are distributed across the greenhouse to collect information and real-time data that support decision-making processes. These sensors measure the crops' physiological status and rate of assimilation and the greenhouse's relative humidity, carbon dioxide, radiation, and temperature levels. A centralized system, to which all components and sensors are connected, is operated and maintained by high-skilled workers and technicians. Cloud-based decision support systems are recently used to monitor, control,

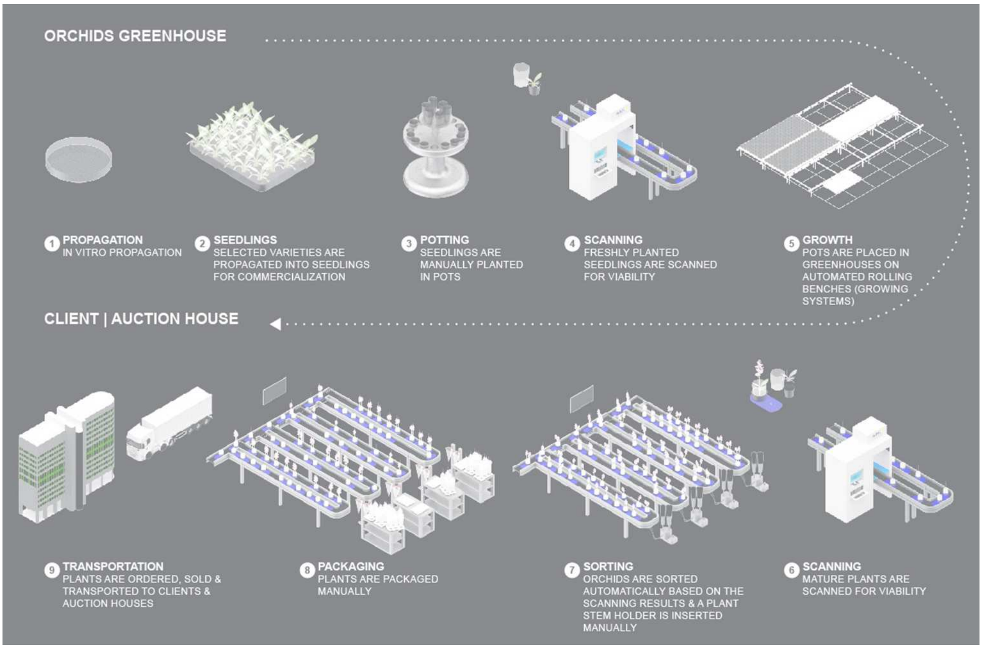

Figure 1. Generalized orchid production steps in a typical Dutch greenhouse involving manual and automated processes

and regulate flows and account for future uncertainties by predicting, simulating, and calculating trade-offs between the inside and the outside. A representative of a company in Westland that specializes in the development of climate control solutions for indoor horticulture, confirmed:

> Each greenhouse is divided into different zones or climate compartments with varying heating and lighting requirements. Through separate management technologies, we cater for the needs of different compartments whether physically isolated or open. One standard software system manages resources, lighting demands, water quality, and nutrient quantities for the different compartments. The grower uses the software to balance the greenhouse ecosystem based on the conditions outside the greenhouse and the costs incurred by resources … The use of integrated packages based on IoT enhances decision-making and improves operational convenience by enabling growers to manage the greenhouse system remotely through apps.

Greenhouses in our sample relied on internal logistic systems, including automated guided vehicles (AGVs) and conveyor belts to reduce the movement of laborers, improve production efficiency, and transport crops from a central growth area to a sorting or packaging station. In potted-plants greenhouses, conveyor belts delivered plants to an imaging unit where morphological characteristics were recorded—a periodic procedure known as automated scanning or phenotyping. Plants that satisfy specific criteria are automatically sorted for delivery. Automated sorting in these greenhouses is achieved with the help of Radio Frequency Identification (RFID) tags embedded in pot holders. Apart from tracking plants inside the greenhouse, RFID tags store data pertaining to each plant. Since space is scarce in Westland, seedling and potted-plant greenhouses embrace automated growing multilevel systems. These technologies consist of large moving trays that hold pots and offer the advantage of optimizing the use of vertical space through stacking. AGVs and overhead cranes transport the trays to and from the growing area. The mobile growing systems involve precision overhead spraying and irrigation, automated cleaners and automated fillers to (un)load the pots to and from a conveyor belt.

Under the guise of improving information management, efficiency, and transparency, productivity monitoring software applications are extensively used in greenhouses for tracking and evaluating the performance of labor. These performance-monitoring technologies prompt competitiveness among seasonal employees by displaying the accomplished work on mounted screens in sorting or packaging areas or by granting access to harvesting workers to track and compare their progress through apps. Inspired by Fordist approaches that seek to exercise labor control and surveillance, these technologies constantly monitor and measure the speed and productivity of workers in real time thereby contributing to rigid organizational structures. As a tomato greenhouse representative emphasizes:

> Workers dial their ID before and after harvesting or packaging. These technologies allow us to locate workers inside the greenhouse and monitor the amount of work and time it takes to perform the activity. Technology enables us to select the most efficient harvester, set goals for the company and bonuses for eligible laborers. They also help us maintain food safety. In case of complaints by retailers, we can track down, through the labor control system, who is responsible for the problem and identify which worker harvested or packed what.

A high-tech enterprise representative added that apart from monitoring the speed, performance, and quality of work done by laborers:

> These systems help stimulate, educate, train, and communicate with workers in different languages to optimize greenhouse production. Laborers in greenhouses become sensors themselves by using these technologies to report and register the growth of diseases and pests. These systems allow owners to develop larger areas of greenhouses with the same number of laborers.

Greenhouses avoid presenting a negative image when tapping into labor monitoring technologies. They confirm that these systems are not punitive; rather they are part of good management practices to review performance and gather information on greenhouse whereabouts and productivity.

Despite competitiveness, greenhouses in our sample seem to value the open culture of innovation in Westland nurtured through government initiatives, research institutions, and organizations. A relevant example is provided by a tomato greenhouse representative who discussed the development of a consortium of greenhouses, tech-firms and research institutions to develop a deleafing robot. Certain growers in our sample take advantage of the open culture to test innovations prior to implementation. One said:

> We make sure that a new machine is tested by four or five growers before us. Based on the efficiency, performance and testing of our competitors, we make a decision to install the machine in our greenhouse.

During interviews, high-tech suppliers noted that automation has further contributed towards specialization of greenhouse production. Historically, greenhouses in Westland cultivated different types of crops. With the proliferation of monoculture, technology was standardized and customized to specific crops. These specialized technologies dictated the internal layout of greenhouses including the number of planting rows, aisles and passages as well as the position of labor in place and time. The ongoing customization of crop-specific technologies to fulfil a particular role limits the potential of greenhouses to develop with future changes in production and consumption patterns, particularly when demand for a certain crop diminishes. This shortfall thus restricts greenhouses' potential for reproduction and accumulation of capital. As an orchid producer notes when asked about the future of greenhouses in Westland:

> The internal layout and technologies used are suited for the growth of orchids and cannot, for example, be used for producing vegetables. Competition in Westland is on the rise and the market is saturated, so we are currently experimenting with different potted plants and new varieties … However, we always wonder will orchids remain in demand in the future. If not, what will happen to all these orchid greenhouses?

Our interviews indicate that environmental control systems and automation technologies are prone by their nature to malfunctions, failures, and obsolescence and thus require monitoring, periodic maintenance, and updates. The periodic updates of digital and industrial platforms incur additional costs and bring about new opportunities for agritech suppliers to provide novel climate services or enforce their service business model that binds greenhouses to ongoing service agreements (lock-in), making it difficult for greenhouse owners to transition to alternative suppliers. Technological failures and repairs also require the intervention of human labor, which is often overlooked or invisible, to adjust machine operations. The disruptions and constant upgrading highlight the persistent challenges in managing CEA as more greenhouse operations become dependent on them (Lockhart and Marvin 2020; Lockhart et al., 2023). The recurrent human intervention required due to malfunction and disruption emphasize the fragility of these systems and their limitations and articulates the need to overcome technological and human–machine interaction challenges in order to be considered reliable enterprises for the future.

In sum, our interviews indicate that greenhouses in Westland are willing to embrace further technologies through different phases of the production process, particularly the harvesting phase which remains resistant to automation. The adoption of technology remains largely uneven and varies geographically and temporally in Westland. While crop-specific technologies generate large profits by optimizing production, they limit the scope of greenhouses and their perspectives of capital reproduction. Productivity monitoring software used in most greenhouses in our sample raises critical questions regarding workers' rights, ethics and privacy. Under the guise of efficiency and speed, monitoring technologies used in indoor horticulture to handle the still necessary human labor devalue work and intensify precarity.

Space

With the scarcity of space, Westland is challenged to accommodate rising housing needs, horticulture productive firms, and their supporting enterprises. The (inter)national competitiveness of the productive cluster conceals rising spatial tensions and challenges pertaining to land scarcity. On one hand, the fierce competition between greenhouses and residential premises for space suppresses the large-scale expansion of greenhouses and constrains Westland's economic and technological viability propelling long-established family-owned firms to move out of the cluster. Faced with the conundrum of spatial constraints, a tomato firm headquartered in Westland, has launched large-scale developments in North Brabant and Zeeland where space is abundant. On the other hand, there is a growing disconnect between greenhouses and residents, who experience the negative implications of the Greenport's growth such as housing shortages, limited spaces for recreation, competition for land, and immigrant labor. These aspects have prompted turn to right wing populist parties, which have capitalized on fears of the "other" and promised to offer solutions to pressing socioeconomic issues in Westland, particularly housing (Hernández-Morales, 2024).

Westland's cluster derives its spatial configuration and arrangement of greenhouses from the underlying polder structure and long-established land consolidation practices. This configuration impedes recent plans to restructure the Greenport. Such a process would be critical for the cluster's long-term competitiveness, growth, and continuity. However, spatial restructuring is also hampered by the scattered private housing and accompanying ownership challenges as well as the varying scales and age of greenhouses.

Conceived as hybrid peri-urban land uses, greenhouses in Westland are mistakenly characterized as rural premises. Throughout the years, they have largely embraced an urban and industrial character. During interviews, greenhouse representatives in our sample denied these erroneous assumptions and appeared to appreciate and take pride in the industrial landscape and character of the cluster. Architecturally, the external structural design and internal layout of greenhouses relies on systematic and quantitative methods that optimize the use of space and increase operational profit and economic efficiency.

While the total productive area is relatively constant, practices of greenhouse and land consolidation, rising competition, and the shift from family-owned to commercial businesses have induced a reduction in the number of firms and materialized in larger greenhouses. This increase in firm size is also attributed to the adoption of automation technologies and the changes in sales channels to direct sales between growers and retailers or supermarkets which have recently gained prominence and largely outcompeted and substituted the prevalent auction system that was dominant in the 1990s (Porter et al., 2011). Except for cut flowers and potted plants which are still traded through auctions, direct supply chains and bulk buying are increasingly common between retailers and large growers, who possess the capacity to manage and handle the processes of logistics and sales (Ingenbleek et al., 2007). However, many large growers remain members of major cooperatives such as Harvest House, Growers United, Prominent Tomaten, and the Dutch Flower Group. Sales organizations and cooperatives, which are major players in Westland, leverage economies of scale and supply chains by streamlining sales from an exclusive network of growers to large retailers.

To counter the large capital investments required to adopt automation technologies and uphold the structural shifts to direct trade streams, growers expanded the planting scale thereby ensuring increased yields and profits. In mapping the ongoing practice of land and greenhouse accretion in Westland, we found that this process not only results in a larger greenhouse footprint but also reduces the number of firms and ultimately increases economies of scale (See Figure 2). Our analysis of geo-spatial and secondary data also revealed a positive correlation between greenhouse size and automation whereby the larger the greenhouse the more likely it employed automation technologies (See Figure 3). Most greenhouses comprising automation technologies are beyond two hectares. Additionally, it was observed that approximately 15 percent of greenhouses in Westland acquired automation technologies and occupied 30 percent of the total productive area. These results are further validated in our interviews where automation was cited as one of the major drivers for expansion. A high-tech supplier in Westland further explains that automation technologies are not implemented in greenhouses with an area less than 0.5 hectares:

> Automation in a 10-hectare greenhouse is more profitable and easier to implement than a five-hectare greenhouse. When automating certain tasks, a larger scale is required to better control operations and gain a higher return on investment.

These findings also align with national tendencies where throughout time, the average size of Dutch greenhouses increased from 0.95 hectares in 2000 to 2.79 hectares in 2019 (Agrimatie, 2020). Compared to 1990, the number of firms in Westland has plummeted from 3,078 (Voskuilen and van Rijswijk, 1997) to 587 greenhouses in 2019 (Wos, 2019).

Through our analysis, we classified greenhouses into three categories based on their size and extent of automation adoption. *Micro-producers*, as we define them, are relatively small greenhouses—less than two hectares—with low investment capacity,

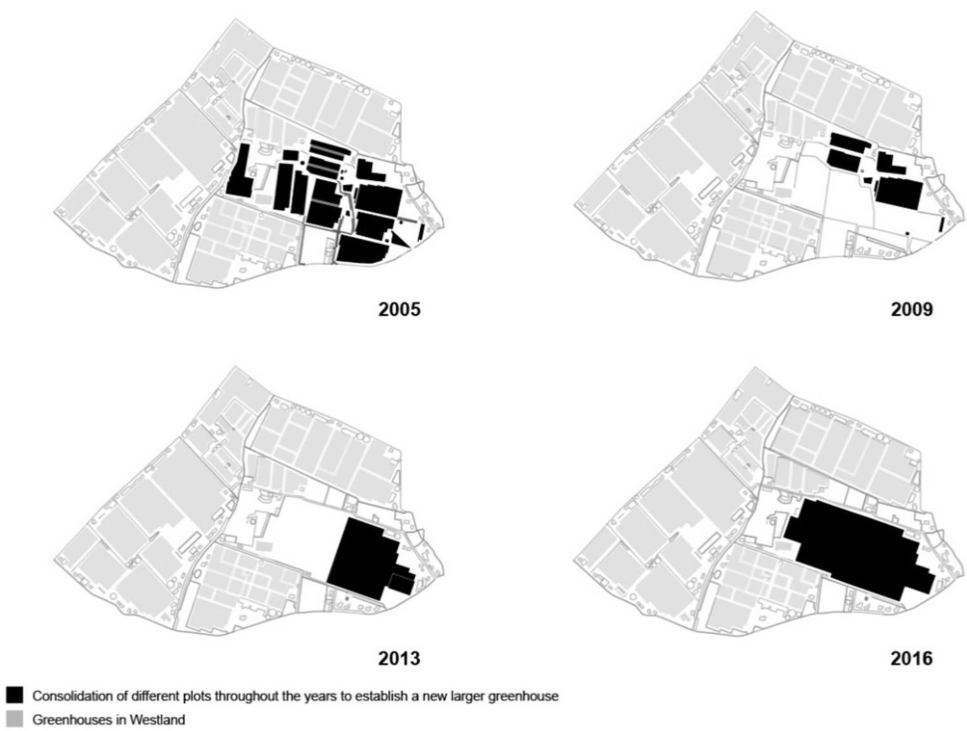

Figure 2. Land and greenhouse consolidation processes over the years in Westland

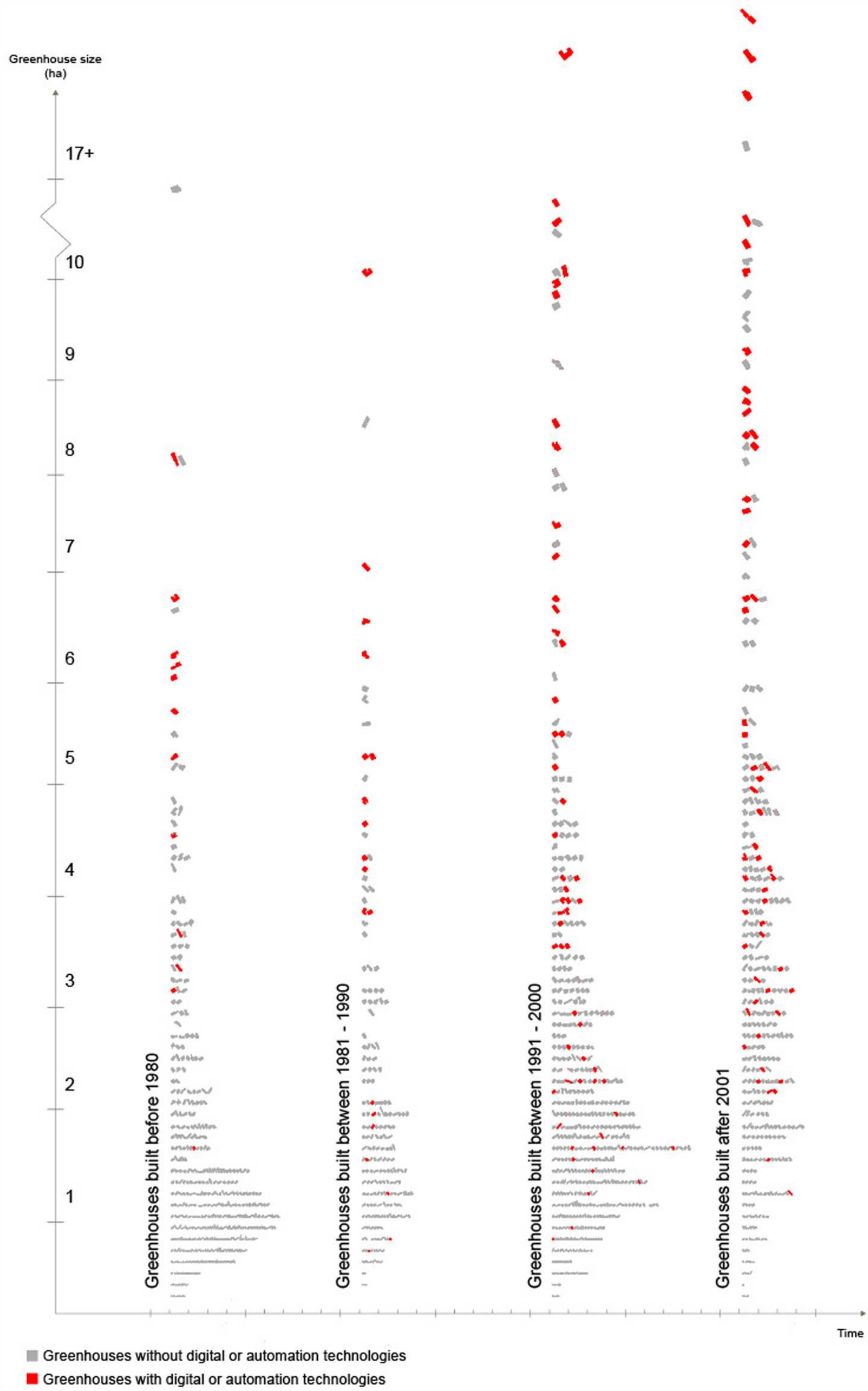

Figure 3. Relationship between greenhouse size and adoption of automation technologies in Westland

minimal number of machines, and limited climate control equipment. They often supply the local region or cooperatives of growers. The firms we refer to as *aspiring producers* are greenhouses that adopted some automation technologies and are between two to five hectares. They have computerized irrigation systems and good climate control equipment with moderate investments in production and digital models. *Global producers* are highly automated greenhouses beyond five hectares with a large production capacity providing global markets, supermarkets, and cooperatives. These are capital and technologically intensive greenhouses with high investments and advanced cultivation and production systems. While some global producers are only reliant on permanent workers, such as large orchid greenhouses, others require substantial numbers of low-skilled seasonal laborers with few permanent high-skilled workers.

By embracing automation, greenhouses have been transformed into complex assemblages of machines and humans. In Westland, a reciprocal correlation exists between greenhouse scale and the uptake of digital and automation technologies. We conclude that, as long as the total productive area remains unchanged, Westland will likely continue to witness a drastic reduction in the number of companies whereby only large-sized greenhouses remain operational. It is likely that this trend will accelerate in the coming years as new automation technologies are adopted, inducing further greenhouse expansion. The competitiveness of the Greenport will dictate further specialization and cheaper products—a practice that will intensify either the concentration of firms, multiplication of spatial products across the landscape, or their relocation outside the cluster. Despite planning policies to contain greenhouse sprawl, the competitiveness of the Greenport and the growers' interests—and thereby capital accumulation—take precedence over calls for housing or those that condemn the growing socio-ecological footprint of greenhouses. As a viable economic region, space and power relations are constantly redefined, incurring deleterious socio-ecological and spatial implications.

Energy

Horticulture infrastructures incur exorbitant energy expenditures to sustain their daily material practices and processes. Energy expenditures in greenhouses are mainly intended for maintaining greenhouse ambient temperature, greenhouse lighting, and machine operation. Dutch greenhouses allocate 75 to 90 percent of the energy for heating and maintaining optimal temperatures for crop production (Montero et al., 2017). Notwithstanding the growing share of renewable energy, the Dutch greenhouse industry accounted for 80 percent of the total energy use in agriculture in 2020 compared with an agricultural output of 69.61 percent (Agrimatie, 2022; CBS, 2022).

Largely contingent upon the crop type and firm size, greenhouses in Westland necessitate different energy requirements and deploy high levels of technological intensity to ensure year-round production. All greenhouse firms interviewed rely on the combustion of natural gas in combined heat and power (CHP) units to meet their energy and heat requirements. Adopted from other industries, Westland has since the 2000s seen the growth and diffusion of CHPs—an innovation that improved energy efficiency and reduced emissions. However, the main reason behind adopting these socio-technical systems is not environmental but rather economic. Perceived as an economic driver of the Dutch economy, greenhouses in Westland received quantity discounts or rebates for the shift to natural gas consumption (Polman et al., 2004). Solvency, firm size, and payback time constituted major drivers for investments. Driven by the need to reduce costs and increase profit, greenhouse firms back then favored CHP technologies over other environmentally friendly systems, with the region's consumption estimated around one billion cubic meters of gas for heating and electricity (Gemeente Westland, 2019).

With rising energy prices and environmental restrictions, high carbon emissions have warranted greater attention to the environmental footprint of greenhouse operations and to the pressing need to invest in energy efficient technologies. Environmental policies, such as dynamic pricing and subsidies, play a role in facilitating transitions to a sustainable cluster by incentivizing the uptake of renewable and clean technologies in horticulture industries. Digitalization and automation technologies are accordingly adopted to mitigate environmental implications, reduce pressures on the ecosystem, and optimize resource consumption. Indeed, greenhouses in our sample are shifting towards investments in energy-saving technologies to reduce costs where a representative of an orchid greenhouse explains the firm's recent transition to geothermal energy:

> Along with CHPs, all of our branches are connected to a geothermal heating system. Currently, around 50 percent of our energy usage is provisioned though sustainable sources. This helps us save natural gas and reduces our emissions per square meter.

Energy saving innovations and renewable sources used in Westland include heat storage systems, heat pumps, heat deliveries, use of multiple screens (permanent or movable), double coverings as well as geothermal, wind, and solar energy. Screens and coatings are aimed at maximizing the use of sunlight and light transmission, preventing energy loss through improved insulation, increasing energy efficiency and energy use to support crop production and management (Pekkeriet et al., 2015). The combination of the sophisticated, hidden, and automated environmental control systems recreates and precisely maintains an internal artificial microclimate suitable for the plant's optimal growth yet distinct from the climatic conditions of a natural outside. While environmental control systems save energy, automation technologies along the production process increase its consumption, particularly with the scaling up of greenhouses which further intensifies demand. A high-tech representative exemplifies these countering tendencies:

> Investing in environmental control systems saves energy compared to traditional greenhouses. However, automation technologies require a certain amount of energy to move plants inside the greenhouse while facilitating the production of a higher number of plants per square meter. These technologies reduce production costs by 10 percent and increase energy expenses by 2 percent which gives the grower a net gain of 8 percent.

Contributing towards a transition to a circular economy, the Organic Carbon dioxide for Assimilation of Plants (OCAP), partnered with greenhouses in Westland to supply the latter with pure CO_2 resulting from industrial processes at the Port of Rotterdam (Ros et al., 2014). Through a former oil pipeline, CO_2 is supplied partially covering Westland's cluster where 89 percent of greenhouses in our sample benefit from this synergetic model. The supply of CO_2 contributes to net reductions of carbon emissions and minimizes the use of natural gas. However, further reductions are harder to achieve, as confirmed by different interviewees, since the demand for CO_2 is seasonal.

Energy expenditures in Westland expand across operations and infrastructures beyond greenhouses. An assemblage of food and packaging companies, auction houses, trade and retailers run expansive cooling and chilling storage facilities to maintain perishable horticultural products at designated temperatures before shipment worldwide. Maintaining the temperature of these ancillary infrastructures entails transnational flows and metabolizations. In this regard, greenhouses in Westland harbor a dynamic network of "metabolic socio-environmental processes" (Swyngedouw and Heynen, 2003: 900) that exhausts local and contextual material landscapes. With gas fields in Groningen nearing depletion, Westland relies on imports of liquified natural gas from Russia and Norway. These findings suggest that energy-intensive operations in Westland and their resulting environmental implications contradict the Greenport's disposition as a sustainable model and its vision to attain climate neutral greenhouses. In the short term, these intensive operations sustain the Greenport economically due to the long payback time of renewable and sustainable investments.

To portray themselves as advanced reliable enterprises, most greenhouse owners during interviews boasted about the various technological innovations adopted and the ways in which the latter supports the greenhouses in reducing their impact on the environment. For example, most vegetable greenhouses in our sample discussed precise fertilizer dosing and water recycling systems used to reduce their water footprint. As part of its corporate identity, an orchid grower interviewed has sought to market his greenhouse as a sustainable company through certifications emphasizing the transparency of its practices. Under the guise of sustainability, horticulture enterprises in Westland are compelled to adhere to new forms of accumulation due to stringent regulations and their own interests to exhibit high corporate social responsibility. They seek to portray a positive image by presenting narratives of circularity. However, these alternative approaches are largely profit-driven. In light of their compliance with stringent regulations towards reducing emissions and the parallel rising risks in energy markets, our interviews suggest that horticultural firms in Westland will be prudent and keen to adopt newer innovations and alternative frontiers of accumulation.

Labor

Infrastructuralized enclosures in Westland are predicated on the mobilization of human labor. With the accession of Central and Eastern European countries to the European Union in 2004, greenhouses were replenished with recruits of cheap seasonal labor as local labor was reluctant to perform tedious repetitive tasks. Despite recent substitutions by automation technologies, foreign labor remains indispensable particularly for operations that require dexterous abilities to handle the fragility of the perishable crops and anomalies of the greenhouse environment. To maximize profit and maintain their competitive advantage, growers interviewed sought to keep labor costs to a minimum as the latter constitutes a significant portion of the total operational and production costs. In this regard, some greenhouses adopted new technologies to reduce the number of low-skilled immigrant labor. Others offshored tasks to areas with widespread availability of low-cost labor and inadequate enforcement of environmental regulations. For example, the largest chrysanthemum breeder in Westland, discussed its global breeding sites in Africa where new breeds are mass-propagated and cuttings are manually harvested from mature plants in production facilities abroad.

Greenhouses interviewed reflected labor market duality where workers with fixed contracts occupy managerial and administrative positions—most of whom are domestic workers employed at higher wages and constitute a small percentage of the workforce—compared to "flex workers" who constitute the majority of the workforce and are largely foreigners.

A tomato greenhouse representative confirmed that:

> Three to four highly skilled workers are only required per each branch whereas approximately 100 temporary workers are employed through different agencies in Westland. Each 10 hectares of production requires four workers for packaging, weighing, and sorting tomatoes. However, five to six laborers are needed during peak times.

The surplus of transient and dispensable workers and the fierce competition have encouraged precarious work and often illegal employment practices. This perpetual precarious process that seeks short-term contracts frees greenhouse owners from providing lifetime job security and paying annual salary increments. However, it imposes pressures and challenges such as uncertainty of labor and the training of inexperienced flex workers when each season arrives. This structural challenge is overcome by technological advancements that substitute for human labor as confirmed by a highly automated orchid greenhouse:

> Most employees are required for the packaging and no laborers are needed anymore inside the growth areas. Substituting labor for technologies in the growth chambers eliminates the need for aisles and increases the number of plants per square meter. To avoid challenges associated with flex contracts, we only employ permanent workers … around 70. Even during peak hours, temporary workers are not employed. Instead, employees are requested to work for longer periods of time.

As growers isolate migrant workers away from production processes, the prospects of receiving training are limited (Siegmann et al., 2022). In contrast, skill reproduction security is high for highly skilled workers with higher paid jobs. The training of high-skilled workers is part of the green education and is conducted through various agricultural education and training centers such as the Wageningen University and Research Centre (WUR), that works with industry partners and focuses on knowledge valorization, the Aeres Training Center through its PTC + Program and the HortiTech Innovation Traineeship, which was recently launched by TNO, AVAG and HortiHeroes (Caggiano, 2014).

The declining number of laborers due to automation, as derived from our interviews, is also evident in the greenhouse horticulture sector across the Netherlands which has seen a reduction of approximately 30 percent in the total annual work unit (AWU) between 2000 and 2018 (Agrimatie, 2019). Apart from automation technologies that substitute for labor, an interviewee attributes the decline to current stringent immigration policies that discourage the channeling of low-wage labor and induce a shortage. In addition to the increasing greenhouse size, some growers interviewed noted the lack of timely access to seasonal unskilled labor and expanding job opportunities for family members beyond the agriculture sector as further reasons for the declining workforce and incentives that prompt firms to adopt new technologies. A high-tech firm noted that the combination of technologies including automated control systems may help growers save up to 80 percent of labor compared to the traditional greenhouse.

Overall, our interviews indicate that the diffusion of automation technologies in greenhouses largely substitutes for low-skilled tasks—which are widely undertaken by foreigners, particularly women. Similar to technologies, labor in greenhouses remains hidden. The invisibility, seasonality, flexibility, and division of labor devalue work and intensify precarity. In view of the high number of temporary workers employed, labor-intensive vegetable firms in our sample appear to be the most eager to embrace automation technologies to reduce the number of low-skilled workers and production

Table 2. Summary of the main findings

Technology	Space	Energy	Labor
- Main reasons to adopt digital and automated technologies include optimizing production processes; scaling-up operations; reducing labor costs; managing information; improving decision-making and maintaining food safety. - The harvesting phase is not automated. - A combination of hardware and cloud platforms are used to collect information and real-time data and support decision-making processes. - Technologies prompted further specialization of greenhouse production. - Crop specific technologies restrict greenhouses in transforming their production processes according to changes in consumption patterns	- Land scarcity in Westland engenders competition between greenhouses and other uses. It hampers the expansion of greenhouses and expels long-established firms out of the Greenport. - Historical consolidation practices and the underlying polder structure have dictated the Greenport's spatial configuration and restricts restructuring processes. - A reciprocal correlation exists between greenhouse scale and the adoption of automation technologies. - Greenhouses in Westland can be classified into three categories according to their scale and investment capacity in automation and digital technologies, namely micro-producers; aspiring producers; and global producers.	- Most greenhouses in Westland rely on CHP units for their energy and heat requirements. - A combination of CHP and energy saving technologies are used not only to reduce emissions but mainly for economic reasons. - The uptake of automation technologies intensifies energy consumption. - Automated environmental control systems emphasize the schism between an internal artificial microclimate suitable for the plant's optimal growth and the climatic conditions of a natural outside. - Greenhouses in Westland are supported by networked metabolic processes that exhaust distant ecological realms. - Under the guise of sustainability and corporate social responsibility, investments in automation technologies are intended to adhere to stringent regulations and to maintain the economic interests and capital accumulation of greenhouses.	- Labor costs constitute a significant portion of the total operational and production costs and thus greenhouses in Westland recruit cheap seasonal labor to maximize profit and maintain competition. - Many greenhouses in Westland adopted new technologies to reduce the number of low-skilled laborers. Others offshored tasks to Africa or South America where labor costs are low. - Observations and interviews revealed that labor market duality characterizes most greenhouses in Westland. - Immigration policies, lack of timely access to seasonal labor, increasing greenhouse size and expanding job opportunities for family members beyond the agriculture sector are major drivers for the adoption of technologies. - The invisibility, seasonality, flexibility, and division of labor in Westland devalue work and intensify precarity

costs and improve their competitiveness globally. In sum, Westland is not only underpinned by global resource flows and material processes but necessitates the circulation of human capital to sustain its infrastructures.

Discussion and Conclusion

Through empirical observations, this article depicted the ways in which automated and digital infrastructures in Westland reconfigure the built environment. It emphasized capital's role in shaping Westland's spatial, social and environmental conditions while intensifying technological diffusion. We drew from semi-structured interviews and field visits of horticulture firms in Westland, to offer an in-depth understanding of the socio-spatial and socio-environmental implications of automation technologies. We supplemented the data obtained from interviews with our analysis of secondary sources and open geospatial data. Overall, Westland can be characterized as a dynamic and rationally optimized ecosystem of highly specialized actors which continuously push technological innovations to adapt to changing demands by consumers, the government, and society at large. Insights from industrial and systems engineering guide the layout and internal flows of contemporary greenhouses, and automated solutions impose new demands in terms of greenhouse size. Greenhouse automation—in the form of mechanization of simple tasks, software, sensors, and advanced, flexible robotics—is widely seen as the key to reducing resource use and labor, the sector's highest cost contributors.

Data derived from interviews and secondary sources revealed that each of the identified types of greenhouse producers exhibits a varying technological intensity. Global producers, particularly vegetable firms, seem to prompt further innovations and high-tech solutions to reduce low-skilled labor. Their voracity to scale-up operations is largely dependent on the availability of space and the need to increase their return on investment. Due to their saturation and high technological intensity, global producers do not generate new long-term job opportunities since few high-skilled personnel are required to manage the greenhouse. Despite their desire to expand and scale operations, aspiring and micro producers appear to be unable to keep up with the ongoing competition largely due to solvency and their limited technological intensity. These producers will likely remain small or medium-sized firms with the possibility of being acquired in the future by global producers who are in dire need of space in Westland. This practice will increase economies of scale and exacerbate inequalities in the cluster. These findings align with various scholars who confirmed greenhouses' voracious consumption of land —a "horizontal pollution" to the idyllic Dutch landscape—and encroachment on residential areas (Mann et al., 2011; Altes and van Rij, 2013).

The increasing digitalization and infrastructuralization in Westland are transforming controlled growth environments into assemblies of privatized hardware and software components that reinforce inequalities of labor and extend into the built environment to create selective and exclusive spaces, produce uneven patterns of urbanization, and orchestrate urban flows, resources, and actors. The increasing gentrification, tensions between production premises and housing and capital intensity in Westland confirm the findings of Carolan (2020) who concluded that digital technologies are associated with material gentrification and capital concentration.

Through our greenhouse visits, the dualism between well-paid, high-skilled workers (mostly men) and insecure, low-skilled laborers, mainly women and migrants, is striking. Correspondingly, automation and digital technologies in Westland, like digital platforms, produce unbalanced power relations and intensify the gendered division of labor. These findings support conclusions by Klerkx et al. (2019) who called for future research to explore the implications of digitalization in agriculture on gender issues. Overall, labor remains a central component for accumulation (Harvey 2000; Smith, 2007).

As automation technologies cannot yet replace certain forms of labor in greenhouses, flexible and seasonal human labor and monitoring systems are a widespread tendency. The prevalence of precarious work, labor flexibility, illegal employment and exploitation regimes earned Dutch greenhouses a negative public image (Kroon and Paauwe, 2014) as the media increasingly reported these practices as “reminders of slavery” (Basekin and Mos, 2017: 1). Labor in these enclosed microclimates remains largely hidden which increases tendencies to devalue work and worsen precarity and exploitation, raising questions regarding the sustainability of the sector. Crisis of public image and policies on minimum wage and immigration are thus expected to contribute to widespread diffusion of automated technologies in the future.

Our results also echoed the work of Kneirim et al. (2019) who found through interviews and surveys of German farmers that farm size affects the uptake of digital technologies given the farm’s capacity to invest. Aside from costs, which is also an impediment that hampers the adoption of technologies in Westland, the authors cited missing standards that facilitate the exchange of data between different systems; limited farmers’ knowledge; and lack of communication between suppliers and farmers as barriers to the uptake of technology (Kneirim et al., 2019).

As spaces of production, automated greenhouses, through their scalable operations, are involved not only in the production of commodities but also of space. Accordingly, greenhouses are transforming into yet another “milieu of accumulation, of growth, of commodities, of money, of capital” (Lefebvre, 1991, as cited in Sadowski, 2020) where automation technologies leverage the new logics and mutations of capital. Additionally, the relocation of greenhouses outside the cluster, the offshoring of tasks to countries with low labor costs, and the drafting of gas from other countries testify to the transnational reach of Westland and its global network of metabolic flows and material processes that reinforce the accumulation of capital. Indeed, digital and automation technologies entail networked material flows that are often connected to distant human and natural systems. Since distant forces and interactions are considered as exogenous factors, their profound implications on the sustainability of various localities are often not well addressed (Liu et al., 2013; Swyngedouw 2013). The geographic distance often emphasizes the invisibility of socioeconomic and environmental ramifications strengthening further the distinction between CEA’s enclosed artificial inside and a remote outside. With the rise of eco-certifications and sustainable sourcing guidelines, future research could adopt analytical approaches to further understand the role of automation technologies and CEA in curating distant socioeconomic and environmental interactions and their implications on sustainability at the local and global scales.

Findings from our interviews highlight ongoing limitations and contradictions in the utilization of technology and energy in controlled environments. The fragility of automation technologies is a prime example that emphasizes the limitations of these socio-technical systems due to the recurrent human intervention required—a finding that has been previously proffered in literature (Lockhart and Marvin, 2020; Muñoz Sanz, 2017). These breakdowns underline the technological challenges that still need to be overcome to consider greenhouses as sustainable models for future food production. While conducing greenhouses to specialization and increasing profits, automation technologies serve a particular role and are thus limited in their scope. More specifically, crop-specific technologies restrict the potential of horticulture firms in Westland to shift production patterns and thus constrain the (re)production of capital. The increasing specialization and the development of crop-specific technologies are driven by market forces and contribute to further rationalization. While crop-specific technologies help firms customize their practices, the capital-intensive top-down systems weaken agro-ecological production systems, disempower firms through their adoption, and restrict conversion to other forms of production given the high investments required. As each technology attends to a specific issue or task, a bundle or package of technologies is often required to optimize operations thereby increasing costs and impeding change. Future research could further explore the implications of increasing specialization, crop-specific technologies, and technological challenges in a firm's long-term sustainability and risk management plans.

Additionally, automation technologies, particularly environmental control systems, emphasize distinctions between an enclosed artificial inside and a natural outside. Demands for higher energy efficiency and reduced CO_2 emissions necessitate the adoption of innovations that further the infrastructuralization of urban space and firm consolidation. This diffusion of automation technologies, under the pretext of sustainability and efficiency, intensifies the use of resources in Westland due to economies of scale. Referred to as Jevon's Paradox (Alcott, 2005), the ongoing sustainable intensification in Westland increases energy expenses given the growing scale of greenhouse operations, thereby countering efficiency gains from "resource saving" technologies. With stringent regulations, greenhouses' sustainability narratives are largely profit driven. Economically, they cannot yet fully shift to sustainable and alternative forms of production and consumption. These results confirm the findings of Broad (2020; 14) who in examining the case of Square Roots, an indoor vertical farming enterprise in Brooklyn, New York, noted that buzzwords, claims of corporate sustainability and myths of transparency often conceal selective organizational practices, disclose certain information, and "downplay aspects of reality." The author's findings also supported conclusions that technological systems in CEA incur exorbitant energy costs and that CEA are not possibly capable of surpassing economic and technological challenges that limit its potential as a future sustainable option (Broad, 2020).

With ideal climatic conditions and location, Westland is the landscape where interdependencies between human–machine ecologies and metabolic flows- for sustaining capital accumulation and the competitiveness of the sector- materialize around a permanent struggle for land, energy, and labor. As planning policies restrict the increase of land for industrial horticulture, the cluster's economic and technological viability is constrained, inducing both a process of business and land consolidation to make space for large-sized automated greenhouses, and a trend of firm migration to other national or international clusters. This constraint and constant reliance on horticultural firms renders Westland a fragile ecosystem and an unsustainable model.

As radical climate variations challenge agriculture to meet future food demands, automated controlled environments emerge as a partial alternative for intensive food production. Our findings suggest that planners should warrant greater attention to socio-technical shifts and their spatial and environmental implications on the larger scale. Our results support the premise that automation technologies affect the scalability of structures and increase the need for space while generating economic gains that are unevenly distributed (Carolan 2020; Kneirim et al., 2019). Planners in collaboration with relevant stakeholders should consider policies that: optimize the use of space through innovative mixed-use approaches, address employment opportunities particularly for vulnerable groups, prompt synergies between horticulture firms and other uses by providing necessary infrastructure, and spur innovations to sustain the economic development of Westland and its transition to a circular economy.

Despite its global leading position, Dutch horticulture is in need of further innovation and a transition towards sustainable food production. While the diffusion of robotic and automation technologies is accelerating, these socio-technical systems have brought about hefty environmental consequences, labor disparities, and new forms of governance. With firms diffusing these technologies globally, additional readings of these automated landscapes which do not omit their broader ecological dimension—the outside—are required.

Acknowledgments

The authors sincerely acknowledge the constructive comments of three anonymous reviewers which substantially improved the quality of the article. The authors would also like to thank all greenhouse owners interviewed for allowing us into their facilities to understand and document different operations. The authors are also grateful for Dr. Anisul Islam for his insightful discussions on horticultural production practices and for Marina Otero Verzier, Marten Kuijpers and the team at Nieuwe Instituut for their support during the earlier stages of the project.

Disclosure Statement

No potential conflict of interest was reported by the author(s).

Notes on Contributors

Grace Abou Jaoude is a research associate at the Institute for Sustainable Urbanism at the Technical University of Braunschweig. Her research focuses on scenario planning methods and urban manufacturing.

Víctor Muñoz Sanz is an assistant professor in the Department of Urbanism of Delft University of Technology. His research examines the architecture and urbanism of the past, present, and future of work. Since 2024, he co-leads the Critical Environments research group.

ORCID

Grace Abou Jaoude http://orcid.org/0000-0001-6570-7988
Víctor Muñoz Sanz https://orcid.org/0000-0002-9604-0925

References

B. Alcott, “Jevons’ paradox,” *Ecological Economics* 54: 1 (2005) 9–21.

Agrimatie, “Arbeid,” *Wageningen University and Research* (2019) https://www.agrimatie.nl/ThemaResultaat.aspx?subpubID=2290&themaID=2264&sectorID=7228&indicatorID=2078 Accessed November 16, 2020.

Agrimatie, “Area Under Greenhouse Cultivation,” *Wageningen University and Research* (2020) https://www.agrimatie.nl/ThemaResultaat.aspx?subpubID=2290&themaID=2286 Accessed November 16, 2020.

Agrimatie, “Netto-energiegebruik land- en tuinbouw licht gestegen,” *Wageningen University and Research* (2022) https://www.agrimatie.nl/ThemaResultaat.aspx?subpubID=2232&themaID=2273. .Accessed May 16, 2023.

W. K. K. Altes and E. van Rij, “Planning the Horticultural Sector: Managing Greenhouse Sprawl in the Netherlands,” *Land Use Policy* 31 (2013) 486–497.

AMO and R. Koolhaas, *Countryside: A Report* (Cologne: Taschen, 2020).

S. Bauriedl and A. Strüver, “Platform Urbanism: Technocapitalist Production of Private and Public Spaces,” *Urban Planning* 5: 4 (2020) 267–276.

E. Basekin and B. Mos, “Roofbouw in de Kassen. De Telegraaf,” *Telegraaf* (November 4, 2017) https://www.telegraaf.nl/nieuws/1050155/roofbouw-in-de-kassen. Accessed October 15, 2020.

F. Belussi, and S. R. Sedita, “The Symbiotic Division of Labour Between Heterogeneous Districts in the Dutch and Italian Horticultural Industry,” *Urban Studies* 45: 13 (2008): 2715–2734.

D. Biehler and G.L. Simon, “The Great Indoors: Research Frontiers on Indoor Environments as Active Political-Ecological Spaces,” *Progress in Human Geography* 35: 2 (2011) 172–192.

T. Blom, A. Jenkins, R. M. Pulselli, and A. A. J. F. Van den Dobbelsteen. “The Embodied Carbon Emissions of Lettuce Production in Vertical Farming,: Greenhouse Horticulture, and Open-Field Farming in the Netherlands,” *Journal of Cleaner Production* 377 (2022) 134443.

G. M. Broad, “Know Your Indoor Farmer: Square Roots, Techno-Local Food, and Transparency as Publicity,” *American Behavioral Scientist* 64: 11 (2020) 1588–1606.

N. Brenner and N. Katsikis, “Operational Landscapes: Hinterlands of the Capitalocene,” *Architectural Design* 90 (2020) 22–31.

M. Caggiano, “AKIS and Advisory Services in The Netherlands Report for the AKIS Inventory (WP3) of the PRO AKIS Project,” (2014) https://430a.uni-hohenheim.de/fileadmin/einrichtungen/430a/PRO_AKIS/Country_Reports/Country_report_Netherlands_final_15_05_2014.pdf. Accessed March 18, 2023.

M. Carolan, “‘Smart’ farming Techniques as Political Ontology: Access, Sovereignty and the Performance of Neoliberal and Not-So-Neoliberal Worlds,” *Sociologia Ruralis* 58: 4 (2018) 745–764.

M. Carolan, “Urban Farming is Going High Tech” Digital Urban Agriculture’s Links to Gentrification and Land Use,” *Journal of the American Planning Association* 86: 1 (2020) 47–59.

CBS, “Landbouw; output goederen en diensten, nationale rekeningen Gewijzigd” (2022) <https://opendata.cbs.nl/statline/#/CBS/nl/dataset/84299NED/table?dl=6ECB9> Accessed May 16, 2023.

CBS, “Veel vreemd vermogen in tuinbouw” (2016) <https://www.cbs.nl/nl-nl/achtergrond/2016/03/veel-vreemd-vermogen-in-tuinbouw>.: Accessed October 25, 2024.

J. H. Chuang, J. H. Wang, and C. Liang, “Implementation of Internet of Things Depends on Intention: Young Farmers’ Willingness to Accept Innovative Technology,” *International Food and Agribusiness Management Review* 23: 2 (2020) 253–266.

CLO, “Land- en tuinbouw: ruimtelijke spreiding, grondgebruik en aantal bedrijven, 1980–2019,” (2020) https://www.clo.nl/indicatoren/nl2119-agrarisch-grondgebruik. Accessed January 15, 2021.

M. S. Dawkins, “Animal Welfare and Efficient Farming: Is Conflict Inevitable?,” *Animal Production Science* 57: 2 (2016) 201–208.

D. Despommier, “The Vertical Farm: Controlled Environment Agriculture Carried out in Tall Buildings Would Create Greater Food Safety and Security For Large Urban Populations,” *Journal für Verbraucherschutz und Lebensmittelsicherheit* 6 (2011) 233–236.

A. Dsouza, L. Newman, T. Graham, and E. D. G. Fraser, "Exploring the Landscape of Controlled Environment Agriculture Research: A Systematic Scoping Review of Trends and Topics," *Agricultural Systems* 209 (2023): 103673.

Dutch Fresh Port, "Over Dutch Fresh Port: Samenwerken in het grootste Agro-Vers-Food cluster van Nederland," (2023) https://www.dutchfreshport.eu/dutch-fresh-port/over-dutch-fresh-port/. Accessed July 28, 2023.

K. Easterling, *Extrastatecraft: The Power of Infrastructure Space* (London: Verso, 2014).

M. Ekers and S. Prudham, "The Metabolism of Socioecological Fixes: Capital Switching, Spatial Fixes, and the Production of Nature," *Annals of the American Association of Geographers* 107: 6 (2017) 1370–1388.

M. Gardezi and R. Stock, "Growing Algorithmic Governmentality: Interrogating the Social Construction of Trust in Precision Agriculture," *Journal of Rural Studies* 84 (2021): 1–11.

G. Giacomelli, N. Castilla, E. van Henten, D. Mears, and S. Sase, "Innovation in Greenhouse Engineering," *Acta Horticulturae* 801 (2008) 75–88.

C. M. Geilfus, *Controlled Environment Horticulture: Improving Quality of Vegetables and Medicinal Plants* (Switzerland: Springer Nature Switzerland, 2019).

Gemeente Westland, "Westlandse Energie Opgave: Deel 1 Strategie" (2019) <https://www.woonwijzerwinkel.nl/wp-content/uploads/2022/05/Westlandse-Energie-Opgave-19-0266745-1.pdf> Accessed 25 October, 2024.

W. Goodman and J. Minner, "Will the Urban Agricultural Revolution be Vertical and Soilless? A Case Study of Controlled Environment Agriculture in New York City," *Land Use Policy* 83 (2019) 160–173.

Greenport West-Holland, "Welcome to Greenport West-Holland" (2019a) https://greenportwestholland.nl/en/about/. Accessed October 19, 2020.

Greenport West-Holland, "Programme 2019–2025: A Leading Region in Health and Happiness" (2019b) https://greenportwestholland.nl/en/about/. Accessed May 29, 2023.

D. Harvey, *Spaces of Hope* (Edinburgh: Edinburgh University Press, 2000).

A. Hernández-Morales, "Living Cities: The Dutch Far Right Takes on Housing," *Politico* (June 20, 2024) <https://www.politico.eu/newsletter/global-policy-lab/living-cities-the-dutch-far-right-takes-on-housing/>.: Accessed September 4, 2024.

V. Hull, and J. Liu, "Telecoupling: A New Frontier for Global Sustainability," *Ecology and Society* 23: 4 (2018) 41.

R. Hoste, H. Suh and H. Kortste. *Smart Farming in Pig Production and Greenhouse Horticulture; An Inventory in The Netherlands*. (Wageningen: Wageningen University and Research, 2017).

M. Ijsselstijn and Y.: van Mil, *Atlas van het Westland: 10.000 Jaar ruimtelijke ontwikkeling* (Bussum: Uitgeverij Thoth, 2016).

P. T. M. Ingenbleek, P. Ederer and J. Christensen, "Flora Holland Flower Auctions: A Dutch Merger in the Face of Globalization" (*Wageningen: European Food and Agribusiness Seminar, Wageningen University*, 2007).

P. Jannink, S. van Wijk, and H. Coumou, *Gebiedsfoto Westland – Oostland: De greenport in beeld*. (Amsterdam: MUST Stedebouw, 2015).

L. Klerkx, E.: Jakku, and P. Labarthe, "A Review of Social Science on Digital Agriculture, Smart Farming and Agriculture 4.0: New Contributions and a Future Research Agenda," *NJAS-Wageningen Journal of Life Sciences* 90–91: 1 (2019) 100315.

A. Knierim, M. Kernecker, K. Erdle, T. Kraus, F. Borges and A. Wurbs, "Smart Farming Technology Innovations – Insights and Reflections from the German Smart-AKIS Hub," *NJAS: Wageningen Journal of Life Sciences* 90–91: 1 (2019) 100314.

B. Kroon and J. Paauwe, "Structuration of Precarious Employment in Economically Constrained Firms: The Case of Dutch Agriculture," *Human Resource Management Journal* 24: 1 (2014) 19–37.

A. Lockhart and S. Marvin, "Microclimates of Urban Reproduction: The Limits of Automating Environmental Control," *Antipode* 52: 3 (2020) 637–659.

E.D. Lioutas, C. Charatsari, G. La Rocca, and M. De Rosa, "Key Questions on the Use of Big Data in Farming: An Activity Theory Approach," *NJAS-Wageningen Journal of Life Sciences* 90–91: 1 (2019) 1–12.

J. Liu, V. Hull, M. Batistella, R. DeFries, T. Dietz, F. Fu, T. W. Hertel et al., "Framing Sustainability in a Telecoupled World," *Ecology and Society* 18: 2 (2013) 26.
R. Macrorie, S. Marvin, and A. While, "Robotics and Automation in the City: A Research Agenda," *Urban Geography* 42: 2 (2019) 197–217.
F. Maffezzoli, M. Ardolino, A. Bacchetti, M. Perona, and F. Renga, "Agriculture 4.0: A Systematic Literature Review on the Paradigm, Technologies and Benefits," *Futures* 142 (2022): 102998.
S. Mann, A. Breukers, J. Schweiger, and G. Mack, "Greenhouse Vegetable Production in The Netherlands and Switzerland: A Grounded Look at Sector Competitiveness," *Competitiveness Review* 21: 4 (2011) 339–351.
L.FM. Marcelis, J.M. Costa, and E. Heuvelink, "Achieving Sustainable Greenhouse Production: Present Status, Recent Advances and Future Developments," in L.F.M. Marcelis and E. Heuvelink, eds., *Achieving Sustainable Greenhouse Cultivation* (Cambridge: Burleigh Dodds Science Publishing) (2019). 1–14.
S. Marvin, "Volumetric Urbanism: Artificial 'Outsides' Reassembled 'Inside'," in O.: Coutard and J. Rutherford, eds., *Beyond the Networked City: Infrastructure Reconfigurations and Urban Change in the North and South* (Abingdon: Routledge, 2015) 227–241.
S. Marvin, L. Rickards, and J. Rutherford "The Urbanisation of Controlled Environment Agriculture: Why Does it Matter for Urban Studies?," *Urban Studies* 61: 8 (2024) 1430–1450.
S. Marvin and J. Rutherford, "Controlled Environments: An Urban Research Agenda on Microclimatic Enclosure," *Urban Studies* 55: 6 (2018) 1143–1162.
L. McCartney and M. Lefsrud. "Protected Agriculture in Extreme Environments: A Review of Controlled Environment Agriculture in Tropical,: Arid, Polar, and Urban Locations," *Applied Engineering in Agriculture* 34: 2 (2018) 455–473.
J. I. Montero, E.J. van Henten, J.E. Son, and N. Castilla, "Greenhouse Engineering: New Technologies and Approaches," *Acta Horticulturae* 893 (2011) 51–63.
J. I. Montero, P. Munoz, E. Baeza, and C. Stanghellini, "Ongoing Developments in Greenhouse Climate Control," *Acta Horticulturae* 1182 (2017) 1–14.
J. W. Moore, *Capitalism in the Web of Life: Ecology and the Accumulation of Capital* (London: Verso, 2015).
V. Muñoz Sanz, "Captives in Futureland," *Archis* 5 (2017) 38–41.
V. Muñoz Sanz, M. Kuijpers, and G. Abou Jaoude, "Agricultural Platforms," *Harvard Design Magazine* 46 (2018) 124–131.
D. Pauschinger and Francisco R. Klauser, "The Introduction of Digital Technologies Into Agriculture: Space, Materiality and the Public–Private Interacting Forms of Authority and Expertise," *Journal of Rural Studies* 91 (2022) 217–227.
PDOK, "Key Register Topography (BRT) TOPNL," (2020). <https://www.pdok.nl/introductie/-/article/basisregistratie-topografie-brt-topnl> Accessed October 18, 2017.
E. J. Pekkeriet and E.J van Henten, "Current Developments of High-Tech Robotic and Mechatronic Systems in Horticulture and Challenges for the Future," *Acta Horticulturae* 893 (2011) 85–94.
E. J. Pekkeriet, E.J. van Henten, E. J. and J.B. Campen, "Contribution of Innovative Technologies to New Developments in Horticulture," *Acta Horticulturae* 1099 (2015) 45–54.
N. B. P. Polman, L.H.G. Slangen, and M.M.P. de Hoon, "The Choice for Different Institutional Arrangements: Contracting for Natural Gas in Dutch Horticulture," in H. J. Bremmers, S. W. F. Omta, and J. H. Trienekens, eds., *Dynamics in Chains and Networks* (Leiden: Wageningen Academic, 2004) 501–509.
M. E. Porter, J. Ramirez-Vallejo, and F. van Eenennaam, "The Dutch Flower Cluster," *Harvard Business School Case* (2011) 711–507.
M. Ros, A. Read, J. Uilenreef, and J. Limbeek, "Start of a CO2 Hub in Rotterdam: Connecting CCS and CCU," *Energy Procedia* 63 (2014) 2691–2701.
S. Rotz, E. Duncan, M. Small, J. Botschner, R. Dara, I. Mosby, M. Reed and E. D.G. Fraser, "The Politics of Digital Agricultural Technologies: A Preliminary Review," *Sociologia Ruralis* 59: 2 (2019) 203–229.

J. Rutherford, and S. Marvin. “Climate-Controlled Conservation: Remaking ‘The Botanical Metropolis of the World’,” *Transactions of the Institute of British Geographers* 50: 2 (2024): e12701.
J. Sadowski, “Cyberspace and Cityscapes: On the Emergence of Platform Urbanism,” *Urban Geography* 41: 3 (2020) 448–452.
A. Sijmonsma, “Another 20 Hectare for Tunisian Glasshouse Project Hicha Joy,” *Hortidaily* (May 19, 2023) <https://www.hortidaily.com/article/9528829/another-20-hectare-for-tunisian-glasshouse-project-hicha-joy/>Accessed September 4, 2024.
R.R. Shamshiri, C. Weltzien, I.A. Hameed, I.J. Yule, T.E. Grift, S.K. Balasundram, L. Pitonakova, D. Ahmad, and G. Chowdhary, “Research and Development in Agricultural Robotics: A Perspective of Digital Farming,” *International Journal of Agricultural and Biological Engineering* 11: 4 (2018) 1–14.
M. Shepherd, J.A. Turner, B. Small, and D. Wheeler, “Priorities for Science to Overcome Hurdles Thwarting the Full Promise of the ‘Digital Agriculture’ Revolution,” *Journal of the Science of Food and Agriculture* 100: 14 (2018) 5083–5092.
K.A. Siegmann, J. Quaedvlieg, and T. Williams, “Migrant Labour in Dutch Agriculture: Regulated Precarity,” *European Journal of Migration and Law* 24: 2 (2022) 217–240.
N. Smith,: “Nature as Accumulation Strategy” *Socialist Register* 43 (2007) 16–36.
M. K. Sott, L. B. Furstenau, L. M. Kipper, F. D. Giraldo, J. R. Lopez-Robles, M. J. Cobo, A. Zahid, Q. H. Abbasi, and M. A. Imran, “Precision Techniques and Agriculture 4.0 Technologies to Promote Sustainability in the Coffee Sector: State of the Art, Challenges and Future Trends,” *IEEE Access* 8 (2020): 149854–149867.
N. Srnicek, *Platform Capitalism* (Cambridge: Polity Press, 2016).
E. Swyngedouw, “Metabolic Urbanization: The Making of Cyborg Cities,” in A. L. Harrison, ed., *Architectural Theories of the Environment* (New York: Routledge, 2013) 163–181.
E. Swyngedouw and N.C. Heynen, “Urban Political Ecology, Justice and the Politics of Scale,” *Antipode* 35: 5 (2003) 898–918.
D. Tilman, K.G. Cassman, P.A. Matson, R. Naylor, and S. Polasky, “Agricultural Sustainability and Intensive Production Practices,” *Nature* 418: 6898 (2002): 671–677.
F. Tonini, and J. Liu, “Telecoupling Toolbox: Spatially Explicit Tools for Studying Telecoupled Human and Natural Systems,” *Ecology and Society* 22: 4 (2017) 11.
X. Tong, X. Zhang, R. Fensholt, P. R. D. Jensen, S. Li, M. N. Larsen, F. Reiner, F. Tian, and M. Brandt. “Global Area Boom for Greenhouse Cultivation Revealed by Satellite Mapping,” *Nature Food* 5: 6 (2024): 513–523.
F. Viviano, “This Tiny Country Feeds the World: The Netherlands has Become an Agricultural Giant by Showing What the Future of Farming Could Look Like,” *The National Geographic* (September, 2017). https://www.nationalgeographic.com/magazine/2017/09/holland-agriculture-sustainable-farming/. Accessed October 16, 2019.
M. J. Voskuilen and J. H. van Rijswijk, *DE GLASTUINBOUW IN HET WESTLAND*, Interne Nota no. 466 (Wageningen: Landbouw-Economisch Instituut, 1997) https://edepot.wur.nl/399861. Accessed July 15, 2020.
A. Walter, R. Finger, R. Huber, and N. Buchmann, “Smart Farming is Key to Developing Sustainable Agriculture,” Proceedings of the National Academy of Sciences 114: 24 (2017): 6148–6150.
C. Weltzien, “Digital Agriculture or Why Agriculture 4.0 Still Offers Only Modest Returns,” Landtechnik 71: 2 (2016) 66–68.
Wos, “Oppervlakte glastuinbouw in Westland stabile,” *WOS* (January 14, 2019) <https://archief.wos.nl/nieuwsarchief/bericht/20190114-oppervlakte-glastuinbouw-in-westland-stabiel> Accessed June 10, 2020.