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Greening the Virtual Smart City: Accelerating Peer-to-Peer Learning in Urban Agriculture With Virtual Reality Environments

Tapan Parikh[1†], Sara Perl Egendorf[2,3†], Isaiah Murray[1], Ali Jamali[1], Bryan Yee[1], Sammi Lin[2], Kendra Cooper-Smith[2], Brendan Parker[4], Koron Smiley[4] and Jenny Kao-Kniffin[2]*

[1] Cornell Tech, New York, NY, United States, [2] School of Integrative Plant Science, Cornell University, Ithaca, NY, United States, [3] Cornell Atkinson Center for Sustainability, Ithaca, NY, United States, [4] Red Hook Initiative, Brooklyn, NY, United States

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***Correspondence:**
Jenny Kao-Kniffin
jtk57@cornell.edu

†These authors have contributed equally to this work and share first authorship

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Urban agriculture is emerging across the United States (U.S.) as a distinct food production system that can help address food security and equity concerns of marginalized, urban communities. While urban farming is accelerating across the nation rapidly, the system of peer-to-peer learning that represents farmer education and training in the U.S. is based on rural agriculture. We describe the development of virtual reality (VR) platforms to support farmer knowledge transfer and innovation that transcend the physical constraints of traditional agricultural extension based on on-farm demonstrations. We feature a VR model representing an organic farm in New York City with details of farm operations, and opportunities to stack educational and training materials along with personal narratives, as part of the virtual farm demonstration. The potential for VR to accelerate innovations in food justice is a critical component of smart cities technologies and should be developed in parallel with modernization efforts with land grant universities and their cooperative extension networks of farmer-to-farmer education and training.

Keywords: cooperative extension, food security, land grant university, urban agriculture, virtual reality

INTRODUCTION

The face of farming is changing rapidly as the national population becomes increasingly urbanized. Rural farmers are declining and represent <2% of the national workforce (Lubell et al., 2014). Meanwhile, urban agriculture (UA) is on the rise nationally and globally and provides an opportunity to develop novel tools and frameworks that can straddle traditional questions about productivity and risk with more nuanced inquiries around participation and equity (Lawson, 2016). One key question for urban farming is about who participates, and who benefits (McClintock et al., 2021)? Farmer-to-farmer networking is a central component of knowledge adoption and transfer that can be augmented by the use of virtual platforms and electronic documentation (Conley and Udry, 2010; Patel et al., 2010). While attention and resources for UA can center on affluent entrepreneurs and recent suburban migrants into cities that operate within the structures of gentrification (Reynolds and Cohen, 2016), there is a need to recognize and support the efforts of working-class communities and communities of color who continue to create the foundation and many benefits of UA. New approaches can and should be developed to connect urban farming with technology innovation and education, to enable new career pathways and collaboration opportunities for sustainable and regenerative agriculture.

Virtual reality and digital media sharing can be seen as modern forms of on-farm demonstrations that characterized the first century of agricultural extension. Peer-to-peer learning dominated American farming in the 20th century through the formalization of the national Cooperative Extension System with the passage of the Smith-Lever Act of 1914 (Gould et al., 2014). Cooperative Extension partners with the United States Department of Agriculture to support the delivery of evidence-based research findings from land grant universities to farmers in rural communities that apply the knowledge gained into their farming practices. Cooperative Extension acts at the local level, whereby each state has at least one land grant university paired with a state-wide Cooperative Extension System with offices of extension agents in nearly every county (Ellison et al., 2017). The system of extension was created during a time when the U.S. population was largely rural and the percentage of farmers in the national workforce was 30–40%. With an infrastructure that still represents the original county-based operations of programming led by extension agents, there are barriers to both extension-to-farmer and farmer-to-farmer knowledge transfer.

A growing number of farming operations in cities indicates the changing demographics of farming but the system of peer-to-peer learning is still based on rural agriculture. Most Cooperative Extension offices are located in rural areas and the farming demonstrations are typically located in rural areas, including university research stations. For urban farmers, gaining access to relevant information on urban farming from land grant universities may require the adoption of new modes of communication. For these reasons, virtual reality and other technologically mediated platforms should be developed to enable farmer-to-farmer networking and community engagement for a range of urban and rural stakeholders that represent our modern constituencies.

We propose the use of virtual reality (VR) in agricultural extension that builds on participatory approaches to Information and Communications Technology (ICT) to address specific racial and economic needs in urban agriculture (UA). We situate this work in New York State, as one of 50 Cooperative Extension systems that has a rapidly urbanizing state population of over 87% urban residents, of which 44% of the state population resides in one municipality—New York City (U.S. Census Bureau, 2020). We describe a pilot participatory VR extension innovation program with Red Hook Farms, a 1.2 hectare organic farm in New York City (Brooklyn). We provide background on VR, participatory approaches to ICT and media dissemination in agricultural extension. We then describe the VR platform being developed with urban farmers in Brooklyn and conclude with a discussion of limitations and possibilities for future work.

VIRTUAL REALITY AND INFORMATION AND COMMUNICATIONS TECHNOLOGY

What Is Virtual Reality?

The Oxford Dictionary defines Virtual Reality as "the computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors." One of the goals of VR is to induce "targeted behavior in an organism by using artificial sensory stimulation, while the organism has little or no awareness of the interference" (LaValle, 2020). In other words, VR is an ensemble of computer-generated displays that direct a person to behave naturally as if they were present in that space, and thereby (at least visually, aurally and sometimes haptically) resembling an *in situ* experience.

For many years, the idea and practice of virtual reality remained cloistered in research labs and for specialized high-performance industries, like medicine, aviation, or the military. For example, pilots in training can learn to fly in a virtual reality experience without having to be in an actual plane. In recent years, driven by applications like gaming and entertainment, and the availability of lower-cost and higher-powered head-mounted displays (HMDs), virtual reality is seeing increased consumer adoption. With this technology, a plethora of opportunities emerge for learning and empathy in immersive environments (LaValle, 2020). By engaging three of the five senses through virtual reality, people are afforded another mode of social interaction (LaValle, 2020). This technology affords a new way of community; one that transcends physical location and two-dimensional screens. Our experience is that whenever these new media and communications technologies reach a price point that favors consumer adoption, farmers are often amongst the first and most enthusiastic adopters. While there are still challenges and gaps on the hardware and software side (as discussed later), we believe that the time is ripe to explore the use of these technologies for emerging applications like agricultural extension.

Why Virtual Reality for Agriculture Extension?

Agricultural extension presents a compelling use case for virtual reality, because of the potential to simulate "*in situ*" experiences, without the cost and expense of traveling to a remote field or demonstration site. In a large state like New York, this could provide opportunities for knowledge transfer and learning between geographically separated locations. For example, an agricultural extension specialist in Western New York might conduct a virtual 600-km "visit" to an urban farm in New York City, as a way to expose community housing residents in Buffalo, NY to the possibilities that urban farming offers. Alternatively, a demonstration farm 200-km away in the premiere organic farming communities of the Hudson Valley could use virtual reality to educate farmers in New York City about new seed varieties, organic pest management, or other innovations. Given the nation-wide and ongoing efforts of Land Grant Institutions to respond to systemic racism and land reform (Matsumoto, 2018; Hill, 2021), we propose the use of participatory VR to co-create equitable and technologically innovative spaces for farmer-to-farmer learning. In the next section, we discuss how our research group and others have used technologies like digital video and mobile phones for the same purpose in other geographic contexts.

Prior Work Using Technology and Media for Distance Learning in Agriculture

To avoid pitfalls and inform the creation of VR for agricultural extension, we look to prior work using technology in agricultural extension that has demonstrated effective co-creation of knowledge and the building of sustainable partnerships between extension agents, larger organizations, and communities. In Gujarat, India, an interactive mobile voice forum known as *Avaaj Otalo* ("voice stoop") revealed the necessity of centering community input as early as the inception and planning stages of extension initiatives. When designing Avaaj Otalo as a voice-based service, it was only by first speaking with community members that wide rates of illiteracy were made known, articulating the barriers of relying on written or SMS-based communication despite the high prevalence of mobile phones (Patel et al., 2010). These interviews also pointed to another critical factor for the sustained engagement and success of the platform: whether participants would be able to hear the voices of peers when interacting with the service rather than scientists (Patel et al., 2012). The shift to center not only community visions in theory, but manifesting such preferences by giving members opportunities to play direct roles within the platform ultimately allowed Avaaj Otalo to serve a dual purpose. Avaaj Otalo not only enhanced the economic prosperity and agricultural efficiency of the region, but also fostered social connectivity through the sharing of stories and experiences and strengthening the inter-communal bonds between neighbors and generations of families (Patel et al., 2010).

Similar initiatives in vastly different locations have also reinforced these findings. In a program developed in Malawi that co-created instructional videos on the utility of composting for restoring soil health and improving crop yields, farmers in follow-up interviews particularly cited that the appearance of neighbors and "fellow farmers" in the videos encouraged them to reconsider experimenting with composting (Cai et al., 2019). Moreover, by incorporating community members' input and participation in the development of the videos, both participants and audience members were able to be left with a more positive perception of the intervention in question than if the knowledge had simply been disseminated through lecture-style videos from high-level extension officers, most of whom are typically isolated and detached from smaller, agrarian villages (Cai et al., 2019). Such a trend reflects the growing desire and preference for participatory approaches to agricultural extension.

In this previous work, the key lessons that enabled success included (1) discussing interests and barriers to technology at each stage of the project (Gandhi et al., 2007); (2) centering farmers from stakeholder communities in informational video and audio platforms (Gandhi et al., 2007; Patel et al., 2012; Cai et al., 2019); and (3) creating platforms that users can use to share their own content and enhance relationships they determine to be important (Patel et al., 2010). We build off of these key findings in our current work, and contribute to work demonstrating that direct involvement of stakeholders can greatly enhance the efficacy of agricultural development interventions.

CASE STUDY: URBAN AGRICULTURE IN NYC

With over 8 million residents, New York City (NYC) has one of the oldest and largest networks of UA practitioners and sites that range from backyard gardens, community gardens, school gardens, commercial farms, rooftop farms, hydroponic and aquaponic systems, to more technical controlled environment agriculture facilities (N.Y.C.A.R., 2021). As of 2021, there are over 550 GreenThumb community gardens throughout NYC (NYC Parks Green Thumb, 2021). These agricultural spaces range vastly in size depending on both the available and allotted space granted by various departments including the Department of Transportation (DOT), Environmental Protection (DEP), and City Planning (DCP). Currently, the largest UA space in NYC spans 13,000 m^2 and produces 13,000 kg of vegetables every year (NYC Department of Environmental Protection, 2019). The Brooklyn Grange rooftop farm and intensive green roofing business was funded in its inception by a $1.38 million grant provided through the New York City DEP's Green Infrastructure Grant Program (NYC Department of Environmental Protection, 2019). It should be noted that the DEP's Green Infrastructure Grant Program excludes non-private NYC property owners from green roof retrofitting, thus creating potential barriers for people who are renters of city-wide apartments, homes and other spaces. In 2018 1,700 people were estimated to be fed by produce from community gardens in NYC (Hara et al., 2018), which represented <0.5% of the of 8.4 million city population. Estimates show that when all NYC available acreage, including vacant lands, lots and other suitable spaces, are utilized for food production, this figure can increase ten-fold (Hara et al., 2018).

VIRTUAL REALITY PLATFORM FOR KNOWLEDGE SHARING IN AGRICULTURE

Despite having many Cooperative Extension office locations in low population centers with low percentages of Black, Indigenous, and People of Color (BIPOC) residents (**Figure 1**), VR presents an opportunity to share best practices in agriculture in different community settings. With VR, connecting extension offices together, and to areas where they are most needed, can facilitate sharing and immersive learning experiences for urban and rural farmers across the state.

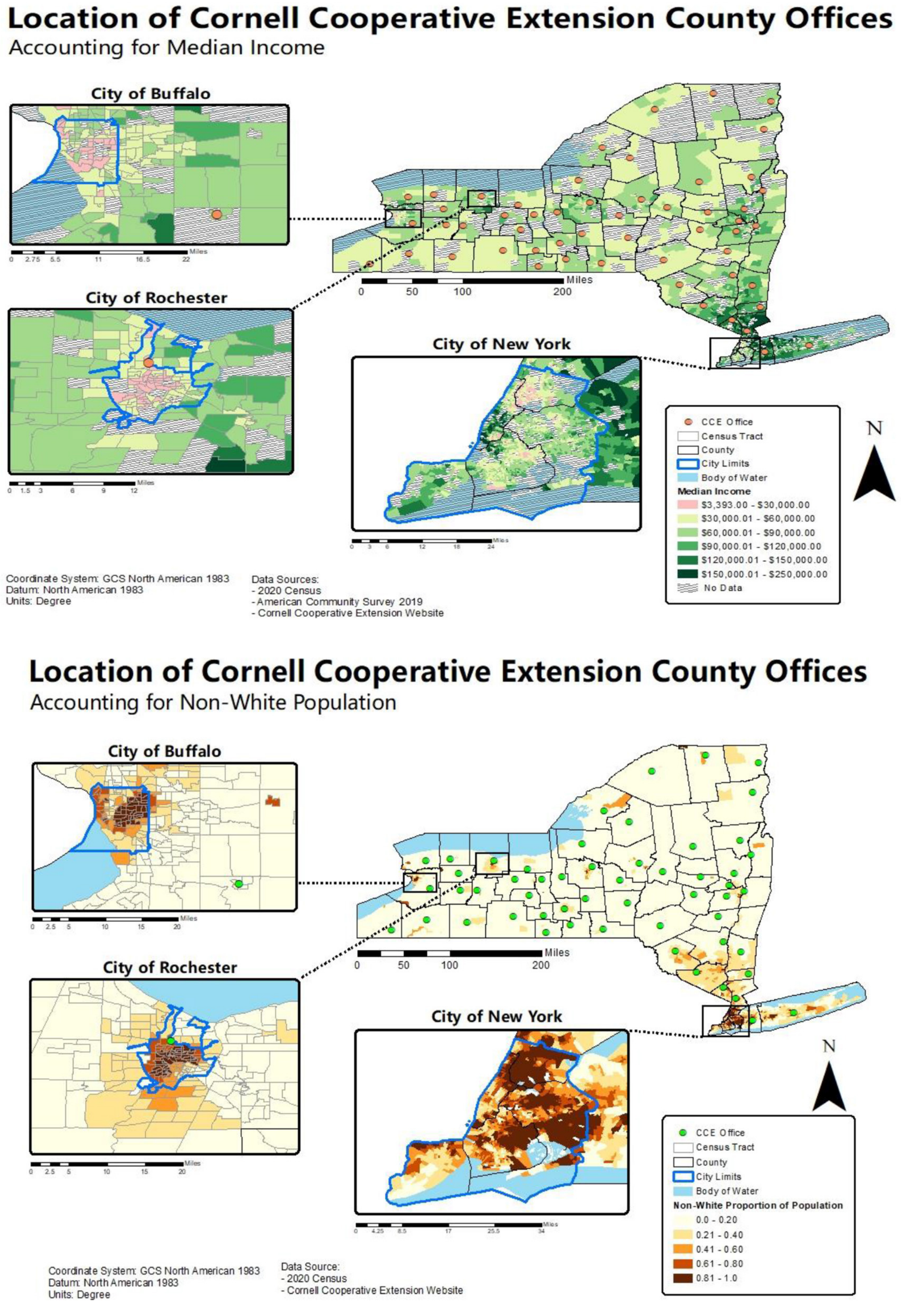

FIGURE 1 | Location of Cornell Cooperative Extension offices in New York State. While spread across the state in over 55 counties, the extension offices are largely absent in the most populous regions with the greatest percentages of non-White residents. Population data are based on the U.S. Census Bureau demographics for NYS (2020) (U.S. Census Bureau, 2019).

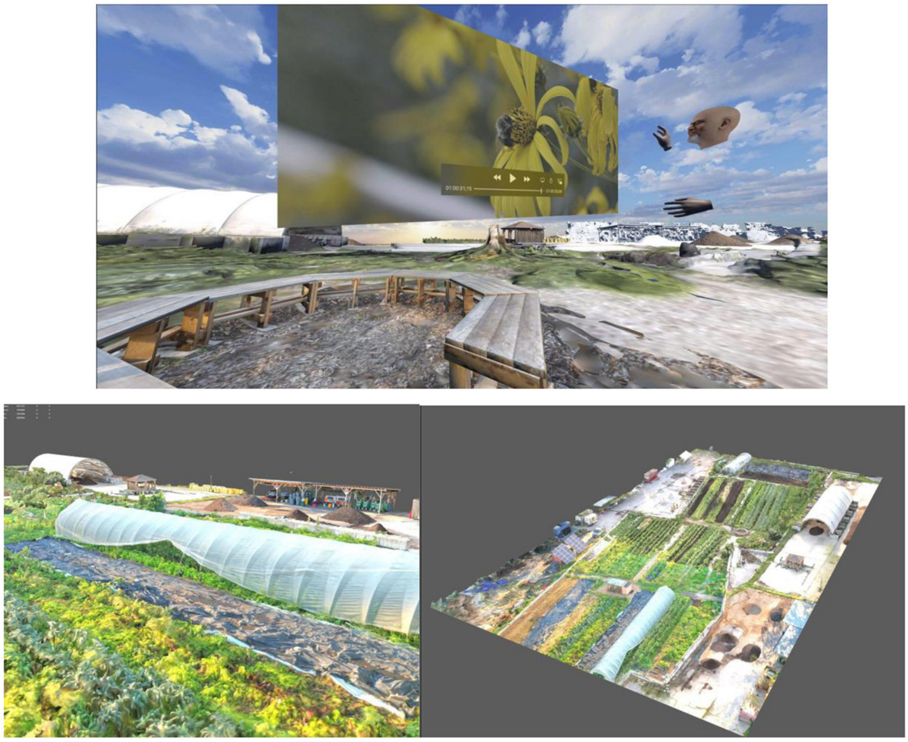

FIGURE 2 | Screenshots of our VR platform showing a user represented by an avatar interacting with an embedded video clip (top image). Aerial views of the 3D model of Red Hook Farm in Brooklyn, New York featuring solar panel arrays, processing shed, postharvest storage, composting area, herbal and medicinal plant garden, high tunnels for vegetable production, apiaries, chicken coop, and diversified perennial and annual crop production.

A VR Platform for Farm Tours and Demonstrations

We have built a prototype platform using the Unity programming environment[1] to realize this vision of remote access to on-farm demonstration and training through Virtual Reality. Several users (we have tested up to 20) are able to simultaneously log on to the platform and experience a tour of Red Hook Farm in Brooklyn, NY. At designated locations on the farm, users are able to "walk around" and experience the 3D environment, while talking to one another and the facilitator using audio or text chat. Multi-user networking capabilities are provided by the Normcore framework[2]

Other media content can also be embedded in the farm environment–including short videos, 3D animations and objects that can be manipulated and interacted with (see **Figure 2**). These are used to provide an introduction to the farm, and for demonstrations of specific techniques and technologies, such as those that would accompany an in-person farm demonstration or tour. At Red Hook Farm, these videos will provide virtual visitors with information about the farm's composting, cooking, and poultry programs, as well as provide testimonials and interviews with farmers, volunteers, youth, and community members.

[1]https://unity.com/
[2]https://normcore.io/

With Cooperative Extension and other partners, Red Hook Farm will use this prototype to introduce new audiences to the farm (including urban farmers from other cities in New York State, like Rochester and Syracuse). Extension staff and other farmers will be able to learn from each other and provide feedback that would enhance the specific practices of urban farmers.

Building 3D Models of Urban Farm Sites

One challenging aspect of this project has been the development of robust and efficient 3D models of urban farms. Farms are typically large in size, and incredibly complex in terms of their 3D topology and textures. As such, they create a compelling context for experimenting with some of the latest techniques in 3D modeling and rendering. For Red Hook Farm, we are using the method of photogrammetry to create a digital replica of the farm. Combining aerial and terrestrial images taken over a course of a few days we were able to gather enough data to generate an accurate and detailed 3D model of the site.

The first step in the process is to bring photos taken from both aerial and terrestrial sources into an image editing software such as Lightoom to match color and to reduce highlights/shadows. This process helps with image alignment and texturing for the next step. We then import the color corrected images into Reality Capture[3], which is used as our photogrammetry solution to generate the pointcloud, high resolution model and initial textures. This is the most computationally intensive process that can take days and significant computing resources to produce results.

Once the high resolution geo is exported out of Reality Capture, the next step is to use a modeling software similar to Zbrush[4] to remesh the geo and reduce the polygonal count so that it is manageable to render using the limited processing power and memory of currently available consumer VR headsets, such as the Oculus Quest 2[5], which retails for about $300. The geometry is then taken into a 3D application such as Autodesk Maya[6] to fix any defects.

Our scans of the farm initially yielded a high quality geometry with over 100 million triangles, along with dozens of 8 kilobyte texture files. A mesh that dense will have the most possible detail, but will be difficult to render and interact with on the limited hardware of a VR headset. To address this limitation, significant areas of interest were then retopologized with low polygon geo to further reduce the overall footprint of the file size. Much of this process must be done manually to maintain detail and high fidelity. The final model, which is still in production, has approximately 823,165 triangles.

Challenges and Limitations

Deploying these complex models on virtual reality headsets can often challenge their hardware and software limitations. As the capabilities of these consumer-oriented headsets improve, performance should also benefit significantly. In the meantime, we are using optimization and segmentation techniques that allow us to store and render these models efficiently. Capturing accurate 3D models of plants from imagery or video is also difficult due to their complex 3D geometry and their movement (e.g., in the wind). To address this limitation, we are experimenting with novel photogrammetry methods that will enable high-quality 3D reconstruction of plants using neural rendering techniques.

Access to virtual reality hardware is also a significant limitation. To address this, we are also developing functionality that would allow users to access the farm models and demonstration content using an Android smartphone. According to Pew Research Center, 76% of U.S. adults in households making <$30,000 a year say they own a smartphone and use that as their main way of going online (Vogels, 2021). In addition, we plan to provide VR headsets that can be loaned out from extension offices across counties.

[3]https://www.capturingreality.com/
[4]https://pixologic.com/
[5]https://www.oculus.com/quest-2/
[6]https://www.autodesk.com/products/maya/overview

CONCLUSION AND FUTURE WORK

This paper has described our work developing a virtual reality platform for peer-to-peer knowledge sharing in urban agriculture, as well as the specific geographic context of New York where it is intended to be deployed. We believe that VR has the potential to become a powerful platform for strengthening and enhancing urban agriculture, for the benefits of urban communities and sustainability, and the provision of broader ecosystem services. In the future, we plan to explore wider deployment of our platform in collaboration with extension offices across New York State, and with Cooperative Extension systems in other regions across the U.S. Doing so will allow us to also conduct research assessing the efficacy of the approach, in comparison to alternatives such as video-conferencing and in-person farm tours. We expect that VR will support an innovative form of civic engagement that can enable cities to become more resilient, sustainable, and just through supporting UA and the many beneficial ecosystem services derived from it.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

TP, SE, IM, SL, KC-S, and JK-K wrote the article. TP, IM, AJ, BY, BP, and KS developed the VR 3D model of the farm. All authors contributed to the article and approved the submitted version.

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