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POLICY BRIEF
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Co-Designing Urban Carbon Sink Parks: Case Carbon Lane in Helsinki

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In order to achieve the goals of carbon (C) neutrality within next 20 year, municipalities worldwide need to increasingly apply negative emission technologies. We focus on the main principles of urban demonstration areas using biochars for C sequestration and explore the lessons learned from a co-creation process of one such park, Hyväntoivonpuisto in Helsinki, Finland. Demonstration sites of urban C sinks in public parks must be safe, visible and scientifically sound for reliable and cost-effective verification of carbon sequestration. We find that different interests can be arbitrated and that synergy that emerges from co-creation of urban C sink parks between stakeholders (scientists, city officials, companies, and citizens) can result in demo areas with maximized potential for impact, dissemination and consideration of principles of scientific experimentation.

Keywords: biochar, carbon sequestration, demonstration sites, soils, trees, urban parks

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INTRODUCTION

The enhanced drawdown of CO_2 from the atmosphere in quantities exceeding 1,000 Gt of CO_2 is critical for meeting the targets to control climate warming, even though the reduction of emissions of greenhouse gases (GHGs) needs to be the primary goal (IPCC 2019; Amonette et al., 2021). While the implementation of more sustainable management practices in agriculture and forestry is essential in mitigation of climate change, the importance of urban vegetation and soils have been underestimated (Brown et al., 2012).

Besides being potential carbon sinks and stores, urban vegetation and soils provide other ecosystem services, such as improved stormwater management, recreation of inhabitants and even food production. In general, green built environment and nature-based solutions in cities yield both environmental and social benefits by improving the quality of urban life. Currently, urban areas act as net sources of GHGs (Velasco and Roth 2010) and the trends for urbanization feed further growth of GHG emissions from cities in future. More sustainable practices are needed in cities to reverse this development. Like many other cities, City of Helsinki aims to become carbon neutral by 2035 (City of Helsinki 2018). This ambitious goal is not easily reached. Significant reductions to current emissions are essential, but also negative emissions technologies, such as biochars, will be increasingly important. Biochars are materials rich in C stable for hundreds to thousands of years (Kuzyakov et al., 2014), produced from biomass that would otherwise mineralize in a relatively short time as CO_2 to the atmosphere. Also, adding urban trees and canopy cover is effective for C sequestration (e.g., Pataki et al., 2011).

Implementation of C drawdown from atmosphere at large scale demands that the reductions can be quantified by measuring and monitoring accurately and cost-efficiently—this remains challenging (Paustian et al., 2016). Further, in carbon market context, it is important that the emission reductions or CO_2 removal are additional to the baseline scenario and the effect of the implemented activity can be reliably estimated.

Demonstration areas provide situated learning opportunities for novel solutions. Yet, if properly planned they can also serve as field trials and provide new knowledge of the principles and suitability of the solutions. Such knowledge is relevant for scientists and for development of new products and services. In addition, demonstrations in urban green areas are visible to public, supporting co-operation and accessibility. The Carbon Lane project brought together actors from different related sectors in Finland (e.g., suppliers of growing media, researchers and policymakers) in a co-creation process including multiple workshops for ideation and knowledge sharing. As part of the project, an urban demonstration site with different biochar-based planting soils and trees was established in Hyväntoivonpuisto, the central park of Jätkäsaari in Helsinki, Finland.

Here we focus on the main principles of urban demonstration areas for C sequestration, particularly those including biochars, and consider the technologies and practices that may be relevant based on scientific soundness and applicability to urban space. We also explore the lessons learned from a co-creation process of one such park.

POLICY OPTIONS AND IMPLICATIONS

Design Principles of Urban Demonstration Sites for Carbon Sequestration

Scientific Soundness

Proper documentation of all practices

We recommend that all materials used on setting up the demonstration site (e.g., biochars, composts, fertilisers) should be sampled representatively prior to adding them in soils, and their quality analysed. The effect of added biochars or other soil amendments can best be predicted from relevant analyses (Bird 2015). Sampling and analysing of biochar should preferably be done according to the guidelines of the European Biochar Certificate (EBC 2012) on-site or alternatively using incremental cross-stream sampling devices in the biochar production unit.

As a part of the carbon sequestration verification process, however, also the persistence of biochars in soil should be assessed. In addition to measurements characterising the fractions of black C (e.g., by benzene polycarboxylic acid (BPCA) technique), the persistence of biochars in soil can also be predicted from cheap and easy-to-measure proxy characteristics like the molar H/C_{org} ratio of biochars. The amounts of materials added, and their C content needs to be measured and documented because the external C input must be considered as a part of the verification process. The starting points including e.g., tree dimensions and initial C stock estimate and initial soil C content should be measured and documented properly. Fertilisation, irrigation and other maintenance practices affecting plant growth and C sequestration through soil nutrient status and water content, should also be recorded.

Experimental Design

In order to assess the effectiveness of treatments tested (e.g., different biochar-based growing media), it is crucial to plan experimental controls so that the treatment effects clearly stand out. Control units (e.g., trees) should be as identical as possible to the units undergoing experimental manipulation. Controls and treatments are kept under same conditions; for example, similar management like watering the trees is conducted for the controls and treatments. Two different types of controls can be used: negative and positive. Negative controls receive manipulation that is expected to have no effect, often using Business-as-Usual is appropriate. Positive control in an experiment is a treatment which is expected to produce expected results and can be used to show that the experimental procedure is working- for example, using unpyrolized wood chips for providing the same amount of C as in biochar-containing treatments.

To avoid random variation or "noise" due to variations in environment and trees, each treatment needs to be replicated (at least 5–10 test subjects, e.g., trees per treatment) and replicates randomised. All measurements and samplings must be conducted avoiding edge effects. Each treatment should be randomly assigned over the area, while representatively considering shade, hilltops, and valleys as well as the distance from the paved routes.

Validation of Carbon Sequestration in Soil

Methods for estimating carbon sequestration are available from laboratory and field scale to ecosystem and regional level measurements (Nayak et al., 2019; Smith et al., 2020). Generally, the estimation of C stocks and potential C sequestration in urban C parks should be based on a combination of data from the laboratory and field measurements and modelling, rather than just a single measurement method.

To verify that soil organic carbon (SOC) sequestration has taken place with a certain treatment at the site, it is often necessary to be able to show an increase in SOC stock over time (Olson 2013). The main challenges in SOC measurements result from the spatial variability of SOC content in heterogeneous soil matrix and the relatively slow temporal changes in soil C stock.

The choice of the methods for the verification of soil and biochar C sequestration deserves careful consideration. There are wide range of techniques available but none of them is clearly superior (e.g., Hammes et al., 2007; Nayak et al., 2019). It would be beneficial to keep the methods (and if possible also devices) used for C determination the same throughout the monitoring period to ensure the comparability of data acquired at different points of time (Olson 2013). For routine analysis, elemental analyses *via* dry combustion has been proposed as the most suitable method for the measurement of total C content in soil: the equipment is widely available and the analysis is relatively cheap, but this method by itself does not provide separation of pyrogenic C fractions from other SOC fractions (FAO 2019).

FIGURE 1 | (A–D) clockwise]. Measurements of tree dimension from young trees in Hyväntoivonpuisto **(A)** and demonstration of how complicated can the collection of leaf biomass samples from street trees higher than 2–3 m be **(B)**. Portable chamber system with infrared carbon dioxide analyzer and temperature and relative humidity probe for soil CO_2 flux measurement **(C)**. Sensors installed on urban tree trunks can be protected by surrounding the entire tree base in custom made steel mesh cage **(D)**.

The effects of biochars on native soil C (priming effect) over time are relevant to be considered as well. The priming effects can even have a larger impact on C sequestration potential than the direct effect of biochar addition, and first long-term field studies on the issue are promising (Weng et al., 2017; Blanco-Canqui et al., 2020). Namely, biochar addition has been found to enhance soil aggregation and hence, the retention of root-derived C by 20% in 10-year experiment in Australia (Weng et al., 2017) and in Midwestern United States, a SOC increase by twice the amount of biochar C applied was reported 6 years after biochar application (Blanco-Canqui et al., 2020). Thus, long-term experiments combined with repeated and representative soil sampling (including subsoil) are one way for the verification of biochar and SOC sequestration.

Nevertheless, since biochars degrade relatively slowly, estimating their degradation under the field conditions requires long timescales (Kuzyakov et al., 2014). Biochar particles are likely also eroded or leached (Obia et al., 2017), cases in which they may be lost from the analyses and calculations but not necessarily as CO_2 to the atmosphere. Hence knowing the amount and longevity of the applied biochar (even by using proxies as H/C_{org} ratios) can be seen as even more important than quantifying the amount of biochar over time with sampling.

Measurements of Vegetation

Plant growth over time is a simple measure for the success of planting and carbon sequestration to its standing biomass. Measuring change in plant dry biomass integrates the effects of C sequestration (*via* photosynthesis) and loss (e.g., respiration, grazing by pests, branch pruning).

Trees allocate the increase in biomass, and thus stored carbon, to plant compartments (such as trunk, fine roots, leaves) with varying longevity. The long-living woody compartments, coarse roots, trunk, and branches, contain the majority of live biomass C. These are more important to measure than short-lived fine roots and leaves which mainly feed the soil carbon pool. Tree biomass equations estimating dry biomass from trunk diameter can be considered a relatively accurate way to non-destructively assess total biomass C sequestration for urban trees (Riikonen et al., 2017; **Figure 1A**). Trunk diameter in itself is fairly simple to measure, but for repeated measurements the measuring height should be permanently marked on the trunk.

If biomass equations are not available for a given taxa or are judged to be unsuitable, the traditional method of measuring plant C stock is based on destructive sampling (Riikonen et al., 2017). This is rarely an option for valuable park trees (**Figure 1B**). Arguably the best non-destructive method is terrestrial laser scanning (McHale et al., 2009; Tanhuanpää et al., 2017), which gives excellent estimates for tree aboveground biomass volume but requires conversion to mass basis to attain C content.

Regarding assessment of C sequestration *via* growth of non-woody plants like grasses and forbs, collecting biomass samples is feasible, but on annual scale, non-woody plant biomass C is less significant. In the case of lawns, the goal usually is a good visual appearance (greenness, evenness) and in case of meadow, presence, diversity, and abundance of flowering plants (e.g., Norton et al., 2019) rather than biomass growth.

Ecosystem Level Measurements

The eddy covariance (EC) technique is an established, yet expensive method to measure the exchange of various compounds, such as GHGs but also water vapour, between the atmosphere and land surface. EC measures fluxes on ecosystem scale, integrating over its entire footprint area (typically few thousands of m^2). Understanding the processes behind the measured fluxes however require partitioning fluxes to their sources (e.g., Nordbo et al., 2012), thus usually also direct independent measurements of flux components are required.

Various chamber methods, both stationary and portable, are useful to complement EC measurements to establish the flux components (**Figure 1C**). A chamber is sealed against soil surface or e.g., a leaf, and an analyser for the gases which either are accumulated in the measuring chamber or led to the analyser while replacement air is vented into the chamber. Stationary, automated chambers allow longer-term measurements but are more expensive to establish (require a constant power source and data loggers). Portable chambers operated on batteries offer lower initial costs due to less required infrastructure and can be used in short-term measurements under supervision, requiring more labour.

Applicability to Urban Space

All carbon fixing treatments used in public demonstration sites need to be safe for humans and environment and hard to vandalise. All materials used in urban environment should be traceable and fulfil local safety criteria. As the EBC sets even higher standards for the quality of biochar (EBC 2012) than REACH regulations, only EBC-certified biochars are recommended in the EU. Biochar treatments need to be evaluated and planned considering practical issues like dustiness. For example, no biochar should be visible on the surface as fine-particles may be eroded with wind or water and large particles may tempt people to use it as barbeque or drawing coal. Rather the top 5 cm of soil should be a cover of gravel or rocks.

Any structures or devices installed for research purposes in public green areas should not interfere with site accessibility. Electrical and other hazardous or valuable research apparatus must be installed behind safety screens (**Figure 1D**). Portable equipment cannot be left unattended, and any soil disturbances caused by sampling must be evened out. Similarly, staff safety must be ensured by wearing reflective clothing, and appropriate training for working in traffic areas should be attended if needed.

Public Awareness

Raising the public awareness of the C sequestration is one of the key objectives of the urban C sink parks. The parks itself, no matter how well planned, will have only a very limited capacity to absorb carbon- thus it is highly important to inspire people to carry out their own actions elsewhere. The means of increasing public awareness are divided into those implemented in an urban demo park and those not bound to the physical park location, such as websites and campaigns using social media influencers (**Table 1**). We propose that the focus is on communication within the park, as it is more effective to influence on people when they are already at the site.

People gather information with all their senses, so the communication should not be limited to written form. A broad palette of actions should be used, including communicating measurement data with interactive and transforming artworks (**Table 2**). The artworks of light, sound and movement could react to the changes of the measured variables such as C drawdown, so the visitors could easily follow the changes happening on different natural phenomena.

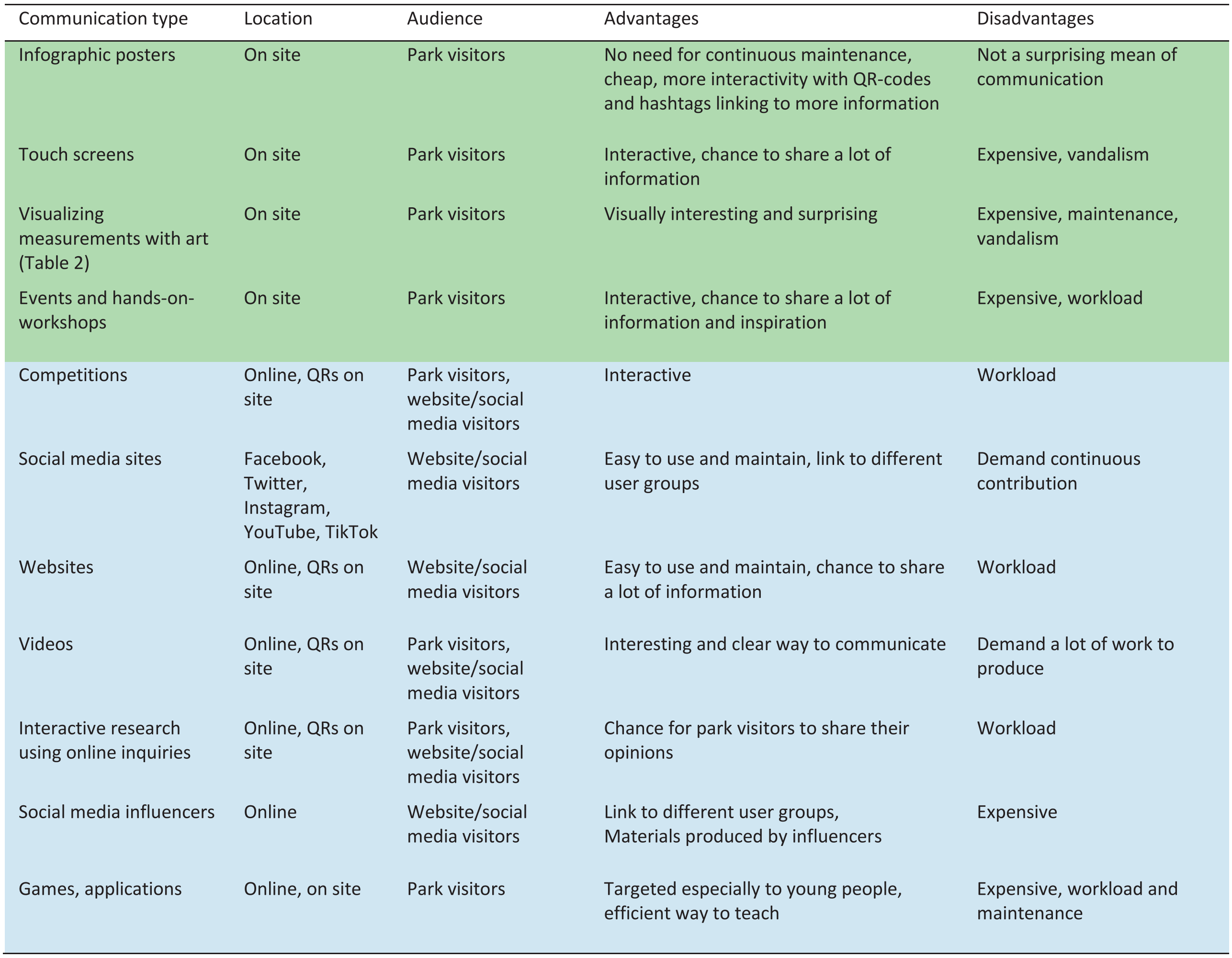
ACTIONABLE RECOMMENDATIONS

Demonstration sites of urban C sequestration methods aid in achieving the goals of carbon (C) neutrality within next 20 year for municipalities. For maximising the impact of such sites and to facilitate validation of C sequestration, they need to be designed in a way that is scientifically sound. Thus, it is crucial to document well all practices and carefully plan the experimental design and follow-up (*Scientific Soundness*). All carbon fixing treatments need to be applicable to urban space (*Applicability to Urban Space*). Most importantly, they must be safe for humans and environment. Raising the public awareness of the C sequestration is one of the key objectives of the urban C sink parks to maximise the demonstration effect by inspiring people (*Public Awareness*).

Regarding the lessons learned from the Carbon Lane case, the main recommendation is to accept that the resources available and the timetables fixed with contractors will likely cause limitations to what extent the general principles outlined in *Design Principles of Urban Demonstration Sites for Carbon Sequestration* can be realised. For instance, when working with novel growing media, the issues to consider include the limited availability, extensive delivery times and properties differing from product sheet due to active product development.

The first proposal of the Jätkäsaari demonstration site (**Figure 2**) was designed following closely the principles outlined in 2.1. The proposal included six different biochar containing planting soils +control in grass areas and five different treatments (+control) with trees. After discussions with stakeholders the proposal was amended iteratively. The final plan of the demonstration area was a compromise with

TABLE 1 | Different communication and engagement methods: green—on site and blue–online.



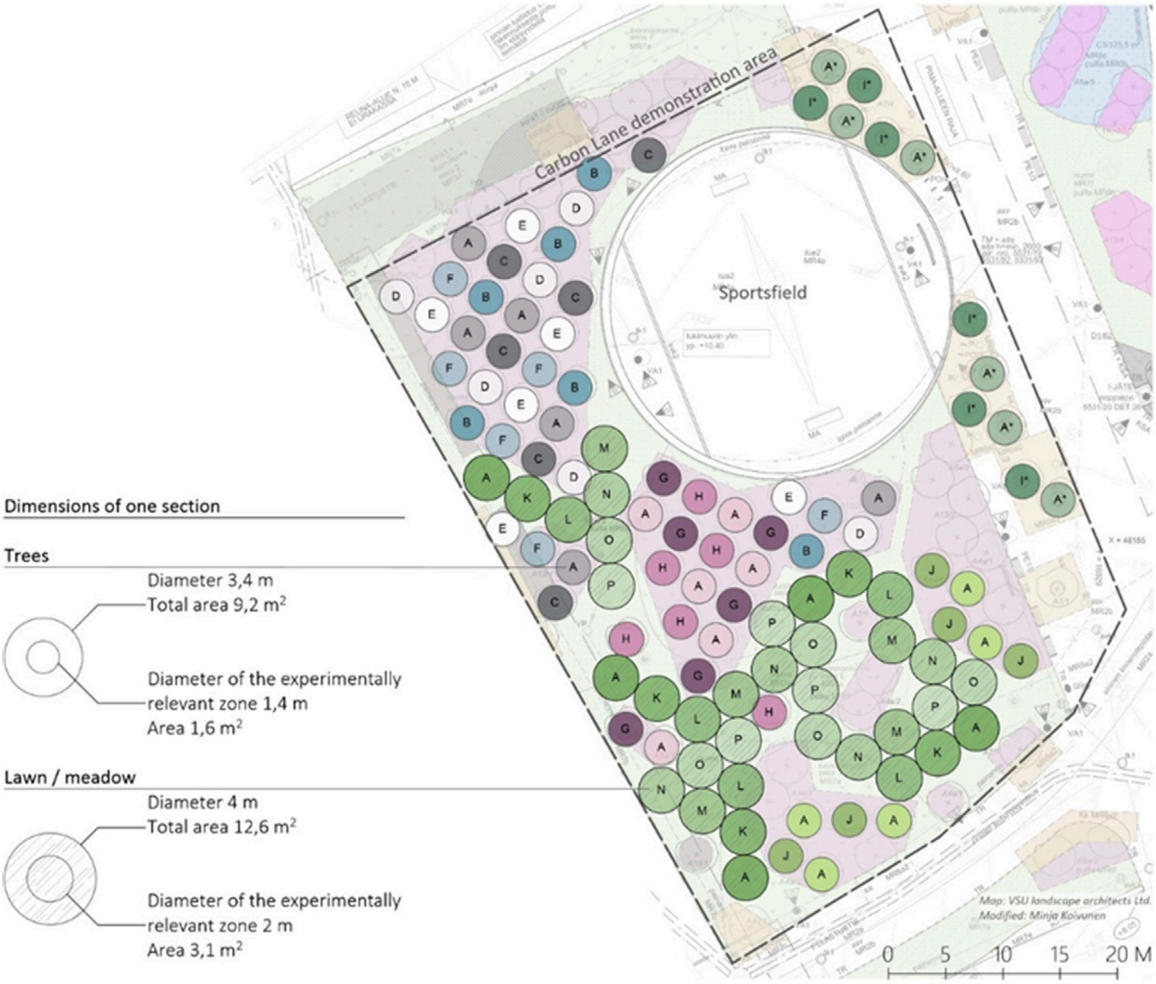
Communication type	Location	Audience	Advantages	Disadvantages
Infographic posters	On site	Park visitors	No need for continuous maintenance, cheap, more interactivity with QR-codes and hashtags linking to more information	Not a surprising mean of communication
Touch screens	On site	Park visitors	Interactive, chance to share a lot of information	Expensive, vandalism
Visualizing measurements with art (Table 2)	On site	Park visitors	Visually interesting and surprising	Expensive, maintenance, vandalism
Events and hands-on-workshops	On site	Park visitors	Interactive, chance to share a lot of information and inspiration	Expensive, workload
Competitions	Online, QRs on site	Park visitors, website/social media visitors	Interactive	Workload
Social media sites	Facebook, Twitter, Instagram, YouTube, TikTok	Website/social media visitors	Easy to use and maintain, link to different user groups	Demand continuous contribution
Websites	Online, QRs on site	Website/social media visitors	Easy to use and maintain, chance to share a lot of information	Workload
Videos	Online, QRs on site	Park visitors, website/social media visitors	Interesting and clear way to communicate	Demand a lot of work to produce
Interactive research using online inquiries	Online, QRs on site	Park visitors, website/social media visitors	Chance for park visitors to share their opinions	Workload
Social media influencers	Online	Website/social media visitors	Link to different user groups, Materials produced by influencers	Expensive
Games, applications	Online, on site	Park visitors	Targeted especially to young people, efficient way to teach	Expensive, workload and maintenance

TABLE 2 | Visualizing measurements with art.

Type of data	Art idea	Interactivity
Soil water content and temperature	Alighted water pipes	Water level would change inside the pipes depending on soil water content. Light intensity would vary depending on soil temperature
GHG-emissions	Machines producing water vapor clouds	Different shape and colour of the clouds
GHG-emissions	Lights e.g., in the trees	Changes of light intensity depending on emission levels
Root growth	Screens to see underground	Underground cameras
Root growth	Lights on ground level presenting the area that roots cover around a tree	Changes of light intensity and area covered depending on the growth area
Soil temperature	Lights of different colour and intensity	Changes of light colours and intensity depending on soil temperature
Atmospheric CO_2 content	Screens with real-time data	Graphs illustrating current level of atmospheric CO_2 contents globally or locally
Soil activity or carbon sequestration	Interactive statue: using perceptible changes like colour, movement, sound and vibration	Reacting to soil processes, e.g., microbiological activity

limitations, the number of treatments and repetitions was determined by delivery schedules, and also the randomisation principle was compromised on. To facilitate construction, the trees are planted in connected pits with two to seven trees per pits clustered together (**Figure 3**). All these modifications can be viewed as local learning processes of realising urban demonstration areas on a general level.

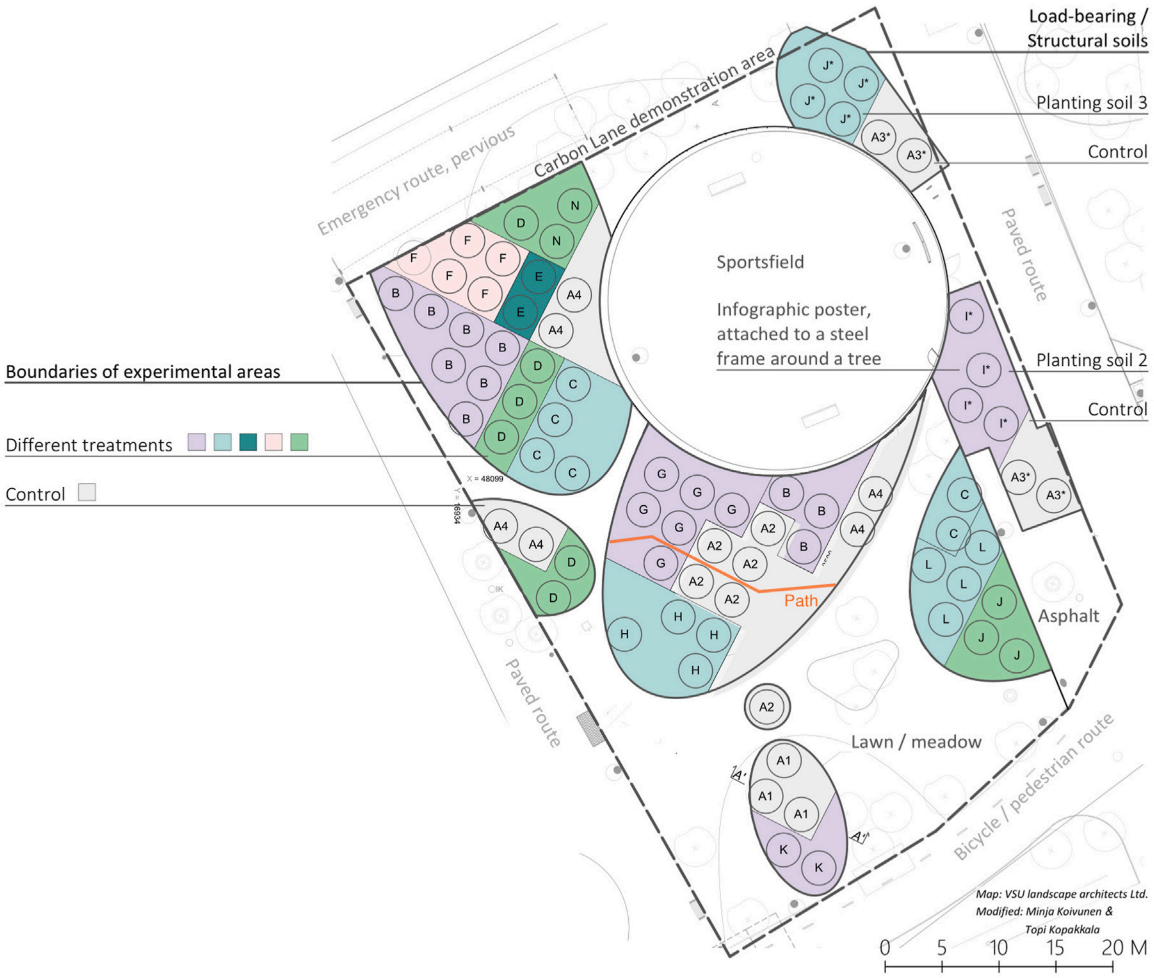
Next, it might be relevant to set and communicate well the common criteria to growing media providers regarding e.g., C or nutrient contents or load-bearing properties of the materials- as



Treatment	Small-leaved Lime *Tilia cordata* 12 pcs	Pin cherry *Prunus pensylvanica* 18 pcs	Ash *Fraxinus excelsior* 12 pcs	Apple 'Makamik' *Malus x purpurea* 38 pcs	Lawn / meadow
1 Control * Structural soil	A	A	A*	A	A
2 Planting soil * Structural soil	J	G	I*	B	K
3 Planting soil		H		C	L
4 Planting soil				D	M
5 Planting soil				E	N
6 Planting soil				F	O
7 Planting soil					P

FIGURE 2 | A proposal with descriptions and visual layout of the Jätkäsaari demonstration site.

well as expected delivery time and location in the heavily trafficked urban centre. In our case, the C and nutrient contents of growing media varied remarkably, requiring repeated top-filling and grass re-seeding in some treatments (**Figure 1A**). Further, the highly varying properties of different growing media could result in challenges when analyzing differences between treatments. For example, prominent variation in nutrient levels might mask effects of biochars on



Map: VSU landscape architects Ltd.
Modified: Minja Koivunen &
Topi Kopakkala

Treatment	Small-leaved Lime *Tilia cordata* 12 pcs	American mountain-ash *Sorbus americana* 21 pcs	Ash *Fraxinus excelsior* 12 pcs	Apple 'Makamik' *Malus x purpurea* 32 pcs	Media volumes approx. m³
1 Control * Structural soil	A1	A2	A3*	A4	300 88
2 Planting soil * Structural soil	K	G	I*	B	300 86
3 Planting soil * Structural soil	L	H	J*	C	290 70
4 Planting soil	M	N		D	183
5 Planting soil				E	25
6 Planting soil				F	60

FIGURE 3 | The final plan of the Jätkäsaari demonstration site.

growth. Controlling such effects would be aided if potentially interfering properties could be standardized or by including additional control treatment which equivalents with these properties.

We found also active communication with contractors and stakeholders to be crucial regarding the follow-up study. As typical landscape construction site documentation is not sufficient for needs of research, the expectations related to documentation of construction process need to be communicated in advance and as specifically as possible, especially if researchers are not able to participate on site during key phases of construction as recommended.

Finally, an effort should be made to predict habits of people, e.g., to foresee future shortcut paths across the park areas and strive towards locating treatment combinations randomly across such potential paths. During summer 2020 an unanticipated dog-walking path appeared across the demonstration area (**Figure 3**) in such a way that all control treatment trees were located on one side of the path. As several of the trees there dried and had to be replaced, it was difficult to deduct what caused the phenomena: the path, the growing media or the nursery quality of the trees.

CONCLUSION

To achieve the goals of carbon (C) neutrality within next 20 year, municipalities worldwide need to increasingly apply negative emission technologies. We focus on the main principles of urban demonstration areas using trees and biochars for C sequestration and found that demonstration sites of urban C sinks in public parks need to be safe, visible and scientifically sound for reliable and cost-effective verification of carbon sequestration. We found that different interests can be arbitrated and that synergy that emerges from co-creation of urban C sink parks between stakeholders (scientists, city officials, companies, and citizens) can result in demo areas with maximized potential for impact.

ETHICS STATEMENT

Written informed consent was obtained from the relevant individual(s) for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

PT: Initial idea, Resources, Planning, Writing, Revision, Correspondence PS, ST, MK, and A-RS: Planning, Writing, Revision. AR, ES, and MJ: Initial idea, Resources, Planning, Writing, Revision TK: Visualization, Writing, Revision.

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